



**UNIVERSITI PUTRA MALAYSIA**

**DEVELOPMENT OF CAPACITY AND LEVEL-OF-SERVICE FOR UNINTERRUPTED  
EXCLUSIVE MOTORCYCLE LANES IN MALAYSIA**

**HUSSAIN HAMID**

**T FK 2006 105**



**DEVELOPMENT OF CAPACITY AND LEVEL-OF-SERVICE FOR  
UNINTERRUPTED EXCLUSIVE MOTORCYCLE LANES IN MALAYSIA**

**By**

**HUSSAIN HAMID**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfilment of the Requirement for the Degree of Doctor of Philosophy**

**August 2006**



## DEDICATION

This work is lovingly dedicated to my late mother, Hajjah Rahimah binti Mohd. Ghouse and late father, Hamid bin Ahmad. May Allah bless their soul.

This work is also passionately dedicated to my beloved wife, Dr. Raja Zarina Raja Shahardin, my three little angels; Wan Nur Hasya Hussain, Wan Nur Hilman Hussain, Wan Nur Hadeeja Hussain, and my father-in-law; Lt. Col. (B) Raja Shahardin Raja Rome for their understanding, sacrifices and supports throughout the times that I have been working to accomplish this research.



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

**DEVELOPMENT OF CAPACITY AND LEVEL-OF-SERVICE FOR UNINTERRUPTED EXCLUSIVE MOTORCYCLE LANES IN MALAYSIA**

By

**HUSSAIN HAMID**

**August 2006**

**Chairman : Professor Ir. Radin Umar Radin Sohadi, PhD**

**Faculty : Engineering**

In developing ASEAN countries, the key road accident problems arise from the high proportion of motorcycles in the mixed vehicle population. Considering that motorcycles are popular mode of personal travel and that they are highly numbered on the roads, the provision of exclusive motorcycle lanes is expected to reduce accidents and improve motorcycle safety. Studies have proven that segregation is the best engineering practice to save lives of motorcyclists. Acknowledging these benefits, the Malaysian government has adopted a policy to provide exclusive motorcycle facilities along its new highways and federal roads. The need to provide this special facility has brought to light the deficiencies in studies related on motorcycle traffic sciences, operations and facility design.

This research initially attempts to establish the characteristics of key components of a motorcycle-traffic system in Malaysia, i.e. the motorcycle-rider unit, motorcyclist space requirement and riding manner along motorcycle lane of various lane widths. Then, it seeks to establish the



fundamental motorcycle speed-flow-density relationships along uninterrupted motorcycle lanes in Malaysia. This would enable the maximum motorcycle flow, critical speed and critical density at capacity conditions to be estimated. Finally the level-of-service criteria for an exclusive motorcycle lane facility would be developed, thus allowing the motorcycle design charts and tables to be produced.

To understand the key components of a motorcycle-traffic system, digital recordings of motorcyclists along the existing motorcycle lanes in Malaysia were captured. Basic dimensions of a motorcycle/rider unit were directly measured. The separation distance between side-by-side motorcyclists was obtained by employing the digital recording technique. The motorcyclist operating space was then established. Three-stages of field and experimental studies was conducted to observe the motorcyclists riding manner along various lane widths from low to high volume conditions.

To establish the fundamental motorcycle speed-flow-density relationships and to develop the level-of-service criteria, the aggregated data from 8 sites ranging from the stable flow to unstable conditions were plotted. A simple linear regression analysis was conducted on the motorcycle speed on motorcycle density function to obtain the best linear regression equation that describes the relationship. Once the motorcycle speed-density relationship was established, the motorcycle speed-flow and motorcycle flow-density relationships were derived. The demarcation of the level-of-

service boundaries for the uninterrupted exclusive motorcycle lanes was guided by the volume-capacity ratio ( $v/c$ ) and service flow rates.

Results of the research revealed that the small- and medium-sized type motorcycles (150 c.c. and below) are the commonly used type in Malaysia. A single static motorcyclist spans about 0.8 m wide, but requires a mean width of 1.3 m to operate. In a lane width of 1.7 m or below, motorcycle flow applies the lane or headway concept. While in lanes of width between 1.7 m and 3.4 m, the motorcycle flow adopts the space concept. This highlights that 1.7 m is the optimum lane width where motorcyclists would travel in a single file, even during low speeds and high motorcycle flow conditions. There is not enough space for faster motorcyclists to pass the slower ones within the 1.7 m motorcycle lanes.

In the headway concept ( $W \leq 1.7$  m), capacity is reached at a maximum motorcycle flow of 3306 mc/hr/lane, corresponding to a critical speed of 13 km/hr and critical density of 235 mc/km/lane. As for the space concept ( $1.7 \text{ m} < W \leq 3.4$  m), capacity occurs at a maximum motorcycle flow of 2207 mc/hr/m. This corresponds to a critical motorcycle speed of 13 km/hr and critical motorcycle density of 0.166 mc/m<sup>2</sup> (or space of 6.0 m<sup>2</sup>/mc). Based on the speed-flow-density relationships and the volume-capacity ratio, the level-of-service boundaries were demarcated. Subsequently, tables and charts of maximum motorcycle flow rates related to level-of-services for different motorcycle lane widths were developed.

The outcome provides useful input in developing design guidelines for motorcycle facilities in countries with high number of motorcycles in the

effort to curb motorcycle safety problems. This study is seen as an initial effort to fill the missing link in basic research of motorcycle traffic sciences, operations and facility design that existed among various land transportation facilities, thus contributing new knowledge to the field of transportation engineering.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia  
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PEMBENTUKAN KAPASITI DAN PARAS PERKHIDMATAN BAGI  
LALUAN KHAS MOTOSIKAL TIDAK TERHALANG DI MALAYSIA**

Oleh

**HUSSAIN HAMID**

**Ogos 2006**

**Pengerusi : Profesor Ir. Radin Umar Radin Sohadi, PhD**

**Fakulti : Kejuruteraan**

Masalah keselamatan jalan raya yang utama di negara-negara ASEAN yang sedang membangun adalah berpunca daripada bilangan motosikal yang tinggi di dalam populasi kenderaannya yang pelbagai. Memandangkan motosikal merupakan mod perjalanan persendirian yang diminati dan juga menyumbang sebagai bilangan kenderaan yang sangat tinggi di jalan raya, maka penyediaan kemudahan laluan khas motosikal dijangka dapat mengurangkan kemalangan dan meningkatkan keselamatan pengguna motosikal. Kajian telah membuktikan bahawa pembinaan laluan khas motosikal merupakan salah satu amalan kejuruteraan yang terbaik bagi menyelamatkan nyawa pengguna motosikal. Berdasarkan kepada kebaikan-kebaikan ini, kerajaan Malaysia telah menetapkan suatu polisi untuk menyediakan kemudahan laluan khas motosikal di sepanjang lebuhraya baru dan jalan raya persekutuan. Keperluan di dalam menyediakan kemudahan khas untuk penunggang motosikal ini menunjukkan bahawa terdapat kekurangan penyelidikan





berkaitan bidang sains trafik, operasi dan rekabentuk kemudahan motosikal.

Kajian ini pada awalnya memberikan tumpuan kepada pemahaman ciri-ciri komponen utama sistem trafik motosikal di Malaysia seperti unit motosikal/penunggang, keperluan ruang bagi penunggang motosikal dan tabiat menunggang motosikal di sepanjang laluan khas motosikal pelbagai kelebaran. Seterusnya, kajian dijalankan untuk menghasilkan hubungan asas bagi kelajuan-aliran-ketumpatan motosikal di sepanjang laluan motosikal bagi segmen tanpa halangan di Malaysia. Ini membolehkan aliran maksimum motosikal, kelajuan kritikal dan ketumpatan kritikal motosikal dianggarkan. Akhirnya, paras-paras perkhidmatan bagi kemudahan laluan khas motosikal dapat dianggarkan. Seterusnya, carta-carta rekabentuk dan jadual bagi kemudahan laluan khas motosikal dapat dihasilkan.

Untuk memahami komponen-komponen utama sistem trafik motosikal, rakaman digital telah dijalankan ke atas penunggang motosikal di sepanjang laluan khas motosikal yang sedia ada di Malaysia. Dimensi asas bagi unit motosikal/penunggang diukur secara terus. Jarak di antara motosikal yang bersebelahan didapati dengan menggunakan teknik rakaman digital. Justeru itu, ruang untuk penunggang beroperasi dapat ditentukan. Tiga fasa kajian di tapak dan secara eksperimen di bawah keadaan aliran rendah sehingga aliran tinggi dijalankan bagi memerhati tabiat menunggang motosikal di sepanjang laluan motosikal yang berlainan kelebaran.

Bagi menghasilkan hubungan asas bagi kelajuan-aliran-ketumpatan dan juga untuk menentukan kriteria paras perkhidmatan, himpunan data dari 8 tapak kajian pada keadaan aliran stabil hingga aliran tidak stabil diplotkan. Analisis regresi linear mudah dijalankan ke atas data berkaitan kelajuan motosikal dan ketumpatan motosikal bagi menentukan persamaan regresi linear yang terbaik didalam menjelaskan perkaitan ini. Dengan tertubuhnya hubungan di antara kelajuan-ketumpatan motosikal ditubuhkan, hubungan antara kelajuan-aliran motosikal dan juga aliran-ketumpatan motosikal dapat diterbitkan. Sempadan-empadan paras perkhidmatan bagi kemudahan laluan khas motosikal ditentukan dengan merujuk kepada nisbah isipadu-kapasiti dan aliran.

Hasil kajian menunjukkan bahawa motosikal bersaiz kecil dan sederhana (150 c.c. ke bawah) merupakan jenis motosikal yang paling banyak digunakan di Malaysia. Penunggang motosikal dalam keadaan statik mempunyai ukuran 0.8 m lebar, sementara penunggang motosikal pada puratanya memerlukan kelebaran minimum 1.3 m untuk beroperasi. Bagi laluan motosikal berkelebaran 1.7 m atau kurang, aliran motosikal adalah berdasarkan konsep lorong atau 'headway'. Bagi laluan motosikal berkelebaran di antara 1.7 m dan 3.4 m, aliran motosikal adalah berdasarkan konsep ruang. Ini menunjukkan bahawa untuk 1.7 m merupakan kelebaran optimum laluan motosikal di mana penunggang motosikal akan menunggang mengikut satu barisan, walau pun di dalam keadaan di mana kelajuan motosikal adalah sangat rendah di dalam aliran motosikal yang tinggi. Ruang adalah tidak mencukupi bagi penunggang

motosikal yang lebih laju untuk memotong penunggang motosikal yang bergerak perlahan di dalam laluan motosikal berkelebaran 1.7 m.

Hasil kajian juga menunjukkan bahawa di bawah konsep 'headway' ( $W \leq 1.7\text{m}$ ), kapasiti dicapai pada aliran motosikal maksimum 3306 motosikal/jam/lorong yang bersamaan dengan kelajuan kritikal 13 km/jam dan ketumpatan kritikal 235 motosikal/km/lorong. Bagi konsep ruang pula ( $1.7\text{ m} < W \leq 3.4\text{ m}$ ), kapasiti berlaku pada aliran motosikal maksimum 2207 motosikal/jam/m. Nilai ini adalah bersamaan dengan kelajuan kritikal 13 km/jam dan ketumpatan kritikal 0.166 motosikal/m<sup>2</sup> (atau ruang 6.0 m<sup>2</sup>/motosikal). Berdasarkan kepada perkaitan kelajuan-aliran-ketumpatan dan juga lengkungan kelajuan-aliran-ruang di bawah konsep ruang, sempadan-sempadan paras perkhidmatan dapat ditentukan. Seterusnya, carta-carta aliran motosikal maksimum yang berkaitan dengan paras-paras perkhidmatan bagi laluan motosikal pelbagai kelebaran telah dihasilkan.

Hasil-hasil kajian adalah berguna di dalam menghasilkan panduan merekabentuk kemudahan laluan motosikal terutamanya bagi negara-negara yang mempunyai bilangan kenderaan motosikal yang tinggi. Kajian ini dianggap sebagai usaha awal di dalam mengisi ketiadaan maklumat di dalam penyelidikan sains trafik, operasi dan rekabentuk kemudahan motosikal yang telah lama wujud di antara pelbagai jenis kemudahan pengangkutan darat yang lain. Justeru itu, kajian ini menyumbangkan pengetahuan yang baru di dalam bidang kejuruteraan pengangkutan.

## ACKNOWLEDGEMENTS

First and foremost, I wish to thank God for giving me good physical health, mental strength, perseverance and dedication towards completing this research work.

I am highly indebted to my supervisor, Prof. Ir. Dr. Radin Umar Radin Sohadi, Faculty of Engineering, University Putra Malaysia who has been very helpful and supportive throughout the entire process of this research works. His critical comments, clear guidance and motivations were invaluable in ensuring that I am continuously along the right track throughout this entire research.

I wish to express my appreciation to the supervisory committee, Assoc. Prof. Dr. Ahmad Farhan Mohd. Sadullah, School of Civil Engineering, University Sains Malaysia (USM) for his critical comments and ideas pertaining to this work. I also appreciate his trips from USM, Penang to UPM, Selangor to attend my presentations on the progress of the research works to the supervisory committee. My utmost gratitude is also due to the supervisory committee, Ir. Dr. Dadang Mohamad Ma'soem, Faculty of Engineering, University Putra Malaysia for his invaluable guidance, comments and support to ensure the success of this research.

I am much indebted to Law Teik Hua, Faculty of Engineering, University Putra Malaysia for his advises and few short lectures pertaining to



Statistical Modelling and SPSS. His clear and simple explanations has somewhat gave me a new perception about Engineering Statistics.

My sincere thanks to Ir. Dr. Safry Kamal Hj. Ahmad (Public Works Department, Malaysia), Nafisah Abdul Aziz (Roadcare's Technical Manager), Hj. Aznam Abdul Rahim (Roadcare's Regional Manager, Selangor) and team, and Mohamed Marzuki Mohamed Hassan for their kind assistance in ensuring that the experimented study along the motorcycle lane of Federal Highway Route 2 (F02), Selangor near Kg. Kerinci could be successfully conducted. Kind appreciations are also due to Syed Amir Syed Abdul Rahman, Nik Muhamad Azhar Nik Mustapha for assisting me with the data collections along the F02 highway and experimented study in the campus of University Putra Malaysia.

Thank you very much indeed to Mohamed Marzuki Mohamed Hassan and Raja Norashikin Raja Shahardin for their assistance and advice pertaining to graphic works for the figures and illustrations.

Lastly, but not least, my sincere appreciation to the National Science Council, Intensification of Research in Priority Areas (IRPA), Malaysia for the grants, and to all who had directly or indirectly contributed to the completion of this research.



I certify that an Examination Committee has met on 9 August 2006 to conduct the final examination of Hussain Hamid on his Doctor of Philosophy thesis entitled “Development of Capacity and Level-of-Service for Uninterrupted Exclusive Motorcycle Lanes in Malaysia” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

**Wong Shaw Voon, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Ratnasamy Muniandy, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Kulanthayan K C Mani, PhD**

Faculty of Medicine and Medical Sciences  
Universiti Putra Malaysia  
(Internal Examiner)

**Ian Johnston, PhD**

Professor  
University of Monash  
Australia  
(External Examiner)

---

**HASANAH MOHD GHAZALI, PhD**

Professor/Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:



This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

**Radin Umar Radin Sohadi, PhD**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Ahmad Farhan Mohd. Sadullah, PhD**

Associate Professor  
School of Civil Engineering  
Universiti Sains Malaysia  
(Member)

**Dadang Mohamad Ma'soem, PhD**

Senior Lecturer  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

---

**AINI IDERIS, PhD**

Professor/Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 16 JANUARY 2007



## DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

---

**HUSSAIN HAMID**

Date: 18 DECEMBER 2006



## TABLE OF CONTENTS

	<b>Page</b>
<b>DEDICATION</b>	ii
<b>ABSTRACT</b>	iii
<b>ABSTRAK</b>	vii
<b>ACKNOWLEDGEMENTS</b>	xi
<b>APPROVAL</b>	xiii
<b>DECLARATION</b>	xv
<b>LIST OF TABLES</b>	xix
<b>LIST OF FIGURES</b>	xxi
<b>LIST OF ABBREVIATIONS</b>	xxv
<b>CHAPTER</b>	
<b>1 INTRODUCTION</b>	<b>1</b>
1.1 Motorcycle Safety Problems in ASEAN Countries	1
1.2 Segregation of Motorcycles: An Effective Road Safety Engineering Program	3
1.3 Benefit-Cost Ratio of Exclusive Motorcycle Lanes	4
1.4 Problem Statement	5
1.5 Objectives of the Study	9
1.6 Relevance of the Study	10
1.7 Scope of Study	11
1.8 Organisation of the Thesis	12
<b>2 LITERATURE REVIEW</b>	<b>13</b>
2.1 Key Components of a Traffic System	13
2.2 Traffic-stream Parameters	14
2.2.1 Volume and Flow	14
2.2.2 Speed	15
2.2.3 Density	18
2.3 Highway Capacity Manual	19
2.3.1 Capacity	20
2.3.2 Level-of-Service	21
2.4 Facilities for Vulnerable Road Users	25
2.4.1 Motorcycle Track	25
2.4.2 Bicycle Facilities	27
2.4.3 Pedestrian Facilities	33
2.5 Calibration of Basic Speed-Flow-Density Relationships	38
2.5.1 Field Data Observations	40
2.5.2 Mathematical Description of Speed-Flow-Density Relationships	41
2.5.3 Statistical Modelling of Speed-Density Relationships	42
2.5.4 Speed-Density Models from Past Studies	45
2.5.5 Derivation of Flow-Speed and Flow-Density Relationships	52
2.5.6 Determining Capacity from Speed-Flow-Density Models	54



3	<b>METHODOLOGY</b>	56
3.1	Phase 1-Defining the Key Components of a Motorcycle Traffic System	56
3.1.1	Sites Reconnaissance	59
3.1.2	Sites Selection and Criteria	60
3.1.3	Standard Field Parameters and Measuring Equipment	62
3.1.4	Pilot study	65
3.1.5	Defining the Design Motorcycle	68
3.1.6	Defining Static Space of Motorcycle/Rider Unit	69
3.1.7	Defining Operating Space of Motorcycle/Rider Unit	72
3.1.8	Defining Riding Manner Along the Exclusive Motorcycle Lanes	75
3.2	Phase 2-Motorcycle Speed-Flow-Density Models, Capacity and LOS Boundaries of Exclusive Motorcycle Lanes	76
3.2.1	Modelling Motorcycle Speed-Flow-Density	76
3.2.2	Determining Capacity for Exclusive Motorcycle Lanes	78
3.2.3	Defining LOS for Exclusive Motorcycle Lanes	78
4	<b>CHARACTERISTICS OF KEY COMPONENTS OF MOTORCYCLE-TRAFFIC SYSTEM IN MALAYSIA</b>	80
4.1	The Design Motorcycle	80
4.2	Static Space of Motorcycle/Rider Unit	84
4.3	Operating Space of Motorcycle/Rider Unit	86
4.4	Riding Manner along the Exclusive Motorcycle Lanes	88
4.4.1	Stage 1: Field Study along F02 Highway	89
4.4.2	Stage 2: Experimented Study at UPM Campus	91
4.4.3	Stage 3: Experimented Study at F02 Highway	93
4.4.4	Riding Characteristics along Various Motorcycle Lane Widths	95
5	<b>MOTORCYCLE SPEED-FLOW-DENSITY RELATIONSHIPS</b>	101
5.1	Observed Data	103
5.2	Scatter Plots of Motorcycle Speed-Flow-Density Relationships	105
5.2.1	Scatter Plots of Headway Concept	106
5.2.2	Scatter Plots of Space Concept	108
5.2.3	New Scatter Plots of Space Concept	110
5.3	Motorcycle Speed-Flow-Density Models (Headway Concept)	113
5.3.1	Model Fitting of Motorcycle Speed-Density Regression Model (Headway Concept)	114
5.3.2	Model Validation of Motorcycle Speed-Density Regression Model (Headway Concept)	116
5.3.3	Motorcycle Speed-Density Equation (Headway Concept)	120
5.3.4	Established Motorcycle Speed-Flow-Density Relationships (Headway Concept)	123

5.4	Motorcycle Speed-Flow-Density Models (Space Concept)	125
5.4.1	Motorcycle Speed-Density Equation (Space Concept)	129
5.4.2	Established Motorcycle Speed-Flow-Density Relationships (Space Concept)	132
<b>6</b>	<b>CAPACITY AND LOS BOUNDARIES FOR EXCLUSIVE MOTORCYCLE LANES</b>	<b>136</b>
6.1	Determining Capacity for Uninterrupted Exclusive Motorcycle Lanes	136
6.2	LOS for Uninterrupted Exclusive Motorcycle Lanes	143
6.2.1	Motorcycle Service Flow Rates	144
6.2.2	Motorcycle Facility Performance and Service Measures	144
6.2.3	LOS Designation for Motorcycle Lanes (Headway Concept)	146
6.2.4	LOS Designation for Motorcycle Lanes (Space Concept)	154
6.2.5	Maximum Motorcycle Flow Rates at Various LOS for Ranges of Motorcycle Lane Widths	157
6.2.6	Sample Calculation to Estimate Service Life of Exclusive Motorcycle Lanes	160
<b>7</b>	<b>DISCUSSIONS AND CONCLUSION</b>	<b>163</b>
7.1	Motorcycle Characteristics and Riding Concepts	163
7.1.1	Headway Concept	164
7.1.2	Hybrid Concept (Headway-Space)	166
7.1.3	Space Concept	168
7.2	Motorcycle Speed-Flow-Density Relationships	170
7.2.1	Motorcycle Speed-Density Relationship (Headway and Space Concepts)	171
7.2.2	Motorcycle Flow-Density Relationship (Headway and Space Concepts)	173
7.2.3	Motorcycle Speed-Flow Relationship (Headway and Space Concepts)	175
7.3	Capacity of Uninterrupted Exclusive Motorcycle Lanes (Headway and Space Concepts)	177
7.3.1	Maximum Flow Rates: Motorcycles vs Cars	180
7.3.2	Maximum Flow Rates: Motorcycles vs Bicycles	181
7.3.3	PWD (Arahan Teknik) vs Research Results	182
7.4	LOS Criteria for Exclusive Motorcycle Lanes	184
7.5	New Estimates of Benefit-Cost Ratio (BCR)	185
7.6	Conclusions	187
7.7	Further Research	190
	<b>REFERENCES</b>	<b>192</b>
	<b>APPENDICES</b>	<b>196</b>
	<b>BIODATA OF THE AUTHOR</b>	<b>221</b>



## LIST OF TABLES

Table	Page	
2.1	LOS Criteria for Basic Freeway Segments	23
2.2	Width of Cycle Lane	27
2.3	LOS Criteria for Uninterrupted Bicycle Facilities	32
2.4	Pedestrian Level of Service on Walkways	38
2.5	Summarised Basic Speed-Density Models	52
4.1	Physical Features of 6 Study Sites along the Exclusive Motorcycle Lane at FO2 Highway	81
4.2	Motorcycles by types as observed at six sites	82
4.3	Range of Motorcycle/Rider Unit Physical Measurements	84
4.4	Physical features of 3 study sites on motorcycle lane at FO2 highway	89
4.5	Descriptions of 3 experimental studies in UPM campus	92
4.6	Descriptions of 3 experimented study sites at FO2 highway	94
4.7	Motorcyclists riding characteristics along different lane widths	96
4.8	Number of lines formed along various lane widths under low and high flow conditions	98
4.9	Motorcyclists riding manner along various lane widths under low and high flow conditions	100
5.1	Study sites and motorcycle lane widths	103
5.2	Measured and computed parameters in Headway concept (1 minute-interval)	104
5.3	Measured and computed parameters in Space concept (1 minute-interval)	105
5.4	Summary of estimates and goodness-of-fit values for motorcycle speed-density regression models (Headway concept)	114



5.5	Summary of residual analysis for motorcycle speed-density regression models (Headway concept)	117
5.6	Summary of estimates and goodness-of-fit values for motorcycle speed-density regression models (Space concept)	125
5.7	Summary of residual analysis for motorcycle speed-density regression models (Space concept)	127
6.1	Values of parameters at capacity conditions for motorcycle facility	136
6.2	Maximum Motorcycle Flow Rates for Motorcycle Lane of various Widths at Capacity Condition	137
6.3	Difference in Motorcycle Flow Rates at Capacity between Headway and Space concepts	140
6.4	Revised Maximum Motorcycle Flow Rates for Various Motorcycle Lane Widths at Capacity	142
6.5	v/c Ratio for Basic Freeway Segments of different Free-Flow Speeds and LOS (HCM, 2000)	146
6.6	LOS Criteria for one-way Exclusive Motorcycle Lane (Headway concept)	153
6.7	LOS Criteria for one-way Exclusive Motorcycle Lane (Space concept)	156
6.8	Maximum Motorcycle Flow Rates for Various LOS and Lane Widths	158
7.1	PWD (Arahan Teknik) Values Compared to Research Results	183

## LIST OF FIGURES

Figure		Page
1.1	Registered Vehicles (by type) in Malaysia for Year 2002	2
2.1	Various Types of Cycle Tracks Used	26
2.2	Bikeway Clearance Requirements	29
2.3	Bicycle LOS and Speed-Flow Relationships for Uninterrupted Flow	32
2.4	Relationships between Pedestrian Speed and Density	35
2.5	Relationships between Pedestrian Flow and Space	35
2.6	Relationships between Pedestrian Speed and Flow	36
2.7	Relationships between Pedestrian Speed and Space	37
2.8	Basic Form of Speed-Flow-Density Relationships	40
2.9	Illustrations of Speed-Density Hypotheses	46
2.10	Speed-Flow-Density Relationships:Greenberg Hypothesis	49
2.11	Speed-Flow-Density Relationships:Underwood Hypothesis	51
3.1	Flow Chart of Overall Research Methodology	58
3.2	Observation from Overhead Pedestrian Bridge	66
3.3	Unknowing Motorcyclists Moving Away from Observer	66
3.4	Front View of a Motorcycle/Rider Unit	70
3.5	Side View of a Motorcycle/Rider Unit	70
3.6	Distances between centres of rear tyres ( $d_1$ ) and effective width ( $d_2$ ) as the faster motorcyclist passed the slower ones	74
4.1	Small-sized Motorcycle (110 c.c.) commonly found in Malaysia	83
4.2	Small-sized Motorcycle representing the Design Motorcycle-vehicle	83
4.3	Front outline of a static motorcyclist - breadth of 0.8 m	85

4.4	Side outline of a static motorcyclist - length of 2.0 m	85
4.5	Side-by-side motorcyclists separation distance of 0.50 m	87
4.6	Operating space of 1.3 m required by a motorcyclist	88
4.7	Study Site 1 at FO2 highway, Selangor (W=2.4 m)	90
4.8	Study Site 2 at FO2 highway, Selangor (W=3.0 m)	90
4.9	Study Site 3 at FO2 highway, Selangor (W=3.3 m)	90
4.10	Experimented Study Site 4 at UPM campus (W=1.5 m)	92
4.11	Experimented Study Site 6 at UPM campus (W=1.9 m)	92
4.12	Experimented set-up at segment of motorcycle lane (W=2.0 m) near Kg. Kerinchi, FO2 highway	94
4.13	Approaching the experimented segment of motorcycle lane (W=2.0 m) near Kg. Kerinchi, F02 highway	95
4.14	Motorcycle speed versus motorcycle flow	97
5.1	Scatter plot of speed-density relationship, N = 90 (Headway concept)	107
5.2	Scatter plot of flow-density relationship, N = 90 (Headway concept)	107
5.3	Scatter plot of speed-flow relationship, N = 90 (Headway concept)	108
5.4	Scatter plot of speed-density relationship, N = 103 (Space concept)	109
5.5	Scatter plot of flow-density relationship, N = 103 (Space concept)	109
5.6	Scatter plot of speed-flow relationship, N = 103 (Space concept)	110
5.7	New Scatter plot of speed-density relationship, N = 193 (Space concept)	111
5.8	New Scatter plot of flow-density relationship, N = 193 (Space concept)	112
5.9	New Scatter plot of speed-flow relationship, N = 193 (Space concept)	112

5.10	Residual P-P plot and Scatter plot of Model (H1) (Headway concept)	118
5.11	Residual P-P plot and Scatter plot of Model (H2) (Headway concept)	118
5.12	Residual P-P plot and Scatter plot of Model (H3) (Headway concept)	118
5.13	Relationship between motorcycle speed and motorcycle density (Headway concept)	124
5.14	Relationship between motorcycle flow and motorcycle density (Headway concept)	124
5.15	Relationship between motorcycle speed and motorcycle flow (Headway concept)	125
5.16	Residual P-P plot and Scatter plot of Model (S1) (Space concept)	128
5.17	Residual P-P plot and Scatter plot of Model (S2) (Space concept)	128
5.18	Residual P-P plot and Scatter plot of Model (S3) (Space concept)	128
5.19	Relationship between motorcycle speed and motorcycle density (Space concept)	133
5.20	Relationship between motorcycle flow and motorcycle density (Space concept)	133
5.21	Relationship between motorcycle speed and motorcycle flow (Space concept)	134
5.22	Relationship between motorcycle flow and motorcycle space (Space concept)	135
5.23	Relationship between motorcycle speed and motorcycle space (Space concept)	135
6.1	Maximum motorcycle flows for various motorcycle lane widths at capacity	137
6.2	Revised chart of maximum flow rates for motorcycle lanes of various widths at capacity	142
6.3	v/c Ratio and Free-Flow Speed Relationship for a Basic Freeway Segment (HCM, 2000)	149





6.4	Motorcycle Speed-Flow Curve and LOS boundaries for uninterrupted motorcycle facility (Headway Concept)	153
6.5	Motorcycle Speed-Flow Curve and LOS boundaries for uninterrupted motorcycle facility (Space Concept)	156
6.6	Chart of Maximum Motorcycle Flow Rates for Various LOS and Lane Widths	159

