UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF COMPOSITE RISK INDEX FOR FEDERAL ROADS IN MALAYSIA

INTAN SUHANA BT MOHD RAZELAN

DEVELOPMENT OF COMPOSITE RISK INDEX FOR FEDERAL ROADS IN MALAYSIA

By

INTAN SUHANA BT MOHD RAZELAN

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

January 2015

COPYRIGHT

DEDICATION

This work is lovingly dedicated to my husband, my soulmate, my number one listener, my ultimate supporter and my shoulder to lean on Badrul Hisham Hasim. May Allah forgive him and bless him with love forever and hereafter. Huge hugs and kisses for my three little angels, Nurin Aisyah binti Badrul Hisham, Nur Nadhiah binti Badrul Hisham and Imran Hariz bin Badrul Hisham for understanding mama's work and for soothing my hearts with their loving attitudes.

This work is also fondly dedicated to my father Mohd Razelan bin Abd Ghani and my mother Shamsiah binti Abd Hamid for their continuous prayers, for looking after my kids when I am away and for their never-ending 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 fulfilment of the requirement for the Degree of Doctor of Philosophy

DEVELOPMENT OF COMPOSITE RISK INDEX FOR FEDERAL ROADS IN MALAYSIA

By

INTAN SUHANA BT MOHD RAZELAN

January, 2015

Chair : Hussain Hamid, PhD

Faculty: Engineering

According to WHO (2013), middle-income countries like Malaysia, Indonesia and several other ASEAN countries suffer the highest traffic fatality rates compared to most developed countries where crash statistics are used to evaluate the safety status of these countries. Crash data has been acknowledged as the most popular and acceptable road safety indicator in recognizing road section's safety status. However, the reliability of crash data in correctly identifying the road section's safety status has been widely argued by road safety experts. In light of that, a new method called composite risk index that would act as a proactive measure in evaluating road section's safety status has been introduced and tested in this research.

This research attempts to fill in the missing links on the role of different road environment factors in producing risk towards road users. Other than that, a significant contribution to the knowledge in the theory of road safety index is made by developing a risk index in evaluating road section's safety status. Identifications of the road environment factors of the existing road networks were done by adopting naturalistic driving method in recording different road environment conditions for 315.5 km length of federal road. The road environment factors for the whole study area were identified by clustering fourteen original attributes into several groups having similar characteristics.

In the development of the composite road environment risk index, several procedures were involved in defining the underlying structures of the original indicators, weighting, normalizing and aggregating the indicators before the composite indexes were developed. A statistical method of principal component analysis was adopted in defining

the underlying structure of the original indicators, clustering the original indicators according to current road conditions and assigning statistical weight to each indicator to avoid the possibility of biased results. After that, z-score method was used to normalize the indicators so that the indicators could be added up and finally, the weighted sum-score method was employed to combine the original indicators and formed a composite index. The validation procedure was carried out by utilizing the Spearman's rho correlation coefficient procedures so that the ability of the composite index to be used in the real world is verified.

The research outcomes revealed four main road environment risk factors for federal roads, namely road operational environment, roadway environment, roadside environment and road infrastructure environment. Following that, three composite road environment risk indexes were successfully developed for three different road environments. Results from the composite index demonstrated that specific attentions should be given on the combinations of motorcycles and heavy vehicles, especially at locations where human activities on the roadside areas are high and signalized intersections are mutually existed. Also, highly developed roadside areas have been recognized to contribute higher risk, especially on the aspect number of accesses and an existence of median.

The outcomes from this research provide useful preliminary inputs in highlighting the role of road environment risks in defining crash factors especially in developing countries. The development of the composite risk index in proactively evaluating road section's safety status is definitely a state-of-the-art method that can be used in other developing countries to evaluate their road section's safety status when the crash data does not exist or in poor quality.

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

PEMBANGUNAN INDEKS KOMPOSIT RISIKO UNTUK JALAN PERSEKUTUAN DI MALAYSIA

Oleh

INTAN SUHANA BT MOHD RAZELAN

Januari, 2015

Pengerusi : Hussain Hamid, PhD

Fakulti: Kejuruteraan

Menurut WHO (2013), Negara-negara berpendatan sederhana seperti Malaysia, Indonesia and lain-lain negara ASEAN mengalami impak daripada kemalangan jalan raya yang lebih besar daripada berbanding kebanyakan negara maju dimana penilaian status keselamatan jalan raya adalah berdasarkan statistik kemalangan yang direkodkan. Data kemalangan telah diiktiraf sebagai penunjuk keselamaran yang boleh diterima pakai untuk menilai tahap keselamatan jalan raya, walaubagaimanapun, kebolehpercayaan terhadap data kemalangan telah diperdebatkan secara meluas oleh kebanyakan pakar keselamatan jalan raya. Oleh kerana itu, satu kaedah baru yang dikenali sebagai Indeks Komposit Risiko yang mengambil pendekatan pro-aktif didalam menilai status keselamatan bahagian jalan raya telah diperkenalkan dan diuji didalam kajian ini.

Kajian ini berhasrat untuk memasukkan pautan yang hilang didalam mengenalpasti peranan faktor persekitaran jalan yang berbeza terhadap risiko berlakunya kemalangan jalan raya yang melibatkan pengguna jalan raya. Selain daripada itu, sumbangan terhadap pengetahuan didalam teori indeks keselamatan jalan raya juga dilakukan dengan pembangunan indeks risiko bagi menilai tahap keselamatan bahagian jalan. Faktor-faktor pesekitaran jalanraya yang sedia ada dilakukan dengan menggunakan kaedah pemanduan secara semulajadi (naturalistik) dimana keadaan persekitaran jalan raya yang berbeza sepanjang 315.5 kilometer telah dirakam sepanjang pemanduan dijalankan. Faktor-faktor persekitaran jalan raya untuk keseluruhan kawasan kajian telah dikenalpasti dengan membahagikan empat belas atribut asal kajian kepada beberapa kumpulan yang mempunyai sifat yang sama.

Didalam proses pembangunan indeks komposit risiko persekitaran jalan, beberapa prosedur telah dijalankan untuk mengenalpasti struktur asas setiap petunjuk keselamatan yang dipilih, pembahagian pemberat, penstrukturan semula petunjuk dan penambahan semua petunjuk asal supaya indeks komposit dapat dibangunkan. Kaedah statistic yang dinamakan 'principal component analysis' telah digunakan didalam mengenalpasti struktur asas setiap petunjuk asal, mengenalpasti sifat petunjuk asal berdasarkan keadaan semasa jalan raya dan pembahagian pemberat statistic bagi mengelakkan terjadinya pembahagian pemberat yang tidak adil. Kemudian, kaedah 'z-score' telah diaplikasi untuk penstrukturan semula bagi memastikan setiap petunjuk dapat ditambah antara satu sama lain dan akhirnya kaedah 'weighted sum-score' telah digunapakai untuk menggabungkan kesemua petunjuk bagi membentuk indeks komposit risiko. Proses validasi dijalankan dengan mengunakan prosedur 'spearman's rho correlation coefficient' dimana keputusan validasi ini akan menentukan kebolehgunaan kaedah indeks komposit ini di dijalan-jalan lain.

Hasil kajian telah mengenalpasti empat faktor risiko persekitaran jalan bagi jalan persekutuan iaitu faktor persekitaran operasi jalan, faktor persekitaran keadaan jalan raya, faktor persekitaran keadaan tepi jalan dan faktor persekitaran infrastruktur jalan. Berdasarkan keadaan jalan semasa bagi tiga jenis jalan persekutuan yang dipilih, tiga indeks komposit risiko jalan raya telah berjaya dibangunkan. Hasil daripada indeks komposit tersebut, perhatian yang khusus perlu diberikan terhadap gabungan diantara motorsikal dan kenderaan berat terutamanya dilokasi persimpangan lampu isyarat yangmana pergerakan pengguna jalan raya juga adalah tinggi. Selain daripada itu, kawasan berkepadatan tinggi juga telah dikenalpasti sebagai kawasan yang berisiko tinggi terutama apabila terdapatnya persimpangan keluar-masuk dan median.

Hasil kajian ini telah berjaya memberikan input-input awal didalam mendefinasikan kepentingan dan sumbangan keadaaan persekitaran jalan terhadap risiko berlakunya kemalangan terutamanya dikalangan negara membangun. Pembangunan indeks komposit risiko ini dilihat sebagai kaedah terbaik yang boleh digunakan untuk menilai status tahap keselamatan jalan raya terutamanya apabila statistik kemalangan tidak wujud ataupun berkualiti rendah.

ACKNOWLEDGEMENT

First and foremost, I wish to thank the Almighty, Allah SWT for giving me strength, perseverance, physical and mental health throughout this amazing educational journey.

I am highly indebted to my main supervisor, Dr Hussain Hamid, Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia who has been very supportive and helpful throughout the whole research process. His critical comments, ideas, guidance and motivations really helped me in going through the entire process successfully.

I also wish to express my gratitude to my supervisory committee Assoc. Prof. Dr Law Teik Hwa for his continuous supports and guidance especially statistical data analysis part, Prof. Dr. Ahmad Farhan b. Mohd. Sadullah, School of Civil Engineering, Universiti Sains Malaysia (USM) for his willingness to travel from USM to UPM to attend my presentations, for his brilliant ideas and comments especially during the early part of the research work.

I am much indebted to Sharifah Allyana Syed Mohd Rahim, Malaysian Institute of Road Safety Research (MIROS) for her kindness in providing me with complete crash data for the study areas and without it, I could never complete my analysis successfully. I am also very much grateful for the help from Alvin Poi Wai Hoong, MIROS for his clear explanations on current issues on road safety during my visit to the MIROS. Thank you very much to Dr. Noor Raha bt Radzuan from Universiti Malaysia Pahang (UMP) for invaluable series of discussion in exchanging ideas and experience that inspires me to deliver the best in completing this research. I would also like to thank my dearest sister, Farah Wahida bt Mohd Razelan for providing me with comfortable accommodations during my trips to UPM and for my loving brother, Farid Izwan B. Mohd Razelan for always supporting and put his trust on me.

Last but not least, my sincere appreciations to Universiti Putra Malaysia for providing me with the grant and to all who had directly or indirectly contributed to the completion of this research.

I certify that a Thesis Examination Committee has met on 19 January 2015 to conduct the final examination of Intan Suhana bt Mohd Razelan on her thesis entitled "Development of Composite Risk Index for Federal Roads in Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Degree of Doctor of Philosophy

Members of the Thesis Examination Committee were as follows:

Associate Professor Dr. Abd Halim Ghazali, PhD
Associate Professor,
Faculty of Engineering,
Universiti Putra Malaysia
(Chairman)

Professor Dr. Thamer Ahmed Mohamed, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Associate Professor Dr. Helmi Zulhaidi Mohd. Shafri, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Associate Professor Dr. Richard Tay, PhD
Associate Professor
Department of Infrastructure Engineering,
Melbourne School of Engineering,
The University Of Melbourne,
Australia
(External Examiner)

_____

ZULKARNAIN BIN ZAINAL
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 26 FEBRUARY 2015

This thesis was 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 were as follows:

Hussain Hamid, PhD
Associate Professor,
Faculty of Engineering,
Universiti Putra Malaysia
(Chairman)

Law Teik Hwa, PhD
Associate Professor,
Faculty of Engineering,
Universiti Putra Malaysia
(Member)

Ahmad Farhan Mohd Sadullah, PhD
Professor,
School of Civil Engineering,
Universiti Sains Malaysia
(Member)

BUJANG BIN KIM HUAT, PHD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date :

Declaration by Graduate Student

I hereby confirm that:

- This thesis is my original work;
- Quotations, illustrations and citations have been duly referenced;
- This thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- Intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- Written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- There is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____ Date: 31 March 2015

Name and Matric No.: Intan Suhana Bt Mohd Razelan. GS30630

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____

Name of Chairman of Supervisory Committee : Hussain Hamid, PhD

Signature: _____

Name of Member of Supervisory Committee : Law Teik Hwa, PhD

Signature:

Name of Member of Supervisory Committee : Ahmad Farhan b. Mohd Sadullah, PhD

TABLE OF CONTENTS

		Page
ABSTRACT		**i**
ABSTRAK		**iii**
ACKNOWLEDGEMENT		**v**
APPROVAL		**vi**
DECLARATION		**viii**
LIST OF TABLES		**xiv**
LIST OF FIGURES		**xvi**
LIST OF ABBREVIATIONS		**xviii**
CHAPTER		**1**
1	**INTRODUCTION**	**1**
1.1	Crash As Road Safety Indicator : Reliability Issues	1
1.2	Problem Statement	2
1.3	Objectives of the Study	4
1.4	Relevance of the Study	4
1.5	Scopes and Limitations of the Study	5
1.6	Organizations of the Thesis	7
2	**LITERATURE REVIEW**	**8**
2.1	The Establishment of Road Safety Indicator in Malaysia	8
2.2	The Concept of Road Safety Index	10
2.3	The Development of Composite Road Safety Index	12
2.3.1	Composite Road Safety Index for Comparing Country's Safety Status	12
2.3.2	Assessing Road Network's Safety Status	14
2.3.3	Evaluating Road Environment's Safety Status	16
2.4	The Framework of Composite Road Environment Risk Index	17
2.4.1	Road Environment Indicators	19
2.5	Statistical Framework of Developing Composite Road Environment Risk Index	21
2.5.1	Univariate Analysis	22
2.5.2	Multivariate Analysis	22
2.5.3	Normalizing Techniques	24
2.5.4	Weighting Techniques	26
2.5.5	Aggregating Techniques	29
2.5.6	Validation Procedure	30
2.6	Summary of Gaps	31
3	**RESEARCH METHODOLOGY**	**32**
3.1	Research Working Framework	32
3.2	Preliminary Works in Building the Road Environment Indicators	34
3.2.1	Sites Selection Criteria	34
3.2.2	Recognition of Study Area	35

3.3 Data Collection Procedures 37
3.3.1 Measuring Equipments 38
3.3.1.1 Test Vehicles 38
3.3.1.2 Video Camera 39
3.3.1.3 Computer / Laptop 39
3.3.1.4 Stop Watch 39
3.4 Methodology for Selecting Road Environment Attributes 39
3.4.1 Criteria of Road Environment Indicators 42
3.4.2 Transformation of Road Environment Attributes to Road Environment Indicators 43
3.4.3 Definition of the Selected Indicators 45
3.4.4 Data Collection of Each indicator 48
3.5 Pilot Study 52
3.6 Determination of Road Environment Risk Factors and Development of Composite Road Environment Risk Index 53
3.6.1 Determination of Road Environment Risk Factor 54
3.6.1.1 Principal Component Analysis – Multivariate Analysis Model 55
3.6.2 Development of Composite Road Environment Risk Index 57
3.6.2.1 Z-Score Method – Normalizing Technique 58
3.6.2.2 Statistical Weighting Method 58
3.6.2.3 Additive Aggregation Method 59
3.6.2.4 Spearman's Rank Order Correlation Coefficient Method 60

4 ROAD ENVIRONMENT RISK FACTORS FOR MALAYSIAN FEDERAL ROADS 63
4.1 The Malaysian Federal Roads 63
4.2 The Environment of Malaysian Federal Roads 64
4.3 Road Environment Risk Factors 65
4.3.1 List of Road Environment Attributes 66
4.3.2 Determinations of Road Environment Risk Factors for Federal Roads 69

5 DEVELOPMENT OF COMPOSITE ROAD ENVIRONMENT RISK INDEX 76
5.1 Composite Road Environment Risk Index: Federal Road 2 76
5.1.1 The Descriptive Analysis 76
5.1.2 Determination of Road Environment Risk Factors for Federal Road 2 – Multivariate Analysis 79
5.1.3 Development of Composite Road Environment Risk Index: Federal Road 2 82
5.1.4 Validation Procedure Composite Index for Federal Road 2 85

5.2 Composite Road Environment Risk Index: Federal Road 12 87
5.2.1 The Descriptive Analysis 87
5.2.2 Determination of Road Environment Risk Factor for Federal Road 12 90
5.2.3 Development of Composite Road Environment Risk Index for Federal Road 12 93
5.2.4 Validation Procedure Composite Index for Federal Road 12 97
5.3 Composite Road Environment Risk Index for Federal Road 3 99
5.3.1 The Descriptive Analysis 99
5.3.2 Determination of Road Environment Risk Factor for Federal Road 3 102
5.3.3 Development of Composite Road Environment Risk Index for Federal Road 3 105
5.3.4 Validation Procedure Composite Index for Federal Road 3 109

6 DISCUSSIONS 111
6.1 Road Environment of Malaysian Federal Road 111
6.2 Road Environment Risk Factors for Malaysian Federal Roads 112
6.2.1 Roadway Environment 112
6.2.2 Roadside Environment 113
6.2.3 Road Operational Environment 114
6.2.4 Road Infrastructure Environment 115
6.3 Composite Road Environment Risk Index 115
6.3.1 Identifications of Road Section's Safety Status via Road Environment Risk Level 116
6.3.2 Identifications of Specific Road Environment Risk Factor and Indicators 117
6.3.3 Road Section's Safety Status: Composite Road Environment Risk Index versus Malaysia PWD Practices 121
6.3.4 Contribution to Safer Roads: Composite Road Environment Risk Index versus iRAP 122
6.4 Risky Road Environment Indicators for Malaysian Federal Roads 125
6.4.1 Road Operational Environment 126
6.4.2 Roadside Environment 129
6.5 An in Depth Investigation on Road Crash Data 133
6.5.1 Composite Road Environment Risk Index versus Crash Data 135
6.5.1.1 Comparisons between Composite Index and Crash Data : Condition 1 136
6.5.1.2 Comparisons between Composite Index and Crash Data : Condition 2 138

6.5.2 The Impact of Crash Data in Validating the Composite Index 139

7 CONSLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH 141
7.1 Conclusions 141
7.2 Recommendations 143

REFERENCES 145
APPENDICES 154
BIODATA OF STUDENT 202
LIST OF PUBLICATIONS 203

LIST OF TABLES

Table		Page
3.1	Number of Crashes and Fatalities in Malaysia Road (2005-2010)	35
3.2	Number of Black Spot Locations in Federal Roads	36
3.3	The Definition of Road Environment Indicators	45
4.1	Road Environment Attributes: Master List	66
4.2	Road Environment Attributes: Comprehensive List	68
4.3	Communalities Values of First Trial	70
4.4	Factorability Test Result for Second Trial	71
4.5	Total Variance Explained for Second Trial	72
4.6	Road Environment Factors Correlation Matrix	73
4.7	Loading Values of Each Attributes/ Road Environment Factor	73
4.8	Road Environment Factor for Malaysian Federal Road	75
5.1	Part of Main Datasets : Federal Road 2	77
5.2	Descriptive Analysis for : Federal Road 2	78
5.3	Frequencies Results : Federal Road 2	78
5.4	Measure of Sampling Adequacy Test Results : Federal Road 2	79
5.5	Communalities : Federal Road 2	80
5.6	Total Variance Explained : Federal Road 2	81
5.7	Road Environment Factors Correlation Matrix : Federal Road 2	81
5.8	Road Environment Indicators Loading Values : Federal Road 2	82
5.9	Weight of Indicators / Road Environment Factor : Federal Road 2	83
5.10	Calculation of Individual Index : Federal Road 2	83
5.11	Spearman's rho Correlation Coefficients : Federal Road 2	86
5.12	Part of Main Dataset : Federal Road 12	88
5.13	Descriptive Analysis : Federal Road 12	89
5.14	Test of Normality : Federal Road 12	89
5.15	Frequencies Analysis Results : Federal Road 12	90
5.16	Measure of Sampling Adequacy Test Results : Federal Road 12	90
5.17	Communalities : Federal Road 12	91
5.18	Total Variance Explained : For Federal Road 12	92
5.19	Road Environment Factors Correlation Matrix : Federal Road 12	92
5.20	Road Environment Indicator's Loading Value/ Factor : Federal Road 12	93
5.21	Weight of Indicators / Road Environment Factor : Federal Road 12	94
5.22	Calculation of Individual Index : Federal Road 12	94
5.23	Spearman's Rho Correlation Coefficient : Federal Road 12	98

5.24	Part of Main Dataset : Federal Road 3	100
5.25	Descriptive Analysis : Federal Road 3	100
5.26	Frequencies Analysis : Federal Road 3	101
5.27	Normality Test : Federal Road 3	102
5.28	Measure Of Sampling Adequacy : Federal Road 3	103
5.29	Communalities : Federal Road 3	103
5.30	Total Variance Explained : Federal Road 3	104
5.31	Road Environment Factors Correlation Matrix : Federal Road 3	104
5.32	Road Environment Indicator's Loading Values / Factor : Federal Road 3	105
5.33	Weight of Indicators / Road Environment Factors : Federal Road 3	106
5.34	Calculation of Individual Index : Federal Road 3	106
5.35	Spearman's Rho Correlation Coefficient : Federal Road 3	110
6.1	Calculation of Individual Index for Section 13 : Federal Road 2	118
6.2	Comparisons between RERI and iRAP	123

LIST OF FIGURES

Figure		Page
3.1	Flow Chart of Overall Research Methodology	33
3.2	The Methodology in Selecting the Road Environment Variables	41
3.3	Transformation of Road Environment Variables to Road Environment Indicators	44
3.4	Vertical Analysis vs. Horizontal Analysis	60
3.5	Flowchart of Methodology in Building the Composite Risk Index	61
4.1	Categories of Roads	63
5.1	Road Section's Composite Index based Infrastructure Environment Risk Factor : Federal Road 2	84
5.2	Road Section's Composite Index based Operational Environment Risk Factor : Federal Road 2	85
5.3	Total Number of Crashes per Section: Federal Road 2	86
5.4	Road Section's Composite Index Based on Roadside Environment Risk Factor : Federal Road 12	95
5.5	Road Section's Composite Index based on Infrastructure Environment Risk Factor : Federal Road 12	96
5.6	Road Section's Composite Index based on Operational Environment Risk Factor : Federal Road 12	96
5.7	Road Section's Composite Index based on Roadway Environment Risk Factor : Federal Road 12	97
5.8	Number of Fatal Crashes per Road Section	98
5.9	Road Section's Composite Index based on Infrastructure Environment Risk Factor : Federal Road 3	107
5.10	Positions of Road Sections based on Composite Index 2: Roadside Environment	108
5.11	Road Section's Composite Index based on Operational Environment Risk Factor : Federal Road 3	108
5.12	Number of Total Crashes per Road Section: Federal Road 3	109
6.1	Road Risk Level for Federal Road 2 : Road Operational Environmen	116
6.2	Road Environment at Section 13 : Federal Road 2	120
6.3a	Number of Motorcycles (MC) and Number of Heavy Vehicles (HV) along Federal Road 2	126
6.3b	Number of Motorcycles (MC) and Number of Heavy Vehicles (HV) along Federal Road 12	127
6.4	Percentage of Roadside Development : Federal Road 3	130
6.5	Number of Accesses: Federal Road 3	131

6.6 Comparisons between Composite Index and Total Number of Crashes: Federal Road 2 136
6.7 Road Environment at Section 4 : Federal Road 2 137
6.8 Road Environment at Section 5 : Federal Road 2 139

LIST OF ABBREVIATIONS

WHO	World Health Organizations
ASEAN	The Associations of Southeast Asian Nations
MIROS	Malaysian Institute of Road Safety Research
iRAP	International Road Assessment Program
usRAP	United States Road Assessment Program
AustRAP	Australia Road Assessment Program
EuroRAP	European Road Assessment Program
ETSC	European Transport Safety Council
SPI	Safety Performance Index
RSDI	Road Safety Development Index
LOSS	Level of Service of Safety
AADT	Annual Average Daily Traffic
LOS	Level of Service
GPS	Global Positioning System
RPS	Road Protection Score
RANKERS	Ranking for European Road Safety
RSI	Road Safety Index
RHR	Roadside Hazard Rating
RPI	Road Performance Index
OECD	Organisation for Economic Co-operation and Development
PCA	Principal Component Analysis
MARA	Majlis Amanah Rakyat
AASHTO	American Associations of State Highway Transportation Officials
PWD	Public Work Department
REAM	Road Engineering Association Malaysia
SWOV	Institute for Road Safety Research

CHAPTER 1

INTRODUCTION

1.1 Crash As Road Safety Indicator : Reliability Issue

Traffic crash statistics such as crash frequencies, crash severities, number of fatalities and amount of material damages are common types of road safety indicators that are acceptable worldwide (Lu, 2006). These indicators have been used for so many years to reflect the safety status of a country, states and the road itself. However, in recent years, there have been arguments between road safety experts on the accuracy and reliability of these indicators in explaining the whole situation of crash, and it has been currently accepted that crash is actually the final outcomes of a sequence of scenarios (Hermans et al., 2008a; SafetyNet 2009; Wilmots et al., 2009; Hassan et al., 2012). Referring crashes as the 'worst case scenarios' depict that crash is actually a result of a series of inter-related conditions. Crash can be prevented by doing early assessment on the physical condition of the road and hazards that largely contributed to crash occurrences. All of these can be achieved by monitoring the condition of road environments and doing a regular checking on the operational condition of the road network (SafetyNet, 2009). Nevertheless, as crash seems to have a good relationship with the conditions of road, crash is easily adopted as a basis for the determination of road safety status.

Using crash data in the determination of road safety status can be categorized as reactive measures. Reactive measures are defined as an improvement made to the road as a reaction to crash (Sayed and Leur, 2000) in an attempt to reduce the re-occurrences of crashes in the future. Reactive measures are solely based on crash records of the selected jurisdiction where improvements works are planned and executed after crash records have been established. The establishment of these records normally takes years to complete since according to the procedure by the Public Work Department or Malaysia, improvement works are mostly targeting 'black spot locations', which are defined as road sections having at least 3 numbers of similar type of crashes or at least 5 number of different type of crashes occurring within 3 years.

The values of life wasted in those crashes are unbearable as according to Melhuish et al. (2003), when life is valued at 1.2 million, Malaysia had lost as high as RM7.5 billion in year 2003 alone to crashes. Hence, it could be argued that it is not acceptable to wait for road crashes to occur or fatalities to be registered before improvement works could be done. Besides that, reactive measures may also be linked to other issues such as the random variations in crash data and the quality of the entered data. These issues are highly important especially when dealing with evaluation of road safety status.

Other than that, crash data is always related to the under-reporting issues, in which a crash that does not involve any injuries (damage only crashes) is often being unreported. When this happened, the identification of true locations that require improvement works can be misleading and incorrect. Most importantly, since road safety status is always being referred by many agencies, inaccurate outcomes would create greater effect to everybody; from road users to the government. Therefore, it is inferred that the reliability of crash data as road safety indicators is highly questionable and is not appropriate to be used in the evaluation of road safety status.

1.2 Problem Statement

In its mission to overcome crash problem, the Malaysian government through its renowned road safety centre, Malaysian Institute of Road Safety Research (MIROS) has set up fatality reduction rates of 5% for its number of death from year 2013 until year 2020 (WHO, 2013). To achieve the target, Malaysian road safety program was initiated by the Ministry of Works, Malaysia. In this program, several engineering approaches were outlined to urgently localize problematic road section, which includes accident prevention (proactive measure), accident reduction (reactive measure), road maintenance and building new roads (Mustafa, 2006). As reactive measure is defined as an improvement made in reaction to crash, proactive measure, on the other hand, is identified as a collision prevention approach that tries to prevent unsafe road conditions from occurring (Sayed et al., 2010).

Sadly, although a lot of crash preventions and crash reduction programs have been initiated, both programs seem to be insufficient in reducing the number of crashes in Malaysian roads. In spite of numerous number of campaigns being held, Malaysian seems to disregard the efforts made by the government, and these programs failed to transform the people's behavior and perceptions towards road safety (Musthar et al., 2013).

The implementation of road safety audit that has been introduced in Malaysia as early as year 1997 aims to instill the aspect of road safety into road network by detecting deficiencies in road safety measure, as well as auditing the road condition (Karim et al., 2003). While the execution of road safety audit is very beneficial for the newly proposed road project, the contribution of this method in bringing up the overall safety status of existing road networks is quite low since in most cases, the road safety audits on existing roads will be carried out in road sections that are heavily burdened by accident issues (Karim et al., 2003; Pietrantonio and Bornsztein, 2010).

Besides using road safety audit, a method called iRAP was introduced in year 2006. iRAP was established with huge objectives to tackle social and economic cost of road

crashes in developing countries like South Africa, Chile and Malaysia (iRAP, 2009). A concept of star rating is introduced in iRAP, where roads are rated from 1 to 5 depending on the level of safety, which is built-in to the road. However, Star Rating is also based on infrastructure related to crash by focusing on the risk posed by road infrastructures (iRAP, 2009).

Road safety audit and iRAP are the procedures currently used in many countries to define their road's safety status for the purpose of road improvement works. Although road safety audit procedures are very good, complete and structured procedures, the contribution in existing road categories is limited only to location where crashes is high and upgrading works is implemented. On the other hand, iRAP is also a very good addition to the current method in defining road safety status of road network. However, evaluating the risk generated from the infrastructures condition alone seems to be incomplete to portray the overall conditions of their roads. As suggested by Rogers and Hashim (2011) through their reports on a pilot study in Malaysia, they have concluded that Malaysia has a unique road environment condition that needs to be further explored before evaluation on the road safety status can be acquired.

Likewise, reactive actions also faced some challenges in its goal to help preventing crash from re-occurring. Most basic procedure of reactive actions is generally based on crash data of the road since this data has numerous crash information such as location of crash (by kilometre of the road) and time of crash (time, day and month). Adopting crash data as a road safety indicator is actually not new. Crashes data are normally used to report current countries' safety status (WHO, 2013) or to interpret the countries' losses due to crash (Melhuish et al., 2003).

By looking at the above circumstances collectively, since the credibility of crash as a perfect road safety indicator is arguable (SafetyNet, 2009) as it cannot reflect the overall status of traffic safety in a country (Hassan, et al. 2012), outcomes generated based on crash data is also questionable. Therefore, the need to develop a new method that combines the concept of proactive action (preventive) and reactive action (reduction) targeting at road environment aspect is very high. The new method should be able to identify road's safety status beforehand and most importantly, should be very useful in reducing the number of crash.

Hence, the argument of this research to the field of transportation engineering is that in maximizing the performance of the road networks and in providing safe road to all road users, a new method to pre-determine road's safety status must be made available. The innovation of defining road section safety status by not relying on the availability of the crash data must be explored so that road improvement works targeting at correct locations and correct road aspects are rapidly initiated. Thus, a state-of-the-art method

that is easy to use, has an ability to capture current road aspects and can give correct road section safety status is highly required.

In terms of contribution to the body of knowledge in road safety discipline, this research aims to establish extensive knowledge on the risk produced by a combination of road environment attributes as one of the crash factors in developing countries so that appropriate attention can be placed on this matter in future road design. The contribution of road environment towards crash has been left unexamined although there is strong possibility that the complexity of road environment deduced high risk to drivers (Rudin-brown et al., 2014).

1.3 Objectives of the Study

The main objective of this study is the development of the composite road environment risk index as proactive measures in identifications of road section's safety status. By using this composite index, a combination of risks produced by specific road environment attributes is explored and the role of road environments as crash factor is proven. However, before the main objectives could be fulfilled, several other specific objectives must be accomplished. The specific objectives are listed below.

i. To identify a set of road environment attributes with high capability in posing direct risks to road users in the Malaysian Federal Road environment.
ii. To determine specific road environment risk factors for Malaysian Federal Roads from a set of road environment attributes.
iii. To develop composite road environment risk index for Federal Road 2, Federal Road 3 and Federal Road 12 of Malaysian Federal Road, in which the safety status of each section within these roads were evaluated.

1.4 Relevance of the Study

The practical output gathered from this research is a set of road environment attributes with high potential in posing direct risk to road users, road environment factors for Malaysian Federal Roads and the composite index pertaining to the road environment conditions of Malaysian Federal Roads.

These results serve as useful guidelines for the road design team by providing a list of road environment attributes that should be focused in designing new roads that have similar characteristics as the Federal Road. Most importantly, this composite index should become an essential tool for the road improvement team during inspections of

road sections of the existing road networks. Based on the composite index values, road sections that require urgent improvement works, sections that have the potential to be hazardous road sections and sections having safe road environment conditions can be correctly pointed out in a short period of time. Besides that, the composite index can also be a time-saving and cost-saving tool as it can directly recognize problematic road environment factors while planning on the best and suitable road improvement procedures for those particular sections. This can save so much time and money during the stages of site recognitions and site inspections.

Apart from that, the composite index itself is seen as an initiative to fill in the missing link between the actual problem on the road and the road improvement procedure proposed by the road traffic agencies. Other than that, the overall research outcome is also seen as an effort to fill in the knowledge gap in the road safety engineering by bringing up the role of road environment in defining crash factors especially in developing countries.

1.5 Scopes and Limitations of the Study

This study focuses on risks posed by road environments towards drivers of passenger car. Therefore, only risks that directly influence drivers of passenger car are considered. Different vehicle modes receive different types of risks. However, since passenger car recorded the highest number of vehicles involved in crash in Malaysia, hence, passenger car is chosen as the vehicle mode.

This study focuses on road environment for Malaysian Federal Roads only. Any other types of road such as state road, municipal road and highway are not considered unless at the point where these roads are crossing or overlapping with the selected federal roads that serve as the study areas.

Type of risks considered in this study is mainly generated from the road environment attributes that have the ability to produce instant risk and directly influence cardrivers while driving. Thus, risks generated from the geometrics or pavements designs of the roads are not considered. In addition, the risks generated from human behavior, in-vehicle conditions and vehicle faultiness are also not covered. Observations were conducted during daytime. However, the elements that are believed to be significant with night-time driving are considered throughout the study.

In explaining the collisions either between vehicles, vehicle-animal, vehicle-other road users such as pedestrians and run-off-road such as skidding to roadsides and hitting objects, these situations are referred as ‘crash’ and not accidents. The word ‘crash’ is chosen in this thesis to describe those above-listed situations since ‘accidents’ depict

that the occasions happen by chance while 'crash' portrays that the situations are the end-results of several processes and it can be avoided.

The term 'indicator' is referred as statements or facts explaining certain conditions of roads. The indicators are not measurements but merely statements that lead to a collection of values for the targeted road aspects. Risk in this thesis is referred to the 'un-safety' state of the targeted road attributes that have potential risk towards car drivers and consequently causing crash. The risk conditions of the targeted road environment attributes are expressed in terms of percentages, ratio or numbers embedded in the indicators. In general, risk indicators are statements explaining the conditions of the targeted road environment attributes that may potentially lead to crash occurrences.

The term 'index' in this thesis is referred to the scores generated from road environment indicators after taking into account the weight of the indicator for the overall study area length. The index is a translation of risk in terms of values so that the comparison of risk level between each road section can be made. Each road environment indicator would produce an individual index for each road section.

The term 'composite index' is referred to a combination of several individual indexes into a single index that can largely describe the target issue in a more comprehensive manner for each road section. The composite risk index is the end-results of this thesis, where it can be compared against similar results from other road sections. The composite risk index will be very useful in identifications of poor road sections from the road environment's point of view.

The term 'low safety status' is used to indicate road sections having low safety level. It may also be referred to poor road sections or problematic road sections. The latter terms are commonly being used by Malaysian authorities to define road areas having high number of crashes, thus, regarded as poor and needs modifications.

1.6 Organization of the Thesis

This thesis is organized as follows. Chapter 1 and 2 briefly discuss the importance of this study, theories, as well as models adopted during the development of the composite index. Chapter 3 focuses on the steps and methods employed to fulfil the needs of each objective.

In Chapter 4 and 5, the data analysis is conducted to establish the sets of road environment indicators, the identifications of road environment factors, the development

of composite index, the identification of hazardous road sections and also the validation procedure to prove the significance and applicability of this research to the real world.

Meanwhile, Chapter 6 discusses the road environment attributes, the road environment factors and the identifications of real road problems using a composite road environment risk index. It also includes comparisons between the outcomes generated from the currently used methods and composite index.

Finally in Chapter 7, the conclusions and recommendations for future research are addressed.

REFERENCES

AASHTO Roadside Design Guide, 4th Edition. ISBN Number: 1-56051-509-8

Abdul Halim, M. I., Ma'some, M.D, Law, T.H. 2005. Pavement Performance Model for Federal Roads. Proceedings of the Eastern Asia Society for Transportation Studies, Volume 5, pp. 428 - 440,

Abdul Manan, M. M., Jonsson, T., & Várhelyi, A. 2013. Development Of A Safety Performance Function For Motorcycle Accident Fatalities On Malaysian Primary Roads. Safety Science Volume 60, 13-20.

Abdul Manan, M,M. 2014. Factors Associated with Motorcyclist' Safety at Access Point along Primary Roads in Malaysia. Doctoral Dissertations. Faculty of Engineering, Lund University, LUND. ISBN : 978-91-7473-904-6 (pdf)

Asian Development Bank (ADB) Report. Vulnerable Road Users in Asian and Pacific Region. ISBN 971-561-133-3.

Assum, T & Sørensen, M., 2010. Safety Performance Indicator for alcohol in road accidents – International comparisons, validity and data quality. Accident Analysis & Prevention, Volume 42, pp 595-603.

Ayati, E., Neghab, M.A.P, Sadeghi, A.A, Moghaddam, A.M., 2012. Introducing roadside hazard severity indicator based on evidential reasoning approach. Safety Science, Volume 50, Issue 7, pp.1618–1626.

Azmi, A.E. & Zainal, S.M.A., 2008. Low Cost Countermeasure at Accident Blackspots : Malaysian Experience. Roads Facilities Maintenance Division Public Works Department Kuala Lumpur, Malaysia. pp.1–11.

Bener, A., et al. 2003. Strategy to Improve Road Safety in Developing Countries. Saudi Med. Journal. Volume 24, Issue 6. pp 603-608.

Berhanu, G., 2004. Models Relating Traffic Safety with Road Environment and Traffic Flows on Arterial Roads in Addis Ababa. Accident Analysis and Prevention, Volume 36, Issue 5, pp.697–704.

Brooks. C., 2002. Speed and Heavy Vehicle Safety. National Heavy Vehicle Safety Seminar, Melbourne, October 2002.

Burstyn, I., 2004. Principal component analysis is a powerful instrument in occupational hygiene inquiries. The Annals. of Occupational Hygiene, Volume 48, Issue 8, pp.655–661.

Castro, M., Paleti, R. & Bhat, C.R., 2013. A Spatial Generalized Ordered Response Model to Examine Highway Crash Injury Severity. Accident Analysis and Prevention, Volume 52, pp.188–203.

Charnes, A., Cooper, W.W. & Rhodes, E., 1978. Measuring The Efficiency Of Decision Making Units. European Journal of Operational Research, Volume 2, Issue 6, pp.429–444.

Coelli, T. 1996. A Guide to Data Envelopment Analysis (Computer) Program (DEAP) Version 2.1: A Data Envelopment Analysis (Computer) Program. CEPA Working Paper 96/08

Cohen, J. 1988. Statistical Power Analysis for the Behavioral Sciences. Second Edition. pp. 284-286. Hillsdale, New Jersey : Lawrence Erlbaum Associates.

Daniello, A. & Gabler, H.C., 2011. Fatality Risk In Motorcycle Collisions With Roadside Objects In The United States. Accident Analysis and Prevention, Volume 43, Issue 3, pp.1167–1177.

Daniels, S. Vanrie, J., Dreesen, A., Brijs, T., 2010. Additional road markings as an indication of speed limits: results of a field experiment and a driving simulator study. Accident Analysis and Prevention, Volume 42, Issue 3, pp.953–960.

Daud, N. Ibrahim, K., Sopian, K. 2008. Hierarchical Bayesian Approach For Ranking Of Accident Blackspots With Reference To Cost Of Accidents. 2nd WSEAS Int. Conf on Computer Engineering And Applications (CEA'08) Acapulco, Mexico, January 25-27, 2008

Delaney, A., Newstead, S. & Watson, L., 2007. The Influence Of Trends In Heavy Vehicle Travel On Road Trauma In The Light Vehicle Fleet. Report 259 by Monash University Accident Research Center (MUARC).

DiStefano, C., Zhu, M., Mindrila, D. 2009. Understanding and Using Factor Scores : Considerations for the Applied Researcher. Practical Assessment, Research and Evaluations. Volume 14, Number 20. ISSN 1531-7714.

Doane, D.P & Seward, L.E. 2011. Measuring Skewness: A Forgotten Statistics? Journal of Statistics Education, Volume 19,.Number 2.

Dong. C, David B. Clarke, Stephen H. Richards, Baoshan Huang. 2013. Differences In Passenger Car And Large Truck Involved Crash Frequencies At Urban Signalized Intersections: An Exploratory Analysis. Accident Analysis and Prevention, Volume 62, pp.87–94.

European Transport Research Council, ETSC. 2001. Transport Safety Performance Indicators. ISBN: 90-76024-11-1 2

Fildes, B. & Lee, S., 1993. The Speed Review : Road Environment, Behaviors, Speed Limit, Enforcements and Crashes. Monash University Accident Research Center. A report prepared for Road Safety Bureau, Roads and Traffic Authority of New South Wales and Federal Office of Road Safety Department of Transport and Communications.

Flahaut, B., 2004. Impact Of Infrastructure And Local Environment On Road Unsafety. Logistic Modeling with Spatial Autocorrelation. Accident Analysis and Prevention Volume 36, Issue 6, pp.1055–1066.

Ghazwan A.H., 2007. Road Safety Development Index. Dissertation Number: 1100 ISBN: 978-91-85715-04-6. Linkoping University

Ghazwan. A. H., 2005. Road Safety In Southeast Asia Factors Affecting Motorcycle Safety, ICTCT Extra Workshop. Campo Grande 2005. Pp.1–7.

Gitelman, V., Doveh, E. & Hakkert, S., 2010. Designing A Composite Indicator For Road Safety. Safety Science, Volume 48, Issue 9, pp.1212–1224.

Hakkert, A.S. and Gitelman, V. 2007. Road Safety Performance Indicators: Manual. Deliverable D3.8 of the EU FP6 Project SafetyNet.

Hammond, A. & Addrianse, A. 1995. Environmental Indicators: A Systematic Approach To Measuring And Reporting On Environmental Policy Performance In The Context Of Sustainable Development. World Resources Institute. ISBN 1-56973-026-1

Haque, M.M., Chin, H.C. & Huang, H., 2009. Modeling Fault among Motorcyclists Involved In Crashes. Accident Analysis And Prevention, Volume 41, Issue 2, pp.327–35.

Hashim, H. 2010. Management Of Road Safety By Public Works Department Of Malaysia –Mundane Routine Or Significant Challenge? 24th ARRB Conference 2010 Melbourne

Hassan, M.N., Hawas, Y.E. & Maraqa, M. a, 2012. A Holistic Approach for Assessing Traffic Safety in the United Arab Emirates. Accident Analysis and Prevention, Volume 45, pp.554–564.

Hermans, E., Van den Bossche, F & Wets, G., 2008a. Combining Road Safety Information in a Performance Index. , Accident Analysis and Prevention 40, pp.1337–13

Hermans, E., Brijs, T. & Wets, G., 2008b. Developing a Theoretical Framework for Road Safety Performance Indicators and a Methodology for Creating a Performance Index. Report Number RA-MOW-2008-010

Hermans, E., Ruan, D., Brijs, T., Wets, G., Vanhoof, K., 2010. Road Safety Risk Evaluation by Means of Ordered Weighted Averaging Operators and Expert Knowledge. Knowledge-Based System 23, pp.48-52.

Hermans, E., Van den Bossche, F. & Wets, G., 2009. Uncertainty Assessment of the Road Safety Index. Reliability Engineering & System Safety, Volume 94, Issue 7, pp.1220–1228.

Hussain H., Radin Umar R.S., Ahmad Farhan M.S., Dadang M.M., 2005. Key Components of a Motorcycle-Traffic System: A Study along the Motorcycle Path in Malaysia, Journal of International Association of Traffic and Safety Sciences, Japan, Volume 29, No.1, pp. 50-56.

Hussain, H. 2006. Development of Capacity and Level of Service for Uninterrupted Exclusive Motorcycles Lanes in Malaysia. Thesis for Doctor of Philosophy. Universiti Putra Malaysia.

iRAP and EuroRAP. 2011. Crash Rate – Star Rating Comparisons. Review of Available Evidence. Working Paper Number 504.2.

Ismail, M.A. Sadiq, R., Soleymani, H.R., Tesfamariam, S. 2011. Developing a Road Performance Index using a Bayesian Belief Network Model. Journal of the Franklin Institute 348. pp. 2539 – 2555.

Jama, H.H.. Grzebieta, R.H., Friswell, R., McIntosh, A.S. 2011. Characteristics Of Fatal Motorcycle Crashes Into Roadside Safety Barriers In Australia And New Zealand. Accident Analysis and Prevention, Volume 43, Issue 3, pp.652–660.

Jamson, S. Wardman, M., Batley, R., Carsten, O. 2008. Developing a driving Safety Index using a Delphi stated preference experiment. Accident Analysis And Prevention, Volume 40, Issue 2, pp.435–442.

Karim, M.R., Abdullah, S., Marjan, J. 2003. Road Safety Audit - Issues And Challenges From The Malaysian Experience. Journal of the Eastern Asia Society for Transportation Studies, Volume.5.

Kononov, J & Allery, B., 2001. Level of Service of Safety: Conceptual Blueprint and Analytical Framework. Transportation Research Record 1840. Paper No. 03-2112.

Kowtanapanich, W., 2011. Public Participation Approach for the Rural Community Black Spot Improvement , Experiences from Thailand. Proceedings of the Eastern Asia Society for Transportation Studies, Volume 8.

Kukic, D.. Lipovac, K., Pesic, D., Vujanic, M. (2013). Selection of a Relevant Indicator: Road Casualty Risk Based on Final Outcomes. Safety Science. Volume 51.

Li, M.-D. et al., 2009. Survival Hazards Of Road Environment Factors Between Motor-Vehicles And Motorcycles. Accident Analysis and Prevention, Volume 41, Issue 5, pp.938–947.

Li, Q., 2009. Evaluation Model Of Region Traffic Safety Based On Principal Component Analysis. *2009* IEEE Instrumentation and Measurement Technology Conference, (May), pp.240–243.

Lu, M. 2006. Modelling the Effects of Road Traffic Safety Measures. Accident Analysis and Preventions, Volume 38. Pp 507-517.

Łukasik, Z., Szymanek, A. 2012. Safety And Risk In Road Traffic: Selected Problems. Transport Problems. Volume 7. Issue 2.

Masuri, M.G., Isa, K.A.M. & Tahir, M.P.M., 2012. Children, Youth and Road Environment: Road Traffic Accident. Procedia - Social and Behavioral Sciences, Volume 38. pp.213–218.

Melhuish,C, Ross, A., Goodge,.M., 2003. Asian Development Bank - Association of Southeast Asian Nations Regional Road Safety Program. Accident Costing Report AC 5 : Malaysia.

Meuleners, L.B., Lee, A.H. & Haworth, C., 2007. Road Environment, Crash Type And Hospitalisation Of Bicyclists And Motorcyclists Presented To Emergency Departments In Western Australia. Accident Analysis and Prevention, Volume 39, Issue 6, pp.1222–1235.

Montella, A., 2003. Assessing Potential for Safety Improvement by Safety Reviews of Existing Roads. , TRB Annual Meeting. pp.1–20.

Moudon, A.V., Lin, L., Jiao, J., Hurvitz, P., Reeves, P. 2011. The Risk Of Pedestrian Injury And Fatality In Collisions With Motor Vehicles, A Social Ecological Study Of State Routes And City Streets In King County, Washington. Accident Analysis and Prevention, Volume 43, Issue 1, pp.11–24.

Musthar, S.H., Muda, M., Adji, B.M., Karim, M.R. 2013. Audience Involvement in Malaysian Road Safety Campaigns Among Young Adults. Proceeding of the Eastern Asia Society for Transportation Studies, Volume 9.

Nardo, M. Saisana, M., Saltelli, A., Tarantola, S. 2005. Tools for Composite Indicators Building. EUR 21682 EN © European Commission. Joint Research Center. 2005

OECD (2008). Handbook on Constructing Composite Indicators – Methodology and User Guide. ISBN 978-92-64-04345-9.

Orfila, O. Coiret, A., Do, M.T., Mammar, S. 2010. Modeling Of Dynamic Vehicle-Road Interactions for Safety-Related Road Evaluation. Accident Analysis and Prevention, Volume 42, Issue 6, pp.1736–1743.

Ossenbruggen, P.J., Pendharkar, J. & Ivan, J., 2001. Roadway Safety In Rural And Small Urbanized Areas. Accident Analysis and Prevention, Volume 33, Issue 4, Pp.485–498.

Pallant, J. 2010. A Step by Step Guide to Data Analysis using SPSS. 4th Edition. ISBN-13: 978-0-33-524239-9 (pb).

Pardillo-Mayora, J.M., Domínguez-Lira, C. a & Jurado-Piña, R., 2010. Empirical Calibration of A Roadside Hazardousness Index for Spanish Two-Lane Rural Roads. Accident Analysis and Prevention, Volume 42, Issue 6, pp.2018–2023.

Pei, X., Wong, S.C. & Sze, N.N., 2011. A Joint-Probability Approach to Crash Prediction Models. Accident Analysis and Prevention, Volume 43, Issue 3, pp.1160–1166.

Pei, X., Wong, S.C. & Sze, N.N., 2012. The Roles of Exposure and Speed in Road Safety Analysis. Accident Analysis and Prevention, Volume 48, pp.464–471.

Pietrantonio, H., .Bornsztein L.L., 2010. Evaluating Road Safety Audit Procedures : Some Questions And A New Method Of Study. European Transport Research Review.

Pour, M.H., Yahaya, A.S., Ghadiri, S.M.R. 2013. Developing a Predictive Model for Run-Off-Roadway Accidents on Malaysia Federal Roads. , AWAM International Conference on Civil Engineering & Geohazard Information Zonation pp.76–83.

Public Work Departments. Arahan Teknik Jalan 8/86

Radin Umar, R. S, Chai W.L., Hussain H, Law T.H., 2001. Modelling of Traffic Accidents along Major Trunk Roads in Malaysia, Journal of the Institution of Engineers, Malaysia, Volume 62

Radin Umar, R.S & Hussain. H. 1998. Time Series Multivariate Traffic Accidents and Fatality Models in Malaysia. Road Engineering Associations Asia and Australasia (REAAA) Journal. January 1998.

RANKERS. (2008). Ranking of recommendations for road infrastructure safety,. TREN-04-FP6TR-S07.36996/001678.

REAM. A Guide on Geometric Design of Roads.

Rifaat S.M., Tay R & De Barros, A. 2011. Effects of street pattern on severity of crashes involving vulnerable road users, Accident Analysis and Prevention, Volume 43, pp. 276-283

Rifaat, S.M., Tay, R. & De Barros, A., 2012. Severity of Motorcycle Crashes In Calgary. Accident Analysis and Prevention, Volume 49, pp.44–49.

Road Environment Safety: A Practitioner's Guide produced by New South Wales (NSW) Road Department

Rogers, L & Hashim, H. 2011. Star Rating Road Improvements: 2009 Malaysia Black Spot Programme. International Road Assessment Programme (iRAP). iRAP Report Number 504.10.

Rudin-brown, C.M., Edquist, J. & Lenné, M.G., 2014. Effects of driving experience and sensation-seeking on drivers ' adaptation to road environment complexity. Safety Science, Volume 62, pp.121–129.

Rummel, R.J. 1967. Understanding Factor Analysis. The Journal of Conflict Resolution. pp 444-480.

Ruotoistenmäki, A & Seppälä., T. 2007. Road Condition Rating based on Factor Analysis of Road Condition Measurements. Transport Policy, Volume 14, pp. 410-420

SafetyNet. 2005. Deliverable D3 . 1 : State of the Art Report on Road Safety Performance Indicators. , Integrated Project No. 506723: SafetyNet. pp.1–177.

SafetyNet. 2006. Building the European Road Safety Observatory Report.

SafetyNet. 2009. Star Rating Roads For Safety- The iRAP Methodology. Report Number iRAP504.04 v1.0.

Saisana, M. & Tarantola, S., 2002. State-of-the-art Report on Current Methodologies and Practices for Composite Indicator Development. A Report Prepared for Joint Research Center, European Commission.

Sayed, T. & Leur, P. De,2000. Developing A Systematic Framework For Proactive Road Safety Planning. ICTCT Proceeding, pp.7–20.

Sayed, T., Saunier, N,. Lovegrove, G., Leur, P. De. 2010. Advances in Proactive Road Safety Planning. Proceedings of the 20th Canadian Multidisciplinary Road Safety Conference, Niagara Falls, Ontario, June 6-9, 2010

Scheiner, J. & Holz-Rau, C., 2011. A Residential Location Approach To Traffic Safety: Two Case Studies From Germany. Accident Analysis and Prevention, Volume 43, Issue 1, pp.307–22.

Schorr, J.P & Hamdar, S. H., 2014. Safety Propensity Index for Signalized and Unsignalized Intersections: Exploration and Assessment. Accident Analysis & Prevention, Volume 71. pp 93-105

Sexton,B., Baughan, C., Elliott, M., and Maycock, G., 2004. The Accident Risk of Motorcyclists. Summary of TRL Report TRL607

Shen, Y. et al. 2011. A generalized multiple layer data envelopment analysis model for hierarchical structure assessment: A case study in road safety performance evaluation. Expert Systems with Applications, Volume 38. pp 15262–15272

Shen, Y. Hermans, E., Ruan, D.,. Wets, G., Brijs, T., Vanhoof, K. 2009. Road Safety Performance Evaluation Based on a Multiple Layer Data Envelopment Analysis Model. 4th IRTAD Conference. 16-17 September 2009. Seoul, Korea. pp.315–324.

.Suraji, A. & Tjahjono, N., 2012. A Confirmatory Factor Analysis Of Accidents Caused. , International Journal of Transport and Engineering. Volume 2, Issue 1. pp.60–69.

Stinchcombe, A., Gagnon, S., Zhang, J., Montembeault, P. & Bedard, M. 2011. Fluctuating Attentional Demand in a Simulated Driving Assessment: The Roles of Age and Driving Complexity, Traffic Injury Prevention, Volume 12, Issue 6. pp 576-587

SWOV. 2010. Fact Sheet on Naturalistic Driving : Observing Everyday Driving Behaviour. SWOV, Leidschendam, the Netherlands. pp.1–53.

Tay R, Choi J, Kattan L & Khan A. 2011. A multinomial logit model of pedestrian-vehicle crash severity, International Journal of Sustainable Transportation, Volume 5, Issue 4, pp. 233-249

Tingvall, C., Stigson, H., Eriksson, L., Johansson, R., Krafft, M., Lie, A. 2010. The Properties of Safety Performance Indicators in Target Setting, Projections and Safety Design of the Road Transport System. Accident Analysis and Prevention, Volume 42, Issue 2, pp.372–6.

Vasconcellos, E.A. 2005. Traffic Accident Risks In Developing Countries: Superseding Biased Approaches. ICTCT Extra Workshop. Campo Grande, 2005.

Wang, F., Di. S, Liu, H, Zhang, W, 2011. Study On Driver's Subjective Perception Of Road Safety and Traffic Safety. International Conference of Chinese Transportation Professionals (ICCTP) 2011, pp.1978–1987.

Wang, X., Lin, H. & Chen, X., 2009. Investigation of Relationship between Level of Service and Safety. International Conference of Chinese Transportation Professionals (ICCTP) 2009, pp.1–7.

Wegman., F Oppe., S. 2010. Benchmarking road safety performance of countries. Safety Science . Issue 48. pp.1203-1211

WHO. 2004. World Report On Road Traffic Injury Prevention. ISBN 92 4 156260 9

WHO. 2013. Global Status Report on Road Safety 2013: Supporting A Decade Of Action.

Wilmots, B. Hermans, E., Brijs, T., Wets, G. 2009. Analyzing Road Safety Indicator Data across Europe : Describing , Explaining and Comparing. , 4th IRTAD Conference, Seoul, Korea. pp.291–299.

Yannis, G., Weijermars, W., Gitelman, V., Vis, M., Chaziris, A., Papadimitriou, E., Azevedo, C.L., 2012. Road Safety Performance Indicators for The Interurban Road Network. Accident Analysis and Prevention.

Yasmin, S, Eluru, N, Pinjari, A.R, Tay, R. 2014. Examining Driver Injury Severity In Two Vehicles Crashes-A Copula Approach. Accident Analysis and Prevention, Volume 76..

Zheng, L., Ismail, K. & Meng, X., 2013. Freeway safety estimation using extreme value theory approaches: A comparative study. Accident Analysis and Prevention, Volume 62, pp.32–41.