Delay Analysis at Signalized Intersections Based on Malaysian Road Conditions

Nurikhwani Idayu ZAINAL ABIDIN
PhD student
School of Civil Engineering,
Universiti Sains Malaysia,
Engineering Campus,
14300 Nibong Tebal,
Pulau Pinang, Malaysia
Tel: +6012 4708775
Email: ayuikhwani@yahoo.com

Ahmad Farhan MOHD SADULLAH
Professor
Deputy General, Malaysian Institute of Road Safety Research (MIROS)
Lot 125-135, Jln TKS 1,
Taman Kajang Sentral,
43000 Kajang, Selangor Darul Ehsan,
Malaysia
Tel: +603 89249200

Wan Hashim WAN IBRAHIM
Professor
Dean, Faculty of Engineering,
Universiti Malaysia Sarawak,
94300 Kota Samarahan,
Sarawak, Malaysia
Tel: +6012 5001471
Email: wiwhashim@feng.unimas.my

Lee Vien LEONG
Lecturer
School of Civil Engineering,
Universiti Sains Malaysia,
Engineering Campus,
14300 Nibong Tebal,
Pulau Pinang, Malaysia
Tel: +604 5996286
Email: celeong@eng.usm.my

Abstract: Capacity analysis for local roads in Malaysia has always been carried out using manuals from other countries. These methods include the Arahan Teknik (Jalan) 13/87, the U.S. Highway Capacity Manual (HCM 2000) and aaSIDRA. However, in 2006, the Ministry of Works Malaysia introduced Malaysia’s very own Malaysian Highway Capacity Manual (MHCM 2006) with hopes that a more accurate outcome will be the result from the usage of this manual. This paper discusses the comparison done to compare the results from the four manuals above with the actual situation on-site. The outcome of the study shows that from all four manuals, the MHCM 2006 gives the result closest to what was obtained on-site.

Key Words: capacity analysis, MHCM 2006, control delay

1. Introduction
The HCM 2000 defines capacity analysis as a set of procedures used to estimate the traffic carrying capacity of transportation facilities over a range of defined operational conditions. The end result of the analysis is the level of service (LOS) of the particular intersection. This value of LOS is what will be used in order to plan and design future facilities (Arnold and McGhee, 1995)

In 2006, the Ministry of Works, Malaysia had introduced the Malaysia Highway Capacity Manual (MHCM 2006). This manual was to be used to help in conducting highway capacity analysis for our local roads. Prior to this, engineers and practitioners in Malaysia have been using other methods from other countries for this purpose. The most common methods used were: Arahan Teknik (Jalan) 13/87, the U.S. Highway Capacity Manual (HCM 2000) and aaSIDRA.
With the development of the MHCM 2006, it is hoped that this manual will be able to assist local engineers and practitioners in carrying out highway capacity analysis and designs for local roads. This is because this manual was based on local traffic conditions and travel behavior, thus would better suit the local roads instead of using manuals form other countries that might or might not suit our roads (Nurikhwani Idayu, 2007).

The Arahan Teknik (Jalan) 13/87 originated from the method used in the United Kingdom during the 50s and 60s. This method was developed by Webster and Cobbe and is clearly not based on local traffic conditions as well as the travel behavior of road users here in Malaysia.

The HCM 2000 on the other hand is a capacity analysis manual developed in the United States. This manual only has three vehicle categories which are the light vehicles, recreational vehicles and heavy vehicles (which includes trucks, lorries and buses). This can become a problem for Malaysia as Malaysia has a high number of motorcycles as can be seen in Table 1 and motorcycles clearly could not be classified in either classes.

Table 1: New Registered Vehicles by Type, Malaysia, 1996-2005 (Source: Road Transport Department, 2007)

<table>
<thead>
<tr>
<th>Year</th>
<th>Motorcycle</th>
<th>Motorcar</th>
<th>Bus</th>
<th>Taxi</th>
<th>Hire &amp; Drive Car</th>
<th>Goods</th>
<th>Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>322,145</td>
<td>318,765</td>
<td>2,620</td>
<td>4,358</td>
<td>2,645</td>
<td>69,234</td>
<td>30,844</td>
<td>750,511</td>
</tr>
<tr>
<td>1997</td>
<td>364,214</td>
<td>372,343</td>
<td>2,947</td>
<td>5,257</td>
<td>1,860</td>
<td>65,160</td>
<td>28,396</td>
<td>840,177</td>
</tr>
<tr>
<td>1998</td>
<td>237,776</td>
<td>159,642</td>
<td>797</td>
<td>3,569</td>
<td>552</td>
<td>11,786</td>
<td>6,342</td>
<td>420,464</td>
</tr>
<tr>
<td>1999</td>
<td>236,779</td>
<td>296,716</td>
<td>508</td>
<td>1,925</td>
<td>1,724</td>
<td>19,987</td>
<td>8,102</td>
<td>565,741</td>
</tr>
<tr>
<td>2000</td>
<td>238,695</td>
<td>344,847</td>
<td>544</td>
<td>2,635</td>
<td>2,883</td>
<td>24,316</td>
<td>11,949</td>
<td>625,869</td>
</tr>
<tr>
<td>2001</td>
<td>234,751</td>
<td>395,891</td>
<td>652</td>
<td>3,169</td>
<td>1,348</td>
<td>25,612</td>
<td>13,866</td>
<td>675,289</td>
</tr>
<tr>
<td>2002</td>
<td>222,685</td>
<td>419,713</td>
<td>919</td>
<td>4,446</td>
<td>1,242</td>
<td>25,415</td>
<td>16,768</td>
<td>691,188</td>
</tr>
<tr>
<td>2003</td>
<td>321,234</td>
<td>424,753</td>
<td>1,014</td>
<td>5,542</td>
<td>1,231</td>
<td>29,975</td>
<td>17,041</td>
<td>800,790</td>
</tr>
<tr>
<td>2004</td>
<td>397,977</td>
<td>472,116</td>
<td>1,290</td>
<td>7,746</td>
<td>1,797</td>
<td>33,169</td>
<td>18,268</td>
<td>932,363</td>
</tr>
<tr>
<td>2005</td>
<td>422,255</td>
<td>537,900</td>
<td>1,568</td>
<td>5,002</td>
<td>3,411</td>
<td>33,532</td>
<td>16,440</td>
<td>1,020,10</td>
</tr>
</tbody>
</table>

On the other hand, the aaSIDRA has only two categories namely light vehicles and heavy vehicles. From these vehicle classes, the same problem is also faced where motorcycles are not taken into consideration for the capacity analysis. This will pose as a problem as motorcycles are too small to be considered as cars and totally eliminating them would greatly affect the outcome of the analysis as Malaysia has a large number of motorcycles on our local roads.

The reason on why it is important to include the motorcycles in the analysis is because there is a high number of motorcycles on Malaysian roads. As given by the Arahan Teknik (Jalan) 13/87, the motorcycle has a passenger car equivalent (Pce) as 0.33 which literally means that it takes about one-third of the place of a passenger car. When this is translated into volume per passenger car unit (Pcu) for the year 1996 based on Table 1, the number of motorcycles will translate into 107 382 pcu which is a very high number. When this high number is not included into the analysis, it will greatly affect the outcome of it as a large portion of the volume has been improperly disregarded.

However, to compare these manuals, a certain parameter was to be determined first. This
parameter must be something that not only can be calculated, but could also be determined on-site using manual observation.

As been said earlier, the outcome for capacity analysis is the value of LOS. To determine the LOS, the value of delay is used as the reference, where the lower the value of delay, the better grading of LOS was given for the intersection. However, only stopped delay can be determined on-site while by calculation, the delay obtained is the control delay.

To overcome this problem, the relationship between stopped delay and control delay had to be determined. Akcelik (1988) claimed there was an assumption the the stopped delay of always 77% of the overall delay. With this assumption in mind, in order to convert the overall delay into stopped delay, a factor of 1/1.3 was applied to the calculated overall delay to obtain the value of stopped delay, thus, all manuals can now be compared.

2. Methodology

For this study, a few methods were used in order to come up with the appropriate results. First, traffic counts were conducted in order to obtain data for the capacity analysis. Data from a total of 12 sites were obtained for this study. During this traffic count, the value of stopped delay was also observed manually, parallel to the traffic count conducted. The TDC-8 (JAMAR Technologies) was used to determine the value of stopped delay on-site.

Next, the data from the traffic count was analyzed using all four manuals which are the MHCM 2006, HCM 2000, Arahan Teknik (Jalan) 13/87 and aaSIDRA. The calculations for Arahan Teknik (Jalan) 13/87 and MHCM 2006 were carried out manually with guidance from the respective manual. For aaSIDRA, the software itself was used to carry out the calculation while HiCAP v.2.0 was used to calculate for HCM 2000.

As commonly known by traffic engineers and practitioners, in order to calculate the delay, there are a few steps of calculation that must be done first. The initial step for this set of procedures is to calculate the saturation flow. From the estimated saturation flow obtained, the v/c ratio could be calculated. All these values are important in order to calculate the delay that will be the end result in determining the LOS of the intersection.

Different manuals have different ways of conducting the capacity analysis. For HCM 2000, two methods were used to estimate the saturation flow while the rest of the procedures were the same. Equation 1 shows the calculation for estimated saturation flow from the HCM 2000 and this equation was used to differentiate both methods.

\[ s = s_o N f_w f_{HV} f_g f_p f_{bb} f_a f_{LU} f_{LT} f_{RT} f_{Lpb} f_{Rpb} \]  

Where,
- \( s \) = estimated saturation flow rate (veh/hr)
- \( s_o \) = base saturation flow rate (pcu/hr/lane)
- \( N \) = number of lanes in lane group
- \( f_w \) = adjustment factor for lane width
- \( f_{HV} \) = adjustment factor for heavy vehicles
- \( f_g \) = adjustment factor for approach grade
- \( f_p \) = adjustment factor for parking activity
The first method is by using the number of vehicles and the heavy vehicle adjustment factor. In Malaysia, there is a wide variety of transportation on local roads. However, when using this method, it does not consider the different vehicle composition found on our roads as the heavy vehicle adjustment factors for the HCM 2000 only takes into consideration recreational vehicles, trucks (which are defined as vehicles with more than four tires touching the pavement) and buses whereas in Malaysia, the vehicles have been categorized into five classes (i.e. cars, motorcycles, lorries, trailers and buses). This method will be known as Method 1 in this paper.

As for the second method used for this study, it represents the current practice of converting the vehicles into passenger car units (pcu) using the pce values obtained from the Arahan Teknik (Jalan) 13/87. When using this method, the heavy vehicle adjustment factor is not used, thus the value for this adjustment factor is then given as 1.00. This method will be known as Method 2 in this paper.

After the estimated saturation flow was determined, the capacity and v/c ratio is calculated. For the HCM 2000, capacity for each approach in an intersection is calculated using Equation 2.

\[ c_i = s_i \left( \frac{g_i}{C} \right) \]  

Where,
- \( c_i \) = capacity of lane group i (veh/hr)
- \( s_i \) = saturation flow rate for lane group i (veh/hr)
- \( (g_i/C) \) = ratio of effective green time for lane group i

After that, the v/c ratio is calculated by dividing the volume of the lane to its capacity as seen in Equation 3.

\[ X_i = \left( \frac{v_i}{c_i} \right) = \frac{v_i}{s_i \left( \frac{g_i}{C} \right)} = \frac{v_i C}{s_i g_i} \]  

Where,
- \( X_i \) = v/c ratio for lane group i
- \( v_i \) = actual or projected demand flow rate for lane group i (veh/hr)
- \( s_i \) = saturation flow rate for lane group i (veh/hr)
- \( g_i \) = effective green time for lane group i (s)
- \( C \) = cycle length (s)
When both the capacity and v/c ratio of the lanes have been determined, the delay is calculated. The delay used in this manual is the control delay. Control delay is a portion of the total delay attributed to traffic signals operation for a signalized intersection which includes initial deceleration delay, queue move-up time, stopped delay and final acceleration delay (TRB, 2000).

To estimate control delay that is used by the HCM 2000, Equation 4 is used.

\[ d = d_1(PF) + d_2 + d_3 \]  

Where,
- \(d\) = control delay per vehicle (sec/veh)
- \(d_1\) = uniform control delay (sec/veh)
- \(PF\) = uniform delay progression adjustment factor
- \(d_2\) = incremental delay (sec/veh)
- \(d_3\) = initial queue delay (sec/veh)

To complete the calculation for the control delay using HCM 2000, other delays must also be calculated. These delays include the uniform delay (Equation 5), the incremental delay (Equation 6) and initial queue delay.

\[ d_1 = \frac{0.5C(1 - \frac{g}{C})^2}{1 - \left[ \min(1, X) \frac{g}{C} \right]} \]

Where,
- \(d_1\) = uniform delay (sec/veh)
- \(C\) = cycle length (sec)
- \(g\) = effective green time (sec)
- \(X\) = v/c ratio or degree of saturation

\[ d_2 = 900T \left[ (X - 1) + \sqrt{(X - 1)^2 + \frac{8klX}{cT}} \right] \]

Where,
- \(d_2\) = incremental delay (sec/veh)
- \(T\) = duration of analysis period (hr)
- \(k\) = incremental delay factor
- \(l\) = upstream filtering/metering adjustment factor
- \(c\) = lane group capacity
- \(X\) = v/c ratio or degree of saturation

For initial queue delay (d_3), this delay is estimated for additional delay caused by the initial queue as the residual queue from the previous cycle. This happens when there is a remaining
queue from the previous queue that did not cross the stop line during the previous green phase. When this happens, additional delay is experienced by vehicles arriving in this period as the vehicles from the previous queue must first clear the intersection.

For MHCM 2006, the calculation of the estimated saturation flow was carried out using Equation 7.

\[
S = \frac{s_o \times N \times f_w \times f_g \times f_p \times f_{bb} \times f_a \times f_{LT} \times f_{RT}}{f_c}
\]  

Where,

- \( S \) = estimated saturation flow rate (veh/hr)
- \( s_o \) = base saturation flow rate (pcu/hr/lane)
- \( N \) = no of lanes for lane group
- \( f_w \) = adjustment factor for lane width
- \( f_g \) = adjustment factor for approach grade
- \( f_p \) = adjustment factors for parking activities
- \( f_{bb} \) = adjustment factor for bus blockage
- \( f_a \) = adjustment factor for area type
- \( f_{LT} \) = adjustment factor for left turning vehicles
- \( f_{RT} \) = adjustment factor for right turning vehicles
- \( f_c \) = adjustment factor for vehicle composition

In regards to the special characteristic of motorcycles in the Malaysian vehicle volume on the road, the vehicle composition adjustment factor has been developed. This adjustment factor includes three factors; the adjustment factor for cars composition, heavy vehicle composition and motorcycle composition. This can be seen in Equation 8.

\[
f_c = f_{car} + f_{HV} + f_{motor}
\]

Where,

- \( f_{car} \) = adjustment factor for vehicle composition (cars)
- \( f_{HV} \) = adjustment factor for vehicle composition (heavy vehicles)
- \( f_{motor} \) = adjustment factor for vehicle composition (motorcycles)

To calculate the respective vehicle composition adjustment factors as mentioned above, the following equations are used. For \( f_{cars} \), Equation 9 is used.

\[
f_{car} = e_{car} \left( \frac{q_{car}}{Q} \right)
\]

Where,

- \( f_{car} \) = adjustment factor for vehicle composition (cars)
- \( e_{car} \) = passenger car equivalent for passenger cars
- \( q_{car}/Q \) = proportion of cars in total volume
For $f_{\text{motor}}$, Equation 10 is used.

$$f_{\text{motor}} = e_{\text{motor}} \left( \frac{q_{\text{motor}}}{Q} \right)$$ \[10\]

Where,

- $f_{\text{motor}} = \text{adjustment factor for vehicle composition (motorcycles)}$
- $e_{\text{motor}} = \text{passenger car equivalent for motorcycles}$
- $q_{\text{motor}}/Q = \text{proportion of motorcycles in total volume}$

Three vehicle categories are included in the heavy vehicles adjustment factor. These three categories are lorries, trailers and buses. For this adjustment factor, the factors for each category are calculated respectively before added together to determine the $f_{\text{HV}}$ as can be seen in Equation 11.

$$f_{\text{HV}} = f_{\text{lorry}} + f_{\text{trailer}} + f_{\text{bus}}$$ \[11\]

Where,

- $f_{\text{HV}} = \text{adjustment factor for vehicle composition (heavy vehicles)}$
- $f_{\text{lorry}} = \text{adjustment factor for vehicle composition (lorry)}$
- $f_{\text{trailer}} = \text{adjustment factor for vehicle composition (trailer)}$
- $f_{\text{bus}} = \text{adjustment factor for vehicle composition (bus)}$

The adjustment factors for the three categories are as in Equation 12, Equation 13 and Equation 14.

$$f_{\text{lorry}} = e_{\text{lorry}} \left( \frac{q_{\text{lorry}}}{Q} \right)$$ \[12\]

Where,

- $f_{\text{lorry}} = \text{adjustment factor for vehicle composition (lorries)}$
- $e_{\text{lorry}} = \text{passenger car equivalent for lorries}$
- $q_{\text{lorry}}/Q = \text{proportion of lorries in total volume}$

$$f_{\text{trailer}} = e_{\text{trailer}} \left( \frac{q_{\text{trailer}}}{Q} \right)$$ \[13\]

Where,

- $f_{\text{trailer}} = \text{adjustment factor for vehicle composition (trailers)}$
- $e_{\text{trailer}} = \text{passenger car equivalent for trailers}$
- $q_{\text{trailer}}/Q = \text{proportion of trailers in total volume}$

$$f_{\text{bus}} = e_{\text{bus}} \left( \frac{q_{\text{bus}}}{Q} \right)$$ \[14\]
Where,
\( f_{bus} \) = adjustment factor for vehicle composition (buses)
\( e_{bus} \) = passenger car equivalent for buses
\( q_{bus}/Q \) = proportion of buses in total volume

To calculate the delay using this manual, the MHCM 2006 has adopted the equations used by the HCM 2000 (please refer Equations 4, 5 and 6). On the other hand, for both manuals, it is also desirable to aggregate the delay values to provide delay for an intersection approach and for the intersection as a whole (Ministry of Works Malaysia, 2006). This is done by using Equation 15 and Equation 16.

\[
\sum_{i} \frac{d_i v_{i}}{v_{i}} = \sum_{A} \frac{d_{A} v_{A}}{v_{A}}
\]

Where,
\( d_{A} \) = delay for approach A (sec/veh)
\( d_{i} \) = delay for lane group i (on approach A) (sec/veh)
\( v_{i} \) = adjusted flow rate for lane group i (veh/hr)

\[
\sum_{i} \frac{d_i v_{i}}{v_{i}} = \sum_{A} \frac{d_{A} v_{A}}{v_{A}}
\]

Where,
\( d_{i} \) = average delay per vehicle for the intersection
\( d_{A} \) = delay for approach A (sec/veh)
\( v_{A} \) = adjusted flow for approach A (veh/hr)

The values of the control delay obtained from calculation using MHCM 2006 and HCM 2000 was converted into stopped delay using the assumption discussed above in the previous section.

For the Arahan Teknik (Jalan) 13/87, a more complicate approach is taken. First, the saturation flow is determined according to the lane width where Equation 17 is used to estimate saturation flow for lane widths greater than 5.5 meters.

\[
S = 525 \ W
\]

Where,
\( S \) = saturation flow (pcu/hr)
\( W \) = lane width (m)

However, Table 2 is referred to for lane widths less than 5.5 meters.
Table 2: Relationship between effective lane width and saturation flow (Source: Ministry of Works Malaysia, 1987)

<table>
<thead>
<tr>
<th>W (m)</th>
<th>3.00</th>
<th>3.25</th>
<th>3.50</th>
<th>3.75</th>
<th>4.00</th>
<th>4.25</th>
<th>4.50</th>
<th>4.75</th>
<th>5.00</th>
<th>5.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>S (pcu/hr)</td>
<td>1845</td>
<td>1860</td>
<td>1885</td>
<td>1915</td>
<td>1965</td>
<td>2075</td>
<td>2210</td>
<td>2375</td>
<td>2560</td>
<td>2760</td>
</tr>
</tbody>
</table>

After the saturation flow has been determined using either Equation 10 or Table 2 above, a series of correction factors are applied to the obtained value. These correction factors include the correction factor for gradient, the correction factor for the turning radius and the correction factor is turning traffic. After the saturation flow has been determined by multiplying with all relevant adjustment factors, the determination of the y value is carried out. Y value is the ratio of flow to saturation flow and is determined using Equation 18. The y value used in calculation would be the highest y value calculated from all approaches within that phase.

\[ y = \frac{q}{S} \]  \[18\]

Where,
\( y \) = ratio of flow to saturation flow  
\( q \) = actual flow on traffic-signal approach converted to pcu/hr  
\( S \) = saturation flow for the approach in pcu/hr

Next is the determination of lost time using the equation by Webster and Cobbe (1966) as seen in Equation 19 and the inter-green time as calculated using Equation 20.

\[ L = \sum_{i=1}^{n} (I - a) + \sum_{i=1}^{n} l \]  \[19\]

Where,
\( I \) = the inter-green time between the phases (s)  
\( A \) = the amber time, usually taken as 3 seconds  
\( l \) = drivers reaction time at beginning of green per phase. In practice, this time is set to 2 seconds but 0-7 seconds can also be used

\[ I = R + a \]  \[20\]

Where,
\( I \) = inter-green time (s)  
\( R \) = all red interval (s)  
\( a \) = amber time (s)

After the lost time has been determined, the optimum cycle time is then calculated. The equation used by the Arahan Teknik (Jalan) 13/87 is given in the Road Research Technical Paper No. 56 as in Equation 21. For practical purposes, the cycle time should be between 45 seconds to 120 seconds.
\[ C_o = \frac{1.5L + 5}{1 - Y} \]  

Where,
- \( C_o \) = optimum cycle time (s)
- \( L \) = lost time (s)
- \( Y \) = ratio of flow to saturation flow

Then the signal settings are determined where green time for each phase is calculated. For each individual phase, the \( Y \) value is first calculated for the respective phases. After that, the effective green time for each signal phase is calculated using Equation 22.

\[ g_n = \frac{Y_n}{Y}(C_o - L) \]

Where,
- \( g_n \) = effective green time of the \( n \)th signal phase
- \( Y_n \) = calculated \( Y \)-value of the same signal phase
- \( C_o \) = optimum cycle time (s)
- \( L \) = lost time (s)

The Arahan Teknik (Jalan) 13/87 uses the following equation in estimating stopped delay for each approach.

\[ d = \frac{9}{10} \left[ \frac{(C(1 - \lambda))^2}{2(1 - \lambda x)} + \frac{x^2}{2q(1 - x)} \right] \]

Where,
- \( d \) = average delay per vehicle
- \( c \) = cycle time (s)
- \( \lambda \) = proportion of the cycle that is effectively green for the phase under consideration (i.e. \( g/C \))
- \( q \) = flow (veh/hr)
- \( x \) = degree of saturation, which is the ratio of actual flow to the maximum flow that can pass through the approach (i.e. \( q/\lambda S \))

As for aaSIDRA, the software itself is used for this study and in this research, aaSIDRA version 2.0 was used. This software is widely used by the Australian government and authorities. This software is also used by Australian academic and research organizations (Troutbeck and Akcelik, 1994). After all values of the delay were obtained, the analysis was carried out to compare all values with the actual value on-site.

3. Results and Discussion

The values of delay, both calculated and obtained on-site can be summarized in Table 2. As can be seen in the table, all values of the control delay have been listed from the respective manuals as well as the value of stopped delay on site that has been converted to control delay.
Table 2: Comparison between the delays from the chosen manuals

<table>
<thead>
<tr>
<th>Site</th>
<th>Observed Control delay on-site (s)</th>
<th>Delay by calculation</th>
<th>MHCM</th>
<th>HCM 2000</th>
<th>Arahan Teknik (Jalan) 13/87</th>
<th>aaSIDRA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control Delay</td>
<td></td>
<td></td>
<td>Control Delay</td>
<td>Stopped Delay</td>
<td>Control Delay</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MHCM</td>
<td>Method 1</td>
<td>Method 2</td>
<td>Method 1</td>
</tr>
<tr>
<td>Nasmir 1</td>
<td>33.8</td>
<td>44.2</td>
<td>29.6</td>
<td>171.5</td>
<td>148.6</td>
<td>193.2</td>
</tr>
<tr>
<td>Nasmir 3</td>
<td>20.41</td>
<td>39.4</td>
<td>414.8</td>
<td>1083.9</td>
<td>60.6</td>
<td>78.8</td>
</tr>
<tr>
<td>Jln Bakar Arang</td>
<td>79.69</td>
<td>72.1</td>
<td>46.8</td>
<td>57.1</td>
<td>246.9</td>
<td>321.0</td>
</tr>
<tr>
<td>Jln Pahlawan</td>
<td>54.73</td>
<td>44.7</td>
<td>43.9</td>
<td>89.5</td>
<td>156.8</td>
<td>203.8</td>
</tr>
<tr>
<td>Jln Badlishah</td>
<td>57.85</td>
<td>46.2</td>
<td>507.1</td>
<td>923.9</td>
<td>83.9</td>
<td>109.0</td>
</tr>
<tr>
<td>Jln Kg Perak 1</td>
<td>150.67</td>
<td>106.5</td>
<td>45.1</td>
<td>49.3</td>
<td>39.9</td>
<td>51.9</td>
</tr>
<tr>
<td>Jln Kg Perak 2</td>
<td>118.17</td>
<td>112.8</td>
<td>41.7</td>
<td>44.1</td>
<td>70.6</td>
<td>91.8</td>
</tr>
<tr>
<td>Jln Stadium</td>
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<td>861.6</td>
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<td>194.4</td>
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</table>

The difference between these values can also be seen graphically as in Figure 1 below.

![Comparison of Delay between manuals and actual value](image_url)

Figure 1: Comparison of Control Delay between Manuals and Actual Value

From the diagram above, the MHCM gives a calculated value that is almost identical to the value obtained on-site. However, it can be seen clearly that some of the methods used have values that are way too much when compared to the actual value obtained on-site. This is especially clear in the HCM method for some of the sites even when the formula used to calculate the control delay for both MHCM and HCM 2000 are similar.

To further compare the precision of the estimated control delay from all manuals towards the
actual value obtained on-site, the results have been summarized graphically in another type of graph as can be seen below. This type of graph resembles a goodness-of-fit type of graph where the y-axis and x-axis of the graph represents the estimated control delay of and actual control delay respectively. The linear line on the graph represents the situation when the actual value of the control delay equals to the estimated value calculated by the respective manuals. The scattered dots on the graph represent the control delay obtained from the study.

As seen from Figure 1, the MHCM has the closest value with the actual value on-site. This is further proved by the Figure 2 below. It can be seen that the dots that represent the delay value obtained from the study are situated close to the linear line that represents the optimum situation when the estimated and calculated value of control delay are the same.

From this observation, it can be summarized that the MHCM is the best manual to be used when conducting a capacity analysis for Malaysian roads as it well represents the actual local traffic conditions and traffic behavior.

Figure 2: Comparison of control delay for MHCM and control delay on-site

Figure 3 and Figure 4 represents the comparison done for HCM 2000 using both methods. A similar pattern was obtained where although some sites have results almost similar to the ones on-site, there were a few results that were very far from the optimum situation, thus showing that the HCM 2000 may be good for some sites, but not good for other sites. From observation, the results that were off the chart were analysis for shared lanes or exclusive turning lane.

The conclusion that can be made from these figures is that HCM 2000 can be used to analyze through lanes in Malaysia, but for shared lanes or exclusive lanes, the results obtained were too far from the actual value.
Figure 3: Comparison of control delay for HCM 2000 (Method 1) and control delay on-site

Figure 4: Comparison of control delay for HCM 2000 (Method 2) and control delay on-site

Figure 5 represents the situation for Arahan Teknik (Jalan) 13/87. As can be seen, the results are not even remotely close to the optimum situation as compared to MHCM and HCM 2000. Whilst the MHCM have all values close to the optimum situation, and HCM 2000 having a few sites that are close, the Arahan Teknik does not have such values as all values are scattered far away from the optimum line. This actually should not be a surprise as the Arahan Teknik, though using a Malaysian name, was adopted from a study in the 1960s.
Lastly, Figure 6 represents the situation faced when using aaSIDRA. A similar pattern can be observed by aaSIDRA as with the HCM 2000 where some sites have values that are close to the optimum values. However, there are still some values that are far from the optimum situation.

Figure 6: Comparison of control delay for aaSIDRA and control delay on-site

4. Conclusion
From this study, it can be concluded that only the MHCM shows a consistent similarity to the actual value that was obtained on site. Other methods, particularly the HCM 2000 and
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aaSIDRA have some results that are similar to the ones on-site but also some results that are too far off. This should not be surprising as the studies conducted to produce this manual were done throughout Malaysia, on our own local roads.

This might be due to the fact that among all manuals compared, only the MHCM takes motorcycles into consideration. As discussed earlier, the volume of motorcycles on Malaysian roads are almost half of the total vehicle volume, being second only to passenger cars. When the motorcycle volume is disregarded, a large portion of the total volume is being compromised when it should not.

The importance of these results is to avoid over-designing or under-designing Malaysian roads. This is because, capacity analysis is usually carried out to evaluate existing traffic conditions and to forecast whether some changes must be done. The forecasted changes would then also be subjected to the capacity analysis to determine whether the planned changes are suitable or not in order to improve the intersection.

When the capacity analysis is carried out using other manuals that are not suitable to local conditions, over-designing or under-designing might happen. This might lead to unnecessary upgrading of roads that costs a lot of money but the worst that can happen is that it might compromise the safety of the intersection.

This study also proves the reliability of the manual when used to carry out capacity analysis and designs for local roads as proven by the comparison of all manuals with the actual result obtained on-site.

Therefore it can be said that for capacity analysis on Malaysian roads, the MHCM is the most suitable method to be used.

5. Acknowledgement
The authors would like to acknowledge the Highway Planning Unit (HPU) from the Ministry of Works, Malaysia for financing this study.

6. References


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