

MODELLING OF TRAFFIC CONTROL DELAYS AT PRIORITY JUNCTIONS
USING ARTIFICIAL NEURAL NETWORK

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***TO MY BELOVED MOTHER FOR HER
ENDLESS LOVE AND SUPPORT***

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ABSTRACT

Traffic delay is an essential aspect taken into consideration in the evaluation of operational performance of priority junctions. Delay is typically described as the excess time taken in a transportation facility in comparison to that of a reference value. Although, there are several methods available for the estimation of traffic control delay, they can lead to different results. A comparative analysis for the estimation of the control delay using the American highway capacity manual and the Malaysian highway capacity manual showed that the theoretical models are not consistent with actual delays observed from sites. This implies that both theoretical models are not directly capable of analysing control delay at priority junctions in Malaysia. This study was carried out to model traffic control delays at priority junctions using Artificial Neural Network (ANN). In this study, data were sampled from eight priority junctions of various configurations. Data pertaining to the analysis of critical gap, follow-up time, and control delay were collected using video camera recording technique. The study was divided into two phases comprising analysis of field data, and the development of ANN and mathematical models using MATLAB software. In the course of data analysis, the research recognized and estimated various variables that influence control delay. To generate the model, an ANN with two hidden layers and several sizes of neurons in the hidden layers were developed. Several mathematical models for estimation of control delay with a reasonable accuracy were developed using the outputs from the ANN model. Findings from this research showed that the range of conflicting flow is from 130 to 2470 veh/h and 120 to 2300 pcu/h, the values of control delays predicted are 3-37 sec/veh and 4-43 sec/pcu, respectively. Accordingly, the minimum and maximum values of traffic control delay occurred for both left- and right-turning vehicles from the minor roads. The modelling results showed that the values of control delay for right-turning manoeuvre from minor road at junction with four lanes major/two lanes minor road were higher than other junctions. This is due to queue delays and stops delay behind the stop line, in order to select an appropriate gap on the major road in the far and near side. Delay values for right-turning manoeuvre from major road at junction with four lanes major/four lanes minor road were greater than other junctions. The analysis revealed that heavy vehicles had the lowest effect on the proposed models, with an increase from 10% to 50%, resulting in the values of control delay to increase from 1% to 3%. On the contrary, the movement flow and conflicting flow had the highest impact, with an increase from 10% to 50% whereby the control delay could increase to 44%. The statistical analyses revealed that the delay estimated using the formula acquired from the ANN model and those from the field studies are equal.

ABSTRAK

Kelewatan lalu lintas adalah salah satu aspek penting yang diambil kira dalam penilaian prestasi operasi persimpangan keutamaan. Kelewatan biasanya digambarkan sebagai masa berlebihan yang diambil dari kemudahan pengangkutan berbanding dengan nilai rujukan. Walaupun terdapat beberapa kaedah yang tersedia untuk menganggarkan kelewatan kawalan lalulintas ianya boleh menyebabkan keputusan yang berbeza. Analisis perbandingan untuk menganggarkan kelewatan kawalan menggunakan manual kapasiti lebuh raya Amerika dan manual kapasiti lebuh raya Malaysia menunjukkan bahawa model teori tidak selaras dengan kelewatan sebenar yang dilihat dari lapangan. Ini menunjukkan bahawa kedua-dua model teori tidak mampu menganalisis kelewatan kawalan pada persimpangan keutamaan di Malaysia. Kajian ini dijalankan untuk pemodelan kelewatan kawalan lalu lintas di persimpangan keutamaan menggunakan Rangkaian Neural Buatan (ANN). Dalam kajian ini, data telah diambil dari lapangan persimpangan utama pelbagai konfigurasi. Data yang berkaitan dengan analisis jurang kritikal, masa tindakan susulan, dan kelewatan kawalan dikumpulkan menggunakan teknik rakaman kamera video. Kajian ini dibahagikan kepada dua fasa yang terdiri daripada analisis data lapangan dan pembangunan ANN dan model matematik menggunakan perisian MATLAB. Dalam menjalankan analisis data, penyelidikan mengenal pasti dan menganggarkan pelbagai pemboleh ubah yang mempengaruhi kelewatan kawalan. Untuk menghasilkan model, ANN dengan dua lapisan tersembunyi dan beberapa saiz neuron dalam lapisan tersembunyi telah dibangunkan. Beberapa model matematik untuk menganggarkan kelewatan kawalan dengan ketepatan yang munasabah telah dibangunkan menggunakan output daripada model ANN. Dapatan kajian ini menunjukkan bahawa dalam julat aliran bertentangan antara 130 hingga 2470 kend/jam dan 120 hingga 2300 ukp/jam, nilai kelewatan kawalan masing-masing diramalkan hampir 3-37 saat/kend dan 4-43 saat/ukp. Oleh itu, nilai minimum dan maksimum kelewatan kawalan lalu lintas berlaku untuk masing-masing kenderaan membelok kiri dan kanan dari jalan kecil. Hasil pemodelan menunjukkan bahawa nilai-nilai kelewatan kawalan untuk pergerakan membelok kanan dari jalan kecil di persimpangan dengan empat lorong jalan utama/dua lorong jalan kecil lebih tinggi daripada persimpangan lain. Ini disebabkan oleh kelewatan barisan dan juga kelewatan berhenti di belakang garisan berhenti untuk memilih jarak sesuai di jalan utama pada jarak jauh dan dekat. Nilai kelewatan untuk membelok kanan dari jalan utama di persimpangan dengan empat lorong utama/empat lorong jalan kecil adalah lebih besar daripada persimpangan lain. Analisis menunjukkan bahawa kenderaan berat mempunyai kesan terendah terhadap model yang dicadangkan, iaitu dengan peningkatan daripada 10% hingga 50% menyebabkan nilai kelewatan kawalan meningkat dari 1% hingga 3%. Sebaliknya, aliran pergerakan dan aliran bertentangan mempunyai kesan tertinggi dengan peningkatan dari 10% hingga 50% di mana kelewatan kawalan boleh meningkat sehingga 44%. Analisis statistik mendedahkan bahawa kelewatan yang dianggarkan menggunakan formula yang diperoleh dari model ANN dan mereka dari kajian lapangan sama.

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LIST OF ABBREVIATIONS

ANN	-	Artificial neural network
AWSC	-	All Way Stop Controlled
BP	-	backpropagation algorithm
CI	-	Computational Intelligence
CDF	-	Cumulative Distribution Function
h	-	hour
HCM	-	Highway Capacity Manual
km	-	kilometre
MSE	-	Mean Squared Error
MHCM	-	Malaysia Highway Capacity Manual
M/M/1	-	Markovian (random) arrivals/Markovian service rate/one
M/G/1	-	Markovian (random) arrivals/generally distributed service times/one
Mph	-	mile per hour
MLP	-	Multilayer Perceptron
P_{HV}	-	proportion of heavy vehicles
pcu	-	passenger car unit
RSS	-	Residual Sum of Squares
sec	-	second
sec/veh	-	second/vehicle
TWSC	-	Two Way Stopped Control
US	-	United States
veh	-	vehicle
veh/h	-	vehicle/hour

LIST OF SYMBOLS

A_x	-	Adjustment factor for movement x
\mathbf{b}	-	Bias vector
$c_{m,x}$	-	Capacity of movement x
$c_{p,x}$	-	Potential capacity of movement x
CF	-	Conflict Flow rate
CG	-	Critical gap
d_Q	-	Desired output vector
D	-	Control delay
D_L	-	Control Delay (left-turning from minor road)
D_R	-	Control Delay (right-turning from minor road)
D_{R-M}	-	Control Delay (right-turning from major road)
$F_a(t)$	-	PDFs of the accepted gap
$F_r(t)$	-	PDFs of the rejected gap
F_t	-	Follow-up time
O_q	-	Output vector
P_{HV}	-	Proportion of heavy vehicles (i.e. large lorry + bus)
P_m	-	Proportion of motorcycle
P_L	-	Proportion of lorry (i.e. lorry + large van)
$t_{c,x}$	-	Critical gap for movement x
$t_{f,x}$	-	Follow-up time
T	-	Analysis time period
TF_L	-	Traffic Flow on minor road (left-turning from minor road)
TF_R	-	Traffic Flow on minor road (right-turning from minor road)

TF_{R-M}	-	Traffic Flow on major road (right-turning from major road)
$v_{c,x}$	-	Conflicting flow rate for movement x
V_x	-	Flow rate for movement x
$v_{c,x}$	-	Conflict flow
W	-	Weight matrix

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CHAPTER 1

INTRODUCTION

1.1 Background of the study

Delay is generally identified as the excess time taken in a transportation facility in comparison to that of a reference value. In this regard, it is the distinction between the time it would consume to traverse a road section under ideal situations and the real travel time. Accordingly, delay is generally taken into consideration as one of the most significant evaluation of the efficiency of priority junctions as recognized by road users.

Generally there are two principal types of priority T-junctions, i.e. the All Ways Stop-Controlled (AWSC) and Two-Way Stop-Controlled (TWSC) (Brilon *et al.*, 1997). The Highway Capacity Manual (HCM) and Malaysia Highway Capacity Manual (MHCM) explained that a three-leg junction could also be considered as a specific form of TWSC junctions, as long as the single minor street is controlled by a stop sign (TRB, 2000, TRB, 2010, MHCM, 2011).

The control of vehicles at priority junctions is a complicated and highly interactive process since each motorist generates their own individual decisions to perform the important manoeuvre, affected by his or her perceptions of speed, distance, as well as their car's performance (Kaysi and Abbany, 2007). Each motorist must also find a safe time for the movement to view existing traffic and traffic signs. Consequently, priority junctions generate a particular issue for potential accidents of vehicles which is appearing from minor road, as well as right-turning manoeuvre from major road as the priority of vehicles is for the ones from the major road (Brilon *et al.*, 1997).

Several models can be found in the literature review for calculating different kind of delay. In this regard, one of the initial delay method appears to be that of (Tanner, 1962). This author suggested one of the initial formulas which was attempted to utilize queuing theory and a steady state situation for calculating the delays at priority junctions. Troutbeck (1986) created a model for estimation of the delay at priority junctions as a function of the subsequent factors: a form factor that quantifies the impact of queuing in the minor road, the minor road flow rate was low, and also based on the degree saturation of the minor road.

Al-Omari & Benekohal (1999) created two distinct methods for calculating service delay and queue delay. I. Kaysi & Alam (2000) examined the effect of motorist behaviour on delay including impatience, experience, and also aggressiveness at priority junctions. Tapio (2004) formulated relationships between traffic flow and delay on the minor streets, while Chodur (2005) examined delay models at priority junctions on urban area. In addition, there are several researchers (Khattak and Jovanis, 1990, Heidemann, 1991, Kyte et al., 1991, Madanat et al., 1994, Tian Zongzhong, 1997, Akcelik et al., 1998a) who attempted to estimate the values of delays throughout different movement at priority junctions. In this case, a complete literature review is provided in Chapter 2.

This study concentrates on the control delay at priority junctions i.e. TWSC, for vehicle movement from minor road, as well as right-turning manoeuvre from major road. In this regard, first, a model of control delay is developed using Artificial Neural Network (ANN) with MATLAB software. Then, several mathematical formulas based on different categories and movements at TWSC junction are extracted from network.

1.2 Problem statement

Most of the above researches were carried out in different countries where geometry, traffic characteristics, traffic rules and also driving behaviour are different from those in Malaysia. In addition, the Transportation Research Board (TRB) (2010) in Highway Capacity Manual (HCM), as well as Malaysia Highway Capacity Manual (MHCM) (2011) provides a procedure for calculating control delay at priority junctions. In order to show that the existing models are not able to estimate the values of control delays at priority junctions, comparative analysis are performed in Chapter 4 between actual control delays and existing models (i.e. HCM's and MHCM's models). Generally, the analysis displays that the calculated control delays utilizing mentioned models are substantially different from the observed data.

More specifically, although the MHCM is provided and edited under Malaysia traffic and geometric characteristics, it cannot estimate the values of control delays in comparison to the actual data at priority junctions precisely. Because, the process is depending on the techniques followed from the United States Highway Capacity Manual. Under these conditions, the outcomes of the delay analysis probably are not directly transferable to a geographic region distinct from that in which they have been acquired. Consequently, there is evidence that local circumstances needs to be examined to present appropriate models to estimate control delay at priority junctions.

1.3 Aim and objective

The aim of the study is to develop an ANN model of traffic control delays at priority junctions for Malaysia traffic conditions. The delay model must be capable of representing and investigating the magnitudes of control delays to drivers at the minor approach and also to the right-turning drivers from major road.

The following objectives are defined in order to achieve the aim of the study:

- (i) To collect and analyse the relevant traffic data at priority junctions for model development and validation purposes.
- (ii) To assess and evaluate the current practices of junction delay assessment methods and their application to the local traffic.
- (iii) To develop mathematical delay models and application graphs for estimating delay at priority junction for ranges of traffic flows.

1.4 Scope of study

Basically, the scope of this study consists of two factors; site study data collection and evaluation of the data gathered. The study sites utilized for the data gathering are selected around Johor Bahru States, Malaysia. The junctions are divided into three categories comprising of four lanes major/four lanes minor, four lanes major/two lanes minor, and two lanes major/two lanes minor road. They are selected such that junctions with diverse rates of traffic flow conditions, compositions, and geometric features. In terms of data collection, several parameters

are extracted from site studies including traffic flow rate on major and minor road, gap acceptance, and also control delay.

In terms of data evaluation, it is separated into two stages: first, analysis of field data using Excel software, and then development of ANN and mathematical models. In the first stage, some parameters including follow-up time and critical gap are evaluated and then observed control delay is compared with those depending on each of HCM's model and MHCM's model in order to show the existing models are not able to estimate the values of control delay at priority junctions, precisely. Then, an ANN and several mathematical formulas of control delay for operational assessment of several categories of priority junctions are developed. Next, in order to validate models, observed control delays from a new priority junction with same geometry and period of data collection were utilized and compared with outputs of proposed formulas. Additionally, the needed data sets associated with each proposed models are substituted into the relationship and applications of the models are shown throughout several graphs.

1.5 Significance of the study

This study investigates and introduces a methodology for field evaluation of control delay at priority junctions with three categories including four lanes major/four lanes minor, four lanes major/two lanes minor, and also two lanes major/two lanes minor road. Additionally, since the control delay formulated is dependent on data gathered with diverse traffic flow and geometric features in Malaysia, it is expected that the new approach would be useful in contributing to the Malaysian practice associated to the operational performance evaluation of priority junctions.

By comparing the observation data set and performance of the models, it is discovered that the ANN can estimate traffic control delays incurred on minor road vehicles and also right-turning manoeuvre from major road at priority junctions more precisely. Therefore, results from this research would present a basis to substantiate the usage of method for calculating control delay which has been arguable for a long time and consequently provides a contribution in that respect.

1.6 Thesis structure

This thesis is arranged in seven Chapters and each one reporting a specific aspect of the whole research. Chapter 1 explains the background of the research, statement of the problem, objectives of the research, scope of research, and also significance of the research.

Chapter 2 consists of discussions on earlier works associated with estimation of traffic delays, critical gap, and follow-up time at priority junction. The Chapter discusses the existing problem concerning approaches utilized in calculating traffic delays, their weaknesses, strengths, and suggestions on the way forward in advancing the existing practice.

Chapter 3 describes the methodology of research that consists of research approach and procedure activities. This Chapter consists of 5 main Sections including artificial neural network, conflicting flow, priority of streams, control delay, critical gap, and follow-up time.

Chapter 4 first identifies the priority junctions at suburban area. Then, data gathering at eight priority junctions are explained. In addition, a complete description

about traffic characteristic at priority junction, as well as data analysis for estimation of traffic composition, critical gap, follow-up time, and control delay is provided. Lastly, a comparative analysis among U.S. Highway Capacity Manual (HCM), Malaysia Highway Capacity Manual (MHCM), and observed control delays is performed. The data and information gathered in this Section are used to develop new mathematical models from ANN's model for estimation of control delay at priority junctions.

Chapter 5 gives the details of the procedure for model development using ANN. In addition, nine mathematical models (i.e. three models for each category of priority junction based on different movements), in which flow rates were taken into consideration in terms of vehicle per hour (veh/h) and nine mathematical models based on Passenger Car Unit (PCU) are developed. Furthermore, some validations and verifications are performed to show the precision of the models.

Chapter 6 provides the application of the models developed. In this matter, several observed data sets from junctions with diverse traffic flow conditions and compositions are used. Then, the need data sets associated with each model are substituted into the relationship and application of the models were shown throughout several graphs.

Chapter 7 outlines the essential conclusions drawn from this research and suggestions for further investigation.

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