Proceedings of the 3rd International Conference on Civil, Structural and Transportation Engineering (ICCSTE'18)
Niagara Falls, Canada – June 10 – 12, 2018
Paper No. 106
DOI: 10.11159/iccste18.106

Traffic Delay Estimation Using Artificial Neural Network (ANN) at Unsignalized Intersections

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Abstract - This study was carried out to the modeling of control delays at unsignalized intersection using Artificial Neural Network (ANN). Although, there are several methods for estimation of delay, they lead to different results. A comparative analysis for estimation of the control delay using Malaysian Highway Capacity Manual (MHCM) showed that the theoretical model was not consistent with actual delays observed from sites. Such a finding implies that MHCM's model was not directly capable to the analysis of control delay at unsignalized intersections in Malaysia. Data pertaining to the analysis of control delay was collected from three intersections of various configurations using video camera recording technique. An ANN with two hidden layers and several sizes of neurons in the hidden layers were developed. Two mathematical models for estimation of control delay from minor road with a reasonable accuracy were developed using the outputs from the ANN's model. A statistical analysis revealed that there is good agreement between formulas acquired from the ANN's model and those from the field studies. The results of this research showed that the neural network is able to predict control delay incurred on minor road vehicles at unsignalised intersection more accurately. The analysis revealed that heavy vehicles had the lowest effect on the proposed formulas, where by increasing from 10% to 50%, the values of control delay could increase from 1% to 3%, while the movement flow and conflicting flow had the highest impact, where within the same ranges; control delay could increase until 39%.

Keywords: Control Delay-Unsignalized Intersection-Artificial Neural Network-Minor Road.

1. Introduction

The unsignalized intersections operate based on relative right-of-way of traffic movements. The vehicle movement from a minor road to the right turn (for left-handed driving conditions in Malaysia) has the lowest right-of-way at any given unsignalized intersection. The performance of an unsignalized intersection is defined by the delay values in low right-of-way movements, where the values of the delays between real and operation time are different. It is therefore an evaluation of effectiveness of an intersection by the drivers. Although it has been demonstrated that the users' conception of quality of service may be problematic to measure, delay is an extensively utilized quality of service evaluation tool for intersections[1].

The control of vehicles at unsignalized intersections is an intricate and extremely interactive procedure since each driver generates their own individual actions to carry out the necessary maneuver, which is influenced by their perceptions of distance, speed, as well as their car's functionality [2]. Each car owner must also obtain a safe time for the movement to view present traffic and traffic signs. Consequently, unsignalized intersections generate a particular problem for probable accidents of cars, which are departing from the minor road, as the priority of vehicles is for the ones from the main approach. [3].

The delay experienced by a driver is caused by a number of elements that are associated to traffic, control, incident and geometrics [4-6]. Control delay consists of preliminary deceleration delay, queue move-up time, stopped delay and ultimate acceleration delay. With regard to site measurements, control delay is specified as the total elapsed time from the time a vehicle halts at the end of a queue to the time the vehicle leaves from the stop line. This overall elapsed time consists of the time expected for the vehicle to travel from the last in-queue situation to the first-in-queue situation such as deceleration of vehicles from free-flow speed to the speed of vehicles in queue [5-6].

Generally, there are two principal types of unsignalised intersections, namely, the Two-Way Stop-Controlled (TWSC) and All-Ways-Stop-Controlled (AWSC) [3]. The Highway Capacity Manual (HCM) reported that a three-leg intersection such as a T-junction could also be considered as a specific type of TWSC intersection, providing the single minor street is controlled by a stop sign. In this study, the magnitudes of control delay were computed on the basis of the formulas from Malaysian Highway Capacity Manual (MHCM) [7], which is similar to the HCM [5-6], as shown in Equation 1.

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

Where;
D = control delay (sec/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).

This study proposed an approach for the calculation of control delays for minor road vehicles turning left and right, separately, which is based on the observed data using neural network.

2. Background Study

2.1. Delay

Tanner's technique considers based on the several factors. Firstly, the minor approach cars would arrive at the intersection at random. Secondly, the major street traffic flow creates an alternating renewal process with the time taken for a bunch of cars to cross the intersection. Thus, having an arbitrary distribution and the gaps between the groups of cars are being distributed exponentially. Thirdly and finally, minor approach cars pass the major road at equally spaced instants during a gap presented, in which there is at least a time constant before the next bunch of cars begin. Tanner's theoretical technique is the first method for calculating the delays for minor vehicles movements at unsignalized intersection [8].

Kimber [9] estimated delays happening at a unsignalized intersection operating at or near capacity. A functional form of the flow/delay relationship was recommended, which contained the time-dependent behavior of queues. In addition, Kimber and Hollis [10] introduced techniques for forecasting queue length and delay at unsignalized intersection. The approach is relatively comprehensive and takes into consideration the stochastic character of traffic demand and capacity.

A linear formula was recommended for minor road service time on the basis of the volume on the conflicting areas. Horowitz [11] modified a current queuing technique of delay at AWSC intersections to indicate empirical information of driver behavior. A study by Akcelik [12] compared three current delay techniques for unsignalized intersections. The author also demonstrated variations in their outcomes and suggested improved forms for these techniques on the basis of the simulation tool. Madanat [13] developed a probabilistic delay technique, highlighting the gap acceptance behavior of motorists at unsignalized intersections, which is appropriate for vehicles during a right turn at a T-intersection.

Kaysi and Alam [14] identified the impacts of driver behavior on control delay (impatience, aggressiveness, experience) at unsignalized intersections. The research indicated that although the absence of control may result in reduced delays at intersections for specific levels of traffic volumes, in which self-organization may be feasible, such intersection performance demonstrated aggressive driving methods, which would probably compromise safety.

Cvitanic *et al.* [15] developed a new model for estimation of control delay at unsignalized intersections. In this matter, a realistic equation for the delay estimates could be derived from the queuing theory model M/G/1. Brilon [16-17] tried computation of delay at unsignalized intersections, which is commonly based on techniques attained from queuing theory. To validate these techniques, a Markov-chain method was established to generate numerically exact outcomes. In addition, stochastic simulations and empirical data were utilized to examine the approximate solutions versus reality. Consequently, a set of equations was produced, which can be used to calculate delays at unsignalized intersections in clear traffic conditions. The method seemed to be a much better fix to the modeled priority type intersections in contrast to existing methods.

Sahraei [18] discussed that method for computation of control delays should consist of the gap size on the major road and length of the queue on the minor approach. In this case, the values of control delay during daytime and twilight time at unsignalized intersections were compared. In addition, the results of an investigation by Sahraei [19] showed that both current techniques, that of HCM [5-6] and Tanner [8], were not capable for measuring the control delays at unsignalized intersections in Malaysia. Nonetheless, Brilon [20] established a new delay formula at unsignalized intersections, which is able to estimate the magnitudes of average delay based on the preliminary queue and variable capacities. Based on the aforementioned characteristics, the method can therefore be utilized for a longer series of time intervals assessed such as a full day assessment.

3. Methodology

ANN applying backpropagation algorithm is a common network that comprises of input, hidden and output layers, which can be utilized to model complicated relationships among inputs and outputs or to obtain patterns in data [21]. As a supervised learning system, when the input is utilized into the network, the network solution is compared to the target solution created for the network. Subsequently, the learning error is computed and utilized to modify the network variables. There are numerous backpropagation algorithms, amongst which the Levenberg-Marquardt learning algorithm offers the greatest efficiency in calculating performance function [22]. In the supervised technique, the error backpropagation algorithm is utilized to train MultiLayer Perceptron (MLP), which is the most effective multilayer feed-forward network of ANN. In regards to Kolmogorov's theorem, ANN applying backpropagation algorithm with one hidden layer can uniformly estimate any continuous function on a compressed input domain to arbitrary precision if the network has a adequately significant number of hidden units [23].

In this present study, the Levenberg-Marquardt algorithm was applied for training the network. To accomplish a proper structure in final functions estimation problems, the Log-sigmoid transfer function (Equation 2) and hyperbolic tangent sigmoid (Equation 3) were applied in the hidden layer [24]. The trained network performance analysis was carried out utilizing Mean Squared Error (MSE), as described below.

$$f(x) = \frac{2}{(1 + e^{-2x}) - 1} \tag{2}$$

$$f(x) = \frac{1}{1 + e^{-x}} \tag{3}$$

The input units were linked to the hidden layers, which were subsequently linked to the output layers. All layers in the network received constant values of input from the bias [24]. The network input to a unit j is provided, as shown in Equation 4.

$$\mathrm{X_j} = \sum\nolimits_{\mathrm{i}} \mathrm{W_{ij}} \mathrm{X_i} + \mathrm{b_i} \tag{4}$$

Where;

X_i = output from the previous layer, W_{ij}=weight of the connection between layer i and j, and b_i = bias.

The weights of the network were randomly initialized throughout a specific range prior to the commencement of the training process. For every input pattern (X_{ij}), the calculation of an output at the output units was dependent on the output from the hidden units applying (Equation 4). The computed output vector (Y_{ij}) was compared against the preferred (i.e. target values) input vector (X_{ij}) [24]. The values of error function (MSE) was identified as the distinction between X_{ij} and Y_{ij}, as shown in Equation 5.

$$MSE = \frac{1}{N} \sum\nolimits_{i=1}^{n} \left(X_{ij} - Y_{ij}\right)^2 \tag{5}$$

4. Data Collection and Site Description

This study aimed to develop a model in ANN and then extracted mathematical formulas for computation of control delay for left- and right-turning maneuver from minor road at unsignalized intersections. Accordingly, the three sites studies (i.e. Tun Teja/Perwira2 and Padi/Padi2, and Stadium/Lengkok Universiti) with 27 hours of data including 9 hours for each intersection (i.e. from 9:00 am until 6:00 pm) were recorded using video camera technique. These recording periods were considered appropriate for evaluating the required traffic parameters under a range of traffic flows. In addition, Ashworth [25] and Puan [26] illustrated the benefits of utilizing a video recording technique for traffic data collection. The said approach has also been deployed in many delay and gap acceptance researches including Ashworth [25], Puan [26], Sahraei [27] as well as Ashalatha and Chandra [28].

The two video cameras were installed on a tripod at an appropriate vantage place at about 1.70 meters close to the intersection to record an unblocked view of whole approaches and turning movements. One video camera was located in the direction of minor road and another was located in the direction of major road.

The chosen intersections for this study were located in Johor Bahru, Malaysia. Figure 1 shows the lane configurations of each intersection with two lanes on the major and minor road. The major street did not have any median, while the minor road had one lane for each direction without flared. These intersections were selected because the preliminary short traffic counts showed reasonable amounts of turning movements which is appropriate for objectives of the field observations. The values of control delay for each vehicle movements on minor road were collected by stop watch. In this case, the vehicle arrival time at the end of queue was recorded by pressing stop watch until those vehicles depart from the stop line. The volumes of traffic on the major road were also enumerated to evaluate their effects on the control delay to the minor road vehicles. The values of accepted and rejected gap were also considered to estimate the values of critical gap for left- and right-turning vehicles from the minor road. During this process, the video was played back in real time.

Based on the collected data, the numbers of vehicles on the major and minor road were 30740 and 6970 during the observation period. In the case of gap acceptance, a total number of 660 and 2926 rejected and accepted gaps for left-turning, as well as 938 and 3387 rejected and accepted gaps for right-turning maneuver from minor road were collected. The values of observed control delay were ranged from 10 sec to 57.70 sec for right-turning vehicles, where it was ranged from 3.00 sec to 15.29 sec for left-turning vehicles from minor road.

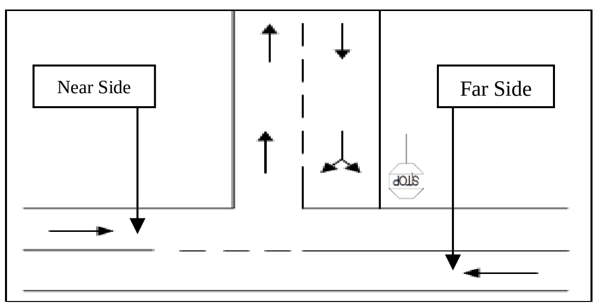


Fig. 1: Lane configurations of each intersection.

5. Analysis and Discussion

5.1. Comparison of Actual Delay and MHCM's Model

In order to show that existing model, i.e. MHCM, were not capable to estimate the magnitudes of control delays, it was computed and then compared against observed values. Traffic flows during left and right turns were extracted from the recorded video acquired during data collection. Accordingly, the values of traffic flow rate on the major and minor road were counted almost 17462 and 2626 vehicles in Tun Teja/Perwira2, while, it was counted around 7758 and 1959 in Padi/Padi2.

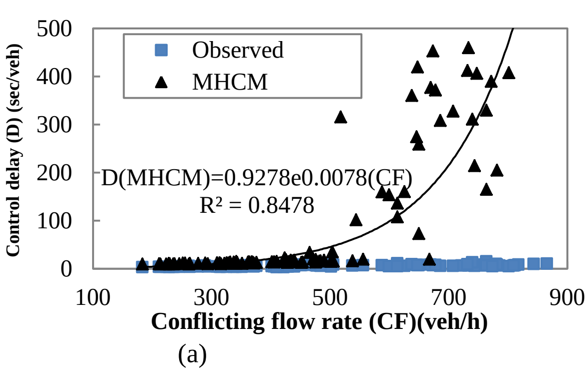
Furthermore, potential and movement capacity were calculated based on the procedures in MHCM [7]. For follow-up time analysis, first the value of follow-up time was measured from the site studies. It was computed based on the time in second between the departure of one vehicle from the minor road and the departure of the next one utilizing the same gap under a condition of continuous queuing. In this case, the average follow-up time value was obtained from individual measurements. Unfortunately, the analysis of follow-up time gives biased results where it was entirely different from the results of the formula in MHCM [7] and HCM [5-6]. Consequently, the values of follow-up time were extracted from specific Table of MHCM [7], as shown in Table 1, based on different proportion of motorcycles for movement.

Table 1: Follow-up time based on the MHCM [7].

Single lane approach	Proportion of motorcycles	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	Right turn from minor road	2.2	2.13	2.05	1.98	1.91	1.83	1.76	1.68	1.61	1.54	1.46
	Left turn from minor road	1.9	1.83	1.75	1.68	1.61	1.53	1.46	1.38	1.31	1.24	1.16

In the current study, the value of critical gap was estimated using equilibrium of probabilities method introduced by Wu [29-30]. The new method has a strong theoretical background (concerning the Markov Chain and equilibrium of probabilities) and robust outcomes. Shortage of homogeneity and consistency resulted in several complex models. In addition, several researches [31-33] confirmed that the methods presuming homogeneity and consistency led to slight variations from other complicated techniques. For the efficiency, this technique presumes that motorists are homogeneity and consistency. The magnitudes of critical gap were estimated 4.67 sec and 3.52 sec for right- and left-turning maneuver from minor road, respectively.

With regard to the above variables, the magnitudes of control delays based on the procedure of MHCM 2011 [7] can be estimated. Figure 2 shows the variation of theoretical (MHCM) and observed control delays from the minor approach to the left and right turns. It can be seen that the higher conflicting traffic volumes in the major street would lead to much higher control delays to minor street vehicles because of limited safe gaps that exist in the major street traffic stream. It can be seen that the values of MHCM's delays were overestimated than observed control delays especially when the conflicting flow rate on the major stream is relatively high. In this regard, the MHCM's model signify a solid relationship between theoretical delays and conflicting flow rate on the major street where the R^2-values are estimated 0.84 (Figure 2a) and 0.95 (Figure 2b) for left- and right-turning maneuver from minor road.



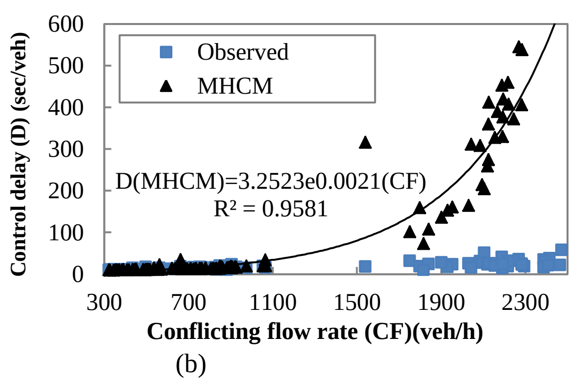


Fig. 2: Comparison between observed and MHCM's delay model at intersections with two lanes major/two lanes minor road for (a) left turn and (b) right turn.

In general, the analysis displays that the calculated control delay utilizing the MHCM's model is substantially different from the observed data sets. In order to verify the comparisons, validation was carried out on the data. In this matter, the delays calculated utilizing MHCM's model and observed data at unsignalized intersection with two lanes major/two lanes minor road were analyzed, as well as the results and interpretations of the comparisons between data are summarized in Table 2.

Furthermore, the values of t-test were estimated 2.262E-09 and 2.767E-08 for left and right-turning vehicles from minor road. This values are lower than 0.05. Consequently, it can be concluded that there is statistically significant difference between actual control delays and estimated values using MHCM's model. In addition, the R^2 show how well the theoretical model fits the observed control delays. The values of R^2 indicate the actual data and results of the MHCM's model could not fall along a 45 degree line. Such findings imply that MHCM's model were not directly applicable to the analysis of control delay at unsignalized intersection in Malaysia. Therefore, it is suggested that a model should be developed for control delays' calculation.

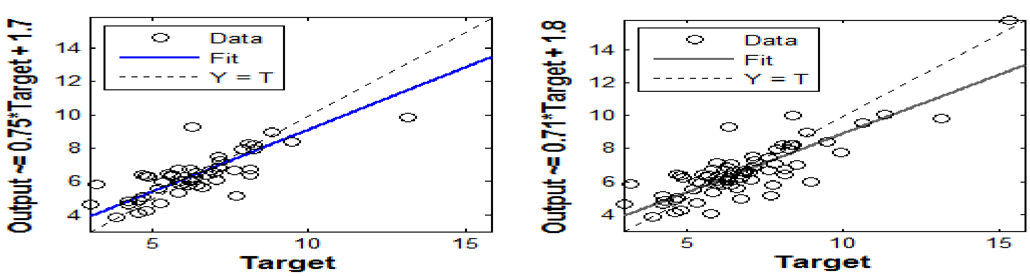
Table 2: Model validation parameters for HCM's model.

Test	left turn	right turn	Test	left turn	right turn
MSE	0.068	0.036	Adjusted R^2	0.15	0.44
RMSE	0.262	0.192	RSS	7.439	3.985
R^2	0.16	0.45	t Stat	2.262E-09	2.767E-08

5.2. Neural Network Model

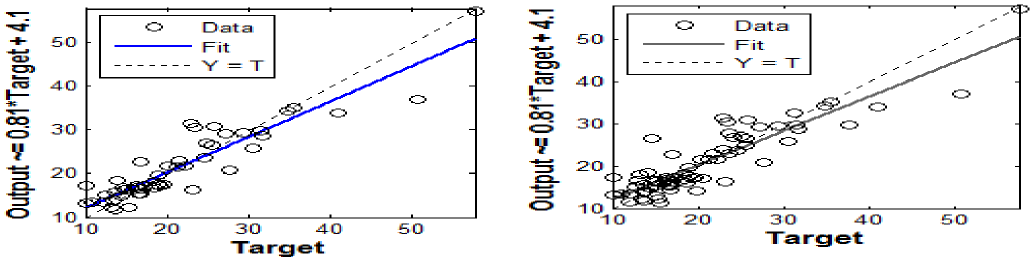
The objective of this study is the development of a model for estimation of control delay to minor road vehicles at unsignalized intersection with two lanes major/two lanes minor road on suburban area. To develop a model, two site studies i.e. Tun Teja/Perwira2 and Padi/Padi2, with 72 data sets were selected. The research recognizes various variables that influence on control delays at major and minor road vehicles including critical gap, follow-up time, conflicting flow rate, traffic flow rate for each movement, proportion of motorcycle, proportion of lorry, proportion of heavy vehicles. These variables were selected as input parameters including 7 items.

In the course of modeling, an ANN with two hidden layer and also with several sizes of neurons in the hidden layers were developed. The numbers of neurons were selected by trial and error during running the MATLAB code in several times to acquire best performing network and lowest obtained error. In this case, networks with 18 and 20 numbers of neurons for left-turning, as well as 14 and 18 numbers of neurons for right-turning maneuver from minor road which had the lowest error and highest fitting regression were designed. For that goal, the data was separated into training (70%), test (15%) and validation (15%) subsets. In particular, 50 samples were utilized for training, and 11 samples were used for validation and test, separately. In regards to this, other data splits such as (80%, 10%, 10%) or (60%, 20%, 20%) did not obtain accurate results. Eventually, based on weights and bias extracted from ANN, two mathematical models for estimation of control delays, in which flow rates were taken into consideration in terms of vehicle per hour (veh/h) were developed. According to Figure 3 (b) and 4(b), the values of fitting correlation for the whole input data for left and right turns from minor road were calculated R=0.83 and 0.90, respectively. In the case of training data (i.e. 70% of the whole data), as indicated in Figure 3(a) and 4(a), the R-values was estimated around 0.86 for left-turning and 0.92 for right-turning movement from minor road. Particularly, R-values for some fitting regression including test and validation data were computed in the ranges of 0.70 to 0.80. These regressions were accepted because most of the scattered points were estimated roughly around the 45 degree line, and as result the network did not need to train again. It can be seen that the ANN is predicting very well the entire ranges of control delay at unsignalized intersections.



(a) Training data (R=0.861) (b) All data (R=0.833)

Fig. 3: Fitting correlation for left-turning movement from minor road.



(a) Training data(R=0.922) (b) All data (R=0.901)

Fig. 4: Fitting correlation for right-turning maneuver from minor road.

Figure 5 and Figure 6 show the variation of control delays (i.e. observed and predicted values) with conflicting flow rate on the major road at unsignalized intersections. As shown in Figure 6, control delays were accumulated in two separate areas. This was because of differences at the values of conflicting flow rate in two different intersections. Generally, the results of this study showed that the observed control delays were in a good agreement with values predicted using ANN's model during morning and evening time.

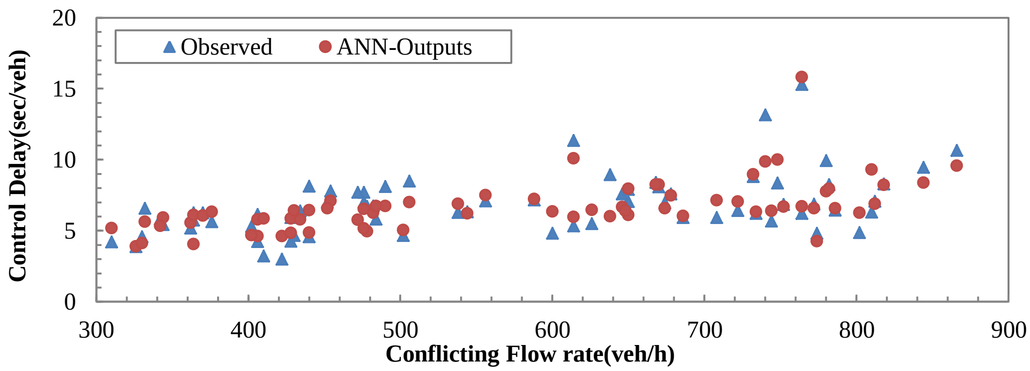


Fig. 5: Comparison between observed control delays and ANN outputs for left turn from minor road.

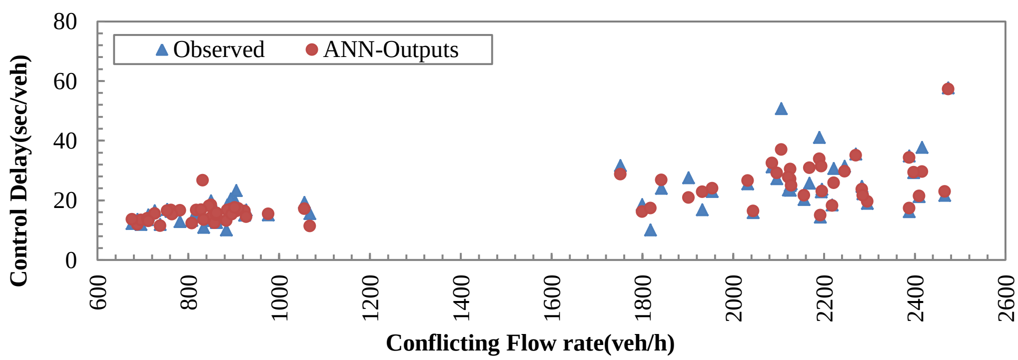


Fig. 6: Comparison between observed control delays and ANN outputs for right turn from minor road.

The explicit mathematical formulas for estimation of the control delays for left- and right-turning vehicle from minor road were extracted from network (i.e. based on weights and bias), as shown in Equation 6 and Equation 7.

$$\text{Control Delay } (D_L) = (0.024*TF_L)+(0.006*CF)+(0.031*F_t)+(0.763*CG)+(0.843*P_{HV})-(1.475*P_m) -(1.691*P_L)-1.10 \quad (6)$$

$$\text{Control Delay } (D_R) = (0.049*TF_R)+(0.006*CF)+(0.021*F_t)+(0.002*CG)-(17.78*P_{HV})+(2.68*P_m) +(0.87*P_L)+1.15 \quad (7)$$

Where;
D_L= Control Delay (left-turning from minor road) (sec/veh), D_R=Control Delay (right-turning from minor road) (sec/veh), TF_L= Traffic Flow on minor road (average left and right turn from minor road) (veh/h), TF_R= Traffic Flow on minor road (average left and right turn from minor road) (veh/h), CF=Conflicting flow rate (veh/h), F_t=Follow-up time (sec), CG=Critical gap (sec), P_{HV}=Proportion of heavy vehicles (i.e. large lorry + bus), (average left and right turn from minor road) (veh/h), P_m=Proportion of motorcycle, (average left and right turn from minor road) (veh/h), P_L=Proportion of lorry (i.e. lorry + large van), (average left and right turn from minor road) (veh/h),

The process of validation was accomplished according to the comparisons between actual data and outputs of the developed formulas (i.e. Equations 6 and 7) using new data from new site study (i.e. Stadium/Lengkok Universiti) for left- and right-turning movements from minor road. In this regard, a total number of 36 new data sets were collected. The results of the validation study on the movements can be seen in Figure 7 and Figure 8.

In this regard, validation was carried out by a rage of movement flow rate from 90 (veh/h) to 266 (veh/h) for left- and right-turning maneuver from minor road. In the case of conflicting flow rate, it was performed for ranges from 184 (veh/h) to 426 (veh/h) for left turn, 324 (veh/h) to 850 (veh/h) for right-turning movement from minor road. The results of the developed formulas were ranged from 3.36 to 6.49 (sec/veh) for left turn, and 10.52 to 22.45 (sec/veh) for right turn from minor road. As can be seen from Figure 7 and 8, it gives a clear illustration of the fact that there is a well agreement between the results of the proposed formulas (Equations 6 and 7) and observed data.

In accord with the models proposed in this study, it was revealed that input parameters had several effects in the results of the control delay. Based on the proposed formulas, in which flow rates were taken into consideration in terms of vehicle per hour (veh/h), by increasing the proportions of lorry, motorcycle, and heavy vehicle from 10% to 50%, the values of control delay could increase to 13%, 9%, and 3%, respectively. In addition, control delay could increase to 39% and 32%, if the values of movement flow rate and conflicting flow rate increase from 10% to 50%. Based on the above comparative results, heavy vehicles had the lowest effect, while the movement flow rate and conflicting flow rate had the highest impact on the proposed models.

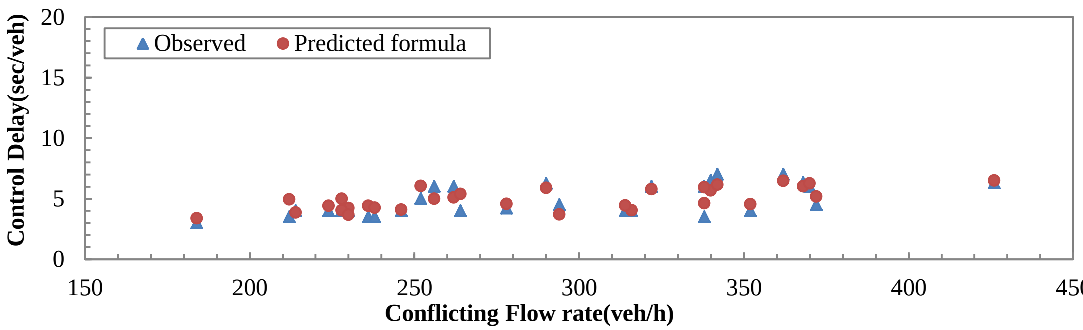


Fig. 7: Variation of observed delays and new mathematical model outcome (Equation 5.8) for left-turning maneuver from minor road.

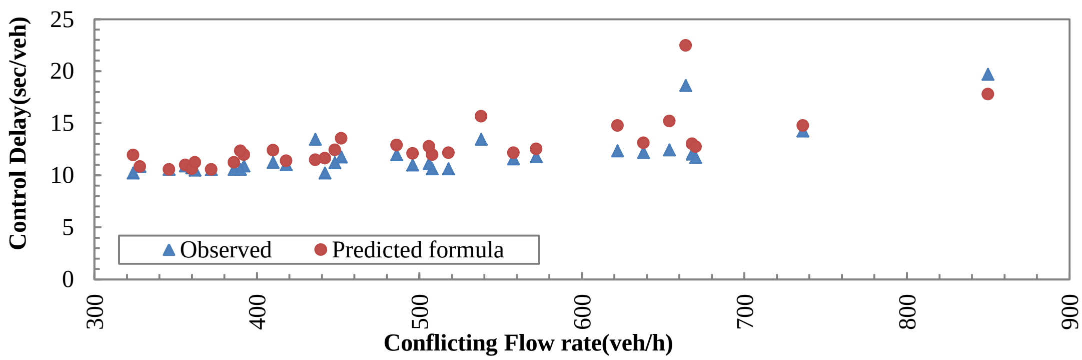


Fig. 8: Variation of observed delays and new mathematical model outcome (Equation 5.9) for right-turning maneuver from minor road.

To confirm this validation, statistical analysis were carried out on the data. From the outcome of the validation parameters presented in Tables 3, the values of root-mean-square error and residual sum of squares were measured close to zero. In addition, results from the t-test evaluation pointed out t-values of 0.273 (left turn from minor) and 0.155 (right turn from minor), which signify that the difference among observed data and results of proposed formulas (Equations 6 and 7) were not statistically different. The values of R^2 indicate the actual data and results of the proposed formulas could fall along a 45 degree line. As observed from these validation data, it is evident that the proposed formulas (Equations 6 and 7) from ANN's model can provide best fit with the target data set (i.e. actual data) and consequently estimation of the control delay at unsignalized intersection was performed precisely.

Table 3: Model validation parameters for proposed formulas.

Test	left turn	right turn	Test	left turn	right turn
MSE	0.024	0.011	Adjusted R^2	0.80	0.79
RMSE	0.155	0.107	RSS	0.795	0.377
R^2	0.81	0.80	t Stat	0.273	0.155

6. Conclusion

This paper discusses the results of the study in the field of traffic control delays incurred on minor approach at unsignalized intersection. The data was collected from three sites studies with 27 hours of data including 9 hours for each intersection (i.e. from 9:00 am until 6:00 pm) using video camera technique. In order to show that existing MHCM's model were not capable to estimate the magnitudes of control delays, it was computed and then compared against observed values. The results showed that the calculated control delay utilizing theoretical model were substantially different from the observed data sets. Such findings imply that MHCM's model were not directly applicable to the analysis of control delays at unsignalized intersection in Malaysia. In the course of modeling, an ANN using the backpropagation algorithm of the MLP artificial neural network with two hidden layer and also with several sizes of neurons in the hidden layers were developed. Eventually, based on weights and bias extracted from ANN, two mathematical formulas for estimation of control delays, in which flow rates were taken into consideration in terms of vehicle per hour (veh/h) were developed. The process of validation was accomplished according to the comparisons between new actual delay and outputs of the proposed formulas using independent data sets of new site study. The results of this research showed that the neural network is able to predict control delay incurred on minor road vehicles at unsignalised intersection more accurately. Based on the results of both proposed formulas, the minor approach traffic delay increased as the volume of major road traffic increased as well. In addition, the analysis revealed that heavy vehicles had the lowest effect on the proposed formulas, where by increasing from 10% to 50%, the values of control delay could increase from 1% to 3%. On the contrary, the movement flow rate and conflicting flow rate had the highest impact, where within the same ranges; control delay could increase until 39%.

Acknowledgement

The authors would like to express deep gratitude to the Ministry of Higher Education Malaysia and Universiti Teknologi Malaysia for providing financial grant (FRGS/2/2014/TK07/UTM/02/2-Q.J130000.7808.4F636) and opportunity to carry out this research.

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