# DEVELOPMENT OF A NEW METHOD OF CAPACITY ANALYSIS AT UNSIGNALIZED INTERSECTIONS UNDER MIXED TRAFFIC FLOW (PRELIMINARY DESIGN FOR INDONESIA) 

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#### Abstract

Capacity at unsignalized intersections are measured with various approaches called as deterministic and probabilistic approaches. Gap acceptance procedure (GAP) is mainly used in United States and several European countries. This method is based on critical gap acceptance and follow up times of vehicles from the minor road. The second method is empirical regression approach which its application is mainly based on research investigation from British research result (Kimber and Coombe, 1980). This method is developed by a large number of measurement field data in modern British streets. New approach called conflict technique which is based on pragmatically simplified concept where interaction and impact between flows at intersection is brought through mathematically formulated. Indonesia Highway Capacity Manual-1997 (IHCM-1997) is one of an example of using the empirical approach, however, due to current behaviour, e.q. no gap acceptance behaviour, unmotorized attendance with 13 classes vehicles and large different speed, no exclusive lanes, no lane discipline and large number of conflict might be expected, therefore, investigation on total basic capacity, $\mathrm{C}_{0}$ and total actual capacity, C of intersection could be necessary to look further. With the conflict technique theoretical framework and First-In-First-Out mechanism for 12 streams of vehicles and 4 streams of pedestrian crossing, this preliminary investigation found that the method could be better to define the real capacity/ capacity conflict and service time of each stream of approaches based on the value of headway departure, $t_{B}$. Results shows that if we applied the value of base capacity, $\mathrm{C}_{0}$ for each of intersections, the value of $\mathrm{t}_{\mathrm{B}}$ are $3.03 \mathrm{~s}, 2.01 \mathrm{~s}, 2.42 \mathrm{~s}$ for intersection I, II and III. With the value of actual capacity, C, we found that $t_{B}$ values as $4.11 \mathrm{~s}, 2.21 \mathrm{~s}, 2.19 \mathrm{~s}$ for each of intersections. Those values seems very reasonable since there are no information on $t_{b}$.


Key Words : Unsignalized intersections, Conflict technique, First-In-First-Out mechanism, Headway departure, Capacity conflict

## 1. INTRODUCTION

In general, capacity at unsignalized intersection is measured with two approaches, e.q. gap acceptance procedure (GAP) and empirical regression method. GAP method mostly used in United States and Europen countries which is based on critical gap acceptance and follow up times of vehicles from the minor road. Empirical regression method is developed by a large number of measurement field data in modern British street to get the representative result. The third method is conflict technique with pragmatical simplified concept where the interaction and impact between flows/ streams from each approaches of intersection is brought through mathematically formulated. Indonesia Highway Capacity Manual (IHCM-
1997) is the current approach to measure the capacity and traffic performance (degree of saturation, delay and queue) ) based on research study of Swedish Road and Traffic Research Institute, SWEROAD. Study were conducted in Indonesia from December 1990 to February 1997.

## 2. GENERAL PROBLEMS

Traffic behaviour in developing countries are largely different from those developed countries. The common rules, e.q. give away, lane discipline and queue are very difficult to figure and to analyze with model such gap acceptance theory with stop or give away mechanism. Traffic composition of each types of vehicles are slightly different with different static and dynamic characteristics called as fast-moving vehicles and slow-moving vehicles. Exclusive lanes, especially for unmotorized or slow-moving vehicles are very uncommon. Impact from large different in speed could be serious problem in traffic operation, safety and capacity. Furthermore, typical road side activities have a very significant effect in reducing the capacity, e.q. pedestrian, stopping and parking vehicles and entering/ leaving vehicles.

## 3. OBJECTIVES OF THE STUDY

a. To conduct further investigation and review on Indonesia Highway Capacity Manual1997 relate to capacity at unsignalized intersection.
b. To develop a new methodology in measuring the capacity of unsignalized intersection relate to headway departure under mixed traffic flow based on conflict technique theoretical framework.

## 4. PROBLEM DESCRIPTIONS

### 4.1 Geometric Design Standard

IHCM-1997 is an up date manual for operational and design traffic flow in Indonesia. Standard for geometric design and road infrastructure are based on manuals of Standar Perencanaan Geometrik untuk Jalan Perkotaan (Direktorat Jenderal Bina Marga, Maret 1992) and Produk Standar untuk Jalan Perkotaan (Direktorat Jenderal Bina Marga, Februari 1987).

Table 1. Type of Intersections and Basic Capacity, $\mathrm{C}_{0}$

| Code of Type <br> of intersection | Number of legs | Number of lanes at <br> minor road | Number of lanes <br> at major road | Basic <br> capacity, $\mathrm{C}_{0}$ <br> (pcu/h) |
| :---: | :---: | :---: | :---: | :---: |
| 322 | 3 | 2 | 2 | 2700 |
| 324 | 3 | 2 | 4 | 3200 |
| 342 | 3 | 4 | 2 | 2900 |
| 344 | 3 | 4 | 4 | 3200 |
| 422 | 4 | 2 | 2 | 2900 |
| 424 | 4 | 2 | 4 | 3400 |
| 444 | 4 | 4 | 4 | 3400 |

Assumption are made that all types of intersections have kerbs, shoulders and medium number of side friction at the urban area and turn-over movement are allowed. Based on the manual that the intersections have zebra crossing at each of approaches/ legs of intersections and there are no stop or give away signs which mean all vehicles have no priority over another.

### 4.2 No Gap Acceptance Behaviour

Current traffic situation in Indonesia, traffic behaviour at unsignalized intersections with the common rules used in developed countries such give away, lane discipline and queue are very difficult to figure and analyze with such behaviour model as stop or give away which is mainly based on gap acceptance theory. Driver behaviour are slightly different from those of developed countries. The intersections are often blocked by drivers trying to `cut the corners` making it difficult to apply capacity manuals from developed countries. Previous study have shown that two-third of vehicles coming from minor road cross through the intersection without waiting the gaps.

Previous field of study have shown that vehicles tend to maintain their speed / reducing the speed (decelerate) while they reach the intersections and if there is no traffic present from the other approaches, a driver can proceed immediately, but if there is vehicles on one or more of the other approaches, based on rules that Left-Have-Right of Way, then the vehicles from the left have priority to pass the intersection. However, in such circumtances, this rule is not followed and not very well understood especially when degree of saturation is higher than 0.8 - 0.9 which traffic behaviour will be more agresif with higher risk that the intersections will be blocked by drivers who compete to pass within conflict area.

### 4.3 Non-Motorized Transport

Most of developing countries, e.q. Indonesia, has different traffic situation from those of developed countries. There are a large number of differences in driver behavior, traffic composition and level of roadside activities. In general, the traffic stream consists of two disctinct categories of vehicles, namely fast-moving (motorized) vehicles and slow-moving (non-motorized) vehicles. The static and dynamic characteristics of these two types of vehicles vary widely. The Indonesia Highway Administration distinguishes between 13 classes of vehicle for its routine classified counts. In the Indonesia Highway Capacity Manual, the following seven vehicle classes were distinguished as Light vehicles (LVs) : passanger cars, jeeps, minibuses, pickups, microtrucks, Medium heavy vehicles (MHVs) : two-axle trucks with double wheels on the rear axle, buses shorter than 8 m , Large trucks (LTs) : three-axle trucks, Truck combinations (TCs) : truck plus full trailer, articulated vehicle, Large buses (LBs) : buses longer than 8 m , Motorcycles (MCs), Un-motorized vehicles (UMs) : mainly tricycles and bicycles.

### 4.4 No Exclusive Lanes For Slow-Moving Vehicles

Exclusive lanes for Non-Motorized Transport (NMT) are rather uncommon in Indonesia. Much less attentions were given in providing adequate and suitable NMT facilities. The strategy in solving urban transportation problems still concentrate heavily on the motorized
transport without much considerations on the role of NMT in the transportation planning. However, a slow-moving vehicle with a speed of about 9 to $12 \mathrm{~km} / \mathrm{h}$ and the speed differences with fast-moving vehicle of about 45 to $60 \mathrm{~km} / \mathrm{h}$ could be a serious problem in traffic operation and might reduce the capacity of the road.

### 4.5 Typical Roadside Activities

Road side activities at the edge of the road is a very typical condition which has a significant impact on traffic flow based on road environmental type (commercial, residential, restricted access). The types of side friction events were recorded manually in the IHCM field surveys :

- PED : number of pedestrians, whether walking or crossing,
- PSV : number of stops by small public transport vehicles
- EEV : number of motor vehicle entries and exits into and out roadside properties,
- SMV : slow-moving vehicles (bicycles, trishaws, etc.)

A single measure of side friction (FRIC) was determined empirically equal to the sum of the weighted impacts of each of the four frictional items as,

$$
\begin{equation*}
\text { FRIC }=0,6 \times \text { PED }+0,8 \times \text { PSV }+1,0 \times \text { EEV }+0,4 \times \text { SMV } \tag{1}
\end{equation*}
$$

## 5. ESTIMATION OF CAPACITY UNDER MIXED TRAFFIC FLOW

The capacity at such traffic situation in Indonesia, e.q. for $2 / 2$ UD (two way-two lane undevided) roads was estimated in such ways :
a. Direct observation of speed and flow rate average per 5 min . Only a few observations can be made due to lack of road sections with maximum flow that could be clearly identified as representing the capacity of the road section itself. The highest ranged value from 2,800 to $3,000 \mathrm{LVU} / \mathrm{h}$ (light vehicle unit/ LVU, is used instead of pcu).
b. Observation of flow rates during short periods of simultaneous bunching conditions in both directions (headways $<5 \mathrm{sec}$ ). The capacity found to be ranging from 2,800 to 3,100 LVU/h.
c. Theoretical estimation from speed-flow density modeling that showing capacity of about $3,000 \mathrm{LVU} / \mathrm{h}$.

The capacity of a road segment is determined as follows :

$$
\begin{equation*}
\mathrm{C}=\mathrm{C}_{0} \times \mathrm{FC}_{\mathrm{W}} \times \mathrm{FC}_{\mathrm{KS}} \times \mathrm{FC}_{\mathrm{SP}} \times \mathrm{FC}_{\mathrm{SF}} \times \mathrm{FC}_{\mathrm{CS}} \quad[\mathrm{pcu} / \mathrm{h}] \tag{2}
\end{equation*}
$$

where
C = capacity (pcu/h)
$\mathrm{C}_{0} \quad=$ base capacity (pcu/h)
$\mathrm{FC}_{\mathrm{W}}=$ adjustment factor for carriageway width
$\mathrm{FC}_{\mathrm{KS}}=$ adjustmetn factor for kerb and shoulders
$\mathrm{FC}_{\mathrm{SP}}=$ adjustment factor for directional split or median
$\mathrm{FC}_{\mathrm{SF}}=$ adjustment factor for side friction
$\mathrm{FC}_{\mathrm{CS}}=$ adjustment factor for city size

## 6. CAPACITY AT UNSIGNALIZED INTERSECTION UNDER MIXED TRAFFIC FLOW

Two two-lane intersection which was investigated for the manual is undevided two two-lane street/ UD (no-median) with total effective width of $5-6 \mathrm{~m}$ for both lane and each streets have an appropraite kerb/berm and side-walks with effective width of $0,5-1,0 \mathrm{~m}$ in urban areas. Intersections are located at urban area with high side friction value. All streams are considered to be equal in hierarchy of priority departure which means that no stop and give away signs.

Traffic flow movement at intersections with no conflict between vehicles within intersection as can be seen as follows

c
Figure 1. Traffic Flow Movement is described by IHCM-1997
Capacity at unsignalized intersection is defined as a result of basic capacity within ideal traffic condition relate to various adjusment factors and corrections which consider the impact of geometric conditions, environment conditions and traffic conditions. It is defined at Indonesia Highway Capacity Manual-1997 that the capacity can be calculated as :
$\mathrm{C}=\mathrm{C}_{0} \times \mathrm{F}_{\mathrm{W}} \times \mathrm{F}_{\mathrm{M}} \times \mathrm{F}_{\mathrm{CS}} \times \mathrm{F}_{\mathrm{RSU}} \times \mathrm{F}_{\mathrm{LT}} \times \mathrm{F}_{\mathrm{RT}} \times \mathrm{F}_{\mathrm{MI}} \quad[\mathrm{pcu} / \mathrm{h}]$
where

| C | = | capacity |
| :---: | :---: | :---: |
| $\mathrm{C}_{0}$ | = | base capacity |
| $\mathrm{F}_{\mathrm{W}}$ | = | adjustment factor for width of approach |
| $\mathrm{F}_{\mathrm{M}}$ | = | adjustment factor for median at major road |
| $\mathrm{F}_{\text {CS }}$ | = | adjustment factor for city size |
| $\mathrm{F}_{\text {RSU }}$ | = | adjustment factor for type of environment, side friction and unmotorized |
| $\mathrm{F}_{\text {LT }}$ | = | adjustment factor for left-turn |
| $\mathrm{F}_{\text {RT }}$ | = | adjustment factor for right-turn |
| $\mathrm{F}_{\mathrm{MI}}$ | = | adjustment factor for ratio of traffic at minor road |

## 7. CAPACITY AT ALL WAY STOP CONTROLLED AND FIRST-IN-FIRST-OUT INTERSECTIONS

A new theoretical approach for determination of capacities at All-Way Stop-Controlled and First-In-First-Out Intersections is based on the Addition-Conflict-Flow method developed from the graph theory. The procedure considers in such a way that the First-In-First-Out
discipline is applied. FIFO intersections are broadly used in the developing countries (e.g. China, India and Indonesia). Because no traffic streams at AWSC intersections possesses the absolute priority of driving, the AWSC intersections can also be considered in such a way that the First-In-First-Out discipline applies.

## 8. DEPARTURE MECHANISM AT AWSC/ FIFO INTERSECTIONS

### 8.1 Capacity Of Streams In A Departure Sequence.

Since all streams at AWSC/ FIFO intersections are considered to be equal in the hierarchy of the priority of departure, the vehicles of different streams must enter the intersection alternatively.


Figure 2. Three Streams In A Departure Sequence
The vehicles in different streams have to pass the same conflict area alternatively one after another. Every vehicle of the stream i occupies the conflict area by exact $t_{B, i}$ second. In the case of only two streams this corresponds to the rule of zipping. That means all streams must have the same capacity in a departure sequence if all traffic flows $\mathrm{Q}_{\mathrm{i}}$ exceed their capacities $\mathrm{C}_{\mathrm{i}}$ (total overload). That is, the capacities of all streams in one departure sequence have under overload condition the same value of

$$
\begin{equation*}
\mathrm{C}_{\mathrm{i}}=\mathrm{C}=\frac{3600}{\sum \mathrm{t}_{\mathrm{B}, \mathrm{i}}} \quad \text { for } \mathrm{Q}_{\mathrm{i}} \geq \mathrm{C} \quad[\mathrm{veh} / \mathrm{h}] \tag{4}
\end{equation*}
$$

The capacity C is equal to the number of the seconds within an hour devided by the sume of the average departure headways of all involved streams, $\mathrm{t}_{\mathrm{B}, \mathrm{i}}$.

Considering the fictive stream configuration (streams in a departure sequence) and searching for the capacity of the stream $3, C_{3}$, then
$\mathrm{C}_{3}=\mathrm{C}_{2}=\mathrm{C}_{1}=\mathrm{C}=\frac{3600}{\mathrm{t}_{\mathrm{B}, 1}+\mathrm{t}_{\mathrm{B}, 2}+\mathrm{t}_{\mathrm{B}, 3}} \quad$ for $\mathrm{Q}_{1} \geq \mathrm{C}, \mathrm{Q}_{2} \geq \mathrm{C}$, and $\mathrm{Q}_{3} \geq \mathrm{C}[\mathrm{veh} / \mathrm{h}]$
The subject stream (minor stream) whose capacity is to be determined, the capacity C will also be admitted in the case that the traffic flow of this stream is lower than the capacity C. Stream 3, e.g., obtain also then the capacity C if its traffic flow is lower than the capacity $\mathrm{C}_{3}=\mathrm{C}$. That is, stream 3 always has the capacity

$$
\begin{equation*}
\mathrm{C}_{3}=\mathrm{C}=\frac{3600}{\mathrm{t}_{\mathrm{B}, 1}+\mathrm{t}_{\mathrm{B}, 2}+\mathrm{t}_{\mathrm{B}, 3}} \quad \text { for } \mathrm{Q}_{1} \geq \mathrm{C} \text { and } \mathrm{Q}_{2} \geq \mathrm{C}[\mathrm{veh} / \mathrm{h}] \tag{6}
\end{equation*}
$$

If however any streams except the subject stream (stream 3) do not consume the admitted capacity, then this capacity can be used by other streams. For the case, that $\mathrm{Q}_{1}<\mathrm{C}$ and $\mathrm{Q}_{2}>\mathrm{C}$ (partial overload for $\mathrm{Q}_{2}$ ), one has the capacity for stream 3

$$
\begin{equation*}
\mathrm{C}_{3}^{\prime}=\frac{3600-\mathrm{Q}_{1} \cdot \mathrm{t}_{\mathrm{B}, 1}}{\mathrm{t}_{\mathrm{B}, 2}+\mathrm{t}_{\mathrm{B}, 3}} \quad \text { for } \mathrm{Q}_{1}<\mathrm{C} \text { and } \mathrm{Q}_{2}>\mathrm{C} \quad[\mathrm{veh} / \mathrm{h}] \tag{7}
\end{equation*}
$$

$C^{\prime}$ is always larger than C .
With analogously for partial overload $\mathrm{Q}_{1}$ with the case of $\mathrm{Q}_{2}<\mathrm{C}$ and $\mathrm{Q}_{1}<\mathrm{C}$, the capacity for stream 3
$\mathrm{C}_{3}^{\prime \prime}=\mathrm{C}^{\prime \prime}=\frac{3600-\left(\mathrm{Q}_{1} \cdot \mathrm{t}_{\mathrm{B}, 1}+\mathrm{Q}_{2} \cdot \mathrm{t}_{\mathrm{B}, 2}\right)}{\mathrm{t}_{\mathrm{B}, 3}} \quad$ for $\mathrm{Q}_{1}<\mathrm{C}^{\prime}$ and $\mathrm{Q}_{2}<\mathrm{C} \quad \quad$ veh/h]
Therefore, for the case that no overload in the conflict stream (stream 1 and 2) occurs the capacity for stream 3
$\mathrm{C}_{3}{ }^{\prime \prime}=\mathrm{C}^{\prime \prime}=\frac{3600-\left(\mathrm{Q}_{1} \cdot \mathrm{t}_{\mathrm{B}, 1}+\mathrm{Q}_{2} \cdot \mathrm{t}_{\mathrm{B}, 2}\right)}{\mathrm{t}_{\mathrm{B}, 3}} \quad[\mathrm{veh} / \mathrm{h}]$
for
or

$$
\mathrm{Q}_{1}<\frac{3600}{\mathrm{t}_{\mathrm{B}, 1}+\mathrm{t}_{\mathrm{B}, 2}+\mathrm{t}_{\mathrm{B}, 3}} \text { and } \mathrm{Q}_{2}<\frac{3600-\mathrm{Q}_{1} \cdot \mathrm{t}_{\mathrm{B}, 1}}{\mathrm{t}_{\mathrm{B}, 2}+\mathrm{t}_{\mathrm{B}, 3}}
$$

$$
Q_{1}<\frac{3600-Q_{2} \cdot t_{B, 2}}{t_{B, 1}+t_{B, 3}} \text { and } Q_{2}<\frac{3600}{t_{B, 1}+t_{B, 2}+t_{B, 3}}
$$

### 8.2 Capacity Of A Stream In Several Departure Sequences.

The capacity of a stream in several departure sequences is the least capacity that this stream obtains in all of the departure sequences, $\mathrm{C}=\min (\mathrm{C}($ SequenceA), $\mathrm{C}($ SequenceB),...)


Figure 3. A Stream Involved In Several Departure Sequences

### 8.3 Capacity Of The Shared-Streams.

The capacity of shared-streams can be determined according to the procedure of Wu (1997), the length of shared/ short lanes can also be taken into account. For the case that all streams on an approach use the same shared-lane the capacity of this shared-lane $\mathrm{C}_{\mathrm{m}}$ is
$\mathrm{C}_{\mathrm{m}}=\frac{\sum \mathrm{Q}_{\mathrm{i}}}{\sum \mathrm{x}_{\mathrm{i}}}$
[veh/h]
where $x_{i}=\frac{Q_{i}}{C_{i}}$ is the degree of saturation of the stream $i$.
$\mathrm{Q}_{\mathrm{i}}=$ flow from the stream i
$C_{i}=$ capacity of i stream

## 9. INTERSECTION OF TWO TWO-LANE STREETS

At intersections of two two-lane streets, there is only one traffic lane in each of the aaproaches. It is assumed that each turning movemet has its own traffic lane at the intersection.


Figure 4. Intersection With 12 Vehicles And 4 Pedestrian Streams And The Critical

## Conflict Areas Between The Streams.

For this type of intersection, the critical conflict can be defined according to the figure as

- Exit-conflicts (departure sequences No. 1, 2, 3, 4)
- Between-conflicts (departure sequences No. 5, 6, 7, 8)
- Entrance-conflicts (departure sequences No. 9, 10, 11, 12)

The capacity of a stream i in a departure sequence with $n$ streams reads as

$$
\mathrm{C}_{\mathrm{i}}=\max \left\{\begin{array}{l}
\frac{3600-\sum_{\mathrm{j}=\mathrm{l}, \mathrm{j} i}^{\mathrm{n}}\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{\mathrm{j}}}{\left(\mathrm{t}_{\mathrm{B}}\right)_{i}}  \tag{11}\\
\frac{3600}{\sum_{\mathrm{j}=1}^{\mathrm{n}\left(\mathrm{t}_{\mathrm{B}}\right)_{\mathrm{j}}}}
\end{array} \quad[\mathrm{veh} / \mathrm{h}]\right.
$$

where
$\mathrm{C}_{\mathrm{i}} \quad=$ capacity of the stream i
$\mathrm{Q}_{\mathrm{j}} \quad=$ flow from the stream j
$\left(\mathrm{t}_{\mathrm{B}}\right)_{\mathrm{i}, \mathrm{j}}=$ headways departure from stream i and j

## 10. CAPACITY OF THE STREAMS

The streams involved in the same conflict area from a departure sequence. The streams are incompatible with each other and they can only enter the intersection alternatively. A stream at AWSC/ FIFO intersections is always involved in several departure sequences. The smallest capacity, which a stream can achieve from these departure sequences, is the decisive capacity. It is hereby assumed that vehicles of two streams, which are compatible with each other, can enter the intersection simultaneously. The streams from the subject approach are involved in different departure sequences. The capacity of each of subject streams are determined by the departure sequences. The capacity of the left-turn stream can be calculated according to the departure sequences No. 1 ( $\mathrm{C}_{\mathrm{s}, \mathrm{L}, \mathrm{A}}$ ), No. 5 ( $\left.\mathrm{C}_{\mathrm{s}, \mathrm{L}, \mathrm{Z1}}\right)$, No.6( $\mathrm{C}_{\mathrm{s}, \mathrm{L}, \mathrm{Z2}}$ ) and No.10L( $\mathrm{C}_{\mathrm{s}, \mathrm{L}, \mathrm{E}}$ ) respectively. The decisive capacity of the left-turn stream is then

$$
\mathrm{C}_{\mathrm{s}, \mathrm{~L}}=\min \left(\mathrm{C}_{\mathrm{s}, \mathrm{~L}, \mathrm{~A}}, \mathrm{C}_{\mathrm{s}, \mathrm{~L}, \mathrm{Z} 1}, \mathrm{C}_{\mathrm{s}, \mathrm{~L}, \mathrm{Z2}}, \mathrm{C}_{\mathrm{s}, \mathrm{~L}, \mathrm{E}}\right)
$$

every subject streams of left-turn are measured in the following way,

$$
\mathrm{C}_{\mathrm{s}, \mathrm{~L}, \mathrm{~A}}=\max \left\{\begin{array}{l}
\frac{3600-\left[\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{\mathrm{O}, \mathrm{R}}+\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{\mathrm{r}, \mathrm{~T}}+\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{l, \mathrm{~F}}\right]}{\left(\mathrm{t}_{\mathrm{B}}\right)_{\mathrm{s}, \mathrm{~L}}}  \tag{12}\\
\frac{3600}{\left(\mathrm{t}_{\mathrm{B}}\right)_{\mathrm{s}, \mathrm{~L}}+\left(\mathrm{t}_{\mathrm{B}}\right)_{\mathrm{o}, \mathrm{R}}+\left(\mathrm{t}_{\mathrm{B}}\right)_{\mathrm{r}, \mathrm{~T}}+\left(\mathrm{t}_{\mathrm{B}}\right)_{\mathrm{l}, \mathrm{~F}}}
\end{array} \quad[\mathrm{veh} / \mathrm{h}]\right.
$$

With the same procedure, the decisive capacity of the through-ahead stream and the right-turn stream can be computed by

$$
\mathrm{C}_{\mathrm{s}, \mathrm{~T}}=\min \left(\mathrm{C}_{\mathrm{s}, \mathrm{~T}, \mathrm{~A}}, \mathrm{C}_{\mathrm{s}, \mathrm{~T}, \mathrm{Z} 1}, \mathrm{C}_{\mathrm{s}, \mathrm{~T}, \mathrm{Z2}}, \mathrm{C}_{\mathrm{s}, \mathrm{~T}, \mathrm{E}}\right)
$$

every subjects of through-ahead can be drawn as

$$
\mathrm{C}_{\mathrm{s}, \mathrm{~T}, \mathrm{~A}}=\max \left\{\begin{array}{l}
\frac{3600-\left[\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{\mathrm{r}, \mathrm{R}}+\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{1, \mathrm{~L}}+\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{\mathrm{o}, \mathrm{~F}}\right]}{\left(\mathrm{t}_{\mathrm{B}}\right)_{\mathrm{s}, \mathrm{~T}}}  \tag{13}\\
\frac{360}{\left(\mathrm{t}_{\mathrm{B}}\right)_{\mathrm{s}, \mathrm{~T}}+\left(\mathrm{t}_{\mathrm{B}}\right)_{\mathrm{r}, \mathrm{R}}+\left(\mathrm{t}_{\mathrm{B}}\right)_{\mathrm{l}, \mathrm{~L}}+\left(\mathrm{t}_{\mathrm{B}}\right)_{\mathrm{o}, \mathrm{~F}}}
\end{array} \quad[\mathrm{veh} / \mathrm{h}]\right]
$$

and

$$
\mathrm{C}_{\mathrm{s}, \mathrm{R}}=\min \left(\mathrm{C}_{\mathrm{s}, \mathrm{R}, \mathrm{~A}}, \mathrm{C}_{\mathrm{s}, \mathrm{R}, \mathrm{E}}\right)
$$

with every subjects of right-turn as

$$
C_{s, R, A}=\max \left\{\begin{array}{l}
\frac{3600-\left[\left(Q . t_{B}\right)_{0, L}+\left(Q . t_{B}\right)_{1, L}+\left(Q . t_{B}\right)_{r, F}\right]}{\left(t_{B}\right)_{S, R}}  \tag{14}\\
\frac{3600}{\left(t_{B}\right)_{s, R}+\left(t_{B}\right)_{o, L}\left(t_{B}\right)_{l, T}\left(t_{B}\right)_{r, F}}
\end{array} \quad[\mathrm{veh} / \mathrm{h}]\right.
$$

## 11. CAPACITY OF THE APPROACH

The approaches of an intersection of two two-lane streets that possess each direction have their own traffic lane (one). Two cases can be distinguished as at figure 5,
a. No separate traffic lane for the turning streams (three streams) as at figure 5.a
b. A separate traffic lane for the left-turn stream (two streams) as at figure 5.b


Figure 5. Lane Distribution At Approaches Of An Intersection Of Two Two-Lane Streets.

Case a. Capacity of the shared traffic lane for three streams L, T and R
In the case of no flared area for the right-turn stream the capacity of the shared traffic lane

$$
\begin{equation*}
\mathrm{C}_{\mathrm{s}, \mathrm{~m}}=\frac{\mathrm{Q}_{\mathrm{s}, \mathrm{~L}}+\mathrm{Q}_{\mathrm{s}, \mathrm{~T}}+\mathrm{Q}_{\mathrm{s}, \mathrm{R}}}{\mathrm{x}_{\mathrm{s}, \mathrm{~L}}+\mathrm{x}_{\mathrm{s}, \mathrm{~T}}+\mathrm{x}_{\mathrm{s}, \mathrm{R}}} \quad[\mathrm{veh} / \mathrm{h}] \tag{15}
\end{equation*}
$$

The capacity of the traffic lane has to checked with the following constraint of

$$
\begin{equation*}
\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{\mathrm{s}, \mathrm{~L}}+\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{\mathrm{s}, \mathrm{~T}}+\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{\mathrm{s}, \mathrm{R}}+\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{\mathrm{s}, \mathrm{~F}} \leq 3600 \tag{16}
\end{equation*}
$$

Case b. Capacity of the shared traffic lane for two streams $T$ and $R$ In the case of no flared area for the right-turn stream the capacity of the shared traffic lane with streams $T+R$ as

$$
\begin{equation*}
\mathrm{C}_{\mathrm{s}, \mathrm{~T}+\mathrm{R}}=\frac{\mathrm{Q}_{\mathrm{s}, \mathrm{~T}}+\mathrm{Q}_{\mathrm{s}, \mathrm{R}}}{\mathrm{X}_{\mathrm{s}, \mathrm{~T}}+\mathrm{X}_{\mathrm{s}, \mathrm{R}}} \quad[\mathrm{veh} / \mathrm{h}] \tag{17}
\end{equation*}
$$

The capacity of the shared lane with streams $\mathrm{T}+\mathrm{R}$ has to checked with the following constraints
$\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{\mathrm{s}, \mathrm{L}}+\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{\mathrm{s}, \mathrm{T}}+\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{\mathrm{s}, \mathrm{R}}+\left(\mathrm{Q} \cdot \mathrm{t}_{\mathrm{B}}\right)_{\mathrm{s}, \mathrm{F}} \leq 3600 \quad[\mathrm{~s}]$

## 12. PRELIMINARY INVESTIGATION

Previous investigated has been done at one of four-legs unsignalized intersection in Indonesia in year of 2000. Four legs intersection in such urban areas in Local City of Singkawang which roads of Jalan Diponegoro I, Jalan Diponegoro II, Jalan Gusti Sulung Lelanang and Jalan Firdaus which contents of various types of vehicles such passanger car, bus, trucks, motorcycle, bicycle, becak (rickshaw-three-wheels) and gerobak/ push cart or kakilima (twowheels). The type of intersection is two way-two lane where median is at Jalan Diponegoro I - Jalan Diponegoro II. Both side of the roads have sidewalks with width of $1,50 \mathrm{~m}$ and details of geometric characteristic can be shown as follows

Table 2. Geometric Characteristic of Intersection I

| Road | Width of approach <br> $(\mathrm{m})$ | Width of lane (m) | Width of median (m) |
| :--- | :---: | :---: | :---: |
| Jalan Gusti Sulung <br> Lelanang | 7.00 | 3.50 | - |
| Jalan Diponegoro I | 13.00 | 6.00 | 1.00 |
| Jalan Firdaus | 7.50 | 3.75 | - |
| Jalan Diponegoro II | 13.00 | 6.00 | 1.00 |

Survey was conducted within effective four days and fiftin hours (15 hours) a day (06.00 21.00). Traffic volume were counted manually by the surveyor who were taken placed at each leg of intersections. An assumption that monday will have the same traffic flow as tuesday, wednesday and thursday and effective of 15 hours of survey will be as $93 \%$ of effective day (24 hours), therefore, number of average traffic flow in one week/ average annual weekly traffic can be estimated as

Table 3. Average Annual Weekly Traffic of Intersection I

| Road | Type of vehicle | Correction factor, FK | Flow (veh/h) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | LEFT | THROUGH | RIGHT |
| Jalan Gusti <br> Sulung  <br> Lelanang  | Motorcycle | 100/93 | 2385 | 11706 | 9839 |
|  | Light Vehicle, LV | 100/93 | 384 | 2013 | 1124 |
|  | Heavy Vehicle | 100/93 | 174 | 580 | 229 |
|  | Unmotorized | 100/93 | 801 | 2268 | 1250 |
| Jalan Diponegoro I | Motorcycle | 100/93 | 6715 | 15920 | 15797 |
|  | Light Vehicle, LV | 100/93 | 1144 | 3196 | 2497 |
|  | Heavy Vehicle | 100/93 | 190 | 675 | 273 |
|  | Unmotorized | 100/93 | 3433 | 3197 | 6904 |
| Jalan <br> Diponegoro II | Motorcycle | 100/93 | 9612 | 13602 | 5339 |
|  | Light Vehicle, LV | 100/93 | 260 | 3195 | 537 |
|  | Heavy Vehicle | 100/93 | 171 | 338 | 162 |
|  | Unmotorized | 100/93 | 2050 | 2873 | 1071 |
| Jalan Firdaus | Motorcycle | 100/93 | 12831 | 8952 | 2755 |
|  | Light Vehicle, LV | 100/93 | 1964 | 2184 | 463 |
|  | Heavy Vehicle | 100/93 | 219 | 438 | 152 |
|  | Unmotorized | 100/93 | 2722 | 1960 | 741 |

In order to calculate the design volume of traffic per day, therefore, we should apply for a number of vehicle/ volume per hour (design hour volume). Based on Indonesia Manual-1997, traffic flow for design purpose can be estimated from percentage of AADT (yearly) as

$$
\begin{equation*}
\mathrm{Q}_{\mathrm{veh}}=\mathrm{AADT} \times \mathrm{k} \tag{19}
\end{equation*}
$$

where
AADT = annual average daily traffic yearly
$\mathrm{k} \quad=$ normal variable of traffic flow $(0.07-0.12)$ as can be seen at table below
Table 4. k - Factor

| Road environment | k - factor/ City size |  |
| :--- | :---: | :---: |
|  | $>1$ million | $<1$ million |
| Arterial and Commercial | $0.07-0.08$ | $0.08-0.10$ |
| Residential | $0.08-0.09$ | $0.09-0.12$ |

Further on calculation for Design Hourly Volume with VJP value of 0.08 as can be seen at table below

Table 5. Vehicle Volume Per Hour

| Road | Type of vehicle | VJP coefficient | Design Hourly Volume (veh/h) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | LEFT | THROUGH | RIGHT |
| Jalan Gusti <br> Sulung  <br> Lelanang  | Motorcycle <br> Light Vehicle, LV <br> Heavy Vehicle,HV <br> Unmotorized | 0.08 | 24 | 119 | 100 |
|  |  |  | 4 | 31 | 11 |
|  |  |  | 2 | 6 | 2 |
|  |  |  | 8 | 23 | 13 |
| Jalan Diponegoro I | Motorcycle Light Vehicle, LV <br> Heavy Vehicle,HV <br> Unmotorized | 0.08 | 69 | 163 | 161 |
|  |  |  | 12 | 33 | 26 |
|  |  |  | 2 | 7 | 3 |
|  |  |  | 35 | 33 | 71 |
| Jalan <br> Diponegoro II | Motorcycle Light Vehicle, LV <br> Heavy Vehicle,HV <br> Unmotorized | 0.08 | 98 | 139 | 55 |
|  |  |  | 3 | 33 | 6 |
|  |  |  | 2 | 4 | 2 |
|  |  |  | 21 | 30 | 11 |
| Jalan Firdaus | Motorcycle <br> Light Vehicle, LV <br> Heavy Vehicle,HV <br> Unmotorized | 0.08 | 131 | 91 | 28 |
|  |  |  | 20 | 22 | 5 |
|  |  |  | 2 | 5 | 2 |
|  |  |  | 27 | 20 | 8 |

Capacity and Level of service of unsignalized intersection were then calculated with software of KAJI Ver. 1.00 which is provided by Indonesia Highway Capacity Manual-1997 based on various inputs, especially design hourly volume and some of adjusment factors which are explained previously.

In such situation and previous investigation based on IHCM that unmotorized were not taken into account as vehicle volume which mean that equivalent as passenger car unit are not necessary instead of they were measured as `side friction` and will reduce the capacity. Adjustment factor for side friction is based on such assumption that effect of unmotorized in capacity is the same as light-vehicle, LV with pcu $=1.0$. With adjustment factor of width of approach, $\mathrm{FC}_{\mathrm{W}}=0.966$, adjusment for major road median, $\mathrm{FC}_{\mathrm{SP}}=1.00$, city size, $\mathrm{FC}_{\mathrm{CS}}=$ 0.820 , side friction, $\mathrm{FC}_{\mathrm{SF}}=0.763$, adjusment for left-turn, $\mathrm{F}_{\mathrm{LT}}=1.226$, right-turn, $\mathrm{F}_{\mathrm{RT}}=1.000$ and ratio of traffic at minor street, $\mathrm{F}_{\mathrm{MI}}=0.844$. Table 1 shows that for type of four legsintersection of 424 will have a total basic capacity, $\mathrm{C}_{0}=3400 \mathrm{pcu} / \mathrm{h}$. Therefore, the actual total capacity of the intersection can be calculated as,

$$
\begin{aligned}
& \mathrm{C}=\mathrm{C}_{0} \times \mathrm{F}_{\mathrm{W}} \times \mathrm{F}_{\mathrm{M}} \times \mathrm{F}_{\mathrm{CS}} \times \mathrm{F}_{\mathrm{RSU}} \times \mathrm{F}_{\mathrm{LT}} \times \mathrm{F}_{\mathrm{RT}} \times \mathrm{F}_{\mathrm{MI}} \\
& \mathrm{C}=3400 \times 0.966 \times 1.000 \times 0.820 \times 0.763 \times 1.226 \times 1.000 \times 0.844 \\
& \mathrm{C}=2129 \mathrm{pcu} / \mathrm{h}
\end{aligned}
$$

Adjustment factor of Left-turn movement of 1.226 is an indication that in such heterogenous traffic flow where traffic composition of small type of vehicles are attended and there were likely no queue in left-turning vehicles which means small types of vehicles can always pass through the intersections. While measuring the capacity at unsignalized intersections with First-In-First-Out mechanism that is the capacity of the conflict of each stream of vehicles, Left-turn, Through-ahead and Right-turn and each of approach should be measured. In spite of traffic flow is homogenous, therefore, to calculate the flow under mixed traffic situation
with various type of vehicles, measuring should be done separately and more details in vehicles characteristic and movement behaviour are necessary.

Between the two approach of ICHM and First-In-First-Out are comparable relatively, because IHCM use the basic total capacity to measure the actual capacity of intersection, however, by using the conflict approach, we have to measure the capacity of each traffic streams of each approaches to get the total actual capacity. Average headways departure of all involved streams, $\mathrm{t}_{\mathrm{B}}$ should be measured accurately. Since there were no information on headway departure of each stream from each leg of intersections, we could used such information of base and actual capacities in order to get the value of headways departure of each condition, therefore, in this brief study, these two approaches could not be compared. This can be rather complicated when various type of vehicles, e.q. slow-moving vehicles/ un-motorized transport with large different in speed and number of each types of vehicle with motorized vehicle are include within the traffic flow. Therefore, departure headways of each type of vehicles from each of approaches were measured separately. The statistical software package should be used to plot the frequency of all data sets which allow easy and continuous variation of class interval of headway data.

Since there are lack of field information/ data as there were presented previously e.q. no information of headway departures, flows of each lanes of double lanes (DL) were not monitored (this was assumpted to be one lane) and traffic split are about $38 \% / 62 \%$ which every stream of each approaches have different percentage of turning movement with range of $11 \%$ to $53 \%$ including unmotorized vehicles, therefore, it should be measured each of approaches as a subject approach which mean that capacity shared lane of each approaches should measured separately. In this preliminary investigation, no pedestrian crossing are taken into account and headway departures of each streams of each approaches are assumpt to be the same, $\mathrm{t}_{\mathrm{B}}$. In this case, between conflict could be the maximum capacity of every approaches, e.q. shared lane capacity of Jalan Diponegoro I can be measured as

$$
\mathrm{C}_{\mathrm{s}}=\frac{1}{\frac{0,19 \mathrm{t}_{\mathrm{B}}}{3600-396,1 \mathrm{t}_{\mathrm{B}}}+\frac{0,38 \mathrm{t}_{\mathrm{B}}}{3600-324 \mathrm{t}_{\mathrm{B}}}+\frac{0,43 \mathrm{t}_{\mathrm{B}}}{3600-240,1 \mathrm{t}_{\mathrm{B}}}}
$$

Each of shared lane capacity of each roads can be seen at table 6 as follows

Table 6. Shared Lane Capacity of Every Approach of Intersection I

| Roads | Shared lane capacity |
| :--- | :--- |
| Jalan Gusti Sulung <br> Lelanang | $\mathrm{C}_{\mathrm{s}}=\frac{1}{\frac{0,11 \mathrm{t}_{\mathrm{B}}}{3600-269,2 \mathrm{t}_{\mathrm{B}}}+\frac{0,52 \mathrm{t}_{\mathrm{B}}}{3600-174,5 \mathrm{t}_{\mathrm{B}}}+\frac{0,37 \mathrm{t}_{\mathrm{B}}}{3600-147,9 \mathrm{t}_{\mathrm{B}}}}$ |
| Jalan Diponegoro I | $\mathrm{C}_{\mathrm{s}}=\frac{1}{\frac{0,19 \mathrm{t}_{\mathrm{B}}}{3600-396,1 \mathrm{t}_{\mathrm{B}}}+\frac{0,38 \mathrm{t}_{\mathrm{B}}}{3600-324 \mathrm{t}_{\mathrm{B}}}+\frac{0,43 \mathrm{t}_{\mathrm{B}}}{3600-240,1 \mathrm{tr}_{\mathrm{B}}}}$ |
| Jalan Diponegoro II | $\mathrm{C}_{\mathrm{s}}=\frac{0,26 \mathrm{t}_{\mathrm{B}}}{\frac{1}{3600-419 \mathrm{t}_{\mathrm{B}}}+\frac{0,53 \mathrm{t}_{\mathrm{B}}}{3600-328,9 \mathrm{t}_{\mathrm{B}}}+\frac{0,21 \mathrm{t}_{\mathrm{B}}}{3600-249,3 \mathrm{t}_{\mathrm{B}}}}$ |
| Jalan Firdaus | $\mathrm{C}_{\mathrm{s}}=\frac{0,50 \mathrm{t}_{\mathrm{B}}}{\frac{0}{3600-303,1 \mathrm{t}_{\mathrm{B}}}+\frac{0,38 \mathrm{t}_{\mathrm{B}}}{3600-324,2 \mathrm{t}_{\mathrm{B}}}+\frac{0,12 \mathrm{t}_{\mathrm{B}}}{3600-209,1 \mathrm{t}_{\mathrm{B}}}}$ |

## 15. CONCLUDING REMARKS

If we apply the total basic capacity, $\mathrm{C}_{0}$ from IHCM for unsignalized intersection with type of 424 is $3400 \mathrm{pcu} / \mathrm{h}$, therefore, we could find the value of average headway departure/ service time, $t_{B}$ as 3.029 seconds for every streams of each approaches. This value could be the ideal headway departure as in ideal condition of traffic flow which every streams from each approches have the same movement behaviour and unmotorized were assumpted to be as passenger car with pcu of 1.00 (most of unmotorized are bicycle). Intersection II and III would have values of 2.014 s and 2.426 s .

As an effects of various condition such geometric design of roads, flows and environment which would reduce or increase the actual capacity from the basic capacity and based on the previous data calculated in such traffic condition, the actual capacity were decreased as 2129 $\mathrm{pcu} / \mathrm{h}$. In term of headway departure point of view, this value was increased as 4.119 seconds for each streams of each approaches of intersection I and 2.214 s and 2.199 s for intersection II and III. However, it rather difficult to get details information since there were no information in service time of every streams of every approaches and every type of vehicles. Further investigations are necessary to get real value of headway departures of each types of vehicles in order to get the real value of basic capacity and actual capacity.

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