Development of Lane Configuration Adjustment Factors for the Capacity Analysis of Signalized Intersections.

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Abstract The capacity analysis procedures for signalized intersections included in Highway Capacity Manual (HCM) needs to consider lane configuration (Lane position and lane number) of a given intersection. However, the attention given to this matter appears to be inadequate. The main objective of this paper is to examine the effects of lane configuration on the saturation flow at signalized intersections of Asian cities. This paper also aimed at developing the saturation flow rate correction factors for lane configuration at signalized intersections. Analysis of variance (ANOVA) was performed to evaluate whether the lane configuration (lane position and lane numbers) of a given intersection had a significant impact on the saturation flow rate. Saturation flow rate adjustment factors for lane configuration are developed dividing the prevailing saturation flow rate by ideal saturation flow rate. It is suggested by the analysis that lane configuration have significant impact on the saturation flow at signalized intersection approaches.

Key Words Capacity reduction factors, Lane configuration, Queue position

I. Introduction

THE Capacity analysis procedure for signalized intersections included in the *Highway Capacity Manual* (HCM) needs to consider the lane configuration (lane position and number of lanes) of a given traffic intersection. However, the attention given to this matter appears to be inadequate. The intersection is a critical area in the effective use of streets and highways. It is the focal point of conflicts and congestion, since it is common to two or more roadways. As a result, the capacity of the intersection, particularly the signalized intersection, has been the subject of much research in recent years. At signalized intersections, the basic capacity is defined in terms of the saturation flow rate, that is, the capacity of the lane or approach assuming that the signal is green at all times. Saturation flow is the basis for the determining of traffic timing and evaluation of intersection performance. Capacity at intersections is based upon the concept of saturation flow and saturation flow rate. Capacity at intersections is defined for each lane group. The lane group capacity is the maximum rate of flow for the subjected lane group that may pass through the intersection under prevailing traffic, roadway and signalized conditions; this is in other words termed as saturation flow rate. The evaluation of capacity at signalized intersections is an important component in the planning operation, and design of urban roadway facilities. Saturation flow rate is estimated by adjusting the ideal or base value to reflect prevailing conditions. The general formula of estimating the capacity at signalized intersections in the *Highway Capacity Manual* [1] procedure can be expressed as:

$$s = s1 \times f1 \times f2 \times \ldots \times fi \qquad (1)$$

Where;

s = capacity under prevailing conditions (vph)

s_1 = capacity under ideal conditions (pcphgpl)

f_1 = adjustment factor for prevailing condition i.

In the chapter nine of HCM,[1] adjustment factors for various parameters are given in table 9-5 through 9-12. These include the adjustment factors for lane width, heavy vehicles, approach grade, parking activity, blocking effect of local buses, left-turn and right -turn movement, area type etc. The adjustment factor for lane configuration is not considered in HCM. It is suggested by the analysis that lane configuration have significant impact on the saturation flow at signalized intersection approaches. The average headway value of inner lane, outer lane and middle lane varies significantly for same lane width. So it is utmost important to include this adjustment factor for capacity analysis at signalized intersections.

The main objective of this paper is to examine the effects of lane position on the saturation flow at signalized intersections of Asian cities. This paper also aimed at examining the effects of number of lanes on the saturation flow. Finally development of the saturation flow rate correction factors for lane configuration at signalized intersections.

II. Previous Research

Stokes in his study suggested that intersection capacity is affected by a number of physical and operational features of the intersection [2]. The author also suggested that there are some external factors which affect intersection capacity and these external factors seem to be site specific, or at least local in nature. Table 1 summarizes the various elements typically affecting the saturation flow rate at signalized intersections.

Table 1. Principal factors affecting saturation flow at signalized intersections [2]

Factors	***Elements affecting saturation flow***
Geometrics	Width of approach, width of lanes, number of lanes, grade, radius of turn, length of turn bay
Operating conditions	Signal timing and phasing arrangements, peaking characteristics, parking activities, bus stop operations
Traffic characteristics	Traffic composition, turning movements, pedestrian activities
Environmental and other factors	Weather, driver behavior, area population, roadway surface conditions, adjacent land uses

Webster and Cobbe [3] established the relationships between intersection geometrics and saturation flow, which is perhaps the best-known research on this topic. They found that saturation flow is a linear function of approach width. According to their studies they suggested that, saturation flow with no turning traffic and with no parked vehicles on the approach is given by

$$s = 160\,w \qquad (2)$$

Where;

s = saturation flow rate (pch)

w = approach width (in feet)

Based on their studies they suggested that saturation flow rate increases by 3% for each 1% downhill gradient and decreases by 3% for each 1% uphill gradient. They also recommended that saturation flow rate for right-turn lanes and left-turn lanes be obtained separately.

Heidemann derived a theoretical model to analyze and describe the split of overall traffic volume among individual lanes and the frequency of lane changing on two-lane and three-lane unidirectional roadways. It was reported that these equations required a few parameters for calibration [4]. Yousif and Hunt reported lane changing behavior in the U. K. and lane utilization for two-lane and three-lane unidirectional carriageways. Observed data and a simulation program which models lane changing behavior were used for this purpose. The results showed high frequencies of lane changing occurring when the flow approaches a value of 1,000 veh/hr/lane [5].

Kimber and Semmens in their studies found that saturation flow at signalized intersections did not depend on the number of lanes, and no significant differences could be detected between near-side, central, and far-side lanes at multilane approaches [6]. Lee and Chen analyzed data from sixteen intersections in Lawrence and concluded that the signal type and the time of the day have a little influence on headways. They also found: vehicles in the inside lane have lower headways than vehicles in outside lane; longer queue lengths appear to produce shorter headways for vehicles [7]. Tsao and Chu analyzed data from two intersections of Taipei and concluded that average headways of heavy vehicles in through lanes are smaller than that of left-turn lanes. So they suggested that different adjustment factors for heavy vehicles should be used for through and left-turn lanes. Their results also suggested that in mixed traffic, the average headways for passenger cars and heavy vehicles are indifferent to the type of the vehicles immediately ahead [8]. Rahman et. al, introduced a new methodology for accounting the effect of large vehicle (vehicles more than four tire) on traffic performance at signalized intersections. Effects of large vehicles are estimated based on the delay caused by large vehicles considering each queue position of vehicle. The authors introduced concept of new PCE estimation method for large vehicles at signalized intersections. Their results suggested that, total delay caused by large vehicles is significant at the beginning of queue; furthermore, for the same percentage of large vehicles if the position of large vehicle in the queue varies, the increased delay caused by large vehicle also varies [9].

An overall review of the studies suggested that there are some controversies among the researchers. Kimber and Semmens concluded that headway of vehicles of inside and outside lanes is equaled on the other hand Lee and Chen found that these two type headways vary. So it is necessary to give attention on this issue. Furthermore past studies on effects of lane position and lane number on the saturation flow were also limited in scope. The main objective of this paper is to examine the effects of lane position on the saturation flow at signalized intersections of Asian cities. This paper also aimed at examining the effects of number of lanes on the saturation flow. Finally development of the saturation flow rate correction factors for lane configuration at signalized intersections.

III. Data Collection

A. Site Selection

Several criteria were used in the selection of study locations. The first was that the locations be in a similarity of land use areas as saturation flow rate varies depending on the land use pattern. The second was that all intersections have exclusive through movement lanes. The third criterion was that the locations be at signalized intersections with relatively heavy peak-hour volumes. The fourth criterion was that studied signalized intersection approaches have ideal conditions, that is, a 3.6 m (12 ft) lane width, a level approach grade, no pedestrians movements, no curb parking present, no near-side or far-side bus stop activity. With such criteria, ten intersections in Yokohama city were selected for this study. The selected intersections of Yokohama, Japan and their associated characteristics are summarized in Table 2. Fig. 1.represented a satellite image of a data collection site.

Table 2. Geometric and operating characteristics of data collection intersections

Intersection ID	*Green time (sec)*	*Speed limit (Km/hr)*	*Number of lanes*	*No. of cycle observed*
YIS – 1	78	50	3	34
YIS – 2	72	40	3	37
YIS – 3	80	50	4	43
YIS – 4	84	50	4	47
YIS – 5	84	50	4	35
YIS – 6	68	40	3	53
YIS – 7	60	40	3	46
YIS – 8	78	50	4	41
YIS – 9	80	50	4	36
YIS – 10	78	50	4	38

Fig 1. Satelite image of a Data collection Intersection

B. Method of Data Collection and Reduction

During the last three decades video tape recorder has proved to be the most popular alternative method of recording traffic behavior. This equipment has provided more satisfactory results than the time laps photography in its early stage. In order to avoid the human error vehicle movements were recorded by using a portable digital video camera system. All fields videotaping of traffic movements were conducted in August to December of 2011. In all more than twenty hours of traffic data were recorded on videotapes for this study. The tapes were first examined in the laboratory to screen out the valid cases. Only platoons containing unimpeded, straight-through passenger car stopped before entering an intersection were considered as valid cases for this study. The valid cases were later viewed on a television screen to extract the headways of passenger cars. Time code (TC) reader software was used to estimate the headways of passenger cars, which gives 1/30 second accuracy. During data processing phase the main manipulation was to input each data element by keystroke while the video tapes were played back.

From the data reduction phase, a total of 360 cycles were found to be valid for this study. For the first vehicle of a queue, its headway was taken to be the time elapse between the start of a green indication and the time at which the rear bumper of the passenger car cleared the stop line of intersection. For the other vehicles in the queue, the headways were taken to be the elapsed time, rear bumper to rear bumper, as successive vehicles passed an intersection stop line.

IV. Effects of Lane Configurations on Headway

Fig. 2 and Fig. 3 represented the relationships between average headways and queue positions of vehicles for different lane position and lane number respectively. As shown in Fig. 2 vehicles in the inner lane of an intersection approach have lower headways than vehicles in the middle lane and vehicles in the middle lane of an intersection approach have lower headways than vehicles in the outer lane. This relationship is true for all the queue positions. The general relationship of headway value of inner lane (h_i), middle lane (h_m) and outer lane (h_o) can be expressed as follows:

$$h_i < h_m < h_o \quad (3)$$

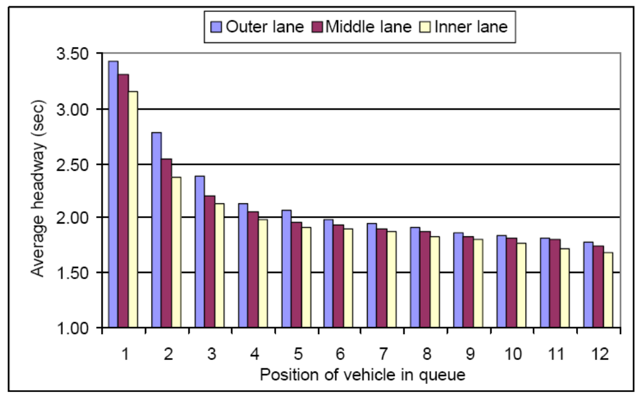

Fig 2. Effect of lane position on entering headways

In case of inner lane proportion of taxi is higher which resulted smaller headway value. According to Rahman et.al. when a taxi is the leader of a queue, its headway is smaller than a passenger car and this is also true for other position in the queue. They also developed saturation flow rate adjustment factors for taxi drivers and concluded that, when proportion of taxi increased from 0% to 100% for through traffic, saturation flow rate was increased by 20%, so capacity improvement possible at any intersections with higher proportion of taxi [10]. Moreover from the observed data it was evidenced that drivers of inner lane vehicles are always in hurry i.e. driving aggressively and some cases leader of the queue touches the stop line of intersection. Drivers of the vehicle at outer lane sometimes influenced by the roadside activities which may be resulted bigger headway value.

As shown in Fig. 3 headway value of a two lane approaches intersections produces the smallest headway value. But from the observed data it was evidenced that there is no general relationships between the headway values and number of lanes.

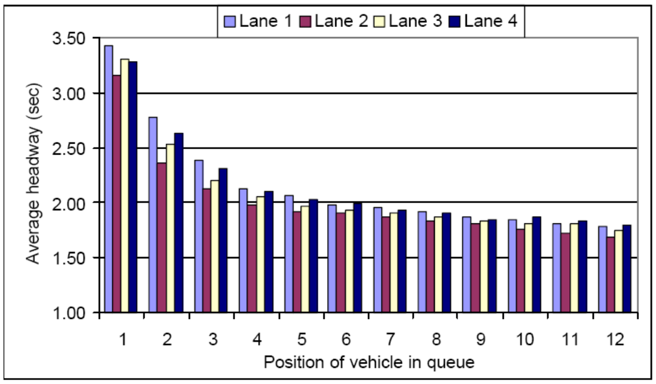

Fig 3. Effect of lane numbers on entering headways

V. Effect of Lane Configurations on Saturation Flow

In this study, saturation headway was calculated according to the HCM procedures. Saturation headway (H_s) was obtained from the average headway after the fourth vehicle in a queue. Saturation flow rate is the reciprocal of saturation headway.

$$Hs = \frac{\sum_{i=1}^{m}\sum_{j5}^{ni} Hij}{\sum_{i=1}^{m}(n_i - 4)} \quad (4)$$

Where,
Hs = saturation headway (sec)
Hij = discharge headway of jth queued vehicle in cycle i (sec)
ni = number of vehicles in queue of cycle i, ni > 4 and
m = total number of cycles during an observation period

One way analysis of variance (ANOVA) tests were conducted in this study to determine the significance of the differences among the saturation headways for different lane positions and lane numbers. The principal of an ANOVA table is to compare the F-value and the $F_{critical}$ value at a given confidence level. If F > $F_{critical}$ the null hypothesis will be rejected. Since the purpose of the test was to evaluate whether the lane configuration had a significant impact on the saturation headway at signalized intersections, the statistical basis for the ANOVA tests was: Ho: The lane configuration does not have a significant impact on saturation headway at signalized intersections and a confidence level of 95 percent (á = 0.05) was set for the tests. The results of the ANOVA on lane positions and lane numbers are presented in Table 3; the results indicate that F > $F_{critical}$. Thus null hypothesis H_o was rejected and we can conclude that lane configuration had a significant impact on the saturation headways, so much attention is required incase of capacity analysis of signalized intersections for different lane type and lane number.

Table 3. ANOVA test results for saturation headway and lane configuration

Parameters	F	$F_{critical}$	Comment
Lane position	7.82	5.14	Ho rejected
Lane number	11.64	3.24	Ho rejected

To observe the differences of saturation headways for different lane positions and different lane numbers t-tests were also performed. Table 4 and Table 5 represented the results of t-tests.

Table 4. Results of t-test for lane positions

Lane position	Observed t value	Critical t value	Comment
Outer vs. Middle	4.56	2.92	Significant difference
Inner vs. Middle	- 0.70	2.92	*Insignificant difference*
Outer vs. Inner	-3.53	2.92	Significant difference

Table 5. Results of t-test for lane numbers

Lane position	Observed t value	Critical t value	Comment
Lane 1 vs. Lane 2	6.08	2.13	Significant difference
Lane 1 vs. Lane 3	3.47	2.13	Significant difference
Lane 1 vs. Lane 4	12.03	2.13	Significant difference
Lane 2 vs. Lane 3	-0.77	2.13	*Insignificant difference*
Lane 2 vs. Lane 4	-0.67	2.13	*Insignificant difference*
Lane 3 vs. Lane 4	0.64	2.13	*Insignificant difference*

It is evident from t-test results that saturation headway of inner lane significantly different from that of middle and outer lane as shown in Table 4. From the t-test results of Table 5 it was concluded that, there is no clear relationship between saturation headways and number of lanes of an intersection approach. Saturation headways of an intersections approach having different lane numbers were not significantly different each other.

VI. Development of Lane Type Adjustment Factors

According to previous analyses the lane configuration factor did have a significant impact on saturation headway. Since saturation headway is one of the major parameters for capacity analysis at signalized intersections, the lane configuration factor had a significant impact on the capacity of signalized intersections. Thus in order to have a better estimation of capacity of signalized intersections; it would be helpful to quantify the impact by developing the lane-type adjustment factor.

In the HCM, adjustment factors are developed by dividing the prevailing saturation flow rate by the ideal saturation flow rate. Thus, saturation flow rate adjustment factors for lane-type $f_{\text{lane-type}}$ were estimated as follows:

$$f_{\text{lane-type}} = S_{\text{prevailing}} / S_{\text{base}} = H_{s(\text{base})} / H_{s\ (\text{prevailing})} \quad (5)$$

Where;

$f_{\text{lane-type}}$ = saturation flow rate adjustment factors for lane-type

$S_{\text{prevailing}}$ = saturation flow rate under prevailing conditions

S_{base} = ideal saturation flow rate

$H_{s(\text{base})}$ = base saturation headway

$H_{s\ (\text{prevailing})}$ = saturation headway under prevailing conditions

It was assume for this study that ideal saturation headway will be achieved at inner lane and saturation headway of inner lane will be considered as base saturation headway. From the observed saturation headway and using Equation 5, saturation flow rate adjustment factors for lane type were calculated and given in Table 6.

Table 6. Estimated value of lane type adjustment factor

Lane-type	Outer lane	Middle lane	Inner lane
Adjustment factor	0.88	0.96	1.00

As shown, adjustment factor for middle lane is 0.96 and 0.88 for outer lane respectively. In order to convenience in application adjustment factor for middle lane and inner lane is recommended 1.00 and for outer lane it is 0.88.

VII. Conclusion

A study on the impacts of lane configurations on the capacity of signalized intersections has been summarized. From the analysis in this study it was concluded that, lane configurations (lane position or lane type and lane number) had a significant impact on the saturation headways. Saturation headway values of inner lanes were the lowest and significantly different from the saturation headway of middle lanes and outer lanes. There is no clear relationship between saturation headway values and number of lanes. Saturation headways of different lane number were not significantly different each other except lane number two. From the analysis in this study, adjustment factor for lane-type was developed, which is 0.88 for outer lane and 1.00 for inner lane and middle lane.

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