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Minor Road Traffic Delays at Priority Junctions on Low Speed Roads in Suburban Areas

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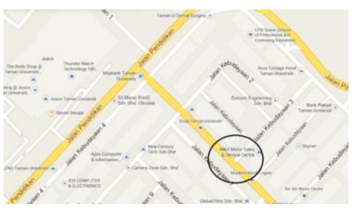
Graphical abstract



Abstract

Traffic delay is one of the important aspects considered in the assessment of the operational performance of intersections. In the analysis of priority or unsignalised junctions, delays to minor road vehicles are often estimated using the existing mathematical models. However, the applicability of such a model depends on the basis and the source of the data with which the model was calibrated. This study was carried out to evaluate traffic delays to minor road vehicles at priority junctions in suburban areas. The data were collected at two priority junctions using video recording technique. The results showed that the day time delays were longer than of those observed during the twilight time. In both situations, delay to minor road vehicles increases as the volume of major road traffic increases. However, the effect of conflicting volume on the delay to the minor road vehicles is not clear. The comparisons between observed delay and the values predicted using the HCM and Tanner's models indicated that, in general, the observed delays are much lower than the values predicted by both models particularly during the day time. Such a finding suggests that both HCM and Tanner's models are not directly applicable to the analysis of delays at priority junctions in Malaysia.

Keywords: Delay; twilight time; minor road; observed delay; Tanner

1.0 INTRODUCTION

In general there are two main types of unsignalised junctions, i.e. the Two–Way Stop–Controlled (TWSC) and All Ways Stop–Controlled (AWSC) [1]. The Highway Capacity Manual (HCM) stated that a three–leg junction (e.g. a T–junction) could also be regarded as a particular type of TWSC intersection, as long as the single minor road approach is controlled by a stop sign [2].

The control of vehicles at priority junctions is a complicated and highly interactive process since each driver creates their own personal decisions to accomplish the essential manoeuvre, influenced by his or her perceptions of distance, speed, as well as their car's performance [3]. Each driver must also find a secure time for the movement to view existing traffic and traffic signs. Therefore, priority junctions create a specific problem for potential accidents of vehicles which were appearing from minor approach as the priority of vehicles is for the ones from the main street, especially in rural and suburban areas [1].

This paper discusses the traffic delay to minor road vehicles based on the observed data and the mathematical models proposed by Tanner [4] and HCM [5].

1.1 Gap Acceptance at Priority Junctions

The American Transportation Research Board [5] suggested that the TWSC analysis methods do not handle a specific style of priority junctions, where one or more right–turning vehicles from the minor into the major approach are permitted to travel unimpeded through the junction [6]. The TWSC junctions give no positive indication or control to the motorist on the minor road as to when it is safe to leave the stop line and proceed into the major road [5]. Motorists who arrive at the minor approach of a TWSC junction may enter the major road by taking a gap in the major road traffic stream. A driver can reject several gaps but may only accept one gap. In general, a driver must identify the gap in the major approach to secure entry, and his or her turn, on the basis of relative priority of the competing traffic streams.

The gap acceptance theory consists of three basic factors, i.e., the dimension and distribution (accessibility) of gaps in the major road, the effectiveness of these gaps to the minor approach drivers, and the relative priority of the various traffic streams at the junction [7]. A gap is described as the time period between the arrivals of two sequential vehicles on the major road traffic stream [8]. Troutbeck [9] described the critical gap as the minimum time period in the major road traffic stream that permits junction entry for one minor road vehicle. Velan and Aerde [10], on the other hand, described the critical gap is the smallest gap that the right turns vehicles will be regarded to accept. According to the HCM [5], driver's critical gap is the lowest acceptable gap. Gaps that are less than the critical gap is usually declined and all gaps bigger than this critical gap are anticipated to be accepted [10]. The determination of the critical gap can be created base on the observations of the biggest rejected and smallest accepted gaps for a given junction [7]. The critical gap can be analysed using different methods such as Greenshields, Raff, Acceptance curve, Logit, Probit analysis, and Siegloch.

1.2 Delay

The delay has been described as a measure of performance at priority junctions and it is often used to assess the 'level of service' (LOS) of priority junctions [5]. Service delay is an important element of the total delay experienced by the drivers on minor approaches at junctions controlled by stop signs. Service delay in principal depends on the conflicting traffic volume, its composition and the right of way at the junction under consideration [11]. There are two methods for calculating of delay at the priority junctions; (1) calculation of delay based on the length of the gap on the major movement which probabilities of acceptance by minor road drivers known as gap acceptance and (2) calculation of delay with queue length of the minor road vehicles which will be determined based on the length of the gap on the major road. In this research, the first method was used for the calculation of delay during day time and twilight time [12].

Guidelines for priority junctions have used various techniques for establishing delay models. Lu and Lall [13] established a non–linear multivariable model for two–way stop–controlled (TWSC) junctions by using 34 hours data collected by video camera in Alaska. The model of minor road traffic delay is described as a function of the minor road traffic volume and the major road traffic volume. The model is also said to have a modest data requirement in comparison with the HCM delay model [14].

Al-Omari and Benekohal [15] established a technique to analyse delay at unsaturated TWSC junctions. The technique was based on the 28–hours traffic data collected at different locations using a video camera recording technique. The model was reported to be able to estimate delays more accurately than the 1994 HCM delay model [14]. Although small dissimilarities exist between the results of these models, there is no clear understanding regarding which of the techniques are more precise [16]. In practice, the HCM delay model is used generally for the evaluation of control delay at priority junctions [16].

The control delays in this study are based on two theoretical methods, i.e. Tanner and Highway Capacity Manual (HCM) methods. Tanner's model [4] assumes that (1) the minor road vehicles arrive at the junction at random, (2) the major road traffic flow forms an alternating renewal process with the time taken for a group of vehicles to cross the junction having an arbitrary distribution and the gaps among bunches being distributed exponentially, and (3) minor street vehicles pass the major street at equally spaced instants during a gap provided that there is at least a time (t) constant before the start of the next group [17]. Tanner's model to estimate the average delays for vehicles on the minor street at unsignalised junctions is represented by the following set of Equations 1–4.

$$W2 = \frac{0.5*\frac{E(y^2)}{Y}+(q2*Y*exp(-\beta2q1)*[exp(\beta2q1)-\beta2q1-1]/q1}{1-q2Y[1-exp(-\beta2q1)]} \qquad (1)$$

Where;

$$E(y) = \frac{exp[q1*(\alpha-\beta1)]}{q1*(1-\beta1q1)} - \frac{1}{q1} \qquad (2)$$

$$E(y^2) = \frac{2*exp[q1*(\alpha-\beta1)]}{(q1^2)*(1-\beta1q1)^{\wedge}2} - \{exp[q1*(\alpha-\beta1)] - \alpha q1*(1-\beta1q1) - 1 + \beta1q1 - \beta1^2q1^2 + (0.5*\beta1^2q1^2)/(1-\beta1q1)\} \qquad (3)$$

$$Y = E(y) + (1/q_1) \qquad (4)$$

$q1$ = major road flow (veh/sec)
$q2$ = minor road flow (veh/sec)
$\beta1$ = minimum time headway in the major road traffic stream (sec)
$\beta2$ = minimum time headway in the minor road traffic stream (sec)
α = the average lag or gap α in the major road traffic stream accepted by minor road drivers when entering the major road traffic stream (sec).
$W2$ = delay to minor road (sec)

The application of Tanner's model as given in Equation 1 to estimate delays to minor road traffic requires various information on the characteristics of both minor and major road traffic streams, i.e. the flow rates of the traffic on both minor and major roads, critical gap, and headways in both the major road and minor road traffic stream. The model proposed by the American Transportation Research Board [5], on the other hand, is much simpler when compared with the Tanner's model. The model, which is also called as the HCM model in this article, is as given by the following Equation 5. In general, the HCM model only requires two main inputs for its application, i.e. (1) the flow rate of the movement to analyse and (2) its corresponding capacity. However, the accuracy of the delay estimated using this HCM model may be argued because it relies on the accuracy of the estimate of the capacity of the minor approach.

$$D=\frac{3600}{Cm,x}+900T\left[\frac{Vx}{Cm,x}-1+\sqrt{\left[\frac{Vx}{Cm,x}-1\right]^2+\frac{\left[\frac{3600}{Cm,x}\right]\left[\frac{Vx}{Cm,x}\right]}{450\,T}}\right]+5 \qquad (5)$$

Where;
D = control delay (sec/veh),
v_x = flow rate for movement x (veh/h),
$c_{m,x}$ = capacity of movement x (veh/h), and
T = analysis time period (h) (T = 0.25for a 15-min period).

2.0 METHODOLOGY

2.1 Studied Parameters and Sites

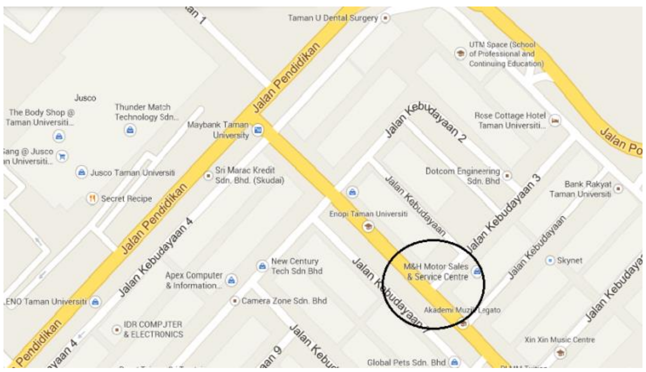
The basic data required for this study are the arrival and departure time of vehicles on the minor approach, the arrival time of the conflicting vehicles in the main stream traffic at the conflict point, and flow rates or the volumes of both minor road traffic and main stream traffic.

It is realised that a relatively accurate measurement of control delays and drivers' critical gap or lag may be obtained from an extensive field observations and large quantity of gap acceptance and rejection data. However, because of limitation in time and resources, the quantity of data to be collected for this study have to be compromised between a reasonable, realistic data collection effort and the need for adequate data for numerical analysis.

Several visits were made to the various priority junctions within urban and suburban areas. The intention was to identify suitable sites for data collection purposes. Selection on sites to be studied was based on the following criteria:

(a) good access and safety for the enumerators and equipment during the data collection process,
(b) good overhead vantage points for video recording purposes,
(c) reasonable traffic volumes on both major and minor approaches so that good quality of data is obtained, and
(d) good sight distances (to ensure that the sight distances do not influence the interactions between drivers)

Unfortunately, priority junctions that have all the criteria described above were difficult to find. Therefore, the site selected for this study was a compromise between the criteria given above. Two priority junctions located in a CBD area in Johor Bahru, Malaysia were selected for the study. Figure 1 and Figure 2 show the location and lane configurations of each junction, respectively. These junctions were selected because the preliminary short traffic counts showed reasonable amounts of turning movements which is appropriate for objectives of the field observations.



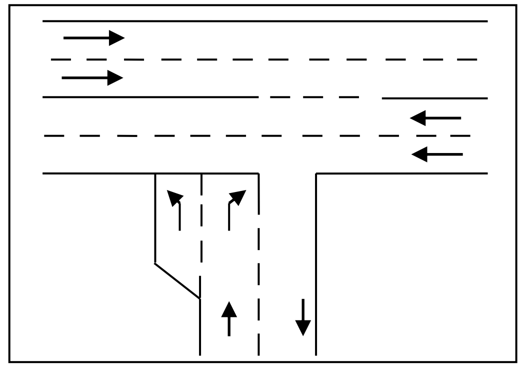
(a) Kebudayaan/ Kebudayaan3 Junction

(b) Titiwangsa3/Titiwangsa4 Junction

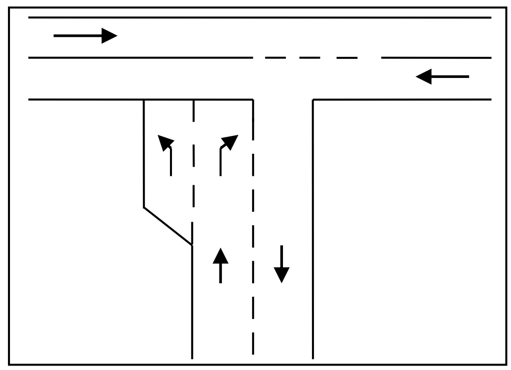
Figure 1 Google maps for the locations of the junctions studied

2.2 Data Collection and Analysis

In this study, field data collections were carried out using video cameras. Ashworth [18] and Othman Che Puan [19] have described the advantages of using a video recording method for traffic data collection. The method has also been used in many delay and gap acceptance studies [18, 19, 20] A total of twenty–four–hour recording period was adopted for the sites. The recording times were from 6.00am to 7.00am for the twilight period data and from 7.00am to 7.00pm for the daytime period data. These recording periods were considered appropriate for evaluating the required traffic parameters under a range of traffic flows.



(a) Kebudayaan/ Kebudayaan3 Junction



(b) Titiwangsa3/Titiwangsa4 Junction

Figure 2 Traffic lanes configuration on each junction studied

Each of the recordings containing the recorded scenes was played back several times to retrieve the data as listed below.

- Vehicle arrival times for major road traffic;
- Vehicle arrival and departure times for vehicles on the minor approaches; and
- Traffic composition

A personal computer based event recorder was used to extract the information defining the above data from the recordings.

For vehicle arrival and departure time data, the recordings were played back in real-time. A vehicle arrival time was recorded by pressing a pre–defined key each time the front of a vehicle reaches a specified reference line. All these arrival and departure time data were extracted using the same time reference for all directions of traffic. This was an important procedure because all events have to be arranged in a correct order based on the individual occurring times for gap acceptance analysis.

For delay analysis, the control delay considered in this study refers to the time a minor road vehicle arrived at the back of the queue until it departed into the major road. The volumes of traffic on the major road were also enumerated to evaluate their effects on the average traffic delay to the minor road vehicles.

3.0 RESULTS AND DISCUSSION

3.1 Estimated Delays based on Tanner and HCM2000 Models

In this study, traffic delays to the minor road vehicles were evaluated based on a 15–minute data interval. The average gap α, minimum time headway in the major road traffic stream β_1 and the minimum time headway in the minor road traffic stream β_2 were derived from the field data. An example of the application of the Tanner's model is as shown below.

q_1=0.26 veh/sec; q_2=0.14 veh/sec;
α =4.01;
β_1=2.1 sec; β_2=1.4 sec

$$E(y)=\frac{\exp[0.26*(4.01-2.1)]}{0.26*(1-(2.1*0.26))}-\frac{1}{0.26} \rightarrow E(y)=9.94$$

$$E(y^2)=\frac{2*\exp[0.26*(4.01-2.1)]}{(0.26\hat{}2)*(1-(2.1*0.26)\hat{}2}-\{\exp[0.26*(4.01-2.1)]-(4.01*0.26)*(1-)-1+(2.1*0.26)-((2.1^2*0.26^2)+(0.5*2.1^2 0.26^2)/(1-(2.1*0.26))\} \rightarrow E(y^2)=170.26$$

$$Y=9.94+(1/0.26) \rightarrow Y=13.82$$

$$W2=\frac{0.5*\frac{170.26}{13.82}+(0.14*13.82*\exp(-1.4*0.26)*[\exp(1.4*0.26)-(1.4*0.26)-1]/(0.26)}{1-((0.14*13.82)*[1-\exp(-(1.4*0.26))])} \rightarrow W2=16.59\ \text{sec}$$

The variations of delays to minor road vehicles based on Tanner's model for the twilight and daytimes at Titiwangsa 3/Titiwangsa 4 junction and Kebudayaan/ Kebudayaan3 junction are illustrated in Figure 3 and Figure 4, respectively.

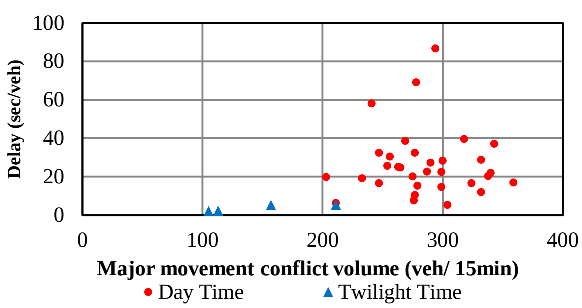


Figure 3 Tanner Theoretical delay at the Titiwangsa 3/Titiwangsa 4 Junction

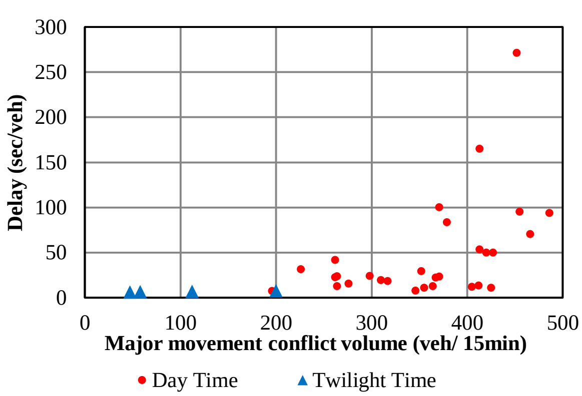


Figure 4 Tanner Theoretical delay at the Kebudayaan/ Kebudayaan 3 Junction

Figure 3 and Figure 4 show that there is no specific trend that can be established to relate the effect of major road traffic volumes on the minor road traffic delays. However, intuitively it can be seen that the higher conflicting traffic volumes in the major road would lead to much higher delay to minor road vehicles due to limited safe gaps that exist in the major road traffic stream. The shorter delay experienced by the minor road vehicles during twilight time was probably because of low traffic volumes in the major road.

In general, estimation of delays based on Tanner model indicates that during the twilight time, minor road vehicles at both junctions experienced delays in the range of 1.49 sec/veh and 8.04 sec/veh for Titiwangsa3/ Titiwangsa4 junction and 3.63 sec/veh and 7.56 sec/veh Kebudayaan/ Kebudayaan3 junction. On the other hand, during the daytime, the lowest level of delay was 5.32 sec/veh and the longest was 271.47 sec/veh.

Figure 5 and Figure 6 show the relationship between the theoretical delays based on HCM and major movement conflict volume for Titiwangsa3/Titiwangsa4 and Kebudayaan/ Kebudayaan3 junctions, during both twilight and daytimes. During twilight time, the delays were between 10.00 sec/veh and 15.00 sec/veh for Titiwangsa3/ Titiwangsa4 junction, where for the Kebudayaan/Kebudayaan3 junction, the delays were fluctuated between 9.00 sec/veh and 11.50 sec/veh for the same period of time. On the other hand, during the daytime, the lowest level of delay 10.46 sec/veh and the longest was 341.36 sec/veh.

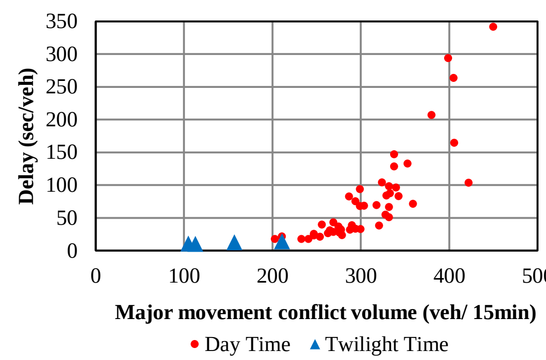


Figure 5 HCM Theoretical delay at the Titiwangsa3/ Titiwangsa 4 Junction

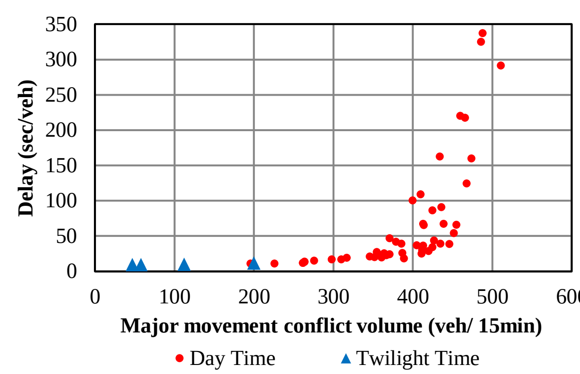


Figure 6 HCM Theoretical delay at the Kebudayaan/ Kebudayaan3 Junction

3.2 Observed Delays and their Comparisons with Tanner and HCM2000 Models

In general, the actual average control delay experienced by the minor road drivers at both junctions was in the range of 1.5

sec/veh to 341.36 sec/veh. Figures 7–10 show the comparisons between the observed delays and the delays estimated using the Tanner's model and the comparisons between the observed delays and the HCM model at both junctions, respectively.

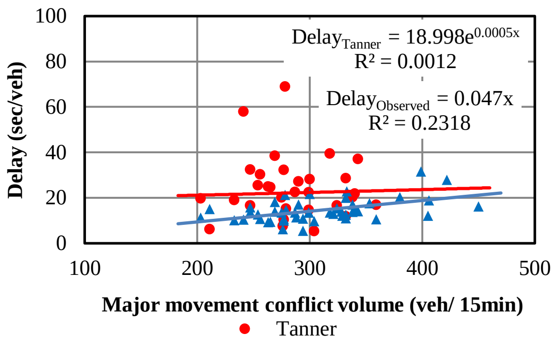


Figure 7 Comparison between observed delays and Tanner's delay model for Titiwangsa3/Titiwangsa4 junction

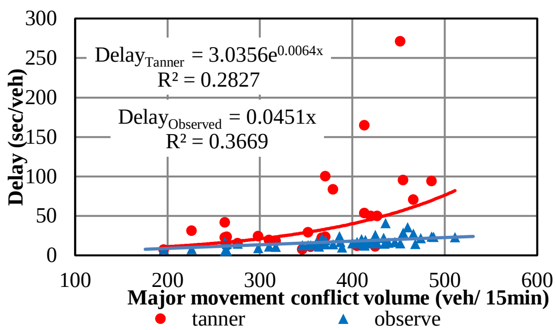


Figure 8 Comparison between observed delays and Tanner's delay model for Kebudayaan/ Kebudayaan3 junction

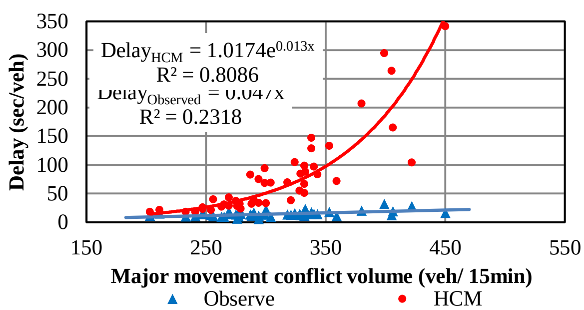


Figure 9 Comparison between observed delays and HCM's delay model for Titiwangsa3/Titiwangsa4 junction

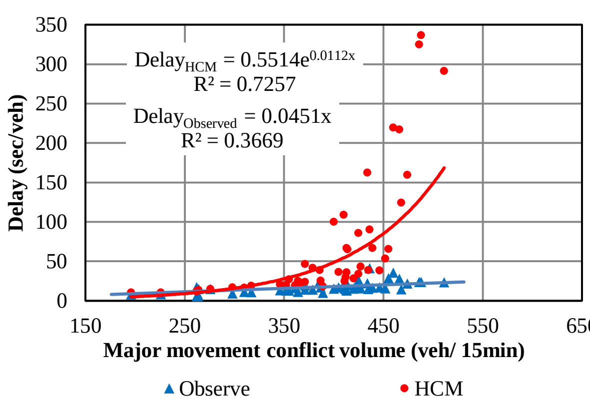


Figure 10 Comparison between observed delays and HCM's delay model for Kebudayaan/ Kebudayaan3 junction

It can be seen from all Figures 7–10 that the delays estimated using both Tanner's and HCM models are higher than the observed values. In general, there is no specific trend in the delays estimated using Tanner's model and delays based on the observed data. This is indicated by relatively small R^2–values for the respective relationships shown in Figures 7–10. However, the HCM model does indicate a strong relationship between delay and conflicting volumes on the major road where the R^2–values, as shown in Figure 9–10, are greater than 0.70.

In order to confirm the observed and theoretical delay comparisons, student t-Test was conducted on the data. The delays estimated using Tanner's model and observed delays during twilight time atTitiwangsa3/Titiwangsa4 junction were analysed, and the results are summarised in Table 1.

Table 1 t–Test results for Tanner's model versus observed delay

	Delay based on Tanner's Model	Observed Delay
Mean	3.76	5.91
Variance	3.23	11.23
Observations	4.00	4.00
t-Test	0.31	

The result shown in Table 1 indicates that the Tanner's model can be used to estimate delays under very low conflicting traffic volumes in the main stream that might exist during the twilight time. The t–test analysis was done for both junctions for the data obtained during the twilight and day times. Table 2 shows the summary of the interpretations of the comparisons between the observed delays and the HCM model and the Tanner's model.

Table 2 The comparisons between HCM and Tanner's models and the observed delays

Time of day	Junction	Observed vs. HCM model	Observed vs. Tanner's model
Twilight	Titiwangsa3/ Titiwangsa4	Significant	Not Significant
Day time	Titiwangsa3/ Titiwangsa4	Significant	Significant
Twilight	Kebudayaan/ Kebudayaan3	Significant	Not Significant
Day time	Kebudayaan/ Kebudayaan3	Significant	Significant

In general, the analysis shows that the average delay estimated using the HCM model is significantly different from the observed values. On the other hand, the difference between the observed delays and the values estimated using the Tanner's model under relatively low traffic volumes is not significant. However, there is a significant difference between the two values especially when the conflicting traffic volume in the major traffic stream is relatively high, i.e. during the day time. It must be pointed out here that the HCM model does not include the effect of conflicting volume of traffic in the major stream. Tanner's model, on the other hand, considers the effect of conflicting volume of traffic in the major stream in terms of the size of critical gap or lag accepted by the minor road drivers.

4.0 CONCLUSIONS

This paper discusses the results of the study carried out to investigate delays to the minor road vehicles at priority junctions located in suburban areas. The data was analysed based on time of day, i.e. during twilight and day time. The results showed that the delays during the day time were higher than of those observed during the twilight time. In both situations, delays to minor road vehicles increase as the volume of major road traffic increases. The results of this research showed that the observed delays were in a good agreement with values estimated using the Tanner's model for the twilight time, but not for the day time data. For both junctions, the observed delays did not support the HCM theoretical method for both the day and twilight time data. Such a finding implies that both HCM and Tanner's models are not directly applicable to the analysis of delays for priority junctions in Malaysia. Therefore, it is suggested that a new empirical method for delays' calculation to be used in the future research.

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References

[1] Brilon, W., R. Troutbeck, and M. Tracz. 1997. *Review of International Practices Used to Evaluate Unsignalized Intersections*. Transportation Research Circular (TRB), National Research Council.

[2] Transportation Research Board (TRB). 1994. *Highway Capacity Manual*. Spec. Rep. No. 209, 3rd Ed., Transportation Research Board, National Research Council, Washington, D.C.

[3] Kaysi, I. and S. A. Ali. 2007. Modeling Aggressive Driver Behavior at Unsignalized Intersections. *Accident Analysis and Prevention*. 39: 671–678.

[4] Tanner, J. C. 1962. A Theoretical Analysis of Delays at an Uncontrolled Intersection. *Biometrika.* 49(1/2): 163–170.

[5] Transportation Research Board (TRB). 2000. *Highway Capacity Manual.* National Research Council, Washington, D.C.

[6] Gattis, J. L. and T. L. Sonny, 1999. Gap Acceptance at Atypical Stop-Controlled Intersections. *J. Of Tra. Eng*. 125: 201–207.

[7] Wachs, M., M. S. John, and E. Robert, 2000. Highway Capacity Manual. *Transportation Research Board (TRB). National Academy of Sciences*. Inc. USA. 522–574.

[8] Sunanda, D., J. L. Jian, and Y. Ping, 2007. Driver Age Differences In Day And Night Gap Acceptance Capabilities. *International Association Of Traffic and Safety Science.* 26: 71–79.

[9] Troutbeck, R. 1992. *Estimating the Critical Acceptance Gap from Traffic Movements*. Physical Infrastructure Centre, Queensland University of Technology, Australia.

[10] Velan, S. M. and M. Van Aerde, 1996. *Gap Acceptance and Approach Capacity at Unsignalized Intersections*. Transportation Research Board., Institute of Transportation Engineers.

[11] Ashalatha, R. and C. Satish, 2011. Service Delay Analysis at TWSC Intersections through Simulation. *KSCE Journal of Civil Engineering.* 15: 413–425.

[12] Mohammad AliSahraei, Othman Che Puan, and Nima Jahandar, 2012. Comparison of Delays between Twilight Time and Day Time. *J. Basic. Appl. Sci. Res*. 2: 9649–9657.

[13] Lu, J. J. and Lall, B. K. 1995. Empirical Analysis of Traffic Characteristics at Two-Way Stop-Controlled Intersections in Alaska. *Transportation Research Record*. 49–56.

[14] Amir, H. S., Z. A. Hedayat, and F. Ardeshir, 2011. Development of a Delay Model for Unsignalized Intersections Applicable to Traffic Assignment. *Transportation Research Board*. 34: 497–507.

[15] Al-Omari, B. and Benekohal, R. F. 1999. Hybrid Delay Models for Unsaturated Two-way Stop Controlled Intersections. *Journal of Transportation Engineering-Asce*. 125(4): 291–296.

[16] Brilon, W. 2008. Delay at Unsignalized Intersections. *Transportation Research Record*. 2071: 98–108.

[17] Hawkes, A. G., 2012. Delay at Traffic Intersections. *Journal of the Royal Statistical Society.* 28: 202–212.

[18] Ashworth, R. 1976. A Videotape–Recording System for Traffic Data Collection and Analysis. *Traffic Engineering and Control*. 17(11): 468–470.

[19] Othman Che Puan. 1999. *A Simulation Study of Speed and Capacity of Rural Single Carriageway Roads*. Division of Civil Engineering, Cardiff School of Engineering, University of Wales Cardiff.

[20] Ashalata R. and Satish Chandra. 2011. Critical Gap through Clearing Behaviour of Drivers at Unsignalised Intersections. *KSCE Journal of Civil Engineering*. 15(8): 1427–1434.