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Capacity Analysis of Priority Intersections with Flare under Mixed Traffic Conditions

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Abstract

The gap-acceptance method is the common approach to assess the performance of the priority intersection which is implemented to regulate low volume of traffic flow. However, among the drawbacks of the gap-acceptance method are the non-compliance to the right of way, and the heterogeneous traffic condition. Conflict method has been developed to overcome these shortcomings. Surveillance equipment is used to obtain the required data, such as traffic volume and occupation time. The occupation time and approaching time of vehicle are used to calculate the capacity of vehicular movements for each conflict group. The results from intersections with flare and without flare are provided. Result comparison has also been made between the conflict method and the HCM 2000. The relationship between the occupation time and critical gap is discovered. The results of the conflict method are found to be comparable with the HCM 2000 using field data.

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Keywords: Conflict method, additive conflict flow, discharging service time, conflict group, gap-acceptance

1. Introduction

Traffic conflicts between vehicular movements are created when two or more roads cross each other. Such conflicts may cause delay and traffic congestion with the possibility of road accidents. Thus, each intersection

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requires traffic control. It is regulated with stop signs, traffic lights, and roundabout. The common type of intersection is the unsignalized intersection, which is used to regulate low volume of traffic flow between the major and minor streets. The Two-Way Stop-Controlled (TWSC) and All-Way Stop-Controlled (AWSC) are among the types of operation for unsignalized intersection. Unsignalized intersection operates without positive indication or control to the driver (Troutbeck and Brilon, 1992). It depends on the driver's decision to take the right opportunity to enter the major street.

The gap-acceptance method assumed the drivers to comply with the priority of right-of-way of each traffic stream. However, the gap-acceptance method has a few drawbacks (Brilon and Wu, 2002). It does not take driver behavior into consideration, particularly on the compliance with priority rules. Forced gap caused by aggressive driver, and polite behavior of drivers that purposely provide gap clearly are not in accordance to the rules of priority. The situation is worsened by heterogeneous traffic, a mix of motorized and non-motorized modes (Prasetijo, 2007; Prasetijo et al., 2011). Therefore, the conflict method has been developed to overcome the problems in the gap-acceptance method. The conflict method simplifies the intersection capacity analysis. It improves the reliability of the techniques used to assess the condition and design of unsignalized intersection.

The key parameter for the conflict method is the occupation time, $t_{B,q}$. It is the time spent by a vehicle for occupying the conflict area. The term $t_{B,q,m}$ and $t_{B,q,i}$ was used (Brilon and Wu, 2002) and implemented for non-priority intersections (Prasetijo et al., 2012), alternatively to describe the occupancy time of vehicles at the conflict area. Another parameter to be considered in the conflict method is the blocking time of conflict area due to approaching vehicle, $t_{B,a}$. Thus, the objectives of this study are to determine the occupation and approaching time of vehicle, and to evaluate the performance of different design of unsignalized intersection based on the occupation time values.

2. Conflict Technique Approach

Two T-intersections in Parit Buntar, Perak has been selected for this study. Parit Buntar Town intersection is labelled as Intersection A, while Jalan Sekolah intersection shall be Intersection B. Both intersections have a typical layout with the combination of shared lane and flared approach. Surveillance equipment is used during field observation. The video captured contains information such as the traffic volume for each stream, the time taken by the vehicles to occupy the conflict area, and the approaching time of major vehicles. Traffic count is conducted beforehand to identify the peak hour for suitable observation period.

A conflict group consists of several movements that cross the same area within an intersection (Brilon and Wu, 2002). Generally, the capacity of a minor stream is expressed by Equation (1). On the other hand, the proportion of time spent by discharging vehicle in the conflict area is calculated using Equation (2). The conflict area can be blocked by the approaching vehicles of higher priority. The proportion of time the approaching vehicle is blocking the conflict area is defined by Equation (3).

$$C_m = C_{max,m} \cdot p_0 \tag{1}$$

Where:

C_m	=	Capacity of movement m	[veh/h]
$C_{max,m}$	=	Maximum possible capacity of movement m	[veh/h]
	=	$\left(\dfrac{3600}{t_{B,q,m}}\right)$	
$t_{B,q,m}$	=	Occupation time of movement m	[s]
p_0	=	Pr(no blockage)	[-]

$$B_{q,m} = \frac{Q_m \cdot t_{B,q,m}}{3600} \tag{2}$$

Where:

Q_m	=	Traffic demand of movement m	[veh/h]
$t_{B,q,m}$	=	Occupation time of movement m	[s]

$B_{q,m}$	=	Proportion of occupancy by discharging vehicle m	[-]

with the restriction of $Q_m \cdot t_{B,q,m} \leq 3600$

$$B_{a,m} = \frac{Q_m \cdot t_{B,a,m}}{3600} \quad (3)$$

Where:

$t_{B,a,m}$	=	Approaching time of movement m	[s]
$B_{a,m}$	=	Proportion of period the conflict area is blocked by approaching vehicle m	[-]

The probability p_0 can also be computed as the product of the probability whereby the conflict area is not occupied by standing or discharging major vehicles, and the probability that the approaching major vehicles are not occupying the conflict area. It is computed using Equation (4). This study focuses on the T-intersection, shown in Figure 1. The capacity of each movement is computed using Equation (5) till Equation (10).

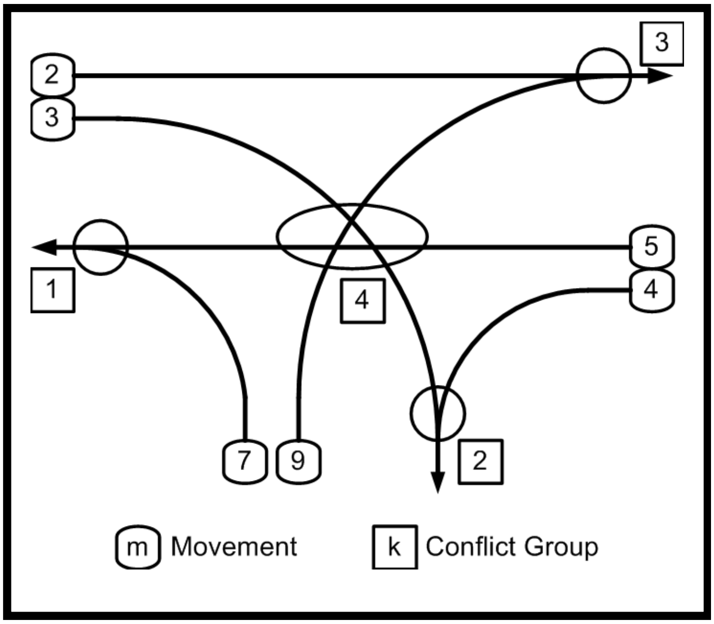

Fig. 1. Conflict groups at a T-intersection

$$p_0 = p_{0,q} \cdot p_{0,a} \quad (4)$$

Where:

p_0	=	Pr(no blockage)	[-]
$p_{0,q}$	=	Pr(no discharging of major stream vehicles	[-]
$p_{0,a}$	=	Pr(no approaching major vehicles)	[-]

and

$$C_2 = C_{max,2} \quad (5)$$
$$C_3 = C_{max,3} \cdot (1-B_{q,5}) \cdot (1-B_{q,4}) \cdot \exp[-(B_{a,5}+B_{a,4})] \quad (6)$$
$$C_4 = C_{max,4} \quad (7)$$
$$C_5 = C_{max,5} \quad (8)$$
$$C_7 = C_{max,7} \cdot (1-B_{q,5}) \cdot \exp[-(B_{a,5})] \quad (9)$$

$$C_9 = C_{max,9} \cdot [1-(B_{q,5}+B_{q,3})]\cdot(1-B_{q,2})\cdot\exp[-(B_{a,5}+B_{a,3}+B_{q,2})] \quad (10)$$

After the actual capacity is determined, the effective occupation time is calculated using Equation (11). A comparison can be made between the capacity values measured using the conflict method and the HCM 2000 for result validation. In HCM 2000, the performance of unsignalized intersection is indicated by the control delay, which is also applicable for the conflict method (Brilon and Miltner, 2005)

$$t_{B,q,m}^* = \frac{3600}{C_m} \quad (11)$$

Where:

$t_{B,q,m}^*$ = Effective occupation time of movement m [s]

C_m = Capacity of movement m [veh/h]

3. Occupation Time of Vehicular Movements

The orientation of vehicular movements at Intersection A is shown in Figure 2. Figure 3 depicts vehicular movements at Intersection B.

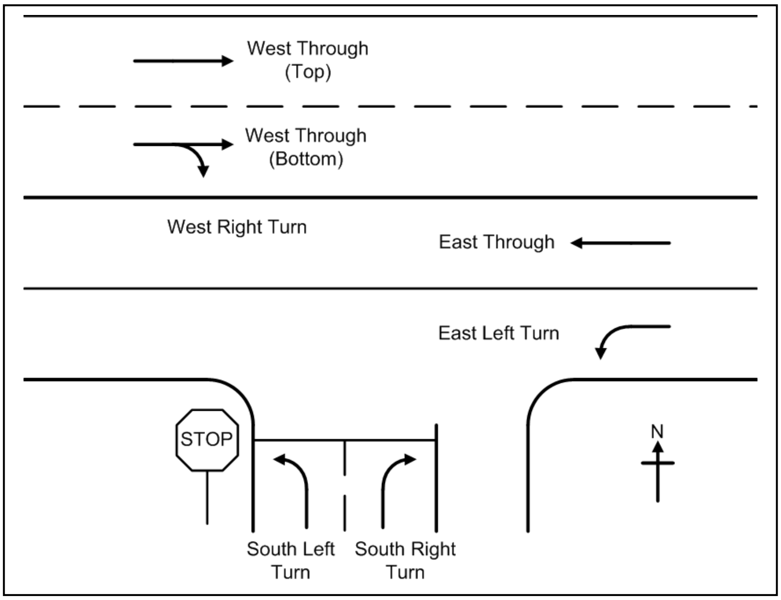

Fig. 2. Vehicular movements of intersection A

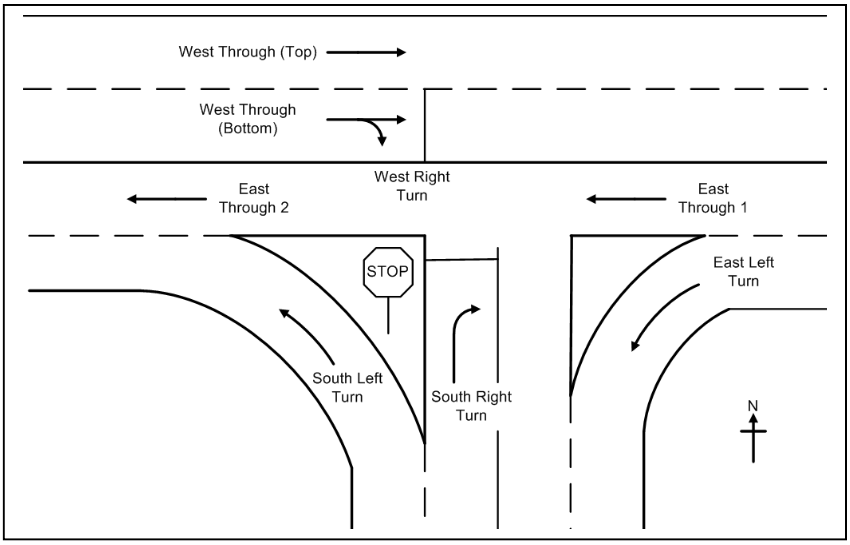

Fig. 3. Vehicular movements of intersection B with flare

Intersection A – no flare

Table 1 shows the occupation time for each movement at Intersection A. South left-turning vehicles have the lowest $t_{B,q}$ for turning movement. The travel distance between the south and west approaches is the shortest. The vehicles are able to cross the intersection faster. As a result, the occupation times of these turning streams are reduced.

Table 1. Occupation time of vehicular movement at intersection A

Vehicle movement	Occupation time (s)
South Left Turn	2.02
South Right Turn	4.85
West Right Turn	2.44
West Through (Bottom)	1.96
West Through (Top)	1.83
East Through	1.94
East Left Turn	1.64

The west right-turning movement has conflict with two movements of higher priority. Being the high-priority movement itself, the west right-turning vehicles have a small $t_{B,q}$. However, the occupation time of this vehicular stream is higher than the south left-turning movement due to the longer travel distance between approaches. It indicates the high travel speed of the west right-turning vehicles when entering the south approach. The highest $t_{B,q}$ is achieved by the south right-turning movement. This movement has the lowest priority among other vehicular movements. The conflict areas contain three major streams of different directions. The south right-turning movement also has the farthest travel distance to be covered in the conflict area.

The bottom lane of the west through movement is shared with the west right-turning movement. The observation of Intersection A showed the tendency of the south drivers to commit forced gap when entering the intersection. Drivers using the west through lane are cautious of the incoming vehicles from the south approach. The $t_{B,q}$ of the bottom lane indicates lower vehicular speed, contrary to the top lane of the west through movement. The top lane of the west through movement is less affected by conflicting vehicles. This lane is located away from the conflict area. Apparently, the vehicles can travel at higher speed. However, the $t_{B,q}$ of both lanes of the west through movement is almost equal. The east through movement is located next to the west through bottom lane. Both vehicular streams are in the same conflict group. Thus, their occupation times are comparable. On the other hand, the east left-turning movement has the lowest $t_{B,q}$ of all movements. This movement has the highest priority and the shortest crossing distance.

Intersection B – with flare

Intersection B introduce flare lane/channelized to improve its performance, especially on turning movements. Therefore, the west right turning vehicles have a shorter distance to cross the conflict area. On the other hand, the south left turning vehicles have a separate lane for left turn manoeuvre. However, the occupation times of both vehicular streams are nearly equivalent, as shown in Table 2. Apparently, they are blocked by the same movement from the east approach.

Table 2. Occupation time of vehicular movement at intersection B

Vehicular movement	Occupation time (s)
South Left Turn	2.52
South Right Turn	4.42
West Right Turn	2.58
West Through (Bottom)	1.35
West Through (Top)	1.29
East Through 1	1.12
East Through 2	1.20
East Left Turn	2.00

The $t_{B,q}$ of the south left turn movement is more than the occupation time of the same movement at Intersection A. The larger conflict area at the west approach of Intersection B is the cause of increased $t_{B,q}$ for the south left-turning movement. The channelization of traffic streams at Intersection B has no influence on the occupation time of the west right-turning vehicles. The value of its $t_{B,q}$ is almost similar to the west right-turning movement of Intersection A.

It is evident that the south right turn movement has the highest $t_{B,q}$. Compared to Intersection A, the channelization of Intersection B has reduced the occupation time of its movements by a small margin. Nonetheless, the south right-turning movements of both intersections are comparable due to similar traffic conflicts. The west approach has two lanes. The bottom through lane is shared with the right turn lane. However, the difference of $t_{B,q}$ values between the top and bottom lanes of the west through movement is insignificant. The shared lane does not impede the movement of the west through bottom vehicles. Similar result is achieved for Intersection A. It is due to the unsaturated condition of both intersections.

Intersection B has a divided south approach. The left turn and right turn of the south approach is separated to increase the capacity of both movements. This condition has created a space in between the turning lanes. Consequently, two streams of east through vehicles are produced. In the east approach, the second through movement has higher $t_{B,q}$ than its first through stream due to larger conflict area. It is also caused by the continuous deceleration of vehicles after leaving the intersection. The occupation times of both through streams are low due to the short travel distance between approaches. The east left-turning movement is supposed to produce small occupation time. In the case of Intersection B, large conflict area has caused this traffic stream to produce a higher $t_{B,q}$, although it has a separate lane. Besides this, drivers are cautious of the incoming vehicles from the west approach, which eventually reduces their vehicular speed.

4. Capacity of Vehicular Movements

Intersection A – no flare

Figure 4 shows the volume and capacity of the turning movements at Intersection A. The capacity values of these movements are expected to be lower than the major stream capacities. It is due to the impeding effect by major vehicular movements. The subject vehicles have to cross the conflict areas when entering the intersection. The volume and capacity of major movements at Intersection A are given in Figure 4. The south left turn stream has the highest capacity among other turning movements, which is the outcome of having a separate lane. The recorded occupation time of this movement is also the lowest. As a result, the south left-turning lane is able to cater more vehicles.

There are three impeding vehicular streams that are blocking the south right turn movement; as a result its occupation time is the highest among other turning movements. Due to the blocking major movements and high $t_{B,q}$, the south right-turning movement has the lowest capacity. The west right turn movement has similar priority with the south left turn stream. However, there is a vast difference between its volume and capacity values.

The major movements have absolute priority over the turning streams. Conflict areas do not obstruct the major street vehicles. In addition, the major streams have low occupation time. Therefore, they are expected to have higher capacity. It is evident from Figure 5. The east left-turning stream has the highest capacity due to the exclusive lane. It provided more space for the vehicles, with reduced traffic conflict. The shared lane condition of the west through bottom movement has minimal impact on its capacity.

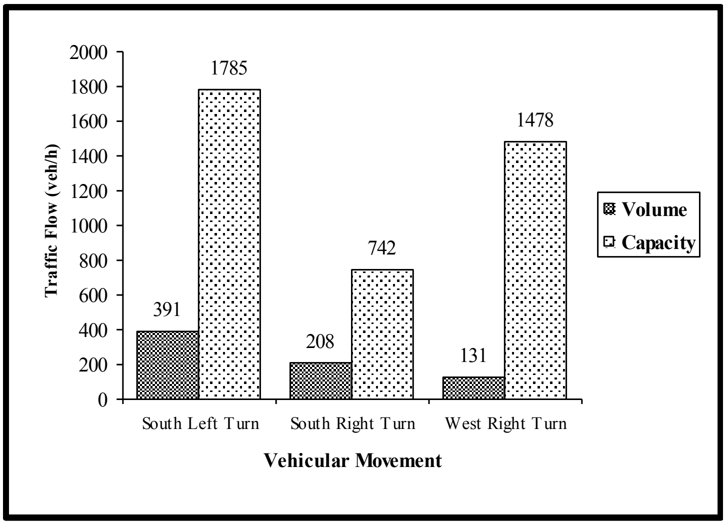

Fig. 4. Volume and capacity of turning movements at intersection A

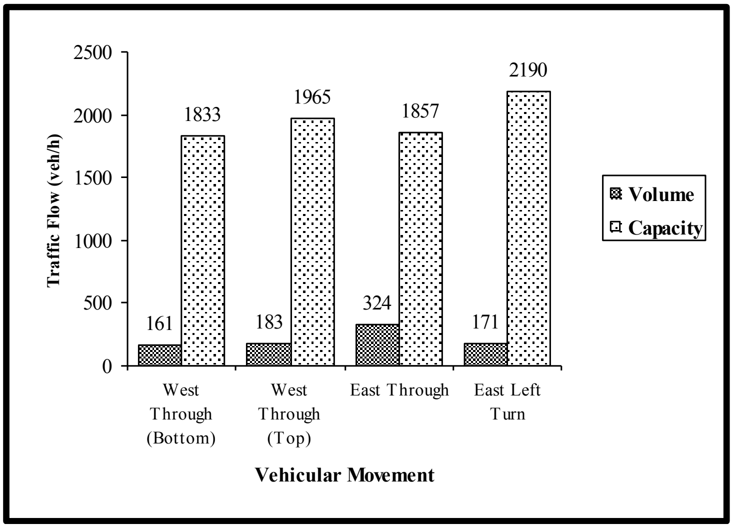

Fig. 5. Volume and capacity of major movements at intersection A

Intersection B – with flare/channelized

In Intersection A, the capacity difference between the south left turn and the west right turn streams is noticeable. However, the volume and capacity of both movements of Intersection B are almost similar. The site investigation has revealed that the south approach is leading towards schools. During peak hour, the traffic movements between the south and west approaches have produced such result, as shown in Figure 6.

The south right turn stream is predicted to have the lowest capacity. In the case of Intersection B, there is improvement over the same movement as compared to Intersection A. The intersection area is smaller, thus reducing the travel distance from the south approach to the east approach.

For west approach, although the bottom lane is shared, the capacity difference between west through and right turn movements is small. The traffic volume of the west through bottom lane is the lowest. This lane is mostly occupied by the west right-turning vehicles. Consequently, the drivers prefer the top lane of the west approach for through movement. Thus, the traffic volume at the top lane is more than the bottom lane, as shown in Figure 7.

The east through stream is analyzed separately due to the geometric condition of Intersection B. In this case, the minimum capacity value is selected for the east through movement. The second through movement has less capacity than the first through stream because of its larger $t_{B,q}$. Therefore, the second capacity value of 2997 veh/h is chosen to determine the control delay of the east through movement.

The least capacity of major movement is achieved by the east left-turning stream. It is due to the larger conflict area. Similar to the west right-turning movement, the drivers of the east left turn stream are being cautious of the incoming vehicles from the west approach.

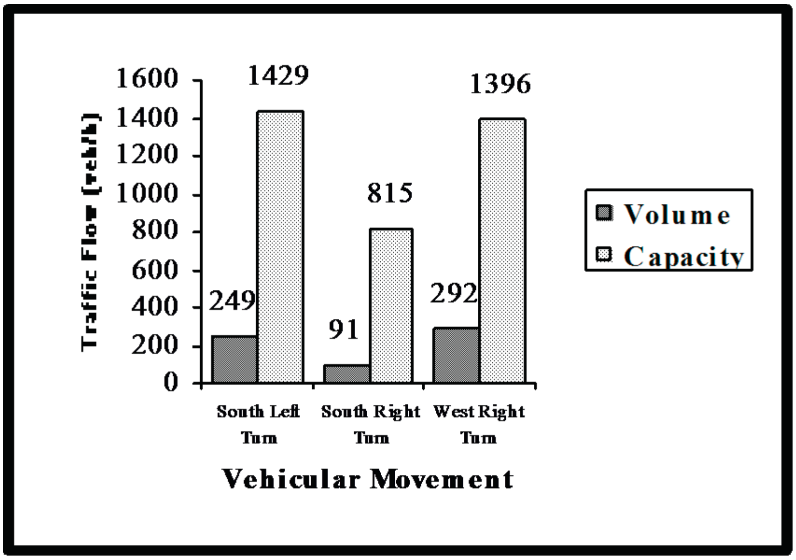

Fig. 6. Volume and capacity of turning movements at intersection B

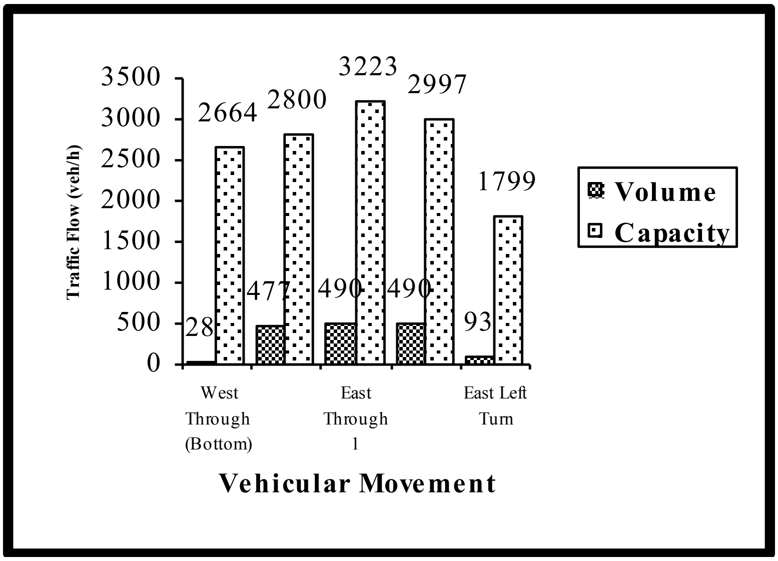

Fig. 7. Volume and capacity of major movements at intersection B

5. Results on Capacity Comparison of Turning Movements

Intersection A – no flare

The capacity comparison between the conflict method and the HCM 2000 procedures for turning movements is shown in Figure 8. The field data is obtained from data collection on site. The given data is based on the parameter values stated in the HCM 2000 (TRB, 2000).

Apart from the HCM 2000 using given data, the capacity values of the vehicular movements at the south approach are almost similar. However, the west right turn stream capacity has noticeable difference between each method.

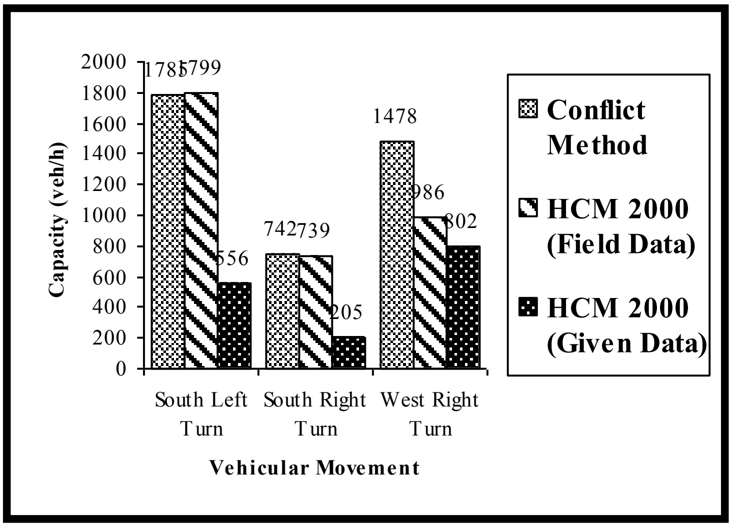

Fig. 8. Capacity comparison of turning movements at intersection A

Intersection B – with flare/channelized

As in Intersection A, the HCM 2000 method using given data has underestimated the turning stream capacity values, according to Figure 9. The south right-turning movement has the worst capacity of 86 veh/h, which is illogical. This anomaly is likely due to software issue during data analysis. The $t_{B,q}$ and $t_{c,field}$ values obtained with both methods are compared in Table 6. The occupation time and the critical gap are shown to be inversely proportional to the capacity, except for the south right turn movement. Small value of $t_{B,q}$ indicates that more vehicles can cross the conflict area, thus increasing the capacity. Similarly, the capacity values also increase when vehicles have small critical gap.

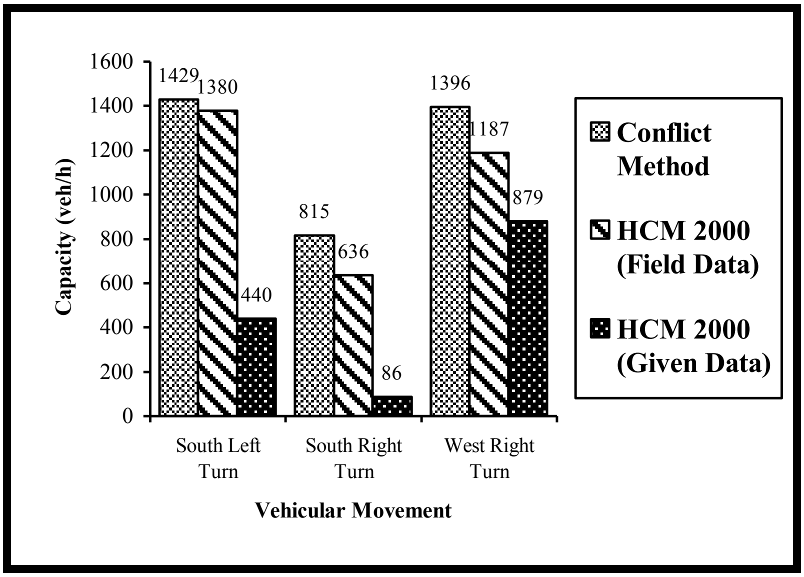

Fig. 9. Capacity comparison of turning movements at intersection B

6. Conclusions

Several methods have been developed to analyze the unsignalized intersection. Among them, the gap-acceptance method is the dominant approach. It is adopted by many countries in their capacity manuals. The gap-acceptance method has a simple concept. It depends on the driver's decision to accept or reject a gap before making any vehicular manoeuvre.

However, there are drawbacks to this approach, such as non-compliance to the priority rules. Efforts have been made to improve the reliability of the unsignalized intersection analysis. Conflict method was proposed to assist the current methods available. It is based on the interaction between vehicular movements and geometric design that created conflict areas in the intersection. According to the results from the data analysis, the following conclusions have been made:

(a) The occupation time is inversely proportional with the capacity of the vehicular movement. Small occupation time indicates that more vehicles are able to cross the conflict area in a given time period, and vice-versa. It can also provide an estimation of the vehicular speed when they are crossing the intersection.

(b) Long duration of occupation time is achieved due to slow-moving vehicles, large intersection area, and multiple blocking major streams. It will increase the delay of the vehicular movement, thus degrading its LOS.

(c) The exclusive lane for turning movement is capable to reduce the delay of vehicular stream. However, it still depends on the vehicular speed, and the traffic volume. On the other hand, the shared lane does not always impede the movement of turning streams, provided that the traffic volume is low.

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