# EVALUATION OF THE MATHEMATICAL MODEL FOR TRAFFIC FLOWING THROUGH A MERGING AREA ON THE MALAYSIA FEDERAL HIGHWAY OPERATION



NUR SYAHIRAH BINTI HUSIN BASRI

UNIVERSITI PENDIDIKAN SULTAN IDRIS

2020

# EVALUATION OF THE MATHEMATICAL MODEL FOR TRAFFIC FLOWING THROUGH A MERGING AREA ON THE MALAYSIA FEDERAL HIGHWAY OPERATION

NUR SYAHIRAH BINTI HUSIN BASRI



THESIS SUBMITTED IN FULLFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE
(MASTER BY RESEARCH)

FACULTY OF SCIENCE AND MATHEMATICS
UNIVERSITI PENDIDIKAN SULTAN IDRIS

2020

UNIVERSITI PENDIDIKAN SULTAN IDRIS
SULTAN IDRIS EDUCATION UNIVERSITY

Please tick (√)
Project Paper
Masters by Research
Master by Mixed Mode
PhD

| |
|---|
| |
| / |
| |
| |

**INSTITUTE OF GRADUATE STUDIES**

**DECLARATION OF ORIGINAL WORK**

This declaration is made on the 10 day of 11 20 20

**i. Student's Declaration:**

I, NUR SYAHIRAH HUSIN BASRI, M 20161000704, FACULTY OF SCIENCE AND MATHEMATICS (PLEASE INDICATE STUDENT'S NAME, MATRIC NO. AND FACULTY) hereby declare that the work entitled EVALUATION OF THE MATHEMATICAL MODEL FOR TRAFFIC FLOWING THROUGH A MERGING AREA ON THE MALAYSIA FEDERAL HIGHWAY OPERATION is my original work. I have not copied from any other students' work or from any other sources except where due reference or acknowledgement is made explicitly in the text, nor has any part been written for me by another person.

Nur Syahirah.

Signature of the student

**ii. Supervisor's Declaration:**

I DR. NURUL AKMAL MOHAMED (SUPERVISOR'S NAME) hereby certifies that the work entitled EVALUATION OF THE MATHEMATICAL MODEL FOR TRAFFIC FLOWING THROUGH A MERGING AREA ON THE MALAYSIA FEDERAL HIGHWAY OPERATION (TITLE) was prepared by the above named student, and was submitted to the Institute of Graduate Studies as a * ~~partial~~/full fulfillment for the conferment of DEGREE OF MASTER OF SCIENCE (APPLIED MATHEMATICS) (PLEASE INDICATE THE DEGREE), and the aforementioned work, to the best of my knowledge, is the said student's work.

10. 11. 2020

Date

Signature of the Supervisor

DR. NURUL AKMAL MOHAMED
Senior Lecturer
Department of Mathematics
Faculty of Science and Mathematic
Universiti Pendidikan Sultan Idris
35900 Tanjung Malim, Perak

UNIVERSITI PENDIDIKAN SULTAN IDRIS
SULTAN IDRIS EDUCATION UNIVERSITY

**INSTITUT PENGAJIAN SISWAZAH /**
***INSTITUTE OF GRADUATE STUDIES***

**BORANG PENGESAHAN PENYERAHAN TESIS/DISERTASI/LAPORAN KERTAS PROJEK**
***DECLARATION OF THESIS/DISSERTATION/PROJECT PAPER FORM***

Tajuk / *Title*: EVALUATION OF THE MATHEMATICAL MODEL FOR TRAFFIC FLOWING THROUGH A MERGING AREA ON THE MALAYSIA FEDERAL HIGHWAY OPERATION

No. Matrik /*Matric's No.*: M 20161000704

Saya / *I* : NUR SYAHIRAH BINTI HUSIN BASRI

(Nama pelajar / *Student's Name*)

mengaku membenarkan Tesis/Disertasi/Laporan Kertas Projek (Kedoktoran/Sarjana)* ini disimpan di Universiti Pendidikan Sultan Idris (Perpustakaan Tuanku Bainun) dengan syarat-syarat kegunaan seperti berikut:-
*acknowledged that Universiti Pendidikan Sultan Idris (Tuanku Bainun Library) reserves the right as follows:-*

1. Tesis/Disertasi/Laporan Kertas Projek ini adalah hak milik UPSI.
   *The thesis is the property of Universiti Pendidikan Sultan Idris*
2. Perpustakaan Tuanku Bainun dibenarkan membuat salinan untuk tujuan rujukan dan penyelidikan.
   *Tuanku Bainun Library has the right to make copies for the purpose of reference and research.*
3. Perpustakaan dibenarkan membuat salinan Tesis/Disertasi ini sebagai bahan pertukaran antara Institusi Pengajian Tinggi.
   *The Library has the right to make copies of the thesis for academic exchange.*
4. Sila tandakan ( √ ) bagi pilihan kategori di bawah */ Please tick ( √ ) for category below:-*

| | | |
|---|---|---|
| ☐ | **SULIT/*CONFIDENTIAL*** | Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub dalam Akta Rahsia Rasmi 1972. / *Contains confidential information under the Official Secret Act 1972* |
| ☑ | **TERHAD/*RESTRICTED*** | Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan ini dijalankan. / *Contains restircted information as specified by the organization where research was done.* |
| ☐ | **TIDAK TERHAD / *OPEN ACCESS*** | |

Nurhalirah .
(Tandatangan Pelajar/ Signature)

Tarikh: 10 · 11 · 2020

(Tandatangan Penyelia / *Signature of Supervisor*)
& (Nama & Cop Rasmi / *Name & Official Stamp*)

DR. NURUL AKMAL MOHAMED
Senior Lecturer
Department of Mathematics
Faculty of Science and Mathematic
Universiti Pendidikan Sultan Idris
35900 Tanjong Malim Perak

Catatan: Jika Tesis/Disertasi ini **SULIT @ TERHAD**, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan ini perlu dikelaskan sebagai **SULIT** dan **TERHAD**.

*Notes: If the thesis is CONFIDENTAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.*

## ACKNOWLEDGEMENT

All Praise to ALLAH S.W.T the Almighty, for giving me the blessing, the opportunity and strength to complete this study. Firstly, I would like to express my sincere gratitude to my main supervisor Dr. Nurul Akmal Mohamed for her kind endless help, generous advice, patience and support throughout the whole study. It is a great honor to work under her supervision.

Next, I also would like to express appreciation to my co-supervisor Dr. Muhammad Akram Adnan from the Faculty of Civil Engineering, Universiti Teknologi Mara (UiTM) for his encouragement and comprehensive advice until this study come to existence.

Then, my thanks and appreciations also go to Universiti Pendidikan Sultan Idris. The financial for this research was provided by Universiti Pendidikan Sultan Idris under Geran Penyelidikan Universiti (GPU) code no 2018-0153-103-01.

After that, I would like to express my eternal appreciation towards my parents, my husband and my daughter who always support me morally as well as economically. Thank you for being around and for never ending motivations that I have been getting all this while. Finally, thanks to anyone who is directly or indirectly involved in this study.

# ABSTRACT

The purpose of this study was to evaluate the mathematical model for traffic flowing through a merging area on the Malaysia Federal Highway operation which ramp areas at Kilometer 31.6 from Shah Alam to Kuala Lumpur, Kilometer 32.9 from Kuala Lumpur to Shah Alam and Kilometer 33 from Kuala Lumpur to Shah Alam. The continuous flow model was used in this study that assumes traffic flow to be similar to the heat equation in regards to the concept of the one-dimensional viscous flow of compressible fluid. The research design used in this study was comparative method. The continuous flow model set an initial condition, together with a set of boundary conditions, was prescribed to solve the partial differential equation. The boundary conditions were selected to assess the suitableness of the design of the entrance ramp in Malaysia. A sample of highway traffic data was collected on the tapered acceleration lane and obtained by the videotaping method. The highway traffic data were provided by the Faculty of Civil Engineering, Universiti Teknologi Mara (UiTM). The Maple programming was used to write an algorithm program to evaluate the solution in terms of Fourier series with a finite number of iterations. The findings of this study disclosed the instantaneous speed ratios at lower values of easiness to flow were converging slower compared to the higher values of instantaneous speed ratio. The instantaneous speed ratio values were found to be more accurate when the additional iteration numbers were considered and the traffic's instantaneous speed ratio for three selected sites on the Malaysia Federal Highway was less than 1.39 at location 0.4 which was less than 1.4 as proposed by theoretical model. In conclusion, the mathematical model was found to be accurate in estimating the safe distance and speed of vehicles on merging area so that the collision can be minimized and for the assessment and decision-making of the configuration of the traffic flow. As the implication, this study on the mathematical model and theories of traffic flow provides the possibilities of the improvement for the design of the entrance ramp in Malaysia.

# PENILAIAN MODEL MATEMATIK UNTUK ALIRAN LALU LINTAS MELALUI KAWASAN GABUNGAN OPERASI DI LEBUHRAYA PERSEKUTUAN MALAYSIA

## ABSTRAK

Kajian ini bertujuan untuk menilai model matematik aliran lalu lintas melalui kawasan gabungan di operasi Lebuhraya Persekutuan Malaysia yang merupakan kawasan tanjakan di Kilometer 31.6 dari Shah Alam ke Kuala Lumpur, Kilometer 32.9 dari Kuala Lumpur ke Shah Alam dan Kilometer 33 dari Kuala Lumpur ke Shah Alam. Teori model ini menggunakan model aliran berterusan yang menganggap aliran lalu lintas serupa dengan persamaan haba berkenaan dengan konsep aliran likat satu dimensi cecair yang dapat dimampatkan. Reka bentuk kajian ini menetapkan keadaan awal, bersama dengan satu set syarat sempadan, ditetapkan untuk menyelesaikan persamaan pembezaan separa. Syarat-syarat sempadan dipilih untuk menilai kesesuaian reka bentuk jalan masuk di Malaysia. Sampel data lalu lintas lebuh raya dikumpulkan di jalur pecutan meruncing dan diperoleh dengan kaedah rakaman video. Semua data lalu lintas lebuh raya disediakan oleh Fakulti Kejuruteraan Awam, Universiti Teknologi Mara (UiTM). Pengaturcaraan Maple digunakan untuk menulis program algoritma untuk menilai penyelesaian dari segi siri Fourier dengan bilangan lelaran yang terbatas. Hasil kajian ini mendedahkan nisbah kelajuan serta-merta pada nilai kemudahan aliran yang rendah lebih perlahan berbanding ketika kita mempunyai nilai nisbah kelajuan serta-merta pada nilai kemudahan aliran yang tinggi, nilai nisbah kelajuan serta-merta lebih tepat apabila nombor lelaran tambahan di pertimbangkan dan lalu lintas nisbah kelajuan serta-merta untuk tiga lokasi terpilih di Lebuhraya Persekutuan Malaysia kurang dari 1.39 di lokasi 0.4 yang kurang dari 1.4 seperti yang di cadangkan oleh model teori. Kesimpulannya, model matematik di dapati tepat dalam menggangar jarak dan kelajuan kenderaaan yang selamat di kawasan penggabungan sehingga perlanggaran dapat di minimukan dan untuk penilaian dan keputusan konfigurasi aliran lalu lintas. Sebagai implikasinya, kajian ini mengenai model matematik dan teori aliran lalu lintas yang berkemungkinan dapat menambah baik rekaan bentuk jalan masuk di Malaysia.

# TABLE OF CONTENTS

## LIST OF TABLES

# LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| BCs | Boundary Conditions |
| IBVP | Initial-Boundary Value Problem |
| IC | Initial Condition |
| PDE | Partial Differential Equation |
| SOV | Separation of Variable |
| vph | Vehicles Per Hour |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 General Introduction



In the civilization era, the highway has become one of the most important parts of the automobile industry. Highways are to move from a destination to another destination within cities and states. The highway can be large or small in the number of lanes that available in each direction. There are different designs across not only Malaysia but also across the world.

Traffic flow can be divided into two major types, which are called interrupted flow and uninterrupted flow. The interrupted flow is an external means that controls the flow of traffic, for example, traffic signal (Choudhary & Gokhale, 2016). Under interrupted flow conditions, the interactions between one vehicle and other vehicles, as well as vehicles and roadway are less critical in describing the flow of traffic. In contrast, the uninterrupted flow which is the

traffic flow is regulated by the interaction between vehicles and roadway (Roess et al., 2004), such as vehicles traveling on an interstate highway are joining in an uninterrupted flow. This study involves with uninterrupted flow which is compatible to continuous flow models.

The research about the expressway has been studied since 1920's (Reddy, 1966; Adnan, 2007; Lazar et al., 2016). Since the beginning of the highway development, the researches about highway always focus on design and the efficiency of construction and highway safety (Hughes et al., 2015). However, the available researches on highway operation mostly emphasize physical study instead of evaluating the mathematical model (Sallis et al., 2004).

Nowadays, Malaysia has developed to be a more progressive country by strengthening the economy and improve the facilities. Due to the civilization, the population increases drastically every year and this leads to an increasing number of automobiles in Malaysia. Therefore, the development of advance highway is not only to avoid congestion but gives various impacts on social economics such as people's ability to access education, employment and services as well.

Most cities and states in Malaysia have been equipped with highways to prevent traffic congestion. Furthermore, the development of new townships and industrial estates can cause an increasing number of vehicles along federal roads. Therefore, the construction of highways is essential to avoid massive traffic jams. The high demand for satisfying the need of the people has triggered the development of advanced highways.

As we know, the highway is one of the most crucial road system for traffic movement and the main infrastructure to generate a country's economy. For example, due to the opening of major ports and airports in Malaysia, the highway becomes the primary facility for smooth movement of goods and people between regions. Although, there are other public transport facilities such as Electric Train Services (ETS), commuter, railways and aircraft but the highway also remains the main preference to the people.

In 2015, Eleventh Malaysia Plan (RMK-11) for the year 2016 to 2020 our government highlights six focus areas in which are achieving universal access to quality health care, providing adequate and quality affordable housing to poor, low and middle income households, creating safer living environments for thriving communities, improving road safety and emergency services to reduce fatalities, enculturating the spirit of 1 Malaysia to foster social cohesion and national unity promoting sports for healthy living and unity. This study emphasizes on the effectiveness of the construction for the merging area in highway operation which corresponds to the fourth focus area of RMK-11. This study will not only stresses the efficiency of the flow of traffic but on road safety as well.

## 1.2 Background of the Study

This study focuses on a continuous flow model for traffic flowing onto the merging area of the Malaysia Federal Highway operation. One of the macroscopic models in use is the continuous flow model, which originated from the hydrodynamic analogy of vehicle flow. It

is based on the assumption that the traffic flow on highways operates in the same way as a one-dimensional viscous flow of a compressible fluid. The solution of partial differential equation for continuous flow model is derived by using the heat equation. In order to solve an initial-boundary value problem (IBVP), an initial condition (IC) together with the set of boundary conditions (BCs) are required. The boundary conditions chosen are compatible with the design of the entrance ramp in Malaysia. The solution of the initial-boundary value problem (IBVP) is obtained in terms of a Fourier series.

Highway traffic data is collected on the tapered acceleration lane and obtained by the videotaping method. This study involves three selected sites along Malaysia Federal Highway which are on-ramp areas at (a) Kilometer 31.6 from Shah Alam to Kuala Lumpur, (b) Kilometer 32.9 from Kuala Lumpur to Shah Alam and (c) Kilometer 33 from Kuala Lumpur to Shah Alam. The Maple programming language (Maple 2017) is used to write a numerical code for evaluating a Fourier series with finite number of iterations.

The parameters are used in this study are instantaneous speed ratio $\frac{V(X,t)}{\overline{V}}$ and easiness to flow $F_0$. Both parameters are essential in analyzing the numerical results in order to observe the convergence pattern for each section. The range values of easiness to flow $F_0$ are from 0.1 to 5.0. The length of the highway upstream side of the merging area point represented as $L$ and $X$ denoted as a specific position along the highway in which varies by 20 meter increments. The location along the highway $X/L$ is plotted as $x$-axis whereas the instantaneous speed ratio is plotted as $y$-axis. The results obtained are essential for determination and decision-making relating to traffic flow ramp design

## 1.3 Problem Statement

The entrance ramps in Malaysia are for right-hand drive vehicles. However, many researches on the highway operation focus on left-hand drive vehicles. Among others are Pipes (1953), Har and Leornads (1962), Drew (1964), Sharma and Swami (2012), Xie and Feng (2013), Li and Chen (2017) and Li (2018). It includes research by Reddy (1966) that considered the theory of traffic flow based on the concept of one-dimensional movement of fluid and gas. Reddy (1966) considered the boundary conditions (BCs) together with an initial condition (IC) that follows the suitableness design of entrance ramp for left-hand drive vehicles. Therefore, it is useful for us to extend the discussion to the entrance ramp for right-hand drive vehicles. It is necessary as we can study and make a conclusion on the possibilities for improving the design of the entrance ramp, specifically in Malaysia.

The merging area on highway operation become increasingly crucial to the highway planners. The increase in the cost of construction and high demand for the highway facilities that includes merging area can cause highway planners to face with the problem of making efficient use of existing roads and in making efficient design specification for new merging area. Therefore, it is significant to study the mathematical traffic flow models e.g. continuous flow model that includes the design of the entrance ramp. This is helps guide the design of entrance ramp so that the time and cost of constructing the new merging ramp can be optimized.

Some studies that focused on developing new car theories and models instead of evaluating the mathematical traffic model, for instance, models by Daganzo (2002), Wong and Wong (2002), Mathew (2014) and Wageningen-Kessels (2015). Several parameters e.g. instantaneous speed ratio and easiness to flow, need to be recognized to develop a new traffic flow model as well as to improve the existing car theories and models. Therefore, it is beneficial to evaluate the mathematical traffic flow model and to determine the parameters which are involved so that we can make a decision and conclusion by comparing the real results to the theoretical results.

## 1.4 Objectives of the Study



The objectives of this study are:

i) to derive the solution of the partial differential equation for a continuous flow model by using the heat equation based on the boundary conditions and initial condition which are chosen for right-hand drive traffic.

ii) to determine the instantaneous speed ratio that involves three selected sites along Malaysia Federal Highway which are on-ramp areas at (a) Kilometer 31.6 from Shah Alam to Kuala Lumpur, (b) Kilometer 32.9 from Kuala Lumpur to Shah Alam and (c) Kilometer 33 from Kuala Lumpur to Shah Alam based on a continuous flow model.

iii) to analyze the findings of numerical results of instantaneous speed ratios and to observe the pattern of the convergence for every value of $F_0$.

## 1.5 Research Questions

The research questions of this study are:

i) how to derive the solution of the partial differential equation for a continuous flow model by using the heat equation based on the boundary conditions and initial condition which are chosen for right-hand drive traffic?

ii) what is the instantaneous speed ratio that involves on Malaysia Federal Highway which are on-ramp areas at (a) Kilometer 31.6 from Shah Alam to Kuala Lumpur, (b) Kilometer 32.9 from Kuala Lumpur to Shah Alam and (c) Kilometer 33 from Kuala Lumpur to Shah Alam based on a continuous flow model?

iii) how to analyze the findings of numerical results of instantaneous speed ratios and to observe the convergence patterns for each values of $F_0$ ?

## 1.6 Significance of Study

This study is conducted to find out the evaluation of the mathematical model of traffic flowing the merging area on highway operation. The findings of this study will give a better understanding of the continuous flow model as well as methods for improving the design of the entrance ramp. The results obtained are essential for evaluation and decision-making relating to traffic flow ramp design.

Other than that, this study will help other researchers and highway engineers to solve various problems in making efficient use of existing highways and improving the design of the entrance ramp. The findings of this study will give benefits and ideas for them regarding the type of mathematical models involve enhancing the efficiency of traffic flow at the merging area.

Last but not least, this study also benefits researchers who will be doing researches that are related to highway traffic flow and design. This study will guides researchers particularly in developing or evaluating the mathematical of traffic flow models.

## 1.7 Outline of Thesis

This thesis consists of five chapters. The chapters included in this thesis are the introduction, literature review, methodology, results and discussion and conclusion. In Chapter 1, the overview of highway development is described. This chapter comprised the background of the study, problem statements, objectives of the study, research questions, and significance of the study as well as outline of the thesis.

In Chapter 2, the overview of the mathematical theories of traffic flow and models, the parameters describing traffic stream characteristics and the effect of merging geometric and vehicles on highway operation are presented. There are three main types of model have been developed which are the microscopic models, macroscopic models and stochastic models. These three models are described in this chapter.

In Chapter 3, the theory of the continuous flow model, formulation of the model, development of the model, setting up the number of iterations into Fourier series solution and justification of the model are discussed. The theory is based on the concept of one-dimensional viscous flow of compressible fluid by using heat equation. The derivation of the solution for partial differential equation is presented in this chapter. The details of computing the numerical results and plotting data are explained in this chapter as well.

In Chapter 4, the overall results and numerical analysis are presented in the form of tables and figures. Implementation by setting up the number of iterations into the Fourier series solution and implementation by justifying the model are presented in this chapter. The parameters involved in this study are instantaneous speed ratio and easiness to flow $F_0$. The range values of $F_0$ are from 0.1 to 5.0.

In the last Chapter 5, the research findings are briefly summarized. This chapter also discussed the findings by referring to the theoretical results. The implications of the study and suggestions for future study are included in this chapter