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# Establishing a new model for estimation of the control delay at priority junctions in Malaysia

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**Abstract:** In analysis of priority junctions, control delays to minor street automobiles are often approximated utilizing the present mathematical models. Nevertheless, the applicability of such a technique depends on the basis and the source of the data with which the model was calibrated. This research was accomplished to establish control delays using Multi-Linear Regression (MLR) for left- and right-turning maneuver from minor road at priority junctions in suburban areas. The data were gathered at two priority junctions utilizing video recording method. In both movements, control delays to minor street automobiles increase as the volume of main street traffic increases. The comparisons among observed control delays and the values estimated utilizing the Malaysia Highway Capacity Manual pointed out that; in general, the observed delays were not in a good agreement with the values computed by theoretical model especially within right turn from minor road. Additionally, the outcomes of this study revealed that the observed delays were in a well agreement with values predicted using the MLR's models for left and right turns. Such a finding signifies that new model is directly applicable to the evaluation of control delays at priority junctions in Malaysia.

**Subjects: Transport & Vehicle Engineering; Civil, Environmental and Geotechnical Engineering; Engineering Economics**

**Keywords: priority junctions; control delay; multi-linear regression; minor street**

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## PUBLIC INTEREST STATEMENT

In order to analysis of priority junction, control delay is very important. This research was conducted because the existing models for estimation of control delay were not accurated. In this case, two priority junctions with four lanes major/four lanes minor road were selected. Then, the two cameras, one for minor and another one for major road were installed. Data for analysis were gathered from 9:00 am until 6:00 pm. The comparisons among observed and theoretical control delays showed that the observed delays are substantially different from the theoretical results. Accordingly, the new models (i.e. for right- and left-turning from minor road) were established using Multi-Linear Regression (MLR) in Excel software. The outcomes of this study revealed that the observed delays were in a well agreement with values predicted using the MLR's models for left and right turns.

## 1. Introduction

A junction is a location where two or more roads join or cross. When one roadway ends at the junction with another roadway, a three-leg junction, or T-Junction is shaped. Some junctions have more than four legs, but this style is usually prevented, since the performance of traffic movements is usually ineffective (Brockenbrough & Boedecker, 2003). Two forms of priority junctions are the main emphasis in modeling uncontrolled junction flow. These are the Two-Way Stop-Controlled junction (TWSC) and All-Way Stop-Controlled junction (AWSC) (TRB, 2010). This article has been focused at priority junction (T-junction) as TWSC junctions.

Stop signs are utilized to control automobile movements at such junctions. At TWSC junction, the stop-controlled approaches are known as the minor road; they can be either public roads or private one. The junction approaches that are not controlled by stop signs are known as the major road approaches. A three-leg junction is taken into consideration to be a regular type of TWSC junction if the single minor road is controlled by a stop sign. Three-leg junctions where two of the three approaches are controlled by stop signs are a special type of unsignalized junction.

Each motorist waiting in minor road has to decide when it is risk-free to cross the junction or merge into the conflicting traffic streams. The potential of the vehicles that maneuver from minor to the major street depends on various forms of control junction and traffic flow at the junctions. In order to maximize safety, motorists wait for a large gap due to merge with major road. Consequently, it causes various delays at the priority junctions. The main benefit of priority junction is that the major street flow does not generally experience any delay. Movements from the minor street, and right turns from major road, are dependent on gaps in the main traffic stream and this affects both safety and capacity. The challenge is that, as major street traffic flow raise, gaps among vehicles get smaller and accidents raise as gap acceptance gets shorter (TRB, 2010).

Performance measurements for TWSC have included capacity (the highest number of vehicles that can cross through a junction from a given way), queue length, gap-acceptance and control delay (Ruskin & Wang, 2002). The primary estimate that is applied to provide a determination of Level of Service (LOS) is control delay. This calculates can be determined for any movement on the minor road (TRB, 2010). This article has been concentrated on establishing of the control delay models for vehicles movement of minor road (i.e. right and left turns) at priority junction on sub-urban areas.

## 2. Delay and gap

TRB (2010) explained that control delay is defined as the total elapsed time from the time a vehicle stops at the end of the queue to the time the vehicle departs from the stop line. Service delay is described as the delay experienced by an automobile at the stop line while waiting for a chance to go into the major traffic stream (Ashalatha & Chandra, 2011).

Tanner (1962) established a new model for estimation the average delay for vehicles on the minor road at priority junctions where major stream traffic has absolute priority. Based on this mode, Tanner (1962) assumed that major stream traffic flow formed as blocks and gaps. There is another method for calculation of control delay at priority junctions which recommend by Box and Worth (1967). Based on this method, vehicles were counted in queue length during 15 min intervals and control delay in term of vehicle per hour was measured.

Lu and Lall (1995) determined a non-linear multivariable model for TWSC junctions by using 34 h data collected by video camera in Alaska. This model evaluated minor road control delays as a function of the subject minor road traffic volume and the major road traffic volume. Kyte et al. (1996) attempted to establish a new practical model for estimation of delay based on queuing theory at priority junctions. In this regard, Kyte et al. (1996) used two specific times which were service time (automobile spend time at the stop line position on minor road until departure to the major road) and move up time (the minimum time for automobile to arrive to the stop line after the previous automobile leaves the stop line). Therefore, Vehicle will spend time on the minor road based on the sum of these two times.

Al-Omari and Benekohal (1999) established a new technique to analyze control delay at unsaturated TWSC junctions. Duration of data collection for their technique was about 28 h of different location by video camera technique. It was identified that their model more closely estimated the field calculated control delays than the Highway Capacity Manual 1994 (HCM 1994).

Among different methods for estimation of control delay, Highway Capacity Manual TRB (2010) has been used generally for the evaluation of delay at priority junctions which is an analytic model based on queuing theory Shahpar, Aashtiani, and Faghri (2011). In this model, the fundamental idea goes back to Kimber, Summersgill, and Burrow (1986). Brilon (2008) reported that the traffic demand over the time must be defined where it is constant during peak periods. On the other hand, capacity is also constant during these times. However, traffic demand and capacity may change during off-peak. Therefore, based on these concepts, Brilon (2008) established various models for estimation of the control delays at priority junction.

Sahraei, Puan, and Jahandar (2012) have mentioned that estimation of control delay are based on the length of the gap on the major road, as well as queue length of the minor movements based on the gap length on the major traffic stream. In addition, a study by Sahraei, Puan, and Yasin (2014) has indicated that the control delays during day time were longer than twilight time at priority junctions in sub-urban areas. Based on this research, it has clearly showed that control delay to minor road vehicles increases as the volume of major road traffic increases. Additionally, Sahraei, Puan, and Yasin (2014) demonstrated that both HCM's and Tanner's techniques were not applicable to the analysis of control delays at priority junctions in Malaysia.

Gaps are generally calculated by evaluating either front or rear bumper of vehicles going a certain reference position. Whenever a gap in the major stream is equal to or higher than a value that a driver on minor street believes large enough for him/her to go into or pass the major approach, the driver accepts this gap (Dissanayake, Lu, & Yi, 2002). This gap is an acceptable gap for that specific driver. Otherwise, the car owner rejects the gap and delays for a larger gap.

Luttinen (2004) explain that gap is the headway between two successive major flow vehicles considered by a minor-flow driver for the reason of crossing or merging. In particular, Dissanayake et al. (2002) who explained that a gap is described as the time interval between the arrivals of two consecutive vehicles on the major road traffic flow.

Madanat, Cassidy, and Wang (1994) mentioned that there are many drivers on the minor road who reject different gaps due to increase safety. To prevent biasing the calculated value by different drivers, Raff take into account the first gap (i.e. the lag) in recognizing the critical gap. This procedure is statistically deficient, because large number of data disregarded Miller (1971). In particular, some empirical documents can indicate the drivers on the minor road have different respond to lag than to gaps. In different condition, the minimum accepted lag is larger than critical gaps for different drivers (Daganzo, 1981).

The Khattak's method supposed a specific negative exponential for the gap distribution. The results of gap distribution could be made mistake if the real traffic at TWSC junctions does not follow of that distribution. Generally, the negative exponential distribution could be utilized during low traffic flows but is not acceptable during high traffic flows (McGowen & Stanley, 2012). In order to resolve of this problem, May (1990) proposed a composite distribution that can be used during high traffic flows. May's method had a proportion of platoon vehicles with a normal gap distribution. The rest of the vehicles have randomly a negative exponential distribution for the gaps.

Critical gap was defined in TRB (1985) as "the median time headway between two successive vehicles in the major street traffic stream that is accepted by drivers in a subjected movement that must cross and/or merge with the major street flow". This definition was changed in TRB (2000) that was the lowest time interval in the major road traffic flow that allows junction entry to one minor road vehicle.

A study by Khattak and Jovanis (McGowen & Stanley, 2012) showed a new method for estimation of critical gap by using the accepted gaps, rejected gaps, or both. In this method, a probability density function was assumed on the basis of the negative exponential distribution for whole gaps on the major road. In this case, Khattak and Jovanis (1990) consider that using negative exponential distribution at TWSC junctions with high flow on the major road was not problematic.

Critical gap was explain in the American Association of State Highway and Transportation Officials Green Book (AASHTO) based on the safety reason for vehicle stop on the minor road which able to see other vehicles on the major approach with minimum available sight distance. Due to increase safety, the critical gap values in the AASHTO is slightly higher than values utilized in the HCM (McGowen & Stanley, 2012). In a research Sahraei and Puan (2014) estimated the values of gap acceptance to minor street automobiles using the maximum likelihood method at priority junctions. In results of this research show that the gap acceptance values decrease when the volume of the major stream traffic increases.

In order to describe about local traffic condition in Malaysia, there was some differentiation between HCM and MHCM. Accordingly, characteristic of traffic flow, including distribution of vehicle types in the traffic stream and directional distribution of traffic can be taken into consideration. In Malaysia, high proportion of motorcycles traverses at junctions. The form of motorcycles prevalent on Malaysian road is that of small size motorcycles where the length of its wheel bases is around 0.5 m. The size is small in comparison to that of other vehicles where the length of motorcycles is around 1.68 m. Because of its small size, drivers of motorcycle can weave in and out of traffic flow. This allows the driver of motorcycles to get closer to the departure line, consequently the theory of FIFO (First in First out) is broken. Motorcyclist's unique characteristic is the fact that they can travel alongside other vehicles within a lane. As result, the flow is not in a structured discipline. Furthermore, the direction of traffic in Malaysia is left-hand driving system which is different with HCM manual.

Regarding to the above literature about traffic delay at priority junction, although small dissimilarities exist among the outcomes of these methods, there is no clear understanding regarding which of the models are more precise. In practice, the Malaysian Highway Capacity Manual (MHCM) delay model is utilized for the estimation of control delay at priority junctions in Malaysia. Because of this issue and also the difference between actual control delays and MHCM's model, this study was accomplished.

## 3. Methodology

### *3.1. Studied parameters*

In the first step, delay was calculated by MHCM (2011) at priority junctions. In general, the MHCM formula (Equation (1)) only needs two major inputs for its application, including traffic flow of movement and also capacity. Next, in order to show that there are some differences between actual and theoretical delays, student *t*-Test was conducted on the data.

$$D = \frac{3600}{Cm,\mathrm{x}} = +0\mathrm{T}\left[\frac{Vx}{Cm,\,x} - 1 + \sqrt{\left[\frac{Vx}{Cm,\,x} - 1\right]^2 + \frac{\left[\frac{3600}{Cm,x}\right]\left[\frac{Vx}{Cm,x}\right]}{450T}}\right] + 5 \qquad (1)$$

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

Eventually, proposed models for estimation of the control delay for vehicles movement from minor road to the major road were established. In general, some properties in the junctions were important for determination of the actual values (i.e. the number of lanes at the junction's arms, flared, shared lane) which were evaluated before data collection. In this case, the camera recorder technique for data collections was used. Each of the recordings including the recorded scenes was played back numerous times to obtain the data as detailed below. In the case of data collection, all appropriate data were collected manually.

- Automobile arrival times for major street traffic;
- Automobile arrival and departure times on the minor street.
- To estimate the values of follow-up time
- To estimate the values of control delays for each vehicles on the minor road.

For automobile arrival and departure time data, the recordings were played back using a Laptop based in real-time. An automobile arrival time were recorded by pressing a stop watch whenever the front of an automobile reaches a particular reference line until those one depart from reference line. All these arrival and departure time data were extracted utilizing the same time reference for all directions of traffic.

For control delay analysis, it was taken into consideration refers to the time a minor road automobile arrived at the end of the queue until it departed into the major street. The procedures of data collection for control delays were performed by stop watch. To do so, the vehicle arrival time at the end of queue was recorded by pressing stop watch until those vehicles depart from the stop line. This procedure is same for all movements for right and left turn from minor road, separately. During this process, the video was played back in real time. The volumes of traffic on the major street were also listed to assess their effects on the control delays to the minor street automobiles.

Depending on the follow-up description, it is the average time gap concerning two cars of the minor stream being queued and getting into the same major road gap one behind the other. This procedure for estimation of follow-up time can be extracted from site studies by stop watch, when one vehicle get into the major road until another one during the same gap on the major road. In order to compute the values of critical gap, only the gaps approved and declined by the minor road motorists can be observed in the site. Because the critical gap cannot be calculated directly, and a method is required that allows the drivers' critical gaps to be approximated utilizing their approved and declined gaps. As a result, the generalized control gap technique using MHCM's method considering the influence of motorcycles is as shown by the following formula.

$$t_{c,x} = t_{c,\text{base}} - \left(t_{c,M} \times P_{M,x}\right) \tag{2}$$

where $t_{c,x}$ = critical gap for movement $x$ (s), $t_{c,\text{base}}$ = base critical gap from Table 1, $t_{c,M}$ = adjustment factor for motorcycle referring to Table 1, $P_{M,x}$ = proportion of motorcycles for movement $x$.

Base values of ($t_{c,x}$) for passenger automobiles are presented in Table 1. The values are based on investigation all over the Malaysia. Modifications also are developed in Table 1 to account for the existence of motorcycles.

For capacity analysis, it was approximated utilizing MHCM manual formula which was comparable to the HCM manual except for potential capacity. In order to obtain a practical value, the potential capacity must be calibrated in the field observation. Consequently, the potential capacity is modified

**Table 1. The base values of critical gap and adjustment factor for potential capacity of movement *x***

| Vehicle movement | Base critical gap, $t_{c,\,base}$ (second) | $t_{c,\,M}$ | $A_x$ |
|---|---|---|---|
| | Multi lane | Multi lane | Multi lane |
| Left turn from minor | 3.3 | 0.252 | 0.5181 |
| Right turn from minor | 4.2 | | 0.4864 |

*Adapted from MHCM (2011).

using a modification parameter, ($A_x$). The modification parameter will create certain that the computed potential capacity will be depending on the Malaysian traffic condition. The value for modification parameter, $A_x$, is displayed in Table 1.

According to the actual delays and also inputs variables including traffic flow for right and left turns, capacity (i.e. The maximum number of vehicle which pass a point of a lane during a time period described as vehicles per hour), follow-up time, and critical gap, the new models have been established using the MLR in Excel software.

MLR takes a class of random variables and attempts to obtain a mathematical relationship between them as a form of linear that best estimates all the individual data points. The model for MLR given ($n$) observations is obtained Equation (3) as follows (Aiken, West, & Pitts, 2003):

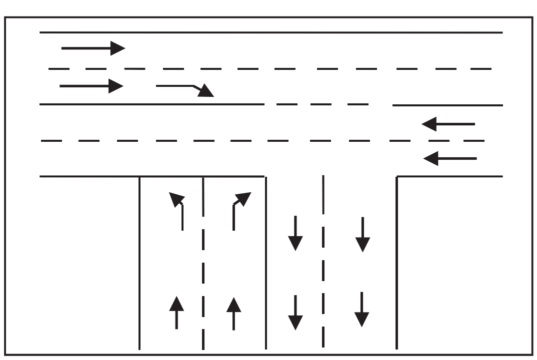
$$Y_i = B_0 + B_1X_{i1} + B_2X_{i2} + \cdots + B_nX_{in}. \quad i = 1, 2, 3, \ldots, n \tag{3}$$

where: $Y_i$ = dependent variable; $B_0$, $B_1$, …, $B_n$ = coefficients; $X_{i1}$, $X_{i2}$, …, $X_{in}$ = independent variables

### 4. Site description and data collection

This research was carried out to establish models in order to estimate control delays at priority junctions with four lanes major/four lanes minor road on sub-urban areas. Accordingly, 18 h data from two priority junctions from 9:00 am until 6:00 pm by the video camera technique were collected. These recording periods were taken into consideration suitable for analyzing the needed traffic variables under a range of traffic flows. Furthermore, the two junctions were chosen because the initial brief traffic counts revealed acceptable levels of turning movements which is suitable for aims of the site observations. Both of them (i.e. Kebudayaan/Kebudayaan3 and Gelang Patah/Ronggeng18) had located around Johor Bahru in Malaysia. Additionally, the lane widths for both site studies on the major and minor road were 3.65 m and the major approaches did not have any median. Figure 1 indicates lane configurations of each junction.

**Figure 1. Lane configuration of each junction.**



## 5. Results and discussion

In the first step, control delay was estimated using MHCM' model and compared by observed delays. Based on the Equation (1), traffic flow during left and right turns from minor road, capacity, follow-up time, and critical gap were estimated, and then control delays for each movement were calculated. Figure 3 indicates the variation between theoretical (MHCM's model) and observed data from minor road to left and right turns separately.

The above variations (Figure 2) clearly show that there are significantly different between MHCM results and observed control delays for left and right turns from minor approach.

Intuitively, it can be found that the higher conflicting traffic volumes in the main street would lead to much higher control delay to minor street automobiles for left and right turns due to limited safe gaps that exist in the main street traffic stream.

Generally, evaluation of control delays depending on MHCM's model signifies that minor street automobiles at both junctions experienced control delays in the range of 8.00 s/veh to around 11.00 s/veh for left turn. On the other hand, the values of control delays for right turn were fluctuated between 14.00 s/veh to around 22 s/veh for first junction with ranges of conflicting flow rate from 800 veh/h to 1200 veh/h, but it was calculated to 237.00 s/veh for second site study. This is because of increasing the ranges of conflicting flow rate from 1600 veh/h to almost 2000 veh/h on the major road and consequently the values of control delay were computed much more than first junction. In addition, Figure 2 indicated that the control delays approximated for right turn utilizing MHCM's models are higher than the observed data mainly when the conflicting traffic volume in the main traffic movement is relatively high. Although the values of theoretical delay for left-turning maneuver from minor road were estimated in the ranges of observed data, it could not fit exactly with them.

In general, the MHCM's model and observed data indicate a good relationship among control delay values and conflicting flow rate on the main road where the $R^2$-values, as shown in Figures 2, are higher than 0.80 except for left-turning observed data where the $R^2$-value was approximated about 0.005. In this regard, the $R^2$-value was calculated low because of high fluctuation of the control delays from 2 s/veh to 15 s/veh for left turn. As result, an appropriate fitted line could not be provided for observed control delays.

The evaluation shows that the computed control delays using the MHCM's models are significantly different from the observed values. In order to confirm the evaluations, student *t*-Test was accomplished on the data. Consequently, the control delays computed using theoretical model and observed values at priority junctions with four lane major/four lane minor road were examined, as well as the outcomes and interpretations of the comparisons between data are summarized in Table 2.

**Figure 2. The variation between theoretical (MHCM) and observed delays for (a) left and (b) right turns.**

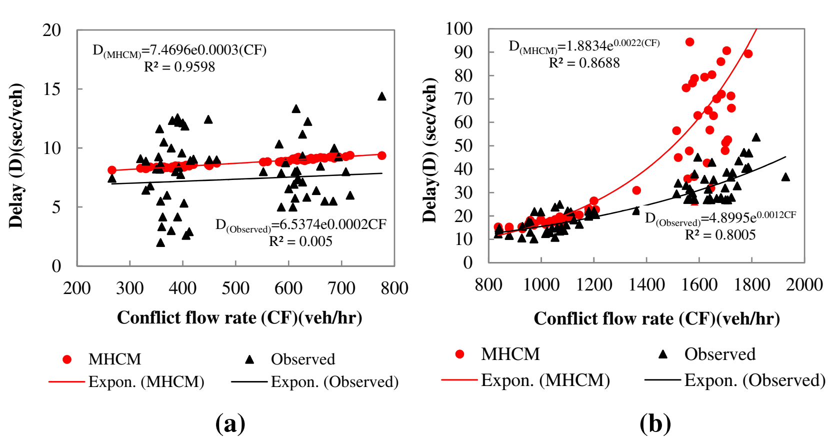


**Table 2. *t*-Test analysis for left and right turns**

| Direction | | | |
|---|---|---|---|
| Left turn | Observation | 72 | |
| | *t*-Test | 1.22E-02 | Significant |
| Right turn | Observation | 72 | |
| | *t*-Test | 8.05E-06 | Significant |

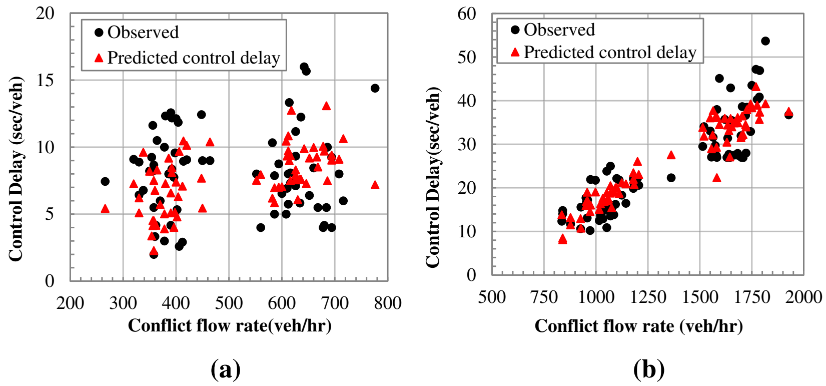



**Figure 3. The comparison between observed and predicted control delays using MLR for (a) left turn and (b) right turn.**

The result shown in Table 2 indicates that MHCM's model were unable to the evaluation of control delays at priority junctions in Malaysia where *t*-Test values were calculated less than 0.05. Consequently, it is recommended that a new empirical technique for control delays' computation to be utilized in the future investigation.

In order to establish new models with MLR using Excel software, input (i.e. independent) and output (i.e. dependent) variables were assessed. In this research, input variables (i.e. four observation parameters) including traffic flow rate on the minor road (left and right turns separately), capacity, follow-up time, and critical gap while the output variable was included observed control delays. These variables were selected because of their relationship with control delays at priority junction. Particularly, the MLR fit a line through multi-independent variables of data points. The values of flow on the minor road was ranged from 40 to 136 (veh/h) for left turn and 60 to 280 (veh/h) for right turn. Furthermore, the values of capacity was ranged from 890 to 1,230 (veh/h) for left turn and 180 to 480 (veh/h) for right turn. In addition, critical gap and follow-up time were estimated around 2.88 and 1.29 (s) for left turn and 3.86 and 1.75 (s) for right turn, respectively.

In order to determine the best fit between independent and dependent variables, regression coefficient was measured for each parameters by excel software. The coefficients for independent variables were determine less than 2.20, while constant parameters were calculated around 32.87 and 15.03 for right and left turns, respectively.

The total number of observations during data collection were determined almost 72 sets (from 9:00 am until 6:00 pm each 15 min intervals). According to the MLR method, as well as inputs and output variables, two models for calculation of control delays (predicted values) for left turn (LT) Equation (4), and right turn (RT) Equation (5) at priority junctions are established as follows:

$$D_{(LT)} = 15.03 + 0.09(TF) - 0.01(CA) - 1.28(CG) - 2.20(FT) \tag{4}$$

$$D_{(RT)} = 32.87 + 0.08(TF) - 0.06(CA) + 0.15(CG) + 0.02(FT) \tag{5}$$

where: TF = Traffic Flow on minor road (veh/h); CA = Capacity (veh/h); CG = Critical Gap (s); FT = Follow-up Time (s)

Based on new models, the fit plots for predicted control delays and actual data for both directions are shown as follows:

The above graphs (Figure 3) indicate the variation between predicted and actual control delays corresponding to conflict flow rate on major road during left and right turns, separately. As shown in Figure 3, control delays were accumulated in two separate areas. This was because of differences at the values of conflicting flow rate in two different junctions. It was accomplished for a range of traffic conflicting flow rate from 260 (veh/h) to 780 (veh/h) for left turn and 830(veh/h) to 1,930 (veh/h) for right-turning vehicle from minor road. Generally, the values of RMSE between observed data and results of control delays using MLR's models were calculated around 0.362 and 0.201 for left and right turns from minor road, which clearly shows that those data were approximately close together. Nevertheless, intuitively it can be found that the greater conflicting flow rate on the main road would due to much greater control delay to minor road automobiles simply because of limited safe gaps that can be found in the main road traffic stream.

These variations show that the observed data ranged from 2.00 (s/veh) to 30.00 (s/veh) for left turn and 10.20 (s/veh) to 53.69 (s/veh) for right turn. Similarly, the values of predicted control delays ranged from 2.28 (s/veh) to 13.09 (s/veh) for left turn and 8.08 (s/veh) to 43.20 (s/veh) for right turn. The results expressed high accuracy in the MLR outputs in predicting control delays incurred on minor vehicles movements into left and right turns to the major road at priority junctions.

## 6. Model validation

Model verification relates to the procedure for making the correctness of the MLR's models. Generally, verifications analyze whether the models capabilities and behaves in agreement with the observed values.

In this study, in order to confirm above models, a total number of 36 data sets from a new priority junction with similar geometry and time period (i.e. from 9:00 am to 6:00 pm) of data collection were observed and it was compared with outputs of predicted formula utilizing Equation (4) and (5). The model validation was performed using a range of traffic flow from 35 (veh/h) to 225 (veh/h) for left turn, 175 (veh/h) to 400 (veh/h) for right-turning vehicle from minor road. In addition, it was accomplished for a range of traffic conflicting flow from 130 (veh/h) to 300 (veh/h) for left turn and 265 (veh/h) to 590 (veh/h) for right-turning vehicle from minor road. The outcomes of the validation including all movements are displayed in the following variations.

The above graphs (Figure 4) indicate the model validation corresponding to the conflict flow rate for left- and right-turning maneuver on the major road. As indicate in graphs (4), the results of the predicted formula (i.e. Equation (4) and (5)) ranged from 1.86 (s/veh) to 7.22 (s/veh) for left turn and 7.46 (s/veh) to 25.84 (s/veh) for right turn. It clearly indicates that the outcomes of predicted model for all movements were computed close to the observed control delays. This was acceptable because most of the scattered points were computed roughly around the 45 degree line, as shown in Figure 5.

In order to confirm the comparisons, student *t*-Test was accomplished on the data. As result, the delays computed using MLR's models and observed values at priority junctions with four lane major/four lane minor road were examined, as well as the outcomes and interpretations of the comparisons among data are summarized in Table 3.

Table 3 shows the amounts of validation parameters for left- and right-turning movements from minor road, separately. The results indicate that the predicted model can be utilized to calculate control delays from minor street at priority junctions in sub-urban areas. In the case of *t*-Test, the

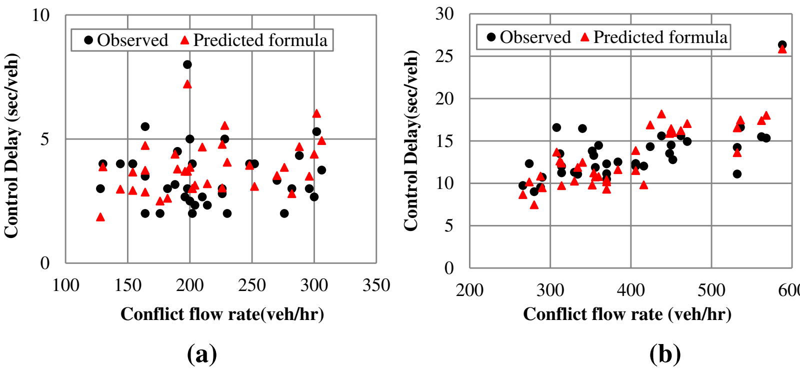



**Figure 4. Comparison between observed control delays and predicted formula for (a) left turn (a) and (b) right turn.**

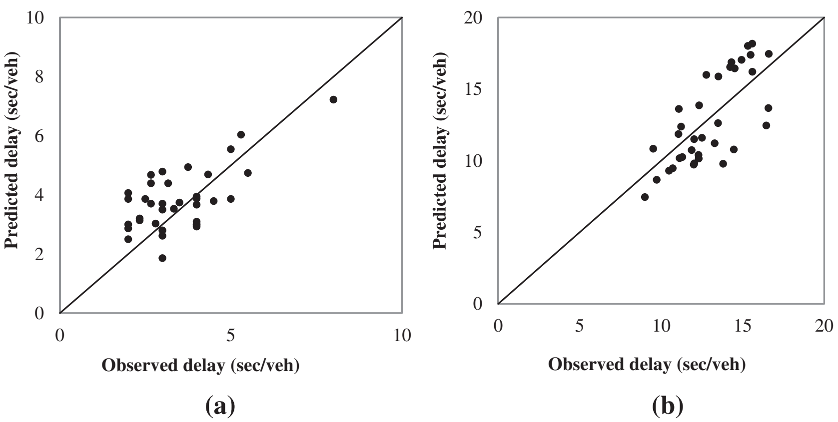



**Figure 5. Comparison of observed and predicted delays using proposed model for (a) left turn and (b) right turn.**

**Table 3. The validation parameters**

| **Direction** | | | |
|---|---|---|---|
| Left Turn | Observation | 72 | |
| | MSE | 0.042 | |
| | RMSE | 0.204 | |
| | RSS | 0.776 | |
| | TSS | 1.348 | |
| | $R^2$ | 0.84 | |
| | *t*-Test | 0.109 | Insignificant |
| Right Turn | Observation | 72 | |
| | MSE | 0.016 | |
| | RMSE | 0.128 | |
| | RSS | 0.456 | |
| | TSS | 1.483 | |
| | $R^2$ | 0.89 | |
| | *t*-Test | 0.422 | Insignificant |

Notes: MSE = Mean Squared Error, RMSE = Root Mean Squared Error, RSS = Residual Sum of Squares, TSS = Total Sum of Squares.

acceptable value is approximately more than 0.05 with 95% interval of confident where the above *t*-Test analysis were calculated almost 0.109 and 0.422 for right and left turns, separately. Consequently, it clearly indicates that the predicted models would be acceptable.

The Mean Squared Error (MSE) and Root Mean Squared Error (RMSE) are to examine of how close a predicted values is to observed data. In this regard, the values closer to zero are significantly better, where Table 3 obviously displays that these values are close to zero. Additionally, the Residual Sum of Square (RSS) and Total Sum of Square (TSS) are to examine of the divergence between the observed values and predicted models. A small RSS indicates a well fit of the model to the observed values. Furthermore, the values of $R^2$ were calculated around 0.84 and 0.89 for left and right turns from minor road. Consequently, the predicted control delays utilizing MLR as displayed in the above formulas and graphs (3, 4) indicated good agreement with those observed data.

## 7. Summary

This paper discusses the outcomes of the research performed to investigate control delays to the minor street automobiles at priority junctions located in sub-urban areas in Malaysia. The data was analyzed depending on time of day, i.e. 9:00 am until 6:00 pm. In this study, observed control delays as targets data and other input variables (i.e. traffic flow on the minor road, capacity, follow-up time, and critical gap) were extracted and new models by MLR were established. In both movements, delays to minor road automobiles increase as the volume of main street traffic increases. For both site studies, the observed delays did not support the MHCM's technique for both movements from minor street. The outcomes of this investigation revealed that the observed delays were in a well agreement with values predicted using the MLR's models for left and right turns. Such a finding signifies that MHCM's model is unable to the evaluation of control delays, while new models are able to compute that at priority junctions.

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