UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF COMPOSITE RISK INDEX FOR FEDERAL ROADS IN MALAYSIA

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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

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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

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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

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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.

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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:

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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:

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Declaration by Graduate Student

I hereby confirm that:

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Signature: _____ Date: 31 March 2015

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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.

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