Capacity of Unsignalized Intersections under Mixed Traffic Conditions

Joewono Prasetijo* , Mehdi Hossein Poura, Seyed Mohammad Reza Ghadiri

School of Civil Engineering, Universiti Sains Malaysia, Nibong Tebal, 14300, Malaysia

Abstract

A new method of capacity analysis at unsignalized intersections has been developed in this study for Indonesia where the driver’s behavior, traffic composition, level of roadside activities are different from those in developed countries. Typical cities in developing countries performed by the heterogeneous traffic mixed including fast–moving vehicles (motorized) and slow–moving vehicles (unmotorized). Traffic rules for examples like give-way or lane discipline are neglected in most cases. The study focused on ten three–leg unsignalized intersections in a suburban city in Indonesia. The new method was based on the interactions between conflict streams (six streams and six conflict points) having the average speed and flow of each stream. All possible conflict streams were considered simultaneously and the interactions were taken into account through empirical regression models. The results of capacity analysis from this proposed method correspond properly with the results from the current Indonesian Highway Capacity Manual (IHCM).

Keywords: Capacity, Unsignalized Intersection, Mixed Traffic, Conflict Streams

1. Background

Capacity at unsignalized intersections is measured by either gap acceptance or empirical regression approaches. The gap acceptance procedure (GAP) was developed in Germany (Harders, 1968) but it has been widely used in the United States and in several European countries. The basic principle of this method is to calculate the capacity at unsignalized intersections based on so–called critical gaps and follow–up times for the vehicles from the minor road. The empirical regression technique which was developed in the United Kingdom (Kimber and Coombe, 1980) is based on regression analysis on field data collected from modern British street. This approach of capacity estimation is also expanded by the consideration of road geometric design, visibility distances, demand flows, turning proportions and vehicle types.

A new method in calculating the capacity at unsignalized intersections is the “Conflict Technique”. This new approach is based on the method “Addition of critical movement flows” (Gleue, 1972). The theory was first developed by Wu (Wu, 1999; Brilon and Wu, 2001) for the American solution of All–Way Stop–Controlled (AWSC) intersections in such a way that the First–In–First–Out discipline applies. The model considers all possible
traffic streams and conflict points at intersections simultaneously. The interaction and impact of flows at the intersection is formulated by a mathematical approach. This procedure can also imply flows of pedestrians and cyclists crossing the intersection in Germany (Brilon and Miltner, 2005).

The concepts of the traffic flow theory in the United States, Europe, and Australia are formulated for motorized four-wheel which constitutes a homogeneous traffic flow. However, modes of heterogeneous traffic flow in developing countries consist of vehicles with varying dynamics and space requirements sharing the same road space. Therefore, the patterns of traffic behavior in developing countries are different from those of developed countries regarding unsignalized intersection. In these countries, the common rules of “give way” and “priority from the left” are not fully respected in most cases. The intersections are often blocked by drivers trying to “cut the corners” and they become more aggressive while approaching the intersections. The main objectives of this paper are two-fold. First, the paper investigates parameters that can be used to describe capacity of unsignalized intersections. Second, this paper develops new procedures of capacity measurement by taking into account mixed traffic flow at unsignalized intersections based on conflict streams.

2. Methodology

2.1. Study area and data collection

Ten three-leg unsignalized intersections in the city of Pontianak, Indonesia were investigated. The data obtained were considered reliable and fulfilling the minimum number of vehicles. Each of the intersections was different from each other in traffic performance and geometric design. Several aspects including traffic flow, road environment, speed, geometric design of the intersections, roadside activities, and type of areas (commercial, residential, limited access) at the major and the minor roads were considered at the given intersections during field investigation. These features were recorded by video camcorders and manually extracted from the videos. The intersections were chosen among places where the rule of priority was non-existent and all streams having an equal right in the hierarchy of departure mechanism. Each intersection was investigated during two expected peak hour periods - in the morning (06.30 – 08.30) and in the afternoon (14.30 – 16.30). All streams were observed by two camcorders (DCR–TRV 270E) with additional cassette (Hi8) placed at 3.5 meter high tripod and positioned at the edge of the road near the corners of the intersection. The position of the camera was chosen in such a way that the traffic movements could be observed clearly. Data from the measurements were counted from the recorded cassettes by using a special time-code machine and by monitors. First, data from the recorded Hi8 cassettes was converted to the VHS (Video Home System) video cassettes in order to get the time-code (the time-code recorder can only operate VHS video cassettes). Second, by viewing the monitor, time instants when the vehicles arrive and depart at specified points of the intersections were transferred into a personal computer using specific software in order to measure speed and flow.

2.2. Vehicle category

At the heterogeneous traffic situation, having an ideal capacity per lane is impractical due to the existence of very loose lane discipline. Each vehicle shares the road space and move by sharing the lateral as well as the linear spaces available. In heterogeneous traffic, entities form two-dimensional queues develop. For this traffic, models based on width acceptance can ultimately produce a good estimate of roadway capacity and assessments of operations and safety of various facilities available. Due to the presence of mixed traffic, it is necessary to categorize vehicles for model development as shown in Table 1.

2.3. Field data measurement
Speed distributions of each type of vehicles at the intersection are the most important characteristics to be measured for analysis. The speed was affected by number of interactions among flow streams, therefore, the speeds were measured based on arrival and departure time of every type of vehicle (as they were recorded) and the distance of every directions could also be measured by using the given line references at the intersection. The stream flows consisted of six streams as presented in Figure 1. The average speed of each stream was measured in relation to the interactions with other streams at the intersection. Typical speed performance of each stream is shown in Figure 2. Further analysis of the relationship between speed and traffic flow streams was established as a linear function (Kimber et al, 1980; Ramanayya, 1988; Bång et al, 1995).

### Table 1. Vehicle Categories for Analysis

<table>
<thead>
<tr>
<th>Vehicles</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck 3-Axle</td>
<td>Light Truck (LT)</td>
</tr>
<tr>
<td>Truck 2-Axle</td>
<td>Medium Heavy Vehicle-Truck(MHV₁)</td>
</tr>
<tr>
<td>Minibuses</td>
<td>Medium heavy Vehicle-Minibus(MHV₂)</td>
</tr>
<tr>
<td>Car</td>
<td>Light Vehicle (LV)</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>Motorcycle (MC)</td>
</tr>
<tr>
<td>Bicycle</td>
<td>Unmotorized-Bicycle (UM₁)</td>
</tr>
<tr>
<td>Rickshaw/Pedicab</td>
<td>Unmotorized-Rickshaw,etc.(UM₂)</td>
</tr>
<tr>
<td>Tricycles</td>
<td>Unmotorized-Tricycles (UM₃)</td>
</tr>
<tr>
<td>Pushcart</td>
<td>Unmotorized-Pushcart (UM₄)</td>
</tr>
</tbody>
</table>

A suitable correlation between the speed of light vehicles (LV) of each stream and flow of each type of vehicle of conflict group was found at almost all of the intersections. The relationship shows a suitable goodness of fit with $R^2$ in the range of 0.537 to 0.989. Therefore, the speed of light vehicles of each stream could be determined as

$$V_{LVi} = Const. - a_{LVi} \cdot Q_{LVi} - a_{HVi} \cdot Q_{HVi} - a_{MCI} \cdot Q_{MCI} - ... - a_{UMi} \cdot Q_{UMi}$$

where $V_{LVi} =$ speed of light vehicle (LV) at stream $i$ [km/h]; $Const.$ = constant value representing free-speed of light vehicle of stream $i$; $a_j =$ speed reduction effect of vehicle $j$ ($j$ = LV, HV, MC, UM) at stream $i$; and $Q_j =$ flow of vehicle $j$ at stream $i$ [pcu/h]

![Figure 1. Scheme of conflict of traffic streams.](image_url)

### 2.4. New approach development

The proposed analyses are based on interactions among streams in terms of speed and flow. Therefore, the parameters of each stream should be analyzed considering the effect of other streams. The scheme consisted of six streams (C–A, C–B, B–C, B–A, A–C, A–B) and six conflict points (1, 2, 3, 4, 5, 6). Furthermore, it is proposed to
have six groups of conflicts (I, II, III, IV, V, and VI) which include all streams’ conflicts and each group with its own subject stream, as shown in Figure 1 and Table 2. Since the study did not use any of the priority rules, six subject streams were defined for analysis. Each stream remains the subject stream of its conflict group and was included in the analysis to find maximum flow. In general, the conflict groups were defined as the subject streams which crossed conflict movement with other streams, e.g. subject stream C–A would only cross one conflict movement with stream B–A, but subject stream B–A would cross more than one stream (C–A, C–B and A–C).

![Typical mean speed of each stream](image)

**Figure 2.** Typical mean speed of each stream.

**Table 2. Interactions of Traffic Streams for Each Conflict Group**

<table>
<thead>
<tr>
<th>Group of Conflict</th>
<th>Subject Stream</th>
<th>Conflict Point</th>
<th>Streams Involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>C – A</td>
<td>1</td>
<td>C – A, B – A</td>
</tr>
<tr>
<td>II</td>
<td>C – B</td>
<td>2, 4, 5</td>
<td>C – B, B – A, A – C, A – B</td>
</tr>
<tr>
<td>III</td>
<td>B – C</td>
<td>3</td>
<td>B – C, A – C</td>
</tr>
<tr>
<td>IV</td>
<td>B – A</td>
<td>1, 4, 6</td>
<td>B – A, A – C, C – B, C – A</td>
</tr>
<tr>
<td>V</td>
<td>A – C</td>
<td>3, 5, 6</td>
<td>A – C, C – B, B – A, B – C</td>
</tr>
<tr>
<td>VI</td>
<td>A – B</td>
<td>2</td>
<td>A – B, C – B</td>
</tr>
</tbody>
</table>

For the present study, it is necessary to consider the traffic flow count for each of the six streams at intersections. Therefore, the scheme of three-leg unsignalized intersections was constructed for simplification and further analysis as it can be seen at Figure 1. Leg A and leg C were treated as the major roads because the traffic flows from these legs were larger than others without any implication to the priority rule. It was observed that the number of vehicles from legs C and A were higher than one from the leg B, thereby justifying leg A and leg C to be considered as majors road and leg B as minor road.

2.5. The relationship between speed and flow

Due to a large number of different parameter values with regard to various types of vehicles in this study, e.g. speed and flow, it is proposed to establish relationships among parameters including each vehicle’s performances (LT, MHV, LV, MC, UM) from each stream as follows:

For conflict group – $i$,

$$V_{LV,i} = A - K_{LV,i} \cdot Q_{LV,i} - K_{LV,streaminvolved} \cdot Q_{LV,streaminvolved} - \ldots - K_{VHi,streaminvolved} \cdot Q_{VHi,streaminvolved}$$ (2)
where $V_{LV_i} =$ speed of light vehicle (LV) stream $i$ [km/h]; $A =$ constant representing free–flow speed of light vehicle [km/h]; $K_{LV_i} =$ speed reduction factor caused by light vehicle (LV) stream $i$; $Q_{LV_i} =$ traffic flow for light vehicle (LV) stream $i$ [pcu/h]; $K_{VI_i} =$ speed reduction factor caused by vehicle type $i$; $Q_{VI_i} =$ traffic flow for vehicle type $i$ [pcu/h].

A suitable correlation between the speed of light vehicles (LV) of each stream and flow of each type of vehicle of conflict group was found at almost all of the intersections. The relationship was established between the speed of light vehicles of a subject stream and the flow of each type of vehicle included in the conflict group. Despite the speed and flow relationship among each type of vehicle from each stream, the relationship among the flow of each stream ($Q_{C_A}, Q_{C_B}, Q_{B_C}, Q_{B_A}, Q_{A_C}, Q_{A_B}$), each conflict group (I, II, III, IV, V, VI) and the speed of each stream ($V_{C_A}, V_{C_B}, V_{B_C}, V_{B_A}, V_{A_C}, V_{A_B}$) was also developed due to the fact that further capacity calculations would be based on each stream performance of every conflict group. The development of this relationship was required for further capacity analysis by the proposed approach, because the analysis would not be possible if the flows of each type of vehicle were counted separately.

3. Capacity of Unsignalized Intersections

3.1 Capacity estimation

Capacities at unsignalized intersections under mixed traffic flow with no gap acceptance behavior should be developed in a rather specific way. The tendency that drivers would not stop their vehicles and become more aggressive while they reach the intersection should be taken into consideration. Since drivers tend to maintain their speed rather than to stop at the intersection, speed is an important task to measure the quality instead of flow. Therefore, speeds of each conflict stream were considered in further analysis. Development of the capacity analysis by conflict stream is described in Figures 3 and 4.

![Figure 3. Stream $Q_C$ influenced by one conflict stream, $Q_B$ (I)](image3)

![Figure 4. Stream $Q_C$ Influenced by Two Conflict Streams, $Q_B$ (I) and $Q_A$ (II)](image4)

The relationships between speed and flow of conflict streams could be described as
\[ V_I = a_I - b_I Q_B - c_I Q_C \quad \text{(3)} \]
\[ V_H = a_H - b_H Q_A - c_H Q_C \quad \text{(4)} \]
where \( V_I, V_H \) = average speed at conflict point I and II [km/h], \( a_I, a_H \) = constant parameter representing free-flow speed at conflict point I and II [km/h], \( b_I, b_H \) = speed reduction coefficient caused by flow stream \( Q_A \) and \( Q_B, c_I, c_H \) = speed reduction coefficient caused by flow stream \( Q_C \). \( Q_A, Q_B, Q_C \) = volume of movements A, B, C [pcu/h].

By using a portion of flow \( f_i \) of each stream \( i \), \( (f_i) \) we have

For conflict point I,
\[ V_I = a_I - b_I f_1 \cdot Q_C - c_I Q_C \rightarrow V_I = a_I - b_I Q_B - c_I \frac{Q_B}{f_1} \quad \text{with} \quad f_1 = \frac{Q_B}{Q_C} \]

The equations can be solved for the flow rates, \( Q_B \) and \( Q_C \) at conflict point I:
\[ Q_C = \frac{a_I - V_I}{(b_I f_1 + c_I)} \quad \text{(5)} \]
\[ Q_B = \frac{a_I - V_I}{(b_I + c_I)} \quad \text{(6)} \]

And for conflict point II, we have:
\[ V_H = a_H - b_H f_2 \cdot Q_C - c_H Q_C \rightarrow V_H = a_H - b_H Q_A - c_H \frac{Q_A}{f_2} \quad \text{with} \quad f_2 = \frac{Q_A}{Q_C} \]

The flow rates \( Q_C \) and \( Q_A \) are
\[ Q_C = \frac{a_H - V_H}{(b_H f_2 + c_H)} \quad \text{(7)} \]
\[ Q_A = \frac{a_H - V_H}{(b_H + c_H)} \quad \text{(8)} \]

For further analysis of the maximum flow of the intersection, the following analogy can be made: If flow \( Q_A \) has reached its maximum flow,
\[ Q_A' = Q_{A\text{-MAX}} \text{ and } V_H = V_H' \quad \text{(9)} \]

Then
\[ Q_B'' = \left( \frac{a_I - V_I - c_I \left( \frac{a_H - V_H' - b_H Q_{A\text{-MAX}}}{c_H} \right)}{b_I} \right) \]
\[ Q_C'' = \left( \left( \frac{a_H - V_H' - b_H Q_{A\text{-MAX}}}{c_H} \right) \right) \]

The total flow of intersection (from the first alternative), \( Q_{\text{int}(1)} \) when \( Q_A \) has reached its maximum flow is
\[ Q_{\text{int}(1)} = Q_A' + Q_B'' + Q_C'' = Q_{A\text{-MAX}} + \left( \frac{a_I - V_I - c_I \left( \frac{a_H - V_H' - b_H Q_{A\text{-MAX}}}{c_H} \right)}{b_I} \right)_{\text{MAX}} \quad \text{+} \quad \left( \left( \frac{a_H - V_H' - b_H Q_{A\text{-MAX}}}{c_H} \right) \right)_{\text{MAX}} \quad \text{(10)} \]

When flow \( Q_B \) has reached its maximum flow,
\[ Q_B' = Q_{B\text{-MAX}} \text{ and } V_I = V_I' \quad \text{(11)} \]

Then
The total flow of intersection (from the second alternative), $Q_{\text{int}}(2)$ when $Q_B$ has reached its maximum flow is

$$Q_{\text{int}}(2) = Q_A'' + Q_B' + Q_C' = \left\{ \begin{align*}
Q_A'' &= \left( \frac{a_B - V_H - c_B Q_B''}{b_B} \right), 0 \right\}_\text{MAX}, \\
Q_B' &= \left( \frac{a_B - V_H - b_Q Q_B''}{c_B} \right), 0 \right\}_\text{MAX}, \\
Q_C' &= \left( \frac{a_I - V_I - b_I Q_C''}{c_I} \right), 0 \right\}_\text{MAX}. 
\end{align*}$$

When flow $Q_C$ has reached its maximum flow, there are two possibilities of maximum flow of $Q_C$: $Q_C' = Q_C'$ at $V_I = V_I'$ (conflict point I) and $Q_C'' = Q_C''$ at $V_H = V_H'$ (conflict point II).

Therefore,

$$Q_C' = \left( \frac{a_I - V_I - b_I Q_C''}{c_I} \right), 0 \right\}_\text{MAX}, \\
Q_C'' = \left( \frac{a_I - V_I - b_I Q_C''}{c_I} \right), 0 \right\}_\text{MAX}.$$ 

Then the maximum flow of $Q_C$ is $(Q_C', Q_C'')_{\text{MAX}} = Q_C'''$

$$Q_A'' = \left( \frac{a_B - V_H - c_B Q_C''}{b_B} \right), 0 \right\}_\text{MAX}, \\
Q_B' = \left( \frac{a_B - V_H - b_Q Q_B''}{c_B} \right), 0 \right\}_\text{MAX}, \\
Q_C'' = \left( \frac{a_I - V_I - c_I Q_C''}{c_I} \right), 0 \right\}_\text{MAX}.$$ 

The total flow of intersection (from the third alternative), $Q_{\text{int}}(3)$ when $Q_C$ has reached its maximum flow is

$$Q_{\text{int}}(3) = Q_A'' + Q_B' + Q_C'' = \left\{ \begin{align*}
Q_A'' &= \left( \frac{a_B - V_H - c_B Q_C''}{b_B} \right), 0 \right\}_\text{MAX}, \\
Q_B' &= \left( \frac{a_B - V_H - b_Q Q_B''}{c_B} \right), 0 \right\}_\text{MAX}, \\
Q_C'' &= \left( \frac{a_I - V_I - c_I Q_C''}{c_I} \right), 0 \right\}_\text{MAX}. 
\end{align*}$$

Where

- $Q_{\text{int}}(1)$, $Q_{\text{int}}(2)$, $Q_{\text{int}}(3)$ = Total maximum flow of intersection [pcu/h]
- $Q_A'_{\text{MAX}}$ = Maximum flow of stream A = $Q_A'$ [pcu/h]
- $Q_B'_{\text{MAX}}$ = Maximum flow of stream B = $Q_B'$ [pcu/h]
- $Q_C'_{\text{MAX}}$ = Maximum flow of stream C = $Q_C'$ [pcu/h]
- $Q_A''$ = Flow stream A while another stream reach its capacity [pcu/h]
- $Q_B''$ = Flow stream B while another stream reach its capacity [pcu/h]
- $Q_C''$ = Flow stream C while another stream reach its capacity [pcu/h]
- $Q_C'''$ = Maximum flow of stream C at second conflict with stream A at $V_I''$ [pcu/h]
- $V_I'$ = Speed at conflict point I while a stream reaches its capacity [km/h]
- $V_H'$ = Speed at conflict point II while a stream reaches its capacity [km/h]

Since the speed at the maximum flow of an intersection was not available or difficult to obtain, the speeds $V_I'$ and $V_H'$ were assumed, therefore the same value of speed for all streams was used in the analysis. In this situation, the maximum flow of intersection was defined as the minimum value of the total flows $[Q_{\text{int}}(1), Q_{\text{int}}(2), Q_{\text{int}}(3)]$ on the intersection.
First, the following coefficients are defined: $f_i = \frac{Q_{C-A}}{Q_{B-A}}$, $f_2 = \frac{Q_{C-B}}{Q_{A-B}}$, $f_3 = \frac{Q_{C-C}}{Q_{B-A}}$, $f_4 = \frac{Q_{C-B}}{Q_{C-B}}$, $f_5 = \frac{Q_{C-C}}{Q_{C-B}}$, $f_6 = \frac{Q_{C-C}}{Q_{B-A}}$

For each conflict point the model is described by a set of equations as follow:

$$Q_{C-A}^{(1)} = \left[ \frac{a_i - V_i}{b_i + c_i f_i} \right]_{\text{max}},$$

$$Q_{C-B}^{(1)} = \left[ \frac{a_i - V_i}{b_i + c_i f_i} \right]_{\text{max}},$$

Similar procedure can be followed for conflict point II to VI.

For the subject stream $Q_{C-A}$ to reach its maximum flow, $Q_{C-A}^{(1)}$ with conflict speed $V_i^{(l)}$, $V_{II}^{(l)}$, $V_{III}^{(l)}$, $V_{IV}^{(l)}$, $V_{V}^{(l)}$, $V_{VI}^{(l)}$, the maximum flow of the intersection is calculated as:

$$Q_{C-A}^{(1)} = \left[ \frac{a_i - V_i^{(l)}}{b_i + c_i f_i} \right]_{\text{max}},$$

where $C = \text{maximum flow (capacity) of the intersection [pcu/h]}$, $Q_{int}^{(i)} = \text{maximum flow of the intersection}$ when $Q_A$ is maximum, $Q_{A-MAX}$ [pcu/h], $Q_{int}^{(i)} = \text{maximum flow of the intersection}$ when $Q_B$ is maximum, $Q_{B-MAX}$ [pcu/h], $Q_{int}^{(i)} = \text{maximum flow of the intersection}$ when $Q_C$ is maximum, $Q_{C-MAX}$ [pcu/h].

### 3.2 Capacity analysis for three-leg unsignalized intersections

Further analysis was performed based on the observed data at three-leg unsignalized intersections as shown in Figure 1. As mentioned earlier, the study consisted of six streams, six conflict points (I, II, III, IV, V, VI), and six groups of conflicts (C–A, C–B, B–C, B–A, A–C, A–B). In general, the conventional traffic analysis does not include speed measurement at intersections. However, the proposed analysis included measurement of the average speed of each conflict point while crossing the intersection. Therefore, the new empirical relation is based on methods relying solely on the average speed of subject streams and the volume of each stream to determine the capacity as the maximum possible volume at the intersection. Speed and flow of each stream, as important parameters, were measured and analyzed for all intersections. Each of them was observed on the basis of each group of conflict. The descriptions of each conflict point are:

First, the following coefficients are defined: $f_1 = \frac{Q_{C-A}}{Q_{B-A}}$, $f_2 = \frac{Q_{C-B}}{Q_{A-B}}$, $f_3 = \frac{Q_{C-C}}{Q_{B-A}}$, $f_4 = \frac{Q_{C-B}}{Q_{C-B}}$, $f_5 = \frac{Q_{C-C}}{Q_{C-B}}$, $f_6 = \frac{Q_{C-C}}{Q_{B-A}}$
The maximum flow of the intersection at Alternative 1 with subject stream $Q_{C-A}$ is

$$C_1 = Q_{C-A}^{(1)} + Q_{C-B,MAX} + Q_{B-C}^{(3)} + Q_{B-A,MAX} + Q_{A-C,MAX} + Q_{A-B}^{(2)}$$

where $Q_{C-A}^{(1)}$ = maximum flow of stream $Q_{C-A}$ as an input flow [pcu/h], $V_i^{(1)} = \text{speed at conflict point } i \text{ when } Q_{C-A}$ reaches its maximum flow [pcu/h], $a_i^{(1)}$, $b_i^{(1)}$, $c_i^{(1)}$ = constant at conflict point $i$ when $Q_{C-A}$ reaches its maximum flow.

Following the same procedure, other alternatives (Alternative 2, $C_2$ to Alternative 6, $C_6$) which $Q_{C-B}$, $Q_{B-C}$, $Q_{B-A}$, $Q_{A-C}$, $Q_{A-B}$ could also be found and all possibilities of maximum flows that might occur at each stream were measured one after another and the maximum flow of the intersection would be the least maximum flow, as shown in Equation 18.

$$C \approx [C_1, C_2, C_3, C_4, C_5, C_6]_{MIN}$$

In order to simplify the calculation and presentation of data and results, a matrix for capacity analysis of the total intersection was used and it is shown in Table 3.

<table>
<thead>
<tr>
<th>Speed at Maximum Flows Subject Stream</th>
<th>Maximum Flows Subject Stream</th>
<th>Maximum Flows Stream</th>
<th>Total Maximum Flow at Intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{C-A}=V_{C-A}$</td>
<td>$Q_{C-A}^{(1)}$</td>
<td>$Q_{C-B}^{(1)}$</td>
<td>$Q_{B-C}^{(1)}$</td>
</tr>
<tr>
<td>$V_{C-B}=V_{C-B}$</td>
<td>$Q_{C-A}^{(2)}$</td>
<td>$Q_{C-B}^{(2)}$</td>
<td>$Q_{B-C}^{(2)}$</td>
</tr>
<tr>
<td>$V_{B-C}=V_{B-C}$</td>
<td>$Q_{C-A}^{(3)}$</td>
<td>$Q_{C-B}^{(3)}$</td>
<td>$Q_{B-C}^{(3)}$</td>
</tr>
<tr>
<td>$V_{B-A}=V_{B-A}$</td>
<td>$Q_{C-A}^{(4)}$</td>
<td>$Q_{C-B}^{(4)}$</td>
<td>$Q_{B-C}^{(4)}$</td>
</tr>
<tr>
<td>$V_{A-C}=V_{A-C}$</td>
<td>$Q_{C-A}^{(5)}$</td>
<td>$Q_{C-B}^{(5)}$</td>
<td>$Q_{B-C}^{(5)}$</td>
</tr>
<tr>
<td>$V_{A-B}=V_{A-B}$</td>
<td>$Q_{C-A}^{(6)}$</td>
<td>$Q_{C-B}^{(6)}$</td>
<td>$Q_{B-C}^{(6)}$</td>
</tr>
</tbody>
</table>

Table 3. Matrix of Maximum Flow of Intersection

3.3 Capacity comparison

The maximum flow at various speeds obtained from the model for all intersections and presented in Figure 5. The iteration of capacity calculation for both speed of 11 and 12 km/h, for example the intersection 1 indicated that the maximum flow decreased from 4577.34 to 3749.67 pcu/h. A similar analysis was performed for all intersections and the results showed that the capacity for the speed range of 10 to 12 km/h was similar to the capacity obtained from Indonesian Highway Capacity Manual (IHCM, 1997). A brief description on the fundamental understanding of the Indonesian highway capacity manual was given in the IHCM-1997. According to the manual, capacity at unsignalized intersections is defined as a result of the basic capacity within ideal traffic conditions related to various adjustment and correction factors, which included the impact of road environment, geometric design, and traffic conditions. The results of maximum flow from the conflict streams model and the manual are comparable and they are given in Figure 5.
4. Conclusions

The following conclusions can be made from the result analysis:

- The data collected from the three-leg intersections were found valuable in the traffic capacity analysis at unsignalized intersections in developing countries, such as Indonesia.
- Speed and flow measured in 5 minute intervals during one hour observations for each intersection was found appropriate for this analysis in developing the model.
- A model was developed by showing relationship between speed and flow at each intersection. The results showed that there is a good relation between speed and flow for each conflict group. Therefore, the capacity of intersections can be developed based on the relationship between speed and flow of streams at various conflict groups.
- The results obtained by the proposed method were compared with the Indonesian Highway Capacity Manual. The method produced similar values of capacity in the speed range of 11 to 12 km/h; hence it can be used for capacity analysis of unsignalized intersections in Indonesia.

References


