

Queue Discharge Characteristics of Straight-through Lanes for Taiwan Depressed Urban Streets

Pin-Yi TSENG^a, Chiung-Wen CHANG^b, Hsin-Yi YANG^c

^a *Department of Traffic Science, Central Police University, Taoyuan, 333, Taiwan;
E-mail: una139@mail.cpu.edu.tw*

^b *Institute of Transportation, Ministry of Transportation and Communication,
Taipei, 105, Taiwan; E-mail: changcwn@iot.gov.tw*

^c *Traffic Division, New Taipei City Police Department, New Taipei, 220, Taiwan;
E-mail: w88934@hotmail.com*

Abstract: In Taiwan, the depressed urban streets were usually sited on intersections in urban area to bypass facilities and avoid the traffic congestion. The traffic flows of depressed urban streets were treated as the un-interrupted flows in the Chapter 10 "Depressed Urban Streets" of 2011 Taiwan Highway Capacity Manual (2011 HCM). But, the signals were usually settled in the depressed urban street upstream and downstream, and the traffic operation was affected by the signal control obviously. The analysis procedure in 2011 HCM was not realistic and practical. In order to explore the characteristics of the depressed urban streets and find the adjustment factor of slope for revising HCM, this study conducted the field data collection in 9 sites in Taipei metropolitan area. It was found that the queue discharge rates of the straight-through lanes of these streets were significantly lower than those of flat streets, and were affected by geometric design. And these findings could be useful for revising works.

Keywords: Capacity, Depressed urban streets, Geometric design, Queue discharge rate

1. INTRODUCTION

The Chapter 10 "Depressed Urban Streets" of the Taiwan Highway Capacity Manual (HCM) in 2001 and 2011 analyzed Taiwan's depress urban streets as the sections with un-interrupted traffic flow (Institute of Transportation, 2001; 2011). The analyses followed the procedures and data of U.S. HCM (Transportation Research Board, 2000). In fact, Taiwan's depress urban streets were between signalized intersections of short distances. In order to avoid grade crossing, these tunnels extended under the crossroad when they approach to the intersection, and the length of a depressed street seldom exceeded 600 m, even the length of the longest Cross-Harbor Tunnel of Kaohsiung City was only 1,600 m. That is, Taiwan's depress urban streets were slope sections on urban roads.

On the other hand, the distance between Taiwan's depress urban streets exit and downstream signalized intersection was very short. As a result, the traffic operations of these depressed streets were influenced by the signalized intersection capacity. And, the depressed street could influence the capacity of the signalized intersection, too. This interactive relationship could be discussed by the characteristic of depressed street downstream queuing vehicles discharge rate (Institute of Transportation, 2012). Therefore, this study collected field data in Taipei metropolitan area, and analyzed the queue discharge characteristics and the interaction with geometric design of depressed urban streets.

2. ESTIMATION METHOD OF LANE CAPACITY

The traditional capacity estimation method was based on the concept of the saturation flow rate. A better alternative to the traditional approach was to estimate the number of queuing vehicle that could be discharged in each signal phase (Lin, *et al.*, 2004; Lin and Thomas, 2005; Lin and Tseng, 2005). The Institute of Transportation (IOT) in Taiwan was employing this approach to revise the 2011 Taiwan HCM (Institute of Transportation, 2011). The last edition of Chapter 13 in the Taiwan HCM used the following equation to estimate the capacity of straight-through and unopposed left-turn lanes.

$$c = \frac{3600}{C} \left[\sum_{i=1}^n N_{gyi} \right] f_v f_g f_b f_s f_z f_p \quad (1)$$

where,

- c : lane capacity (vph),
- C : signal cycle length(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 traffic mix and 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 intersection location, and
- f_p : adjustment factor for pedestrian.

The adjustment factors of Eq. (1) presented in 2011 Taiwan HCM could reflect the impacts of different field conditions, and were proposed from relative researches. The main conditions include the traffic mix and direction, slope, bus station, roadside parking, intersection location, and pedestrian etc. For example, if the N_{gyi} value indicated the discharge queuing vehicles of left-turn lane, then there is no impact from bus operation, so the f_b is not necessary to adjust, $f_b = 1$.

There were six types of straight-through lanes in the last Chapter 13, and they were shown in Table 1. The N_{gyi} estimation model of each type was listed in Table 2, where g should be determined as per the following equation:

$$g = G + \beta \quad (2)$$

where,

- g : effective time phase (s),
- G : green interval (s),
- β : extended queuing discharge time after the green interval (s), default value: 3.5 s.

Table 1. Straight-through lane types in 2011 Taiwan HCM

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 (2011).

Table 2. Straight-through lane N_{gvi} estimation models

Lane type	Estimation model	g (s)	Eq.
S1	$N_{gvi} = -0.77 + 0.475 g + 1.273 \times 10^{-3} g^2$	5~55	(3.1)
	$N_{gvi} = -3.69 + 0.598 g$	>55	
S2	$N_{gvi} = -0.98 + 0.426 g + 1.105 \times 10^{-3} g^2$	5~60	(3.2)
	$N_{gvi} = -5.40 + 0.566 g$	>60	
S3	$N_{gvi} = -0.59 + 0.428 g + 1.250 \times 10^{-3} g^2$	5~50	(3.3)
	$N_{gvi} = -4.36 + 0.566 g$	>50	
S4	$N_{gvi} = -0.88 + 0.437 g + 1.783 \times 10^{-3} g^2$	5~50	(3.4)
	$N_{gvi} = -3.70 + 0.582 g$	>50	
S5	$N_{gvi} = -0.71 + 0.422 g + 1.500 \times 10^{-3} g^2$	5~70	(3.5)
	$N_{gvi} = -8.68 + 0.638 g$	>70	
S6	$N_{gvi} = -1.28 + 0.425 g + 1.150 \times 10^{-3} g^2$	5~50	(3.6)
	$N_{gvi} = -3.24 + 0.522 g$	>50	

Note: g refers to effectively used signal changing interval (seconds) by extending green time interval by about 3.5 seconds, N_{gvi} refers to the number of queuing straight-through small vehicles that can be discharged in g -second time interval of available time phase i .

Source: Institute of Transportation (2011).

The f_g (slope adjustment factor) of 2011 Taiwan HCM followed the 2001 Taiwan HCM (Institute of Transportation, 2001), defined as:

$$f_g = 1 - 0.015S \quad (4)$$

where, S is slope of road (%); upward slope (upslope) is positive, downward-slope is negative.

Chapter 18 of Taiwan HCM used the following equation to estimate the capacity of even exclusive motorcycle lane at signalized intersection (Institute of Transportation, 2008; 2011):

$$c = (4,836 + 1,900W_{90}) \left(\frac{G + \Delta G - L_s}{C} \right) (1 - 0.005S) \quad (5)$$

where,

- c : lane capacity (vehicles/hour),
- W_{90} : road width of utilization rate 90% (m),
- G : green time (≥ 10 seconds),
- ΔG : time spent by queuing vehicles entering intersection after green light (recommended: 3.5 seconds),
- L_s : start-up lost time (recommended: 2.9 seconds),

S : slope (%); upward slope is positive, downward slope is negative, and
 C : cycle length (seconds).

As the grade could influence the traffic flow operation at signalized intersection, this study aims to discuss the influence of upslope on the discharge capacity of downstream signalized intersections of Taiwan's depressed urban streets by gathering and analyzing field data.

3. FIELD DATA COLLECTION

At present, there were two main configuration of common depressed urban streets in Taiwan:

A. Physical separation (divided streets)

The two-way running vehicles were divided by physical facilities, generally there were more than two lanes in one way. There were three common road types:

A-1: two motorbike forbidden lanes, only for cars,

A-2: inside lane forbidding motorbikes, outside lane for both motorbikes and cars,

A-3: two motorbike forbidden lanes and one exclusive motorbike lane.



(a) A-1



(b) A-2



(c) A-3

Figure 1. Divided depressed Taiwan urban streets

B. Marking separation (un-divided streets)

There were two common narrow-width streets:

B-1: only one lane for cars and motorbikes mixed traffic, and

B-2: one lane for cars and one divided exclusive motorbike lane.

These depressed streets similar to that shown in Figure 2 were often seen in the west Taiwan cities, underground passing the western-railway.



(a) B-1

(b) B-2

Figure 2. Un-divided depressed Taiwan urban streets

In order to discuss the queuing vehicle discharge characteristics at downstream signalized intersection of depressed urban streets under various situations, this study made field investigation of nine lanes shown in Table 3. The no. 1~4 lanes were type S1, no. 5~6 lanes were type S4, no. 7 lane was type S5. All of these types had definitions in Table 1. The No. 8 and 9 in Table 3 were un-divided and divided exclusive motorbike lanes respectively. The general geometric conditions of various lanes were shown in Table 4.

Table 3. Field survey sites of Taipei depressed streets

No.	Street (Direction)	Downstream signalized intersection	Lane type (see Table 1)	No. of car lanes	Configuration
	Fu-Shing N. Rd. (N)	Bintze St.	S1	2	• A-2
2	Fu-Shing N. Rd. (S)	Minzu E. Rd.	S1	2	• A-2
3	Kee-Lung Rd. (N)	Songlong Rd.	S1	2	• A-1
4	Lin-Shing S. Rd. (S)	Roosevelt Rd.	S1	2	• A-3
5	Lee-Shing Rd. (S)	Dayong St.	S4	1	• B-2
6	Bar-Der St. (N)	Fu-Shing Rd.	S4	1	• B-2
7	Chung-Hsia E. Rd. (E)	Tianjin St.	S5	1	• B-1
8	Lin-Shing S. Rd. (S)	Roosevelt Rd.	exclusive motorbike lane (undivided)	2	• A-3
9	Bao-An St. (S)	Chengchi St.	exclusive motorbike lane (divided)	1	• B-2

4. DATA ANALYSIS AND COMPARISON

4.1 Divided, without Express/slow Traffic Separation Device, not Adjacent to An Exclusive Bus Lane (S1 Lanes)

Table 13.7 of Chapter 13 of the Taiwan HCM indicated that the representative queuing vehicle discharge rate of S1 straight-through express lane on even section can be estimated by Eq. (3.1) in Table 2. Figure 1 compared the discharge rate of even S1 lane estimated by Eq. (3.1) with the discharge rate of four downstream S1 lanes of depressed street in Table 1. It was observed that the discharge rate of depressed-street downstream S1 lane was lower than the representative queuing vehicle discharge rate of lane of the same type on even section.

Table 4. Geometric conditions of surveyed lanes

No.	Length of block section (m)	Length of depressed urban streets (m)	Lane width (m)	Average slope of depressed streets (%) ^a	Average slope within upstream 100 m (%) ^c
1	710	590	3.7	+4.3	+1.4
2	710	590	3.25	+6.2	+6.7
3	1,265	1,080	3.0	-2.1	-2.1
4	800	460	3.0	+5.9	+5.5
5	300	257	3.2	+4.8	+5.3
6	400	302	3.2	+4.4	+2.0
7	445	231	3.5	+4.0	+1.0
8	800	460	3.0	+5.9	+5.5
9	300	166	3.5	+5.2 ^b	+5.2

Notes: a. average slope from lowest point to site with upslope of +2%.

b. average slope from lowest point to downstream intersection stop line (slope +4.7%).

c. average slope within upstream 100 m of downstream stop line.

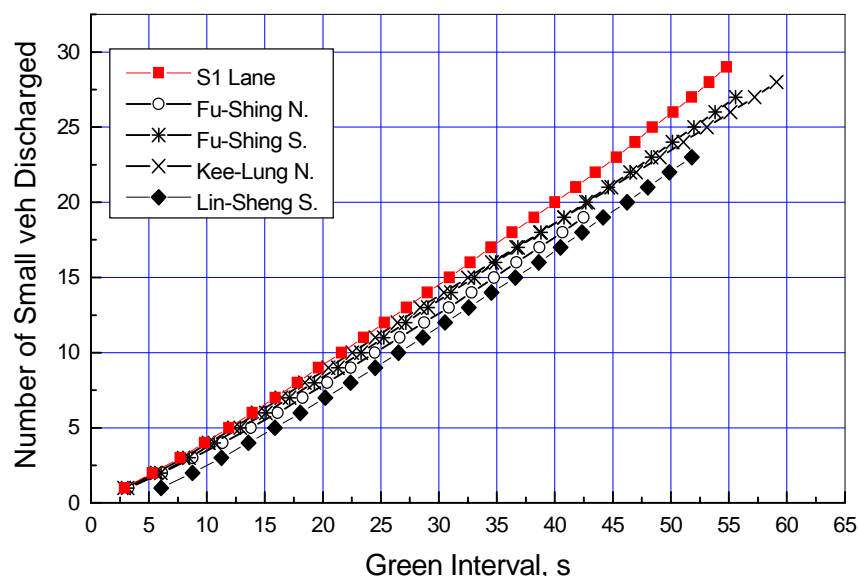


Figure 3. Relationship between passenger cars discharged on depressed urban streets and flat streets of S1 type lanes by green interval

If $(N_{gyi})_d$ represented the number of queuing vehicles on the depressed street downstream lane that can be discharged in green time interval, the ratio of $(N_{gyi})_d$ of the section with depressed street to N_{gyi} of even section was shown in Figure 3. In this figure, the slope of various lanes was the average slope from the stop line to the upstream 100 m. According to Figure 3, regardless of the length of the green time interval, the average queuing vehicle discharge rate of four depressed-street downstream lanes was approximately 90% of the discharge rate of the lane on even section. The slope influences the discharge rate more significantly when the green time interval was shorter than 20 seconds. When the green time interval exceeded 40 seconds and the slope was less than 7%, the discharge rate of depressed-street downstream lane approached to 50% of discharge rate of the lane on even section. The slope of southbound lane on Fu-Shing N Rd. was 6.7%, higher than the 5.5% slope of southbound lane on Lin-Shing S Rd., but the discharge rate was higher. It may

because the lanes on Fu-Shing N Rd. were wider. However, there have not yet been sufficient data to evaluate the influence of lane width.

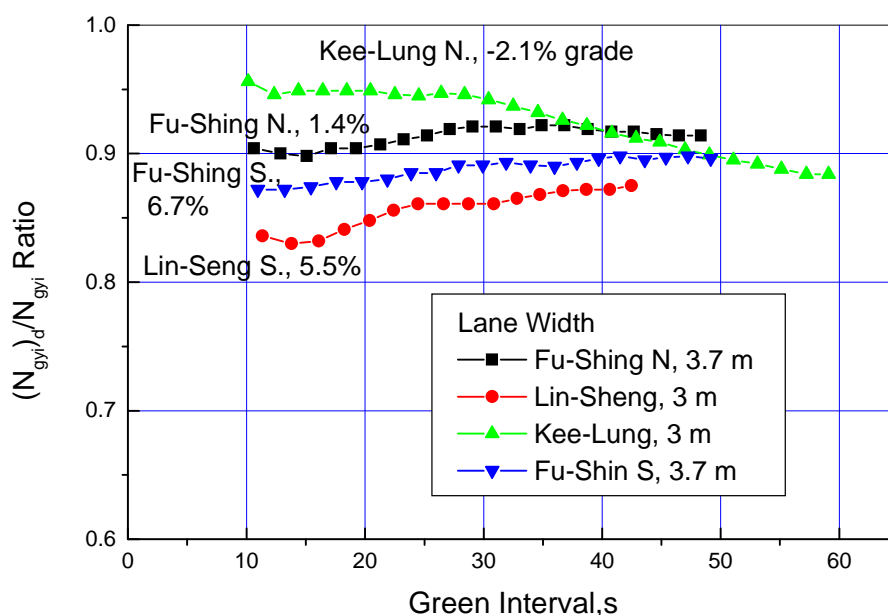


Figure 4. Ratio relationship between passenger cars discharged on depressed urban streets and flat streets of S1 type lanes by green interval

According to the above queuing vehicle discharge characteristics, this study used the following reduced relation to stipulate the influence of average slope of depressed-street downstream but within upstream 100 m of stop line on the discharge rate.

If the green time interval was shorter than 20 seconds, then

$$f_g = 0.93 - 12.38 \times 10^{-3} S \tag{6a}$$

If the green time interval was longer than or equal to 20 seconds, then

$$f_g = 0.92 - 6.39 \times 10^{-3} S \tag{6b}$$

In the above two equations, $f_g = (N_{gyi})_d / N_{gyi}$, was the adjustment factor for depressed-street downstream lane slope influencing queuing vehicle discharge rate. S was the average slope (%) within upstream 100 m of depressed-street downstream intersection stop line.

4.2 Undivided, with and without Express/slow Traffic Separation Device (S4 and S5 Lanes)

Table 13.7 of Chapter 13 of Taiwan HCM, 2011 used the following model to estimate the representative discharge rate of queuing vehicles of straight-through express lane (S4 lane) on even sections with center marking and with express/slow traffic separation device, as shown in Eq.3.4 of Table 2. The same table of HCM used Eq.3.5 of Table 2 to estimate the representative discharge rate of queuing vehicles of even straight-through express lane (S5

lane) on the sections with center marking and without express/slow traffic separation device.

Figures 5 and 6 compared the queuing vehicle discharge rates of S4 and S5 lanes on even section and depressed streets downstream section respectively. It was observed that the depressed-street downstream lane had lower discharge rate. If $(N_{gyi})_d$ represented the discharge rate of depressed-street downstream lane, the ratio of field $(N_{gyi})_d$ to N_{gyi} of even section estimated by Eq.3.4 and Eq.3.5 was shown in Figure 7.

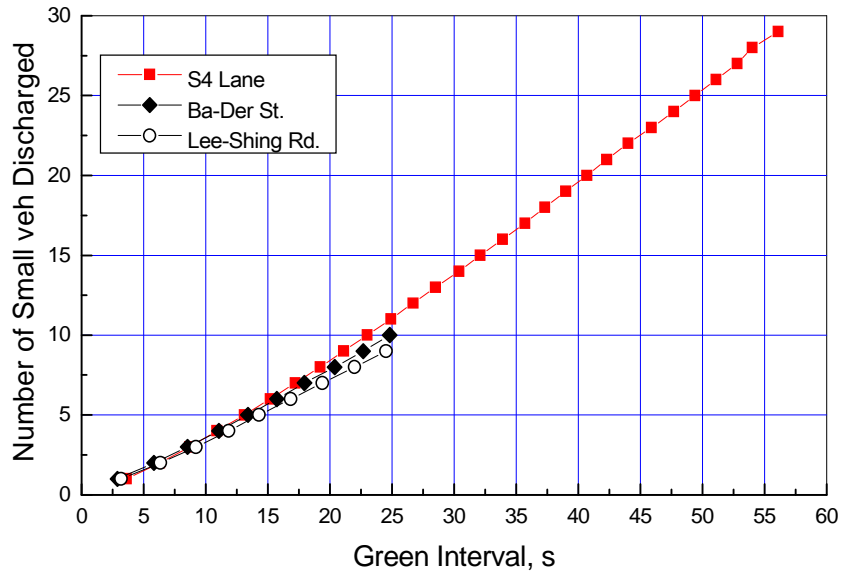


Figure 5. Queue discharge rate of depressed urban streets and S4 lanes

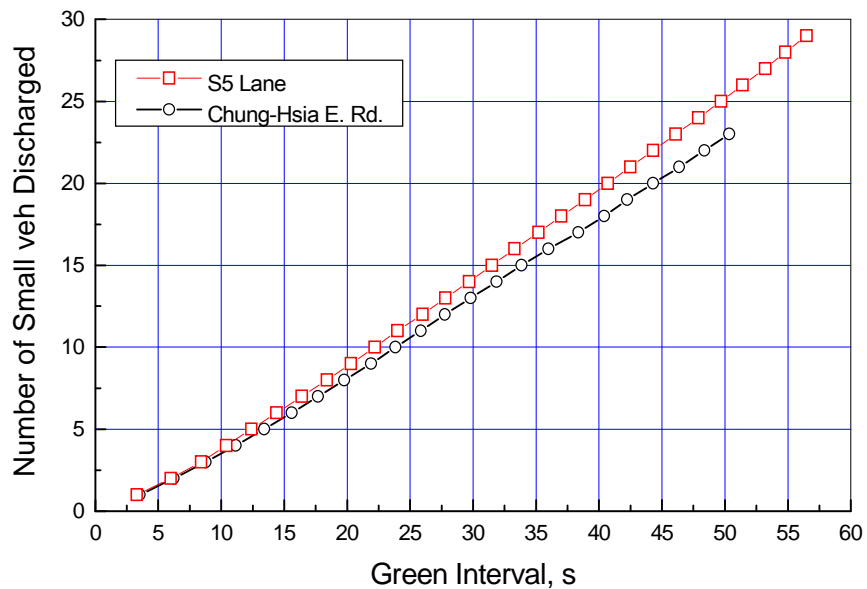


Figure 6. Queue discharge rate of depressed urban streets and S5 lanes

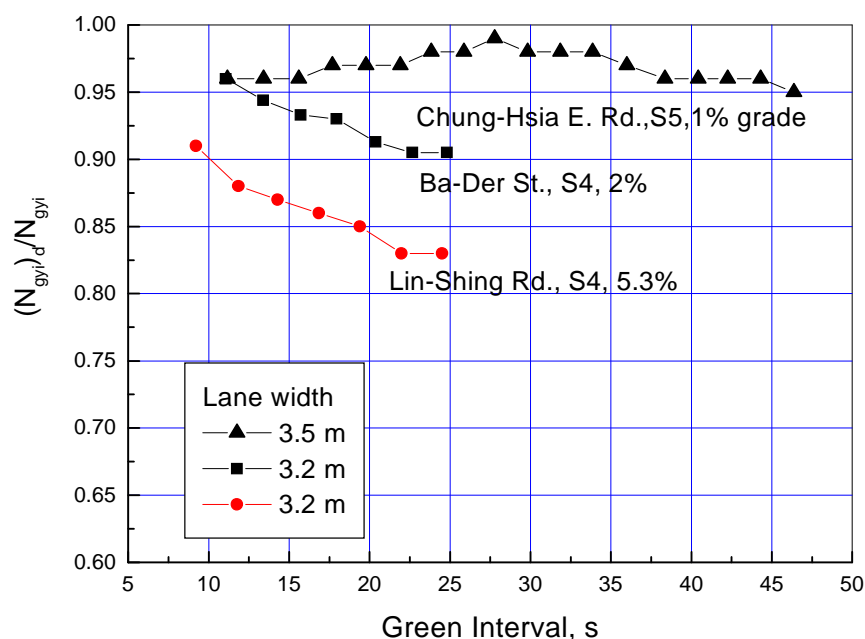


Figure 7. Relationship between the ratio of cars discharge rates of depressed streets and flat lanes (S4 and S5) under undivided road by green time interval

Among the three depressed urban through lanes in Figure 7, the eastbound S5 lane on Chung-Hsia E. Rd. was quite flat, the slope is only 1%, and it was slightly wider than the other two lanes. The ratio of the discharge rate of this lane to the discharge rate of S5 lane did not significantly vary by green interval. It was about 97% of the discharge rate of even section lane. The northbound lane on Bade St. and Lin-Shing Rd. had higher slope and smaller lane width. The ratio of the discharge rate of the two lanes to the discharge rate of S4 lane significantly varied by green interval, but the ratio shown to be stable when the green time exceeded about 22 seconds.

According to Figure 7, this study used the following adjustment factor to represent the influence of depressed-street on the discharge rate of marking separation lane (S4 or S5 lane):

If the green time interval was shorter than 20 seconds,

$$f_g = 0.77 + 0.23e^{-\frac{S}{5.708}} \quad (7a)$$

If the green time interval was longer than or equal to 20 seconds,

$$f_g = 0.72 + 0.28e^{-\frac{S}{5.537}} \quad (7b)$$

In the two equations, f_g represented the ratio of $N_{gyi}/(N_{gyi})_d$ in Figure 7 (i.e. depressed-street downstream slope adjustment factor). S represented the average slope (%) within upstream 100 m of stop line.

4.3 Exclusive Motorbike Lane

Figure 8 showed the relationship between the discharge rate and green interval of depressed motorbike lanes on Lin-Shing S Rd. and Bao-Ann St. The discharge rate of the aforesaid lanes reached its maximum within 10 seconds of green interval, and then decreased markedly and kept at an approximately stable value. This discharge characteristic was different from the discharge characteristic of exclusive motorbike lane in Chapter 18 of Taiwan HCM (Figure 9). Figure 9 showed the discharge rate had not reached a peak before dramatic decline.

Chapter 18 of HCM suggested using the average discharge rate after 10 seconds of green interval to estimate the saturation flow rate. According to this suggestion, the saturation discharge rate of exclusive lane on Lin-Shing S Rd. and Bao-Ann St. was 5,042 and 5,805 vehicles/hour respectively. An applicable start-up lost time might be estimated when these saturation discharge rates were used to estimate the capacity. The recommended start-up time in Chapter 18 of Taiwan HCM was 2.9 seconds. As the discharge rates of exclusive lanes on Lin-Shing S Rd. and Bao-Ann St. had reached a peak before dramatic decline, the applicable start-up lost time of these two lanes approached to 0 second.

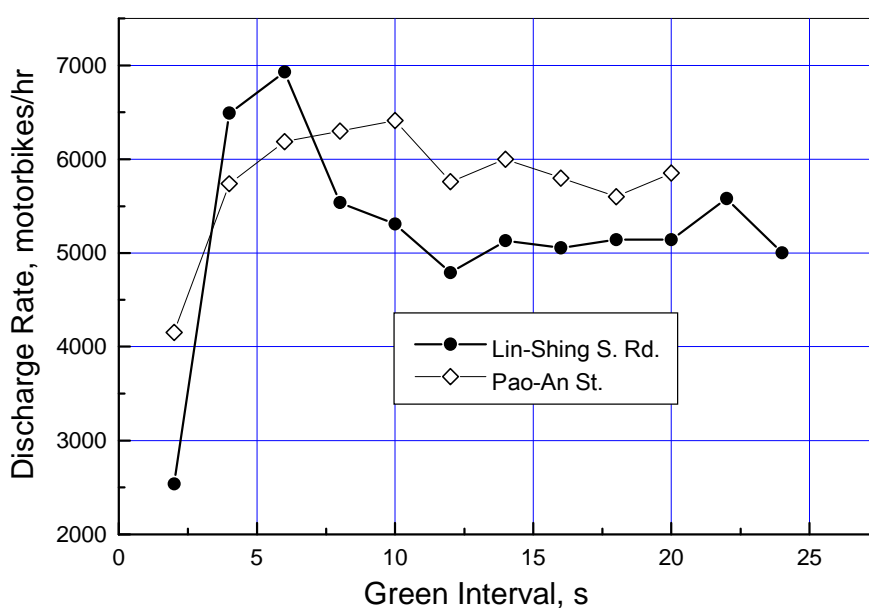


Figure 8. Relationship between discharge rate of downstream exclusive motorbike lane of depressed urban street by green interval

Chapter 18 of Taiwan HCM used the following model to estimate the saturation flow rate of exclusive motorcycle lane:

$$Q_{max} = 4,836 + 1900W_{90} \tag{8}$$

where,

- Q_{max} : saturation flow rate (motorbikes/hr), and
- W_{90} : road width of occupancy 90% during discharge of vehicles (m).

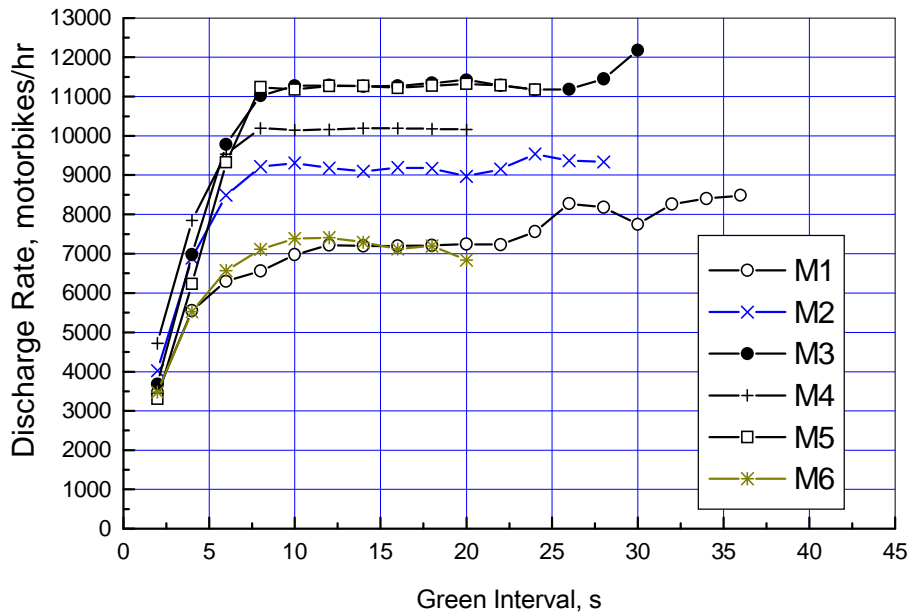


Figure 9. Relationship between queue discharge rate of motorbikes on exclusive motorbike lane by green time in Taiwan HCM

The W_{90} value of Lin-Shing S Rd. and Bao-An St. was 1 m and 2.7 m respectively. If the two W_{90} values were used in Eq.10.12 to estimate the saturation flow rate without depressed-street and slope, the saturation flow rate of exclusive lanes on Lin-Shing S Rd. and Bao-An St. should be 6,736 and 7,876 vehicles/hour respectively. The actual saturation flow rate was only 5,042 and 5,805 vehicles/hour. The ratio of actual saturation flow rate to flat section saturation flow rate was 0.75 and 0.74 respectively.

Based on the actual saturation flow rate was about 25% lower than the expected/saturation flow rate of even section, it might be because the average slopes within upstream 40 m and 100 m of exclusive lane stop lines on Lin-Shing S Rd. and Bao-An St. were very high, between +4.8% and +5.5%. Therefore, this study set the depressed-street downstream slope adjustment factor as:

$$f_g = 1 - 0.049S \tag{9}$$

5. DISCUSSIONS

According to the field investigation and data analysis of depressed urban streets in Taipei metropolitan area, and as compared with the characteristics of queuing vehicle discharge rate of even lane in Taiwan HCM, 2011, it is discussed as follows:

- 1) The present recommended slope adjustment factor in Chapter 13 and Chapter 18 of Taiwan HCM was referenced by U.S. 2000HCM, the discharge capacity of driveway decreases by 1.5% (Eq.4) as the slope increases by 1%, and that of exclusive motorbike lane decreases by 0.5% (Eq.5). However, the U.S. HCM had no practical definition of slope, according to Taiwan's field data, this simple relationship could not represent the influence of practical upslope in Taiwan.

- 2) In terms of the influence of upstream ascending driveway of stop line, besides the slope, the green interval and lane width had potential influence. Due to limited field data, the influence of lane width did not be determined at present, but the different green intervals had different effects, it was likely to be related to the hill-start operation of vehicles.
- 3) The lane widths, the average slope within upstream 100 m of stop-line and the slope adjustment factor f_g of Taipei urban depressed-streets, were listed in Table 5. Although Table 5 could not establish an effectively influence relationship, but it provided more knowledge with the influence of upslope on the queuing vehicle discharge capacity of signalized intersections.

Table 5. Adjustment factor of slop and average slop of urban depressed streets

No.	Lane type	Name of lane	Average slop of upstream 100m (%)	Lane width (m)	Adjustment factor for slope (f_g)
1	S1	Fu-Shing N. Rd. (N)	+1.4	3.70	0.91
2	S1	Fu-Shing N. Rd. (S)	+6.7	3.25	0.86
3	S1	Kee-Lung Rd. (N)	-2.1	3.00	0.93
4	S1	Lin-Sheng S. Rd. (S)	+5.9	3.00	0.80
5	S4	Lee-Shing Rd. (S)	+4.8	3.20	0.93
6	S4	Bar-Der St. (N)	+4.4	3.20	0.86
7	S5	Chung-Hsia E. Rd. (E)	+4.0	3.50	0.97

- 4) The f_g of depressed exclusive motorbike lane obtained in this study was shown as Eq.9, the saturation flow rate decreased by 4.9% as the slope increases by 1%, far larger than the recommended value (0.5%) in 2011 Taiwan HCM. It meant the upslope influenced the discharge of motorbikes on the exclusive motorbike lane obviously.
- 5) The part of other straight-through lanes shown that the 2011 Taiwan HCM had underestimated the effect of upslope on reducing the capacity of discharging queuing vehicles.

6. CONCLUDING REMARK

In academic development or practical application viewpoint, the upslope of stop-line upstream approach section could reduce the queuing vehicle discharge ability of signalized intersection. However, Taiwan HCM had no field data to estimate the influence of upslope on the discharge ability or capacity reasonably. This study used the field data of nine depressed-street lanes in Taipei metropolitan area to discuss the slope adjustment factor of straight-through lane and exclusive motorbike lane. The results showed that the f_g were from 0.80 to 0.97, that is, the queue discharge rate decreased sensibly and larger than the recommended value in 2011 Taiwan HCM. The slope adjustment factor in 2011 Taiwan HCM referenced by the U.S. HCM was not applicable in Taiwan environment, and they were underestimated. Although the slope adjustment factor relationship were not very precise, the existing research findings had been used for revising the Chapter 10 "Depressed Urban Streets" of 2011 Taiwan HCM, still providing the influence of upslope on the queuing vehicle discharge capacity of signalized intersections.

In order to get more precise characteristics, this study suggests collecting more field data of slope sections extensively in the future, the upslope part can be implemented at

depressed-street downstream signalized intersections, and the downward-slope part can be implemented at bridge downstream signalized intersections or off-ramp of elevated urban streets. During the collection of data, different lane patterns shall be discussed, and compared with domestic data of Taiwan HCM, so as to know the influence of slope (including upslope and downward-slope) on the queuing vehicle discharge capacity, and to determine the slope adjustment factor f_g applicable to Taiwan.

REFERENCES

- Institute of Transportation (2001) *2001 Highway Capacity Manual of Taiwan Area*, Report No. 90-16-1183, Ministry of Transportation and Communication, Taiwan.
- Institute of Transportation (2008) *Capacity and Service Analysis of Exclusive Motorcycle Lanes, Urban Bus Transit Facilities, and Urban Arterials (2/3)*, Report No. 97-94-1248, Ministry of Transportation and Communication, Taiwan.
- Institute of Transportation (2011) *2011 Highway Capacity Manual of Taiwan*, Report No. 100-132-1299, Ministry of Transportation and Communication, Taiwan.
- Institute of Transportation (2012) *Traffic Flow Characteristics of Toll Plazas, Tunnels, and Upgrade Segments on Freeways and other Roadways (2/3)*, Report No. 101-96-1315, Ministry of Transportation and Communication, Taiwan.
- Lin, F. B., and Thomas, D. R. (2005) Headway Compression During Queue Discharge at Signalized Intersections. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1920, TRB, National Research Council, Washington, D. C., 2005, pp. 81-85.
- Lin, F. B., Tseng, P. Y. and Su, C. W. (2004) Variations in Queue Discharge Patterns and Their Implications in Analysis of Signalized Intersections. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1883, TRB, National Research Council, Washington, D. C., pp. 192-197.
- Lin, F. B and Tseng, P. Y. (2005) Fallacies and Implications of Conventional Saturation Flow Model of Queue Discharge Behavior at Signalized intersections, *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 6, pp.1610-1623.
- Transportation Research Board (1985) *Highway Capacity Manual*, National Research Council, Washington, D. C.
- Transportation Research Board (2000) *Highway Capacity Manual*, National Research Council, Washington, D. C.