A study on motorcycle equivalent unit and capacity estimation in urban streets

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1. INTRODUCTION

The growth of urban traffic is recognized as problem in metropolitan areas in the country, with significant effects on economy, travel behavior, land use and cause of discomfort for millions of motorists. Vietnam likes most developing countries which have to face with many serious traffic problems in over the world. Various vehicle classes in a running lane, lack of traffic law understanding and unconscious of road user, etc. Besides, almost urban streets have two lanes that are smaller than 7.5 m, citizen tends to concentrate in center of cities for working and living. Backwardness in planning is parameter that makes traffic more complicated. For a decade, Hanoi in particular and Vietnam in general try to find a best solution for current traffic problem, included developing a public transport system by bus, improving parking system, expanding arterial streets and main street…but the effectiveness isn't very attractive because they can't catch up with the fast rising of private vehicles, especially motorcycle and car. Furthermore, traffic volume estimation business isn't very good. It leads to the ineffectiveness of road and to be short of planning vision. As regards traffic flow estimation, many studies have been done but most of them use passenger car unit as a vehicles conversion standard to estimate highway capacity, etc. Generally, this method isn't very good because traffic flow is chiefly dominated by two-wheel motorcycles. In Hochiminh city, 98% households own motorcycle, 400 motorcycles/1000 population. In Hanoi, 1000 population have 296 motorcycles. At present, car ratio per year is rising but amount of cars are still very small in comparison with amount of motorcycles. That's why traffic condition in Vietnam doesn't like other countries that traffic is dominated by car. As a result, a vehicle conversion solution using motorcycle equivalent unit should be mentioned, replaced the passenger car unit and it's useful for the capacity estimation

2. RESEARCH OBJECTIVES

This study focuses on building a new approach of MEU and capacity estimation that used car following model and statistical concept as basis. Main objectives of the study are listed here below:

(1) Investigate the traffic performance at road segments under mixed traffic conditions, e.g. speed, flow.

(2) Investigate parameters that can be used to describe MEU.

(3) Develop new procedures of MEU measurement which take into account mixed traffic flow at road segments.

3. LITERATURE REVIEW

According to Highway Capacity Manual 2000, PCU or passenger-car equivalent is "the number of passenger cars displaced by a single heavy vehicle of a particular type under specified roadway, traffic, and control conditions."

Cuthbert (1983) has promoted an analytical approach to define PCUs factors on surveys of traffic flows at selected locations (in Indonesia) which offer the following conditions: saturated flow for significant periods; no end constraints on the link under survey; mix of vehicle types. His approach represents the traffic under saturated conditions and number of stops, but it's difficult to find the situations at every road in every Vietnam city.

"Projected area method" is one of methods that concerning to projected area of vehicles. In this approach, Chandra & Sikdar (1999) have developed a passenger car unit factor for a vehicle class based on dynamic and static vehicle performance and geometric variables. The adjustment factor for the presence of vehicles other than cars is based on PCUs. This adjustment factor correlates with the flow rates of passenger cars only and mixed traffic streams that are equivalent in terms of drivers' perception of the level of service (LOS). LOS on a segment of highway is defined in terms of two variables: speed and volume. These two variables alone should be able to explain the relative effect of individual vehicles on traffic stream in terms of PCUs.

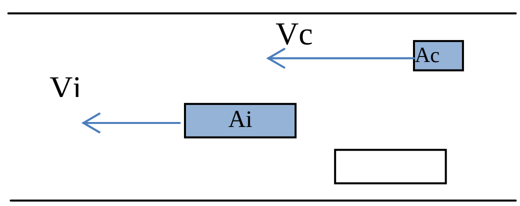

Figure 1: PCU estimation by Chandra & Sikdar

The *PCUs* of a vehicle class are taken as given by

$$PCU_i = \frac{V_c / V_i}{A_c / A_i} \quad (1)$$

Where

V_C : Mean speeds of cars (c) in traffic stream (km/h)
Vi : Mean speeds of vehicles type i in traffic stream (km/h)
A_C : respective projected rectangular areas of cars (m^2) on road

Ai : Respective projected rectangular area of vehicle class i (m^2)

The mean velocity is defined as :

$$V_i = \sum_{j=1}^{K} a_{ij}(n_j V_j) + d_i\left(\frac{1}{N}\right) \quad (2)$$

Where

- Vi : Mean speed of vehicle i (km/h)
- aij : Regression coefficients
- di : Regression coefficient
- K : Total number of vehicle categories in traffic stream
- nj : Number of vehicles of j category passing through the observation point per unit time (veh)

$$N = \sum_{j=1}^{K} n_j \quad (3)$$

Henk van Zuylen & Ning Wu (2007) estimated PCU as equation of speed and effective area that based on 2 modal – flow (car and truck) at any given level of service (LOS) in combination with Greenshields model. Zuylen model is improved from St.John model (1976). **Y et al (2006)** have same idea with Henk van Zuylen & Ning Wu but they have different viewpoint in approach. From Chandra model, they expanded the projected area and called effective area. They explained that, vehicles need an effective area among surrounding vehicles, the product of longitudinal space and latitudinal space is effective area.

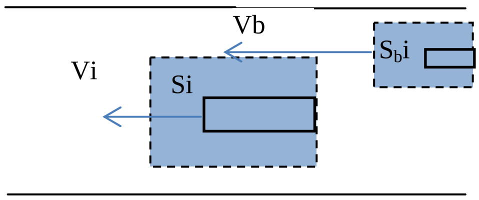

Figure 2.2: PCU estimation by Zuyen & Ning Wu

$$PCU = \frac{\dfrac{V_b}{V_i}}{\dfrac{L_b.W_b}{L_i.W_i}} \quad (4)$$

Where

- V_b: Optimal speed of basic vehicles (car or motorcycle) within mixed traffic stream (km/h)
- V_i: Optimal speed of vehicle class i within mixed traffic stream (km/h)
- LB : Effective length of basic vehicles (m)
- WB : Effective width of basic vehicles (m)
- Li : Effective length of vehicle class i (m)
- Wi : Effective width of vehicle class i (m)

4. DATA COLLECTION

The study has investigated 5 main road segments in Hanoi, Vietnam. 5 road segments have typical traffic flow characteristics. Each of the segments has 2 physical separated lanes. Survey time was selected during peak hours in working days and good condition of weather (From 06h30 AM– 08h00 AM and 5h00 PM – 7h00PM). Camcorders were placed at about 10 - 15 meter high at the edge of streets, from these points the traffic movement is observed very clearly and wasn't obstructed by anything. Four collected vehicle categories are motorcycle, car (sedan), bus, van. In these, motorcycle was chosen as equivalent unit because motorcycle is main private vehicle of Vietnamese and it dominates every urban streets. The samples are collected from recorded clips to ensure random condition, the location of vehicle is placed into Decartes coordinate grid in Avistep software to calculate speed and other parameters in proposed model.

5. METHODOLOGY

5.1 Situation

Consider a real situation of a running vehicle on a road (figure 2) in mix traffic condition, most people think that, the more space between vehicle and adjacent vehicles, the faster it can run. This argument isn't wrong but it isn't enough. Sometime, we see that, vehicles run at the same speed with different surrounding areas which are resulted by those vehicles and adjacent ones. Of course, if the space between vehicles is too small, the vehicle must reduce its speed to avoid collision.

This phenomenon denotes that, there is a "best effective distance" between the concerned vehicle and adjacent vehicles for stabilizing motorcycle speed. If the space between the concerned vehicle and adjacent vehicles are smaller than "the best effective distance", the concerned vehicle might slow down. In the case of the opposite situation, according to field survey, the concerned vehicle trends to maintain initial speed and trajectory. Some vehicles might accelerate and change their trajectory to overtake front vehicle. This study will not mention these situations because they aren't general. Wherefore, there are unnecessary spaces for stabilizing the speed of the concerned vehicle and they should be cut off.

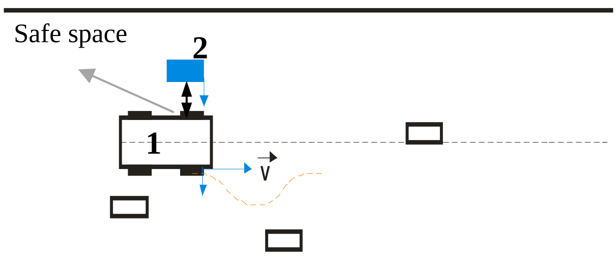

Figure 2: Safe space for avoiding collision

5.2 "Optimal effective distance" in latitude

a. Best effective distance in latitude

In general conditions, the trajectory of a running vehicle (vehicle 1) on a road is considered as a line. It maintains a safe space for adjacent vehicles (see figure 2).

Assuming that, safe space of vehicle 1 is the maximum distance in latitude which vehicle 1 can shift to avoid collision with vehicle 2, when vehicle 2 suddenly shifts towards vehicle 1 because of some certain reasons. According to the safety theory, at speed *v*, the trajectory of leading wheels (dash curve) and safe space are illustrated in figure 3.

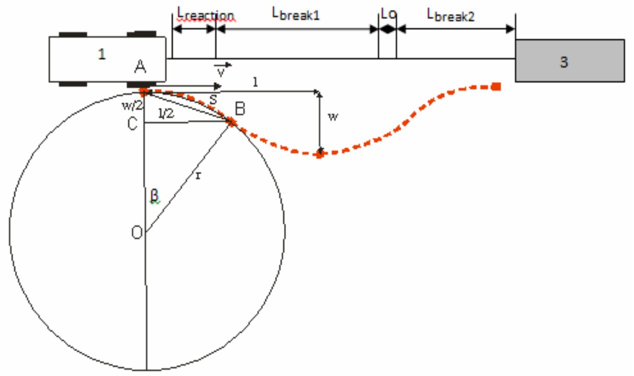

Figure 3: The trajectory and safety space of vehicle 1

For manoeuvre, driver has to control the leading wheels to turn left or turn right for creating possible safe space. Suppose that the time for manoeuvre is equal to the reaction/perception time (Δt = 1s). Vehicle 2 shifts toward vehicle 1 on a maximum range. Immediately, vehicle 1 has to respond in the same direction. The maximum distance that could create by vehicle 1 when avoiding collision with vehicle 2 is called **best effective distance in latitude** (*w*)

In the figure 3, the outside wheel of vehicle 1 moves on arc $\overset{\frown}{AB}$ of the circle O, radius r.

we have:

$$\begin{cases} w = 4.r.(\sin\dfrac{\beta^o}{2})^2 = 4.r.(\sin(\dfrac{v.\Delta t.90^o}{\pi.r}))^2 \\ l = \sqrt{4.r.w - w^2} \end{cases} \qquad (5)$$

Where:

- w: best effective distance in latitude (m)
- l: distance from initial location to farthest location of vehicle, project on x-axis (m)
- v: speed of vehicle 1 (m/s)
- r: minimum radius of circle O that made by vehicle 1's outside wheel. This radius is calculated on the conditions of stability against overturning. (m)

In the set of equations (5), r is unknown parameter. For determining r value, we have to deal with the problem of running vehicle on a horizontal curve. In this case:

$$=> r = \frac{v^2}{g.(\mu_{lati} \pm i_{lati})} \qquad (6)$$

Where

- i_{lati}: cross slope of road
- μ_{lati} : lateral force coefficient
- g: gravitation field acceleration (g ≈ 9.8 m/s^2)

From (5) and (6) we get:

$$\begin{cases} w = 4.(\dfrac{v^2}{g.(\mu_{lati} \pm i_{lati})}).(\sin(\dfrac{v.\Delta t.90^o}{\pi.r}))^2 \\ l = \sqrt{4.r.w - w^2} \end{cases} \qquad (7)$$

b. Optimal effective distance in latitude

In the aspect of theory, the best effective distance in latitude (*w*) in the set of equations (7) is a distance that ensures the safety of vehicle at speed *v*. However, in point of fact, sometimes latitudinal distance between two neighbour vehicles is smaller than *w*. There are many reasons for this problem, such as driver's sex, driver's reaction ability, component of traffic flow, vehicle class,…When vehicle 1 still runs at speed *v* in an unsafe distance to *v*, this means the area which surround the vehicle 1 is large enough for avoiding crash with others, driver doesn't care his safety or because of some other reasons. Thus, to estimate the optimal effective distance in latitude of each sample (vehicle), we have to choose between 2 values:

- Theoretical value: *w – calculate in item 5.2 a above*
- Surveyed value: w_f – measure on video clip.

There are 2 cases:

- The 1st case: $w_f < w$, we follow reality, and choose w_f . In fact, on the field, vehicle 1 can run well at speed *v* and distance w_f to vehicle 2.
- The 2nd case: $w_f \geq w$, vehicle 1 doesn't need a big distance like w_f to maintain speed *v*, the residual should be cut off from w_f to *w*. In this case, *w* is optimal choice.

Hence, the general equation is:

Optimal effective distance in latitude = min(w, w_f) at speed v

5.3 "Optimal effective distance" in longitude definition

a. Best effective distance in latitude

Normally, when running on a road, most vehicles don't care how many vehicles behind them. Therefore, the space between a vehicle and rear vehicles won't be mentioned in this study. On the contrary, let's look at the figure 4, vehicle 1 cares for vehicle 3– the next leading vehicle of vehicle 1, because vehicle 3 directly influences on the safety of vehicle 1. According to car following model, the minimum distance which made by vehicle 1 for keeping safety with vehicle 3 is estimated as follows:

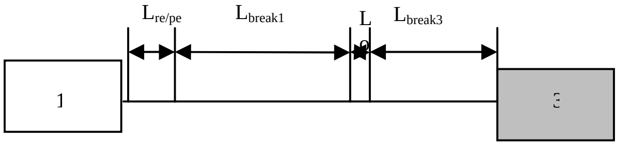

Figure 4: Car following model

The safety distance in latitude of vehicle 1 is the distance caused by its braking action from speed *v* to *zero,* in the case of vehicle 3 stops suddenly. This distance is called the best effective distance in latitude *(L)*. We have

$$L = L_{re/pe} + L_{brake\text{-}veh1} + L_o - L_{brake\text{-}veh3} \quad (8)$$

Where

- L: the minimum safe distance or the best effective distance in latitude (m)
- $L_{re/pe}$: the distance that vehicle 1 passes over in reaction/perception time of driver (m)
- $L_{brake\text{-}veh1}$: the distance that vehicle 1 passes over in braking time of driver 1(m)
- $L_{brake\text{-}veh3}$: the distance that vehicle 3 passes over in braking time of driver 3 (m)
- L_o: Safe distance between two vehicles, its value is depended on vehicle 1's type (m)

In this situation, we have some assumtions :

- $L_{re/pe} = v.\ \Delta t$; Where *Δt is reaction/perception time of driver (normally, $\Delta t = 1s$)*
- L_o: Safe distance between two vehicles depend on type of vehicle. In this study:

$$L_o^{mc} = 0.5m$$

$$L_o^{car,bus,smallvvan} = 1m$$

From the car following theory and above assumtion, we have:

$$L = v_1\Delta t + k_1.\frac{v_1^2}{2g(\varphi_1 \pm i_{long})} - k_3.\frac{v_3^2}{2g(\varphi_3 \pm i_{long})} + L_o \quad (9)$$

Where:

- v_1, v_3: speed of vehicle 1, vehicle 3 (km/h)
- k_1, k_3: safety coefficient of vehicle 1, vehicle 3
- φ_1, φ_3: braking coefficient of vehicle 1, vehicle 3
- i_{long} : Longitudinal slope of road

b. Optimal effective distance in longitude

Similar to the case of optimal effective distance in latitude (item 5.2), in point of fact, sometimes longitudinal distance between two consecutive vehicles is smaller than the minimum safe distance of vehicle 1. We have to find optimal effective distance in longitude as follows:

Optimal effective distance in longitude = min (L, L_f) at speed v

Where, *L_f is the surveyed effective distance in longitude on a field*

5.4 Optimal effective area estimation

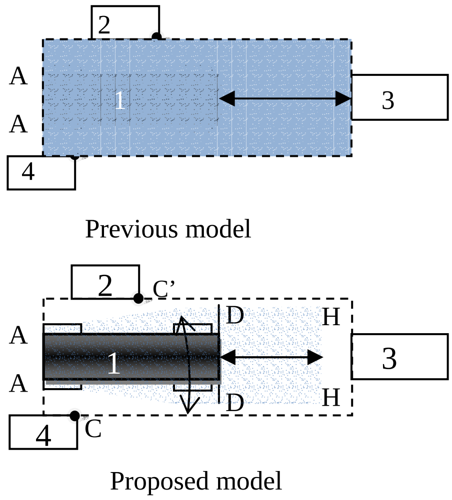

Figure 5: unnecessary area in the previous models

The previous models like **Zuylen & Ningwu** or **Y et al** defined effective area as a projected rectangular boundary (dash rectangle) made by vehicle 2, 3, 4 around vehicle 1. According to the viewpoint of this model, previous methodologies have determined effective area fast and simply but it might be not precise because when running on a road, in the case vehicle 1 has to maneuver for avoiding collision with vehicle 2 or vehicle 4, it just uses its leading wheels. For more details, let's look at figure 6; maximum maneuver area looks like the trapezoid AA'D'D (in fact, A'D'DA isn't an trapezoid but real shape area of it is close to the trapezoid A'D'DA. Therefore, for simplicity, the proposed model assumes that the trapezoid A'D'DA is maximum maneuver area of it). Any vehicle which overlaps on the trapezoid AA'D'D might influence on the speed and the movement of vehicle 1. Looking at vehicle 4 in figure 6, we see it overlap on ABDN at representative point C, right side of the trapezoid AA'D'D. Hence, ACPN is the optimal effective area on the right of vehicle 1. Conversely, we regard the trapezoid ABDN as the optimal effective area on the right of vehicle 1 if vehicle 4 doesn't overlap it.

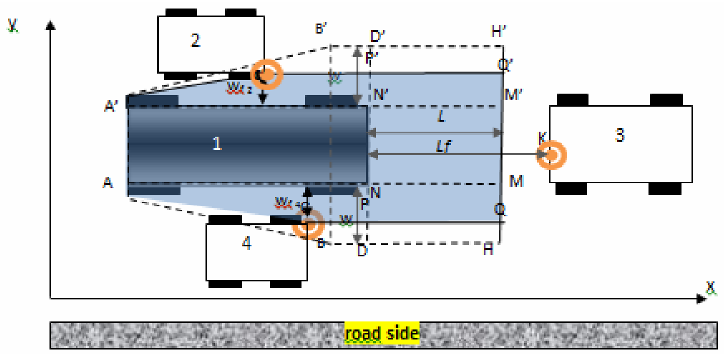

Figure 6: The optimal effective area of a vehicle

The optimal effective distances between vehicle 1 and vehicle 3, vehicle 2, vehicle 4 make the optimal effective area of it.
From figure 6, We have many situations that the vehicle 1 is influenced by surrounding vehicles.
Assuming that every surveyed vehicle parallels with roadside, we set a Cartesian coordinates on video clip and get the speed and surrounding coordinates of vehicles 1: *A'*$(x_{A'},y_{A'})$, *N'*$(x_{N'},y_{N'})$, *N*(x_N, y_N), *A*(x_A, y_A), *C'*$(x_{C'},y_{C'})$, *C*(x_C, y_C), *K*(x_K, y_K),
Where

C, C' is representative point of vehicle 4 and vehicle 2

A', A, N, N' - Top left, bottom left, top right, bottom right coordinates of vehicle 1 respectively

K is representative point of vehicle 3

From these coordinates, we can estimate the function of lines: A'B', A'N, N'N', B'D' , AB, AN, BD.
Assuming that the equation of line AB and A'B' are:

$y = ax+b$ (equation of line AB)

$y= cx+d$ (equation of line A'B')

Generally, we have algorithm for this:

- Check the effective distance conditions of vehicle 1 in latitude by both side

+ Left side, check the conditions of C' inside A'B'D'N'

$$if \begin{cases} \dfrac{y_{C'}-d}{c} \le x_{C'} < x_{N'} \\ y_{N'} < y_{C'} < y_{N'} + \mathrm{w} \end{cases} then\, S^{left\,veh1}_{optimal} = S_{A'C'PN'}$$

$$else\ S^{left\,veh1}_{optimal} = S_{A'B'D'N'}$$

+ Right side, check the conditions of C' inside ABDN

$$if \begin{cases} \dfrac{y_C-b}{a} < x_C < x_N \\ y_N \text{ - } \mathrm{w} < y_C < y_N \end{cases} then\, S^{right\,veh1}_{optimal} = S_{ACPN}$$

$$else\ S^{right\,veh1}_{optimal} = S_{ABDN}$$

- Check the optimal effective distance in longitude

$$L^{longitude}_{optimal} = \min(L, L_f)$$

$$where \quad L_f = x_K - x_N$$

- Calculate optimal effective area of vehicle 1

$$S^{vehicle1}_{optimal} = S^{left\,veh1}_{optimal} + S^{right\,veh1}_{optimal} + \left[\min(\mathrm{w}, \mathrm{w}_{f2}) + (x_{N'} - x_N) + \min(\mathrm{w}, \mathrm{w}_{f4})\right].\left[\min(L, L_f)\right] \quad (10)$$

5.5 Motorcycle equivalent unit estimation

As defined above, MEU value helps us to know that a certain vehicle can be replaced by how many motorcycles. MEU of a stopping vehicle is equal to area of that vehicle divided by area of a motorcycle. This area is called ***static areas***. According to this reason, if we know the necessary areas of a certain running vehicle and a running motorcycle, we can estimate MEU of that running vehicle and this area is called ***dynamic area.***

We know that dynamic areas have high impacts on speed of running vehicles. Dynamic area is representative face of other parameters as density, traffic component, environmental parameters, etc. It affects directly and powerfully on vehicles speed. This research aims to estimate regression functions of dynamic areas by speed of vehicles i and motorcycles. From motorcycle's regression functions, the model sets the motorcycle's speed at the mean speed of vehicles i to estimate MEU_i. Above argument is interpreted hereafter:

- Step 1: Collect data of vehicles from video clips to calculate "the optimal effective area" and speed for each vehicle
- Step 2: Estimate regression function of Optimal effective area *(S)* by speed (*V)*. For simple, S_i and S_{mc} function will be estimated as cubic functions

$$S_k = f_k(v_k) = aV_i^3 + bV_i^2 + cV_i + d$$

$$S_{mc} = f_{mc}(v_{mc}) = a1V_{mc}^3 + b1V_{mc}^2 + c1V_{mc} + d1$$

Where, *i is vehicle class i (motorcycle, car, bus, van,…)*

- Step 3: Motorcycle equivalent unit of vehicle class *i* at mean speed v_i of them on traffic flow is estimated as following:

$$MEU_i = \frac{f_k(v_i)}{f_{mc}(v_i)} = \frac{aV_i^3 + bV_i^2 + cV_i + d}{a1V_i^3 + b1V_i^2 + c1V_i + d1} \quad (11)$$

6. RESULTS

The results show high confidence of S(v) function in comparison with other models. An example of S(v) is figured below.

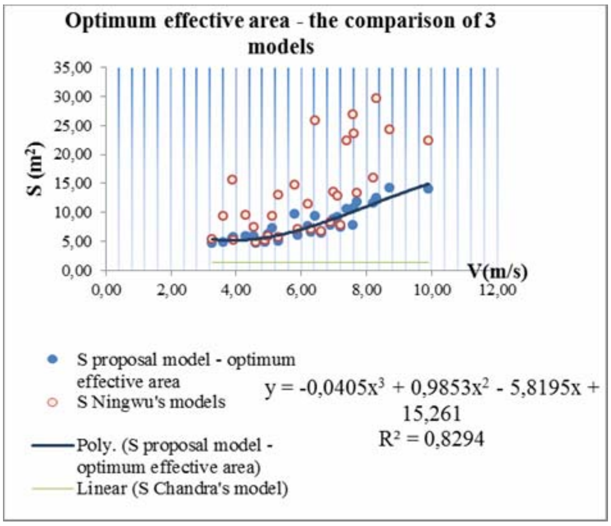

Figure 7: Optimum effective area – the comparison of 3 models

This leads to the fluctuation of MEUs on streets are rather low. Streets have same lane width also have same MEU value, reflected good stability of proposed model.

Street	Model	MEU Sedan	MEU Van	MEU Bus
Kim ma	Proposal	2.97	3.45	8.28
	Zuylen & Ning Wu and Y et al	2.41	2.97	6.76
	Chandra&Sikdar	6.02	7.72	23.45
Tay son	Proposal	3.51	3.75	8.96
	Zuylen & Ning Wu and Y et al	3.16	3.09	6.06
	Chandra&Sikdar	6.02	7.72	23.45
Giai phong	Proposal	3.03	3.44	8.24
	Zuylen & Ning Wu and Y et al	2.80	3.19	7.68
	Chandra&Sikdar	6.02	7.72	23.45
Tay son 2	Proposal	3.26	3.64	8.36
	Zuylen & Ning Wu and Y et al	3.78	4.01	9.29
	Chandra&Sikdar	6.02	7.72	23.45
Thai ha	Proposal	3.41	3.84	9
	Zuylen & Ning Wu and Y et al	3.94	4.56	8.70
	Chandra&Sikdar	6.02	7.72	23.45

7. CONCLUSIONS

Proposed models of MEU have some difference in comparison with previous models as follow:

Proposed model of MEU is more flexible than the others because it deals well with traffic situations. Moreover, it can be applied for many kinds of segments even intersection.

MEU results in proposed model are quite stable. This also demonstrates that proposed model is better than the others.

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