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# The City Location Factor for Queue Discharge Behaviors

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**Abstract:** Exploring queuing behavior of different types of lanes at signalized intersections is helpful for establishing the methodology for capacity analysis of each lane or group of lanes. In Taiwan's latest revised HCM, straight lanes and un-opposed left-turn lanes at signalized intersections were respectively divided into six types and four types in officially. The field data showed that queue discharge characteristics varied with the lane type and the location of the city, and the nonlinear regression models could accurately describe the discharge behavior of each lane type. Based on these regression models, the influence of the city location factor, $f_z$, could be used to adjust the queue discharge behaviors among different cities. Therefore, this study collected queue discharge data in several Taiwan cities, performed statistical analyses, and compared the field data to determine $f_z$. This study found that $f_z$ is an important parameter for comparing queue discharge behavior among cities.

***Key Words***: *Signalized intersection, Un-opposed traffic flow, Queuing vehicle, Discharge behavior, City location factor*

## 1. INTRODUCTION

The traditional estimation method of traffic lane capacity at signalized intersections (including USA, UK, Sweden, Australia, and Taiwan) is based on the concept of the saturation flow rate (Akcelik, 1982; Kimber, *et. al*, 1986; Petersen and Imre, 1977; Teply, *et. al*, 1995; Transportation Research Board, 2000). This concept states that after the start of the green light, the average queuing discharge rate will soon reach a stable maximum value called the saturation flow rate. However, according to the field data from urban and suburban signalized intersections in Taiwan, the queuing discharge characteristics of the straight-through, right-turn or left-turn lanes differ greatly from the concept of the saturation flow rate (Institute of Transportation, 2003; 2004; 2005). Field data from Poland (Tarko and Tracz, 2000), USA (Hawaii and Long Island, New York) showed the same characteristics (Li and Prevedouros, 2002; Lin and Thomas, 2005). As shown by the field data of suburban multi-lane highways in Taiwan, the queuing discharge rate often keeps on rising after the $12^{th}$ queuing vehicle passes the stop line, and it's very hard to decide when the discharge rate stabilizes (Institute of Transportation, 2003; 2004; 2005). In studying the characteristics of the discharge at urban signalized intersections, the Institute of Transportation (IOT) found that the straight-through and unopposed left-turn (including single left-turn, double left-turn and triple left-turn lanes) queuing discharge characteristics were the same as the suburban discharge behavior (Institute of Transportation, 2007; 2008). Therefore, the traditional estimation of capacity using the saturation flow rate concept might not apply to the urban signalized intersections in Taiwan.

Most of the data of Chapter 13, Signalized Intersections, of the "2001 Highway Capacity Manual of Taiwan" (2001 Taiwan HCM) (Institute of Transportation, 2001) were cited from the 1991 Taiwan HCM (Institute of Transportation, 1991), USA 1994 HCM (Transportation Research Board, 1994), and Canada signalized intersection analysis method (Teply, *et al.*, 1995). By the end of 2007, the IOT had used field data to provide an alternative capacity analysis method. As pointed out in the revised Chapter 13 of 2008, the capacity of a lane or a group of lanes at a signalized intersection can be estimated by a simulation model or by analytical methods. Simulation is recommended as the analysis tool in Chapter 13. But, if the traffic is unopposed, and the purpose of the analysis is just to estimate the capacity, the analytical method (including formula, tables and graphs) can be used.

Although the alternative capacity estimation method was put forward in the revised Chapter 13, it requires more domestic data and establishes some adjustment factors. This study collected queue discharge data of straight-through lanes and unopposed left-turn lanes in 7 Taiwan cities, and performed statistical analyses to determine the adjustment factor of city location, $f_z$. The queuing discharge behaviors of the same type lane in different cities were also compared by using $f_z$.

## 2. ESTIMATION METHOD OF LANE CAPACITY

The traditional capacity estimation method is based on the concept of the saturation flow rate. Saturation flow is considered to be a steady maximum rate of queue discharge after the green light has been turned on. It is traditionally assumed that, after the start of the green light, the discharge rate of queuing vehicles will reach its saturation flow after four or five vehicles have entered the intersection, and that this saturation flow will be maintained until shortly after the signal change interval begins. Based on this assumed behavior, the U.S. HCM (Transportation Research Board 2000) suggests that the saturation flow be determined as the average discharge rate of the queuing vehicles after the fourth queuing vehicle enters the intersection. According to this concept, capacity can be estimated as follows:

$$c = S\frac{g}{C} = S\frac{G+Y-L}{C} \tag{1}$$

where

- $c$ = capacity of a lane or group of lanes (vehicles/h or vph),
- $S$ = saturation flow (vph),
- $g$ = effective green,
- $C$ = cycle length (s),
- $G$ = green interval (s),
- $Y$ = signal change (or intergreen) interval (s), and
- $L$ = lost time (s).

When using equation 1, the saturation flow rate and the lost time are estimated independently, and are not easily determined from the field data. The saturation flow rate is normally estimated according to the following equation:

$$S = S_0 f_1 f_2 \ldots\ldots f_n \tag{2}$$

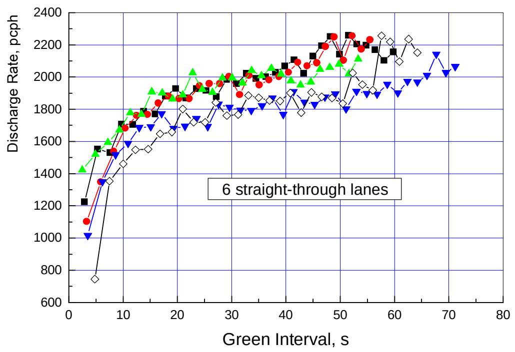
where

- $S_0$ = saturation flow rate under the basic condition (vph),
- $f_1, f_2, \ldots\ldots, f_n$ = adjustment factors for vehicle types and lane width.

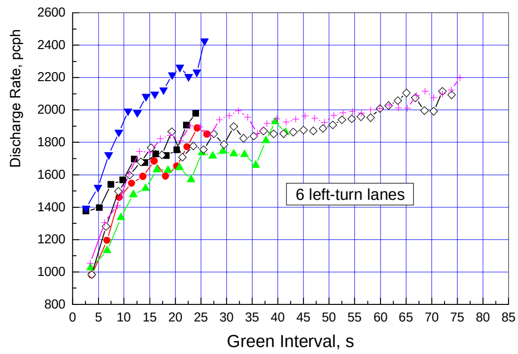
Chapter 13 of 2001 Taiwan HCM sets $S_0$ for a lane width of 3.5m as 1950 vph (Institute of Transportation, 2001). $S_0$ is set as 1900 pcu/h in 2000 U.S. HCM (Transportation Research Board, 2000); $S_0$ is set as 2080 pcu/h in the U.K. analysis method (Kimber, *et al*., 1986). The analysis method used in Canada mentioned that different cities have different $S_0$, and that they ranged between 1550 and 1850 pcu/h (Teply, *et al*., 1995).

The calibration of lost time is another issue. Lin *et al*. (2004) points out that there are currently no reliable models to relate lost time to the green interval and to account for the effects of lane location. In fact, transportation professionals often have to use default lost time for capacity estimation. The U.S. HCM suggests that, in the absence of reliable information, a default lost time of 4 s be used. As will be discussed below, the use of a default lost time can lead to significant errors in the subsequent estimation of lane capacity and vehicle delay.

Recently, field data from Taiwan and U.S. (Lin *et al*., 2004; Lin and Thomas, 2005) showed that the actual discharge behavior was far removed from the traditional discharge concept of a saturation flow rate. As shown in Figure 1, in Taiwan the urban straight-through queuing discharge rate usually increases 20s after the green light turns on. It is difficult to decide after which queuing position the discharge rate stabilizes. Unopposed left-turn queuing discharge rates have a similar characteristic as shown in Figure 2. Using Equation 1 to estimate the capacity of a common lane will give rise to serious problems (Li and Prevedouros, 2002; Lin and Thomas, 2005).




Source: Institute of Transportation (2008).
Figure 1 Straight-through lane queuing discharge characteristic




Source: Institute of Transportation (2008).
Figure 2 Left-turn lane queuing discharge characteristic

A better alternative to the traditional approach is to estimate the number of queuing vehicles that can be discharged in each signal phase. The newest edition of Chapter 13 in Taiwan HCM (Institute of Transportation, 2009) uses the following basic equation to estimate the capacity of straight-through and un-opposed left-turn lanes.

$$c = \frac{3600}{C}\left[\sum_{i=1}^{n} N_{gyi}\right] f_V\, f_g\, f_b\, f_S\, f_Z\, f_P \tag{3}$$

where

$c$ = lane capacity (vph),
$C$ = signal cycle (s),
$N_{gyi}$ = mean of the queuing vehicles to be discharged under a specific condition in the green interval and the signal switch interval of the $i^{th}$ available time phase (vehicles),

$n$ = available time phase,
$f_V$ = adjustment factor for vehicle type and traveling direction,
$f_g$ = adjustment factor for slope,
$f_b$ = adjustment factor for bus station,
$f_S$ = adjustment factor for roadside parking,
$f_Z$ = adjustment factor for city where the intersection is located,
$f_P$ = adjustment factor for an opposed pedestrian.

Adjustment factors in equation 3 vary with $N_{gyi}$. For example, if the $N_{gyi}$ value includes all vehicles and traveling directions, then the $f_V$ adjustment is unnecessary (in other words, $f_V = 1.0$).

There were eight kinds of lanes included in revised Chapter 13. The adjustment factor $f_z$ of the first straight-through lane and the fifth un-opposed left-turn lane are studied in this research. Straight-through lanes in revised Chapter 13 include 6 types as shown in Table 1. The $N_{gyi}$ estimation model of each type is listed in Table 2, where $g$ shall be determined as per the following equation:

$$g = G + \beta \tag{4}$$

where
$g$ = effective time phase (s),
$G$ = green interval (s),
$\beta$ = continued queuing discharge time after the green interval (s), default value: 3.5 s.

Table 1 Straight-through lane type division

| Lane Type | Lane Characteristics |
|---|---|
| S1 | divided, without express/slow traffic separation device, not adjacent to an exclusive bus lane |
| S2 | divided, without express/slow traffic separation device, adjacent to an exclusive bus lane |
| S3 | divided, with express/slow traffic separation device |
| S4 | undivided, with express/slow traffic separation device |
| S5 | undivided, without express/slow traffic separation device |
| S6 | left side adjacent to express/slow traffic separation device |

Source: Institute of Transportation (2008).

Table 2 Straight-through lane $N_{gyi}$ estimation models

| Lane Type | Estimation Models | Green Time ($g$, sec.) |
|---|---|---|
| S1 | $N_{gyi} = -0.77 + 0.475\, g + 1.273 \times 10^{-3} g^2$<br>$N_{gyi} = -3.69 + 0.598\, g$ | 5~55<br>>55 |
| S2 | $N_{gyi} = -0.98 + 0.426\, g + 1.105 \times 10^{-3} g^2$<br>$N_{gyi} = -5.40 + 0.566\, g$ | 5~60<br>>60 |
| S3 | $N_{gyi} = -0.59 + 0.428\, g + 1.250 \times 10^{-3} g^2$<br>$N_{gyi} = -4.36 + 0.566\, g$ | 5~50<br>>50 |
| S4 | $N_{gyi} = -0.88 + 0.437\, g + 1.783 \times 10^{-3} g^2$<br>$N_{gyi} = -3.70 + 0.582\, g$ | 5~50<br>>50 |
| S5 | $N_{gyi} = -0.71 + 0.422\, g + 1.500 \times 10^{-3} g^2$<br>$N_{gyi} = -8.68 + 0.638\, g$ | 5~70<br>>70 |
| S6 | $N_{gyi} = -1.28 + 0.425\, g + 1.150 \times 10^{-3} g^2$<br>$N_{gyi} = -3.24 + 0.522\, g$ | 5~50<br>>50 |

Source: Institute of Transportation (2008).

Unopposed left-turn lanes in the revised Chapter 13 include 4 types as shown in Table 3, the $N_{gyi}$ estimation model of each type is listed in Table 4.

Table 3 Unopposed traffic left-turn lane type division

| Lane Type | Lane Characteristics |
|---|---|
| L1a | undivided, single left-turn |
| L1b | divided, single left-turn |
| L2 | divided, double left-turn |
| *L3* | divided, triple left-turn |

Source: Institute of Transportation (2008).

Table 4 Unopposed left-turn lane $N_{gyi}$ estimation models

| Lane Type | Estimation Models | Green Time ($g$, sec.) |
|---|---|---|
| L1a | $N_{gyi} = -1.46 + 0.478\,g + 7.085 \times 10^{-4}\,g^2$ | 5~60 |
| | $N_{gyi} = -2.32 + 0.535\,g$ | >60 |
| L1b | $N_{gyi} = -0.22 + 0.374\,g + 2.394 \times 10^{-3}\,g^2$ | 5~35 |
| | $N_{gyi} = -1.41 + 0.492\,g$ | >35 |
| L2 | $N_{gyi} = -0.94 + 0.442\,g + 1.122 \times 10^{-3}\,g^2$ | 5~65 |
| | $N_{gyi} = -4.61 + 0.571\,g$ | >65 |
| L3 | $N_{gyi} = -0.25 + 0.397\,g + 6.219 \times 10^{-4}\,g^2$ | 5~40 |
| | $N_{gyi} = -1.50 + 0.452\,g$ | >40 |

Source: Institute of Transportation (2008).

## 3. ESTIMATION METHOD OF $f_z$

### 3.1 Adjustment factor for the 2001 Taiwan HCM

In the 2001 Taiwan HCM, factors are used in Table 5 to adjust the capacity variation due to the difference in the location of the signalized intersections (Institute of Transportation, 2001). The current adjustment factor considers very few conditions. There are two main practical problems, the first is how to decide what is downtown and what is a suburban area, second there are no recommended values cited beyond what is available in Table 5.

Table 5 Intersection location adjustment factor in 2001 Taiwan HCM

| City | Downtown Area | Suburban Area |
|---|---|---|
| Taipei | 1.00 | 0.91 |
| Tainan | 0.94 | 0.92 |
| Kaohsiung | 0.97 | 0.93 |

Source: Institute of Transportation (2001).

### 3.2 Determination of $f_z$

The IOT collected field data in Taipei, Taichung, Tainan and Chiayi, and found that $N_{gyi}$ varied with the lane type and city location (Institute of Transportation, 2007; 2008). When the lane type is the same, the queuing discharge rate of a lane in a large city is often neither higher nor lower than the discharge rate in a small city. Therefore, the capacity estimation in the revised Chapter 13 estimated by means of a basic model established on data from Taipei city, then determined the adjustment factor, $f_z$. The main reason for using Taipei data as the basic model is due to the fact that Taipei has a variety of traffic lanes, traffic control conditions, and long queuing lengths. Consequently, the basic $N_{gyi}$ models were established based on huge amounts of field data on traffic lanes collected over several years by the IOT. This study plans to collect field data of traffic lanes shown in Tables 1 and 3 wherever possible, and try to estimate the adjustment factor $f_z$.

Taking S1 lane as example, this study introduces the following procedure to determine adjustment factor $f_z$. Compared with the lanes in Taipei city (shown in Figure 3), the discharge rate of S1 lane in another city was not definitely low. For example, the discharge rate in Taichung was higher than that of Taipei, and those in Chiayi and Tainan were generally lower than those of Taipei and Taichung, while Chiayi had the lowest discharge rate. Figure 4 shows the ratios of the discharge rate of Chiayi, Tainan, and Taichung to Taipei's rate under different green intervals. Figure 4 shows that during the green interval of 20s~40s, the discharge rate of the lane in Taichung was about 2%~6% higher than in Taipei, the discharge rate in Chiayi was 5% lower than in Taipei, while the discharge rates of Tainan showed a great variation in their discharge rate, and was from 3%~9% lower than that of Taipei.

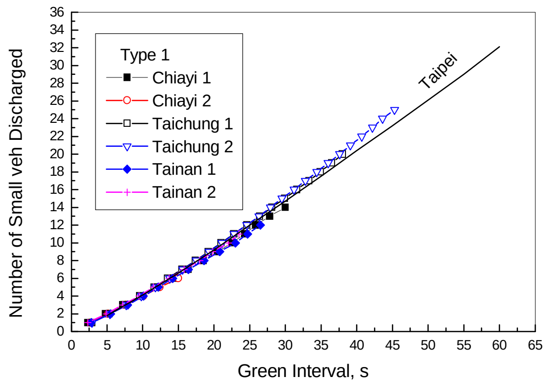



Figure 3 Comparison of the discharge rate of an S1 lane in another city with the same lane type in Taipei

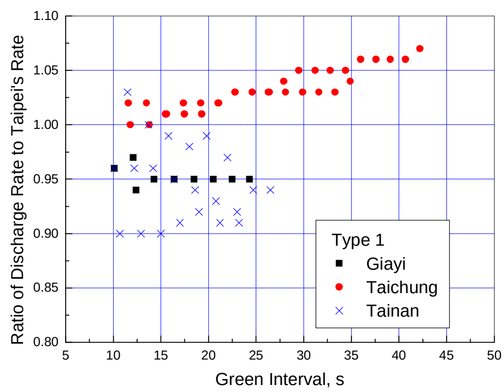



Figure 4 Ratio of the discharge rate of an S1 lane in another city and the discharge rate in Taipei

The city location factor $f_z$ was determined by using Figure 4. Thus the $f_z$ of a type S1 lane in different cities was: 1.00 in Taipei, 1.04 in Taichung, 0.95 in Tainan, and 0.95 in Chiayi. In practice, an $N_{gyi}$ estimation model of the S1 lanes in Table 2 can be used to obtain a basic discharge rate, then factor in the city location factor $f_z$, and then estimate the discharge rate.

The adjustment factor for other lane types in different cities can be determined in the same manner. In case of other types of lanes, the discharge rate can be estimated by using the equations in Table 2 and factor in $f_z$. The estimation logic and the procedure for unopposed left-turn lanes are applied the same way.

## 4. FIELD SURVEY

The estimation models of $N_{gyi}$ in Table 2 were created using the field data of Taipei's signalized intersections. However, even in the same type of lane, the discharge behavior may differ for different cities. Therefore, this study conducted a field data survey in various cities, including supplementary surveys in Tainan and Chiayi, and new survey in Kaohsiung, Chongli, Hsinchu and Taoyuan. These discharge data may strengthen the research results of the IOT and help determine the city location factor $f_z$. This study also consulted the IOT and was able to obtain its field data. Table 6 shows the summary information, which includes 32 straight-through lanes and 14 unopposed left-turn lanes.

Table 6 Analysis of field survey locations in various cities

| City | | Taichung | Tainan | Chiayi | Hsinchu | Kaohsiung | Taoyuan | Chongli |
|---|---|---|---|---|---|---|---|---|
| Population (1,000 persons) | | 1043 | 760 | 272 | 394 | 1515 | 377 | 351 |
| Area (km$^2$) | | 163.4 | 175.6 | 60.0 | 104.2 | 153.6 | 34.8 | 76.5 |
| Straight-through Lane | S1 | 2 | 3 | 2 | -- | 2 | 2 | 2 |
| | S3 | 3 | 1 | 3 | -- | 2 | -- | -- |
| | S4 | -- | -- | -- | -- | 2 | -- | -- |
| | S5 | 2 | 2 | 2 | -- | 2 | -- | -- |
| Unopposed Left-turn Lane | L1a | 1 | 1 | 1 | -- | 1 | -- | -- |
| | L1b | 2 | 2 | 1 | 1 | 1 | 1 | 2 |

Note: 1. Except for Taipei, there were no exclusive bus lanes in the other cities, and this study did not collect data about S2 type lanes.
2. Due to resource constraints, type S6, L2 and L3 type lanes were not included in this study.

There could be larger vehicles (i.e., buses, trucks) in the queues, although they are very few of them on the urban roads. This study focused on establishing a model based on passenger cars, and therefore eliminated the data of the large vehicles in queue and the following queuing vehicles. In practice, the large vehicles could be considered in the analysis and replace them with passenger cars (*pce*).

## 5. DATA ANALYSIS AND DETERMING $f_z$

### 5.1 Processing the field data

The field data was processed as follows:

(1) The discharge data of large vehicles and the following vehicles was eliminated.

(2) The average discharge headway at each queuing position on each survey location was calculated by the mean of each cycle. This study used the rule-of-thumb to eliminate the discharge headway data more than 2.5σ away from the mean.

(3) For the purpose of data reliability and representativeness, this study did not analyze the queuing position data of sample sizes below 15.

After the above initial data processing, the average discharge headway was obtained of each queuing position in the different types of lanes surveyed in various cities. Can the discharge data of the same type of lane in the same city be pooled? Taking Table 7 for example, the survey data of two S1 lanes in Taoyuan can use the above data process method to obtain the average discharge headway of each queue position. By using the statistical *t*-test to compare two average headways of the same queue position under two different sites, Table 7 shows that in Taoyuan all similar queuing positions have similar average discharge headway between two S1 lanes. Therefore, this study pooled the original data of 2 lanes and obtained a representative S1 discharge behavior for Taoyuan. This study adopted the same approach to analyze the same type of data in every city. The results all show that cars at a queuing position of the same type of lane in the same city have the same average headway. The integrated data is shown in Table 8.

Table 7 Test statistics of the field data of two locations at an S1 lane in Taoyuan

| Queuing Position | Location 1 (Dahsin W. Road/Yung-an Road) | | | Location 2 (Jinguo Road/Dahsin Road) | | | *t*-value |
|---|---|---|---|---|---|---|---|
| | Average Headway (s/car) | Standard Deviation (s/car) | Sample Size | Average Headway (s/car) | Standard Deviation (s/car) | Sample Size | |
| 1 | 3.58 | 0.61 | 50 | 3.90 | 0.69 | 40 | -1.64 |
| 2 | 2.94 | 0.83 | 50 | 3.09 | 0.53 | 43 | -0.76 |
| 3 | 2.52 | 0.57 | 50 | 2.50 | 0.48 | 47 | 0.13 |
| 4 | 2.31 | 0.53 | 49 | 2.27 | 0.56 | 46 | 0.25 |
| 5 | 2.03 | 0.38 | 44 | 2.04 | 0.40 | 48 | -0.09 |
| 6 | 2.24 | 0.62 | 45 | 2.11 | 0.46 | 47 | 0.81 |
| 7 | 1.92 | 0.42 | 39 | 2.04 | 0.49 | 41 | -0.83 |
| 8 | 1.91 | 0.40 | 37 | 2.07 | 0.50 | 47 | -1.15 |
| 9 | 2.09 | 0.49 | 36 | 1.90 | 0.49 | 45 | 1.23 |
| 10 | 1.91 | 0.45 | 39 | 1.85 | 0.50 | 41 | 0.40 |
| 11 | 1.90 | 0.48 | 32 | 1.88 | 0.50 | 40 | 0.12 |
| 12 | 1.91 | 0.41 | 32 | 1.89 | 0.42 | 37 | 0.14 |
| 13 | 1.76 | 0.29 | 29 | 1.88 | 0.38 | 38 | -1.04 |
| 14 | 1.86 | 0.42 | 30 | 1.77 | 0.47 | 40 | 0.60 |
| 15 | 1.92 | 0.43 | 27 | 1.75 | 0.36 | 39 | 1.21 |
| 16 | 1.77 | 0.41 | 19 | 1.66 | 0.23 | 23 | 0.77 |
| 17 | 1.91 | 0.52 | 17 | 1.81 | 0.46 | 21 | 0.44 |
| 18 | 1.59 | 0.37 | 10 | 1.71 | 0.27 | 10 | -0.59 |

Note: all statistical $t$ values in this table failed to reach a significant value, 1.69 at $\alpha = 0.05$.

Table 8 Field data after being integrated into this study

| Queuing Position | S1 | | | S3 | | | | S4 | S5 | L1a | L1a | L1b | L1a | L1b |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Taoyuan | Chongli | Kaohsiung | Taichung | Tainan | Chiayi | Kaohsiung | Kaohsiung | Kaohsiung | Tainan | Chiayi | Chiayi | Kaohsiung | Kaohsiung |
| 1 | 3.67 | 4.06 | 3.08 | 3.10 | 2.80 | 2.70 | 3.49 | 3.04 | 4.07 | 3.21 | 2.78 | 2.52 | 2.47 | 3.33 |
| 2 | 3.01 | 2.83 | 2.88 | 2.52 | 2.56 | 2.55 | 2.54 | 2.79 | 2.75 | 2.56 | 2.49 | 2.39 | 2.91 | 2.18 |
| 3 | 2.51 | 2.49 | 2.51 | 2.31 | 2.37 | 2.27 | 2.33 | 2.47 | 2.42 | 2.38 | 2.24 | 2.25 | 2.56 | 2.00 |
| 4 | 2.29 | 2.27 | 2.26 | 2.02 | 2.42 | 2.06 | 2.28 | 2.34 | 2.37 | 2.04 | 2.19 | 2.17 | 2.41 | 2.06 |
| 5 | 2.04 | 2.06 | 2.19 | 2.04 | 2.07 | 1.85 | 2.19 | 2.48 | 2.35 | 2.04 | 2.08 | 2.11 | 2.33 | 2.00 |
| 6 | 2.17 | 2.04 | 2.18 | 1.90 | 2.05 | 2.01 | 1.91 | 2.27 | 2.19 | 1.87 | 1.96 | 2.01 | 2.29 | 2.03 |
| 7 | 1.98 | 1.94 | 2.16 | 1.96 | 2.04 | 1.94 | 1.92 | 2.20 | 2.14 | 1.82 | 1.97 | 1.93 | 2.29 | 2.01 |
| 8 | 2.00 | 1.84 | 2.15 | 1.80 | 2.07 | 1.74 | 1.87 | 2.06 | 2.17 | 1.82 | 1.97 | 1.90 | 2.16 | 2.03 |
| 9 | 1.98 | 1.91 | 2.05 | 1.94 | 2.05 | 1.96 | 1.90 | 2.11 | 2.10 | 1.89 | 1.93 | 1.96 | 2.10 | 2.07 |
| 10 | 1.88 | 1.87 | 2.01 | 1.91 | 2.00 | 1.82 | 1.91 | 2.03 | 2.17 | 1.81 | 1.82 | 1.97 | 2.02 | 1.96 |
| 11 | 1.89 | 1.73 | 2.03 | 1.82 | 2.01 | 1.82 | 1.85 | -- | 2.09 | 1.77 | 1.82 | 1.98 | 2.04 | 2.05 |
| 12 | 1.90 | 1.73 | 1.99 | 1.85 | 2.05 | 1.79 | 1.79 | -- | 2.14 | 1.72 | 1.63 | 1.79 | 1.84 | 1.86 |
| 13 | 1.83 | 1.71 | 1.95 | 1.90 | 2.09 | 1.89 | 1.82 | -- | 2.03 | 1.70 | 1.62 | 1.79 | 1.75 | 1.96 |
| 14 | 1.81 | 1.75 | 1.96 | 1.83 | 2.00 | 1.72 | 1.81 | -- | 1.94 | 1.74 | -- | 1.79 | -- | 1.94 |
| 15 | 1.82 | 1.85 | 1.97 | 1.84 | 2.03 | 1.91 | 1.86 | -- | 2.00 | -- | -- | -- | -- | 2.04 |
| 16 | 1.71 | 1.79 | 1.90 | 1.82 | 2.06 | 1.90 | 1.88 | -- | -- | -- | -- | -- | -- | -- |
| 17 | 1.85 | 1.62 | 1.89 | 1.76 | 2.08 | 1.75 | 1.86 | -- | -- | -- | -- | --- | -- | -- |
| 18 | 1.65 | 1.62 | 1.78 | 1.66 | -- | -- | 1.81 | -- | -- | -- | -- | -- | --- | -- |
| 19 | -- | -- | 1.74 | 1.77 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 20 | -- | -- | 1.66 | – | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

### 5.2 Determination of the city location factor

This study applied the above data processing and the $f_Z$ determination approach from section 3.2 to obtain the city location factor $f_z$ of straight-through lanes (see Table 9) and unopposed left-turn lanes (see Table 10). These two tables were then combined with the research results of the IOT.

Table 9 City location factor $f_Z$ of straight-through lanes

| Lane Type | City | City Location Factor, $f_Z$ |
|---|---|---|
| S1 | Taipei | 1.00 |
| | Taoyuan | 0.93 |
| | Chongli | 0.94 |
| | Taichung | 1.04 |
| | Tainan | 0.95 |
| | Chiayi | 0.95 |
| | Kaohsiung | 0.92 |
| S2 | Taipei | 1.00 |
| S3 | Taipei | 1.00 |
| | Taichung | 1.06 |
| | Chiayi | 1.08 |
| | Tainan | 1.00 |
| | Kaohsiung | 1.02 |
| S4 | Taipei | 1.00 |
| | Chiayi | 0.90 |
| | Kaohsiung | 1.02 |
| S5 | Taipei | 1.00 |
| | Taichung | |
| | Green interval < 30s | 1.10 |
| | Green interval ≧ 30s | 1.15 |
| | Tainan | 1.14 |
| | Chiayi | 0.97 |
| | Kaohsiung | 1.00 |
| S6 | Taipei | 1.00 |

Note: this study primarily investigated S1, S3, S4 and S5 lanes.

Table 10 City location factor $f_Z$ of unopposed left-turn lanes

| Lane Type | City | City Location Factor, $f_Z$ |
|---|---|---|
| L1a | Taipei | |
| | Green interval ≦ 30s | 1.24 |
| | Green interval < 30s | 1.00 |
| | Taichung | 1.15 |
| | Chiayi | 1.16 |
| | Tainan | 1.14 |
| | Kaohsiung | 1.06 |
| L1b | Taipei | 1.00 |
| | Taichung | 1.43 |
| | Tainan | 1.15 |
| | Hsinchu | 1.25 |
| | Taoyuan | 1.11 |
| | Chongli | 1.13 |
| | Chiayi | 1.11 |
| | Kaohsiung | 1.09 |
| L2 | Taipei | 1.00 |
| | Taoyuan | 0.89 |
| L3 | Taipei | 1.00 |

Note: this study primarily investigated L1a and L1b lanes.

## 5.3 Discussion

Basically, the city location factor $f_z$ reflects the discharge characteristics of a city. Compared with the basic model of Taipei, $f_z > 1.0$ indicates that the discharge rate is higher than that of Taipei for the same type of lane; $f_z < 1.0$ indicates that the discharge rate is lower than that of Taipei. A greater $f_z$ value for the same type of lane in various cities also implies a higher discharge rate. Based on the $f_z$ values shown in Tables 8 and 9, the discharge characteristics of the straight-through lanes and unopposed left-turn lanes in various cities can be discussed in further detail.

It is known from the comparison of straight-through lane discharge rates in various cities that:

(1) For type S1 lanes (divided, without express/slow traffic separation device, not adjacent to exclusive bus lane) Taichung has the highest discharge rate ($f_z$ = 1.04). This may indicate that the drivers in Taichung are in more of a hurry. Discharge rates of other cities were roughly within 0.92~0.95, and below the discharge rate of Taipei.

(2) Type S2 lane (divided, without express/slow traffic separation device, adjacent to exclusive bus lane)
Since other cities had no exclusive bus lanes, no S2 lane data was collected in other cities.

(3) Type S3 lane (divided, with express/slow traffic separation device)
Chiayi ($f_z$ = 1.08), Taichung ($f_z$ = 1.08) and Kaohsiung ($f_z$ = 1.02) had higher discharge rates than Taipei. Tainan's discharge rate ($f_z$ = 1.00) was approximate equivalent to that of Taipei.

(4) Type S4 lane (undivided, with express/slow traffic separation device)
Kaohsiung ($f_z$ = 1.02) had a slightly higher discharge rate than that of Taipei, and Chiayi's discharge rate ($f_z$ = 0.90) was lower than that of Taipei.

(5) Type S5 lane (undivided, without express/slow traffic separation device)
The discharge rates of Taichung ($f_z$ = 1.05 or 1.10) and Tainan ($f_z$ = 1.14) were higher than that of Taipei. The discharge rate of Kaohsiung ($f_z$ = 1.00) was approximate that of Taipei. Chiayi's ($f_z$ = 0.97) was slightly lower than that of Taipei.

(6) Type S6 lane (left side adjacent to express/slow traffic separation device)
There was only data collected from 2 lanes in Taipei, and therefore it was recommended to increase the survey data if possible in the future.

Comparisons of the discharge rates of unopposed left-turn lanes in various cities:

(1) Type L1a lane (undivided, single left-turn)
The discharge rate before the 30s green light turned on ($f_z$ = 1.24) was higher than that after the 30s interval ($f_z$ = 1.00). The discharge rates in Taichung ($f_z$ = 1.15), Chiayi ($f_z$ = 1.16) and Tainan ($f_z$ = 1.14) were similar, while Kaohsiung's was slightly higher than Taipei's and somewhat lower than that of the other cities.

(2) Type L1b lane (divided, single left-turn)
Taichung had the highest discharge rate ($f_z$ = 1.43). The discharge rates of the other cities were all higher than that of Taipei. This might imply that drivers in other cities were more aggressive than those in Taipei.

(3) Type L2 lane (divided, double left-turn)
Data was only collected in Taoyuan, and the discharge rate there was smaller than that of Taipei ($f_z$ = 0.89).

(4) Type L3 lane (divided, triple left-turn)
There was no field data collected in other cities.

The difference in discharge behavior for the same type of lanes among various cities may be due to the urban road geometry, driving behavior, and how strict the traffic laws are enforced in that city. In order to construct a better methodology to analyze the capacity and the level of service at signalized intersections, it is necessary to collect as much as possible the various local field data to determine the driving behavior in that area.

## 6. CONCLUSIONS

Using the traditional concept of saturation flow rate to estimate the capacity of a lane or a group of lanes is not adequate for Taiwan. A better alternative to the traditional approach is to estimate the number of queuing vehicles that can be discharged in each signal phase. The IOT in Taiwan employed this approach to revise the Taiwan HCM. Several adjustment factors (i.e. city location, bus influence, etc.) were investigated in detail. This study focused on the adjustment factor $f_z$ for straight-through lanes and unopposed left-turn lanes in various cities.

According to the traffic characteristics and the capacity analysis of urban signalized intersections in the revised HCM Chapter 13 by IOT, straight-through lanes can be divided into six types and unopposed left-turn lanes can be divided into four types. The IOT showed that the queuing discharge characteristics varied with lane type and position, and that a nonlinear regression model can reflect precisely the discharge characteristics of most types of lanes. Therefore, this study collected the queuing discharge data on straight-through and unopposed left-turn lanes in cities of varied size including Hsinchu City, Taoyuan City, Chongli City, Taichung City, Chiayi City, Tainan City, and Kaohsiung City. Moreover, this study derived an analysis process to determine the city location factor, $fz$ , as shown in Tables 9 and 10). Finally, a comparison of the discharge rates of various types of lanes in different cities was discussed in section 5.3. These findings not only strengthen the capability of IOT analysis model but also the value of enhanced application.

Research on highway capacity and analysis of the level of service plays a key role in traffic control and traffic management. Taiwan still needs to invest substantial resources to establish an analysis methodology in compliance with local traffic characteristics.

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