MODELING ON THE EFFECT OF GEOMETRIC AND TRAFFIC PARAMETERS ON SPEED-FLOW-GEOMETRY RELATIONSHIP FOR URBAN ROADS IN JOHOR BAHRU STREET NETWORK

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

Urban roads are essential transportation facilities and require a sound planning and design. It serves as major routes and access points to the land uses situated in the urban area. In an effort to overcome issues involving the accurate prediction of traffic flow operation due to the increasing traffic flow and wide range of urban roads' features, this study examines the speed-flow relationship for the complex conditions of urban road facilities. The main aim of this study is to develop new empirical models of speed-flow-geometry relationship for urban roads. A multilinear regression analysis technique was used to develop new models with varying cross-sectional and longitudinal parameters of urban roads. The parameters considered in the modelling are average travel speed (ATS), traffic volume, median existence, lane number, roadside friction, driveways access density, intersections density, and traffic calming device density. Data for the study were collected at 197 urban streets in Johor Bahru using moving observer method. Using a correlation matrix, it was found that the values of Pearson correlation (r) related to the ATS were 0.41, 0.36, 0.30, 0.28, and 0.25 for road side friction, access density, intersection density, traffic flow, and median existence, respectively (at 95% confidence level). All the five developed models were statistically significant with R2 values ranging from 0.64 to 0.98 (at 95 % confidence level). Furthermore, for models of road's category of one number of lane and without a median, the ATS increased by 5 km/h when they occurred in low roadside friction comparing to that of high roadside friction conditions. Intersection density and traffic calming density were found to reduce the ATS by the same values of coefficients in the model of road's category with high roadside friction. Accordingly, the ATS reduced by 1 km/h as the number of intersection and traffic calming devices increased by 13/100 m. For models of road's category of two numbers of lanes and high roadside friction, the only two longitudinal parameters that significantly predicted the ATS were traffic calming devices and access driveways with similar values of coefficients, depending on the median existence conditions. Furthermore, for the roads without median and high roadside friction, the ATS decreases by 1 km/h as the number of traffic calming increases by 2/100 m. However, for the roads with median and high roadside friction, the ATS decreases by 1 km/h as the number of access driveways increases by 5/100 m. The main application of these models is the ability to be used as a planning and design tool for urban roads. This is because they could be used to predict the overall reduction of speed of traffic flow according to the current or planned view of the surrounding geometric and traffic parameters of urban roads. Findings from this study suggested that there is a need to review the models provided in the MHCM to include a wide range of parameters affecting the speed-flow relationship on urban roads.

ABSTRAK

Jalan bandar adalah kemudahan pengangkutan yang penting dan ia memerlukan perancangan dan rekabentuk yang baik. Ia berfungsi sebagai laluan utama dan titik akses penggunaan tanah yang terletak di kawasan bandar. Dalam usaha mengatasi masalah yang melibatkan ketepatan ramalan operasi aliran lalu lintas yang disebabkan oleh peningkatan aliran lalu lintas dan pelbagai ciri jalan bandar, kajian ini menyelidik hubungan laju-aliran untuk keadaan kompleks kemudahan jalan bandar. Matlamat utama kajian ini adalah untuk pembangunan model empirikal baru bagi perhubungan laju-aliran-geometri untuk jalan bandar. Satu teknik analisis regresi pelbagai linear digunakan untuk membangunkan model-model baru dengan parameter keratan rentas dan membujur jalan bandar yang berbeza. Parameter parameter yang dipertimbangkan dalam pemodelan adalah purata laju perjalanan (ATS), adalah isipadu lalu lintas, kewujudan median, bilangan lorong, geseran tepi jalan, kepadatan akses jalan masuk, kepadatan persimpangan, kepadatan peranti pengaman lalu lintas. Data untuk kajian ini dikumpul dari 197 jalan bandar yang dianggap sesuai sebagai sampel di Johor Bahru menggunakan kaedah pengamatan bergerak. Menggunakan matriks korelasi, didapati bahawa nilai korelasi Pearson (r) yang berkait dengan ATS adalah 0.41, 0.36, 0.30, 0.28, dan 0.25 masing-masing untuk geseran tepi jalan, kepadatan capaian, kepadatan persimpangan, aliran lalu lintas, dan kewujudan median (pada tahap keyakinan 95%). Semua lima model yang dibangunkan adalah signifikan secara statistik dengan julat nilai R^2 dari 0.64 sehingga 0.98 (pada tahap keyakinan 95%). Selanjutnya, untuk model jalan raya dengan satu lorong dan tanpa median, ATS meningkat sebanyak 5 km/j ketika ia berlaku pada geseran tepi jalan yang rendah berbanding dengan keadaan geseran di tepi jalan yang tinggi. Kepadatan persimpangan dan kepadatan peranti pengaman lalu lintas didapati mengurangkan ATS dengan nilai pekali yang sama dalam model kategori jalan dengan geseran tepi jalan yang tinggi. Oleh itu, ATS berkurang sebanyak 1 km/j apabila bilangan persimpangan dan peranti pengaman lalu lintas meningkat sebanyak 13/100 m. Untuk model kategori jalan raya dengan dua lorong dan geseran tepi jalan yang tinggi, dua parameter membujur yang meramalkan ATS secara signifikan adalah peranti pengaman lalu lintas dan akses jalan masuk yang mempunyai nilai pekali yang serupa, bergantung pada keadaan kewujudan median. Tambahan lagi, untuk jalan raya tanpa median dan geseran tepi jalan yang tinggi, ATS menurun sebanyak 1 km/j apabila bilangan peranti pengaman lalu lintas meningkat sebanyak 2/100 m. Walau bagaimanapun, untuk jalan raya yang mempunyai median dan geseran tepi jalan yang tinggi, ATS menurun sebanyak 1 km/j apabila bilangan akses jalan masuk meningkat sebanyak 5/100 m. Aplikasi utama model ini adalah kebolehgunaan sebagai alat perancangan dan rekabentuk jalan bandar. Ini kerana ia boleh digunakan untuk meramal keseluruhan penurunan halaju aliran lalu lintas berdasarkan pandangan semasa atau perancangan geometrik persekitaran dan parameter trafik jalan bandar. Dapatan dari kajian ini mencadangkan bahawa terdapat keperluan untuk mengkaji model-model yang disediakan dalam MHCM untuk menyertakan pelbagai parameter yang memberi kesan kepada hubungan laju-aliran jalan-jalan bandar.

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LIST OF ABBREVIATIONS

AASHTO	-	American Association of State Highway and Transportation Officials
DSA	-	Descriptive Statistical Analysis
FFS	-	Free Flow Speed
HCM	-	Highway Capacity Manual
HPU	-	Highway Planning Unit
JBRN	-	Johor Bahru Roads Network
MHCM	-	Malaysian Highway Capacity Manual
MLRA	-	Multi-Linear Regression Analysis
MOM	-	Moving Observer Method
MTES	-	Manual of Transportation Engineering Studies
PCU	-	Passenger Car Unit
RA	-	Regression Analysis
SUR	-	Surveyed Urban Roads

LIST OF SYMBOLS

AccessD	Access Driveway Density
ATS	Average Travel Speed
IntersD	Intersection Density
L	Length
M	Median Case
NL	Number of Lanes
Pcu/h	Passenger car unit per hour
R^2	Coefficient of Determination
RTD	Right Turn Driveways
SF	Side Friction
TCSD	Traffic Calming Speed Device
TV	Traffic Volume
TFD	Traffic Flow Direction
Veh/h	Vehicle per hour
VIF	Variance Inflation Factor

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CHAPTER 1

INTRODUCTION

1.1 Introduction

To provide a high-performance level of urban roads with geometric and traffic design features that can readily accommodate high vehicular flow is challenging. Typically, these challenges are encountered within the inner city or municipal roads used for transportation, planning, and engineering units. This is because the process requires the ability to simultaneously balance the three objectives of planning, design, and safety.

One of the popular methods applied for the design and planning of road facilities is the speed-flow relationship model (HPU, 2006). This is because these two traffic variables, speed and flow, are traditionally used in the assessment of traffic operations on roads (TRB, 1994). Various studies have been conducted to examine this fundamental relationship. However, most of the studies were not focused on the type of urban road facility (HPU, 2006; Li and Jiang, 2009; Lum. *et al.* , 1998).

Empirically, the ability to collect speed and traffic volume (TV) of urban roads is more complicated compared to other types of roads facilities. This is due to the fluctuation of traffic volume, which is caused by the numerous control points and driveways distributed along the urban roads' segments. To date, limited studies were conducted on the subject resulting in a poor assessment of the surrounding geometric and traffic parameters of urban roads. Therefore, there is an evident need for empirical studies that would directly address the speed-flow relationship under the effects of a sufficient number of geometric and traffic parameters' conditions on the urban road's facility.

On the other hand, it was necessary to provide model that can cater this wide range of geometric and traffic features as input parameters to predict the response as average travel speed over predetermined urban road segment length. The Multiple Linear Regressions (MLR) represent the best decision to provide this kind of models (Areerachakul and Sanguansintukul, 2009; Song and Lu, 2017; Su *et al.*, 2012). The Multiple Linear Regressions is a method of demonstrating that response (dependent) variable, *Y*, varies with a set of independent variables, X_1 *to* X_n (Freund and Littell, 2000). The variability that the response variable exhibits have two components: systematic and a random part. The systematic variation of Y can be modelled as a function of the X variables. The least squares method is used to estimate the parameters of the model, based on observed values of these variables, by minimizing the sum of squared differences between the actual Y values and the values of Y predicted by the regression equation (Freund and Littell, 2000). As a result, MLR equation allow to predict the effect of wide range of geometric and traffic variables on the travel speed because it represents a weighted linear combination of the independent variables (Areerachakul and Sanguansintukul, 2009).

1.2 Problem Statement

In comparison to rural roads, it is well known that the main features of urban roads facilities are high densities of people and business shops surrounding the roads (AASHTO, 2011). Accordingly, wide range of geometric and traffic controls devices exist along this type of road facility in order to keep a stable balance between the activities of people, business shops, and traffic flow movements. In order to design an urban road facility with satisfactory operational performance, it is necessary to evaluate and analyze the real condition of traffic flow movement in this complicated case of geometric and traffic parameters. The importance of speed-flow relationship is that it can be used for design and planning analysis for the urban roads (HPU, 2006; Van Aerde and Rakha, 1995). However, this is contingent on either the speed-flow relationship reflecting the real conditions of the urban roads or governments can effectively utilize it as a planning, design, or analysis tool for urban cities.

Various studies affirmed that the speed-flow relationship gradually improved due to the enhancement of geometric and traffic features of the urban road facility (Qu, Zhang and Wang, 2017; Williams, 2001). However, most of the studies that were carried out to develop speed-flow relationship models for urban roads did not consider the effect of a sufficiently wide ranges of geometric and traffic parameters in these models as a numerical coefficient's values. Furthermore, most of these studies were conducted in different countries where the features of geometric and traffic on urban roads are different from those in Malaysia. In the Malaysian Highway Capacity Manual MHCM 2006, the speed-flow relationships were developed to examine the effects of the numbers of driveways, signalized intersections, and high turning movements for the urban roads (HPU, 2006). According to certain ranges of these parameters, a series of developed curves between the average travel speed and traffic volume were plotted.

In a more specific manner, although the MHCM 2006 models were developed and evaluated according to the Malaysian urban roads' geometric and traffic conditions, however, they could not be applied to examine a wide enough number of these geometric and traffic parameters. For instance, these MHCM 2006 models did not consider the impact of the median condition, number of lanes, number of intersections over the length of the segment and traffic calming speed devices extended over the urban road segment. Apart from these, various studies confirmed the impact of different parameters on the travel speed on urban roads that were not involved in the MHCM 2006 models such as number of lanes, side friction and median exitance. Under this situation, the outcomes of MHCM models of speed-flow relationship could provide inaccurate tool for design, analysis, and planning urban roads facilities. Consequently, there is evidence to evaluate a wide range of adequate and necessary number of geometric and traffic parameters on speed-flow relationship for urban roads facilities.

1.3 Aim and Objectives

This study aims to evaluate the effects of geometric and traffic parameters on speed-flow-geometry relationship for urban roads. To achieve this, the following objectives are set forth:

1. To determine the significant factor of roadways' geometric and traffic variables for model development of speed-flow-geometry relationship for urban roads in Johor Bahru street network.
2. To develop and validate empirical models of speed-flow-geometry relationship for urban roads in Johor Bahru street network
3. To evaluate the effects of geometric and traffic variables on the speed-flow-geometry relationship for urban roads in Johor Bahru street network.
4. To develop and validate an application graphs for evaluating the speed-flow-geometry relationships with ranges of geometric and traffic parameters values for urban roads segments.

1.4 Scope and Limitation of the Study

The scope of this study comprised of two aspects: field data collection and evaluation of the data collected. In terms of the field data collected, all surveyed urban roads were selected from the Johor Bahru Roads Network. These were selected such that segments with different ranges of geometric and traffic parameter are utilized. Based on the study's scope, some parameters were excluded from measurement due to insignificant variation in their field values such as posted speed limit and lane width. In terms of the of data collection period and duration, there were no specific with regard to them, as randomly selected periods were used to account for peak and off-peak periods. Likewise, duration for the data collection was not constrained to 15 minutes interval, but it was based on the traffic volume conditions of the surveyed urban roads as well as the minimum required number of test vehicle's run during the data collection period time. In terms of data analysis, all the data were first extracted and prepared for modelling using Microsoft Excel software. Subsequently, the models for speed-flow-geometry relationship were developed using the multilinear regression analysis technique. For the data preparation using Microsoft Excel sheets, every measured data point that represented an outlier or missing results based on the trip streams running the test vehicle (TV) was removed from the batch.

All speed-flow-geometry relationship models were then developed using SPSS 22 software. The models were then validated using different observed data sets from new on-site urban roads with the same geometry. These were utilized and compared with outputs of the proposed models. Additionally, the required data sets associated with each of the proposed models were substituted into the relationship and applications of the models illustrated in several graphs. A key limitation of this study is that all surveyed urban roads must be of the two-way direction type. This is because the Moving Observer Method (MOM) is not suitable for measurement of the required traffic data for the study on one-way direction roadways. Another limitation of the study is that the data collection on all surveyed urban roads was only conducted during daylight hours. This is because the visibility of traffic flow stream in the nighttime is difficult to count, particularly when vehicles' classification for the stream of traffic flow needs to be recognized.

1.5 Significance of the Study

Given the immense importance of speed-flow relationship, this study is highly significant for on-site applications of the developed models. This is because the type of speed-flow relationships developed in this study are empirical-based by effectively considering a wide range of geometric and traffic features in the field. These parameters include median condition, lane number, side friction, traffic calming instruments devices, intersection density, driveway density, and right turn density. Accordingly, its significant use as a planning and design tool was extended by comparing it to previous models developed.

Furthermore, previous models developed based on speed-flow relationship did not cover the assessment of a wide range of these parameters as presented in this study. In the MHCM (2006), the speed-flow relationship developed models for urban roads were accomplished by assessing only two parameters namely; signal intersection and driveway densities. However, the application of the models developed in this study could be explored for more than eight parameters. In addition, the models can be adopted when the speed-flow relationship is implemented as planning and design tools by the authorities in Malaysia.

Lastly, this study presents an example of how to generate the data required to develop a speed-flow relationship model using the MOM. The method has the advantage of collecting instantaneous traffic volume and travel speed concurrently. In addition, the MOM is cheap and straightforward for application on the site. Therefore, the success of developing this model relationship using the MOM is a significant contribution that can be explored and applied for future research studies.

1.6 Thesis Outline

The thesis is made up of seven Chapters. This section provides brief information about each Chapter. Chapter 2 presents a theoretical background on the speed-flow relationship on urban roads. It provides the theoretical arguments on which the research hinges. Furthermore, broad definitions and discussions on the urban road facility, historical reviews of the empirical speed-flow relationship models developed, and the review of the HCM models of speed-flow relationship on urban roads and the main technique used to collect the data in the field are presented. Lastly, the impact of parameters on speed-flow relationship on urban roads and broad descriptions of the parameters adopted for assessment in this study were highlighted.

Chapter 3 describes the methodologies of this study. This consisted of descriptions of all methods used to collect the data in the field, analysis techniques applied for the results, and the model development building stages. Under the first part, subsections including the data resource, the site requirements of the selected roads, description of all equipment used for the data collection are presented. The second part presented a review of all analysis methods of the study such as the multilinear regression analysis technique, grouping the roads based on their features, traffic volume composition, and all statistical tests requirements to accomplish the analysis of the results obtained.

Chapter 4 presents the sequential data analysis framework and results obtained as well as their discussions. The main table of the results was presented and discussed in this Chapter. Experimental results, descriptive statistical analysis and graphical presentation analysis of the results are presented in detail in this Chapter. The main idea of classification of the parameters into two groups; namely, longitudinal parameters and cross-sectional parameters were described in detail in this Chapter. Lastly, the primary evaluation of the results was performed through correlation analysis of the data among all parametric matrices.

Chapter 5 presents the core part of the study. It describes the stepwise details of the models' development building process of the speed-flow-geometry relationship. These stages include the models' parameters definition, along with model estimation, verification and validation. According to the number of groups of the roads in the previous Chapter, all the sequential stages for model development were applied for each group. Finally, the summary table that contains all the models developed was presented and discussed based on the implication of the models.

Chapter 6 focuses only on the application of the successful models developed in the previous Chapter. Each model that has successfully fit the relationship between the dependent and independent variables was applied using the data sets that were used in the model development process. In this Chapter, a series of graphs were drawn according to the flexibility of the developed formula for each model. In each graph, different linear trend lines were drawn from the axis of the dependent variable (average travel speed) and continues straight down until it ends at the X-axis (traffic volume). The number of these lines and intercepts of each line depend on the natural model-formula of each model. Chapter 7 outlines the essential conclusions drawn from this research and suggestions for further investigation.

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LIST OF PUBLICATIONS

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1. Al-Bahr, T. M., & Puan, O. C. (2018). Speed-Flow Relationship for Urban Roads: A Preliminary Assessment. *Advanced Science Letters*, *24*(6), 4172-4176. **(Indexed by ISI)**

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2. Al-Bahr, T. M., Puan, O. C., Hassan, S. A., Idham, M. K., & Ismail, C. R. (2019, May). Parameters affecting fluctuation in traffic stream on urban roads. In *IOP Conference Series: Materials Science and Engineering* (Vol. 527, No. 1, p. 012067). IOP Publishing. **(Indexed by SCOPUS)**

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3. Al-Bahr, T. M., Puan, O. C., Mushairry, M. (2016). Speed–Flow Relationship for Urban Roads: A Preliminary Assessment. In International Conference on Science, Engineering, Management and Social Sciences (ICSEMSS 2016). Johor Bahru, Malaysia.: Universiti Teknologi Malaysia, Faculty of Built Environment.