ROAD SAFETY INDEX DEVELOPMENT FOR MULTI-LANE HIGHWAYS IN THAILAND

BY

PIMNAPA PONGSAYAPORN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (ENGINEERING AND TECHNOLOGY)

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

THAMMASAT UNIVERSITY

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A Thesis Presented

By

PIMNAPA PONGSAYAPORN

Submitted to
Sirindhorn International Institute of Technology
Thammasat University
In partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE (ENGINEERING AND TECHNOLOGY)

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MAY 2016

Acknowledgements

I would like to thank to my thesis committee for their supervision and invaluable guidance on my research. Moreover, I would like to gratefully acknowledge the financial support from Transportation Research Center (TREC), Sirindhorn International Institute of Technology, Thammasat University. Lastly, I am gratefully thanks for the support from my beloved family and friends.

Abstract

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Each year, almost 1.24 million people died as a result of the road traffic accidents (World Health Organization (WHO), 2010), despite the provision of safety systems within the vehicle and environment. Most of road traffic deaths and injuries took place in low income and middle income countries. Similarly, road traffic accidents in Thailand have been one of the major causes of injuries and loss of lives since Thailand was ranked the third in the list of countries having highest road traffic deaths worldwide with 38.1 road fatalities per 100,000 inhabitants per year in 2010 World Health Organization (WHO), 2010). Thus, this research proposes to study the international practices in road safety, such as the International Road Assessment Programme (International Road Assessment Programme (iRAP), 2014) and other Road Safety Index (RSI) development studies to develop the RSI evaluation tool that appropriates for the road and traffic conditions in Thailand. The results of this study provide further evidence of the contributions to the fields of road safety evaluation.

Keywords: Road Safety Index, Crash Modification Factors, Accident Risk Factors, Road Assessment Program

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Abbreviation and Acronyms

AADT	Annual Average Daily Traffic
AMF	Accident Modification Factor
ARF	Accident Risk Factor
AusRAP	Australian Road Assessment Program
CMF	Crash Modification Factor
CRF	Crash Reduction Factor
EuroRAP	European Road Assessment Program
iRAP	International Road Assessment Program
RAP	Road Assessment Program
RSI	Road Safety Index
RAI	Road Assessment Index
usRAP	U.S. Road Assessment Program

Chapter 1
Introduction

Each year, almost 1.24 million people died as a result of the road traffic accidents (World Health Organization (WHO), 2010), despite the provision of safety systems within the vehicle and environment. In accordance with the Commission for Global Road Safety (2006), road traffic deaths and injuries illustrate a serious and rapidly aggravating public health crisis especially in developing countries. Most of road traffic deaths and injuries took place in low income and middle income countries. Similarly, road traffic accidents in Thailand have been one of the major causes of injuries and loss of lives since Thailand was in the third rank in the list of countries having highest road traffic deaths worldwide with 38.1 road fatalities per 100,000 inhabitants per year in 2010 (World Health Organization (WHO), 2013). In table 1.1, the number of road traffic accidents, fatalities, and injuries on highways in Thailand have been increased significantly from year 2012 to year 2014 which implies that the problem has not yet been solved seriously.

Table 1.1 Number of accidents, fatalities, and injuries on highways in Thailand.

Items	**Year**		
	2012	**2013**	**2014**
Accidents	11,013	11,125	13,259
Fatalities	1,549	1,740	2,115
Injuries	9,675	10,043	11,906

Source: Department of Highways (2015)

The problem of deaths and injuries by reason of road accidents is now considered as a global issue. Nowadays, many countries concerned about the growth in the number of casualties and seriously injured on the roads. According to World Health Organization (WHO) (2010), General Assembly announced that 2011–2020 is the Decade of Action for road safety to stabilize and then reduce the forecasted level of worldwide road traffic deaths by increasing awareness and action in national, regional, and global levels.

In accordance with the dilemma above, this research proposes to study the international practices in road safety, such as the iRAP (International Road

Assessment Program) and other Road Safety Index (RSI) development studies to develop the RSI that appropriates for the road and traffic conditions in Thailand.

1.1 Problem statement

The complexity of the road safety problem is resulted from a number of factors and indicators involved in the road traffic accidents. The International Road Assessment Programme (iRAP) (2014) is a registered foundation dedicated to alleviate more than 3,500 global road deaths that occur every day. The objective of this study is to assess the road safety performance and inspect the high-risk roads or road sections. iRAP concentrates on more than 50 different road attributes that have an effect to the possibility of the accidents. Moreover, improving the road safety need to consider both historical data of accidents and road attributes. Hence, this research attempts to develop the RSI from the Accident Risk Factors (ARFs) and Crash Modification Factors (CMFs) which is derived from the road attributes data.

The number of road crashes are affected by at least one of the 3 elements: human errors, infrastructure defects and vehicle defects (Laksanakit, 2014). However, not everything significantly involved in road safety can be counted. Human errors are subjective variable and vehicle defects are difficult to control due to the difference in production processes of the companies. Hence, this research focuses on the road attributes or infrastructure defects rather than human errors and vehicle defects. Moreover, this research is developing the Road Assessment Programme (RAP) by developing the RSI to evaluate the road safety level of the roads.

According to International Road Assessment Programme (iRAP) (2014), the Star Rating Score (SRS) of each crash types is calculated by multiplying the CMFs of that crash type together. The crash types involve run-off road, head-on, intersections, and property access point. However, differences in road and traffic conditions among Thailand and other countries can introduce the difference in ARFs or crash types. As a result, this research is emerged to develop the Road Assessment Program (RAP) that suits for driving behavior and road and traffic conditions in Thailand.

1.2 Research objective

Normally, the operation on multi-lane highways is more complex than two-lane highways because of the increased lane changing and turning maneuvers. Thus the traffic volumes on multi-lane highways are typically higher than on two-lane highways (Sayed and de Leur, 2008). Therefore, this study intends to assist in the evaluation of safety performance of the multi-lane highways in Thailand. Moreover, this research focuses only on car occupant road users because this vehicle type accounted for 31.05 per cent or almost one-third of the accident statistics by vehicle types as in figure 1.1 (Bureau of Highway Safety, 2014).

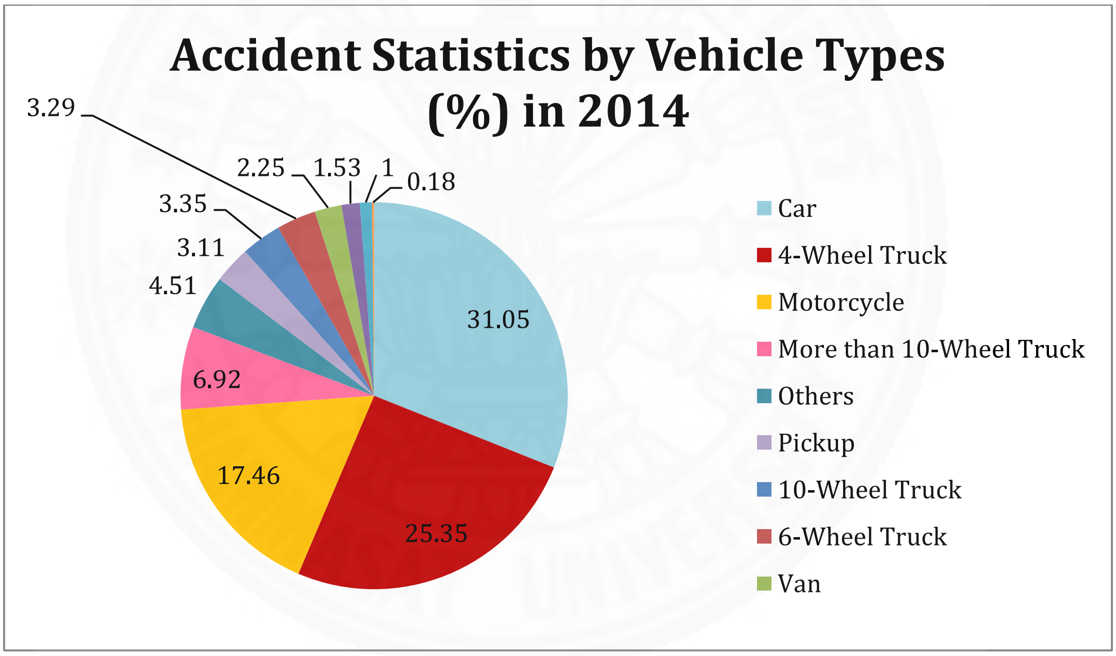

Figure 1.1 Accident statistics by vehicle types (%) in 2014.

This study develops methodologies and approaches for constructing RSI. The primary objective of this research is to integrate and conclude a number of road safety knowledge and information and then convert the different road attribute indicators into a single value which is the RSI. Secondary objective is to identify road safety performance level and location in a more comprehensive manner through the Star Rating method to track the vulnerable sections.

In order to develop efficient measures to alleviate the number of road traffic deaths and injuries, it is necessary to understand the processes that result in accident occurrences, where RSI can serve this objective (Gitelman et al., 2014).
To be objective, the road characteristic problems have to be put and interpreted in road contexts and conditions in Thailand. Hence, local research is required to provide a scientific approach. This study will help government or road safety agency to take appropriate decisions, set the exact targets and prioritize the future road improvement project.

1.3 Overview

This research presents 5 chapters. It progresses through introduction, literature review, methodology, results and discussion, and conclusion.

Chapter 1 presents the background of this research with the problem statement and research objectives. This chapter proposes to briefly present the outline of this thesis as well as explain the reasons why the road safety field is of interest. A brief explanation of the RSI concept is presented and the objective of the study is emphasized. In addition, this chapter outlines the structure of the thesis.

Chapter 2 presents the literature review from the field of road safety. It critically analyzes the theoretical frameworks that are used in the specific fields that lead to a framework for this study.

Chapter 3 describes the methodology and the research methods. The chapter describes the participants of the proactive method for the road safety assessment of the study and the way this study was implemented.

Chapter 4 shows the result of RSI evaluation and star rating of the case study highways. The improvement prioritization of the highways is also provided in this chapter.

Chapter5 presents a summary of the research accomplished in this study in the context of RSI and star rating construction. Moreover, the recommendations for future work in the road safety assessment framework are provided in this chapter.

Chapter 2
Literature Review

The main idea of this literature review is to present the background information, the current state of road safety evaluation method and compile a comprehensive collection of applicable works to support this research.

A number of different methods have been applied to estimate the safety performance of roadway segments. To be able to provide a comprehensive literature review it is necessary to expand on a number of topics. The topics which this literature review covers are:

- Road Assessment Program (RAPs),
- Road Safety Index Studies,
- Crash Types in RAPs, and
- Crash Modification Factors (CMFs)

2.1 Road assessment program (RAPs)

A review of international practices in Road Assessment Programs (RAP) was made to identify the appropriate method that would be suitable for Thailand.

2.1.1 European Road assessment programme (EuroRAP)

EuroRAP is an international not-for-profit association including the road safety organization and road authorities in Europe. EuroRAP is the road assessment program which considers the relationship among road attributes condition, the accident opportunity, and the accident severity.

There are 4 protocols working together to identify the safety ratings of the roads, determine the high risk roads, explore the source of risk, and prioritize the improvement of the roads.

1. Risk mapping emphasizes on identifying high risk roads by showing the crash rates. This protocol assumes that the road users are behaving according to the road regulation.

2. Performance tracking evaluates the change of risk on the roads over the time. This is a method for assessing the success of the investment in safer roads.

3. Star ratings divides the road safety score in to 5 star ratings from 1-star (black) which means least safe roads to the 5-star (green) which means the safest roads.

4. Safer Road Investment Plans (SRIP) presents the cost effective way to improve the number of fatalities and serious injuries (EuroRAP, 2009).

2.1.2 Australian road assessment program (AusRAP)

AusRAP is a program run by the Australian Automobile Association (AAA) and State and Territory motoring clubs, dedicated to saving lives through advocating for safer road infrastructure (Australian Automobile Association (AAA), 2013). This methodology was applied from the EuroRAP to build on the European equivalent adjusting to the road context in Australia (Metcalfe and Smith, 2005).

There are 2 key protocols including risk mapping which assesses historical data of crash rates and star ratings which assesses the inherent safety of roads (Metcalfe and Smith, 2005).

2.1.3 U.S. Road assessment program (usRAP)

usRAP was originated from EuroRAP. usRAP assesses the risk of crash possibility on U.S. roads and provide the crash risk information to the public and highway agencies in accessible formats. Crash-risk information helps the vehicle occupants make precise driving decisions and helps road or traffic agencies make strategic decisions about standards of roads and roadway improvements and countermeasures. The main idea of usRAP is to reduce the fatal and serious-injury crashes in the United States.

Three protocols are being conducted by usRAP to support the highway road safety management:

1. Risk Mapping
2. Performance Tracking, and
3. Star Ratings (usRAP, 2009)

2.1.4 International Road Assessment Programme (iRAP)

iRAP is a not-for-profit organization dedicated to saving lives through safer roads (International Road Assessment Programme (iRAP), 2009). It is a tool for road infrastructure safety improvement.

The iRAP Protocols included:

1. Risk Maps apply historical data of accidents to indicate the actual fatalities and injuries number on a road network.
2. Star Ratings is an inspection of road attributes and road's design safety level which involved in the accident possibility and its severity.
3. Safer Roads Investment Plans provide approximately 90 proven road improvement alternatives with affordable and economical options for increasing road safety level and saving lives.
4. Performance Tracking combines Star Ratings methodology and Risk Maps together to track road safety performance and establish policy positions.

This research is placed on applying the iRAP Star Rating methodology as a road safety assessment tool which is a basis for road infrastructure safety improvement to prevent thousands of deaths and serious injuries.

The crash types involved in iRAP for car occupants include run-off road, head-on (loss-of-control), head-on overtaking, intersections, and property access. However, there are 3 crash types which are not included in iRAP Star Rating: a sideswipe crash, rear-end crash, and a recovery (which means a car begins in unsteady state but a crash does not actually occur due to the in time recovery) because they do not bring about a significant number of deaths or serious injuries.

Star Ratings can be illustrated in 5 levels depending on the road safety level. 5- and 4-star indicates the safest roads which ensure an efficient and safe road infrastructure. The road safety attributes with these star levels are suitable with the general traffic speeds. The safe road must possess the road attribute that help reduce the accident occurrence or accident severity, such as separation of opposing traffic by a wide median or barrier, good line-marking and intersection design, wide lanes and sealed (paved) shoulders, roadsides free of unprotected hazards, such as poles, and good provision for bicyclists and pedestrians, such as footpaths, bicycle lanes and pedestrian crossings.

1- and 2-star indicates the least safe roads with no road safety attributes which are suitable for the general traffic speeds. These are often single-carriageway roads with frequent curves and intersections, narrow lanes, unsealed shoulders, poor line markings, hidden intersections and unprotected roadside hazards such as trees, poles and steep embankments close to the side of the road. They also do not adequately accommodate for bicyclists and pedestrians with the use of footpaths, bicycle paths and crossings.

The least safe roads (1- and 2-star) indicate no road safety attributes that are suitable for the road traffic characteristic. The road attributes in these road safety levels generally have a potential to cause the serious injury or fatal accidents. These are often single-carriageway roads with frequent curves and intersections, narrow lanes, unsealed shoulders, poor line markings, hidden intersections and unprotected roadside hazards, such as trees, poles and steep embankments close to the side of the road. They also do not adequately accommodate for bicyclists and pedestrians with the use of footpaths, bicycle paths and crossings. Table 2.1 shows the origins of each road assessment study and their protocols.

Table 2.1 Summarized data of each RAPs.

Methodology	Prototype	Indicators
EuroRAP	-	1. Risk mapping 2. Performance tracking 3. Star ratings
AusRAP	EuroRAP	1. Risk mapping 2. Star ratings
usRAP	EuroRAP	1. Risk mapping 2. Performance tracking 3. Star ratings
iRAP	EuroRAP and AusRAP	1. Risk mapping 2. Performance tracking 3. Star ratings

2.2 Road safety index studies

Haji (2005) proposed a method combining a number of road safety indicators into a single index called “Road Safety Development Index (RSDI).” This index is expected to use as a standard in comparing, ranking and determining the road safety levels in different countries and regions worldwide. RSDI is constructed from 8 indicators including traffic risk, personal risk, vehicle safety, roads situation, road user behavior, socio-economic index, road safety organizational index, and enforcement index.

Choocharukul et al. (2014) developed the concept of Road Assessment Index (RAI) calculation. This study used RAPs as references in rating of the road safety level which is a proactive approach for monitoring and evaluating the road safety levels. RAI is divided into 5 levels: A to F on the basis of safety scores from the least risky area to the most risky area literally. The score of each crash type is determined by the consideration of the percent reduction in Accident Reduction Factors (ARFs)

Gitelman, Vis, Weijermars, and Hakkert (2014) constructed the Safety Performance Indicators (SPIs) as a road safety index for the European Countries by using the EuroRAP as a basis. SPIs determine the current safety level of the existing roads by focusing on 3 main crash types: run-off road, head-on impacts, and severe impacts at intersections.

Hoque, Ashifur Rahman, and Smith (2014) and regarded iRAP in their studies. Both studies identified the high risk routes in Bangladesh by applying the iRAP method in assessing the road safety level. Moreover, the studies also focus on the crash types to develop their own measurements.

These studies indicated that there are a lot of countries including Thailand studying about road assessment programs since the last decade to develop their own standards and tools for the road safety assessment.

2.3 Crash types in RAPs

The traffic accident data are the significant indicator in both prioritizing the target crash types and in-depth study in identifying the contributory factors of the events chain (Bin Islam & Kanitpong, 2008). According to previous studies, it indicates clear evidence that there are differences in significant crash types due to different driving styles, road conditions, and environment. Each study considers only crash types which cause the serious injuries and fatalities in the study areas. For example, according to International Road Assessment Programme (iRAP) (2014), a sideswipe crash, rear-end crash, and a recovery (that is, where a crash is initiated but a crash does not actually occur) are not included in the iRAP Star Rating methodology as they do not make up a significant number of death or serious injuries. Table 2.2 shows the differences in ARFs which defined by the crash types among the previous studies.

Table 2.2 Comparison of the Accident Risk Factors (ARFs) of each study.

Methodology	**Risk Category Color** **(From low risk to high risk)**	**Star Rating**	**Crash Types**
EuroRAP	Green, Yellow, Orange, Red, and Black	1-5	1. Pedestrians and cyclists 2. Head-on (between oncoming vehicles) 3. Single vehicle leaving the carriageway 4. Junctions

Methodology	Risk Category Color (From low risk to high risk)	Star Rating	Crash Types
AusRAP	Dark Green, Light Green, Yellow, Red, and Black	1-5	1. Run off road on straight 2. Run off road on curve 3. Head-on 4. Rear-end 5. Other
usRAP	Dark Green, Light Green, Yellow, Red, and Black	1-5	1. Run-off road 2. Head-on 3. Intersection
iRAP	Dark Green, Light Green, Yellow, Red, and Black	1-5	1. Run-off road 2. Head-on (Loss of control) 3. Head-on (Overtaking) 4. Intersection 5. Property Access

Source: EuroRAP (2009), Australian Automobile Association (AAA) (2013), usRAP (2009), and International Road Assessment Programme (iRAP) (2009).

2.4 Crash modification factors (CMFs)

In this research, CMFs are also termed Collision Modification Factors (CMFs) or Accident Modification Factors (AMFs), all of which function in exactly the same way. According to Sayed and de Leur (2008), the highway safety assessment after the improvement is based on the change in the frequency and/or severity of collisions, both increase and decrease. The improvement can be the change in highway design and/or the traffic control feature. The change in frequency and/or severity of collisions or safety performance is commonly known as CMFs.

$$\text{CMF} = \frac{N_w}{N_{w/o}}$$

Where,

CMF = Collision modification factor.

N_W = Expected number of collisions with improvement.

$N_{W/O}$ = Expected number of collisions without improvement

Crash Reduction Factors (CRFs) have a very similar functionality in that they represent the reduction in the number of collisions that is expected by a specific treatment. CRF is converted to CMF by the equation (Sayed & de Leur, 2008):

$$\text{CMF} = 1 - \text{CRF}$$

Using a modification factor instead of a reduction factor allows the factor to indicate whether the treatment will produce an increase or decrease in the number of collisions. (CMF greater than 1 indicates an increase, while CMF less than 1 indicates a decrease, and unlike the case of CRF, the sign is always positive) (James, Chen, & Persaud, 2010).

According to the literature, RAPs have been generally accepted that it is very effective way in identifying the high risk roads or road sections. Some countries have developed their own RAP, such as Europe, Australia, and United States that finally merged to be international-based criteria or iRAP. Moreover, iRAP is a base study of other countries for developing the new RAPs.

In Thailand, there were also reviews and studies about iRAP. The road conditions were considered to make a RAP that suits for Thailand. This study found out that the RAP for Thailand can be applied by using the iRAP as a reference but there must be the improvement in accordance with the road conditions and environment in Thailand, for example, driving styles, weather, and road attributes that there will be a further study about this topic. Lastly, this review is expected to benefit to those who are interested in road safety related matters.

Chapter 3
Methodology

Research methodology begins with the literature review in Thailand and international studies which consists of the Road Assessment Program (RAP), accident-related factors and Black Spot Identification method. In this research, a crash is defined as a collision occurring on a public road and involving at least one moving vehicle. It causes the damage and injury or casualty. The terms “crash”, “collision” and “accident” are typically used interchangeably. This research is principally modified from the road safety performance assessments by the iRAP.

Before initiating the road safety assessment, the multi-lane highway will be selected to conduct the research by using a traffic volume as decision criteria because the high risk roads are generally high volume roads. Traditionally, these high risk roads are considered to have higher death and serious injury crash rate than the other roads.

The safety problems especially for vulnerable road users are considerably compounded by the lack of suitable road attributes. Eliminating high risk roads by upgrading the infrastructure system is obviously the most credible approach for road safety improvement especially in low-income and middle-income countries (Hoque et al., 2014). Thus, the proactive approach is required to investigate and assess the high risk road network characteristics by the RSI.

3.1 Accident risk factors (ARFs)

The factors in this study bases on the available accident data. The ARFs based on reported crash history are the most common factors used as a countermeasure to assess road safety performance. It is the accident occurrence probability for each crash type. Because of the random possibility of crashes, crash frequencies absolutely fluctuate all the time at any given site. The randomness of accident occurrence shows that only short term crash frequencies are not a precise and reliable estimator of longterm crash frequency. Thus, this research calculates the ARFs of each crash type from the average of 3-year historical data of accidents in Thailand.

According to (Highway Accident Information Management System (HAIMS), 2010), the historical data of accidents is demonstrated in table 3.1.

Table 3.1 3-year historical data of accidents in Thailand.

Crash Types	2011		2012		2013		2011 - 2013	
	Persons	%	Persons	%	Persons	%	Persons	%
Run-off road	5,540	52.2	5,863	53.2	6,245	56.1	17,649	53.9
Head-on	124	1.2	136	1.2	139	1.3	400	1.2
Rear-end	2,132	20.1	1,918	17.4	1,815	16.3	5,864	17.9
Angle	570	5.4	628	5.7	601	5.4	1,800	5.5
Sideswipe	999	9.4	954	8.7	841	7.6	2,793	8.5
Pedestrian	136	1.3	132	1.2	118	1.1	386	1.2
Not related*	1,106	10.4	1,381	12.5	1,366	12.3	3,853	11.8
Total	**10,607**	**100.0**	11,013	100.0	11,125	100.0	32,745	100.0

* Driver inattention or impairment.
Source: Highway Accident Information Management System (HAIMS) (2010)

In this research, the historical data of accidents which occurred as a result of driver inattention or impairment will not be counted as it is not because of the road failure, e.g., wrong-way driving, the mechanical failure of a motor vehicle, etc. Hence, the historical data of accidents proportion of each crash types in this study is showed in figure 3.1.

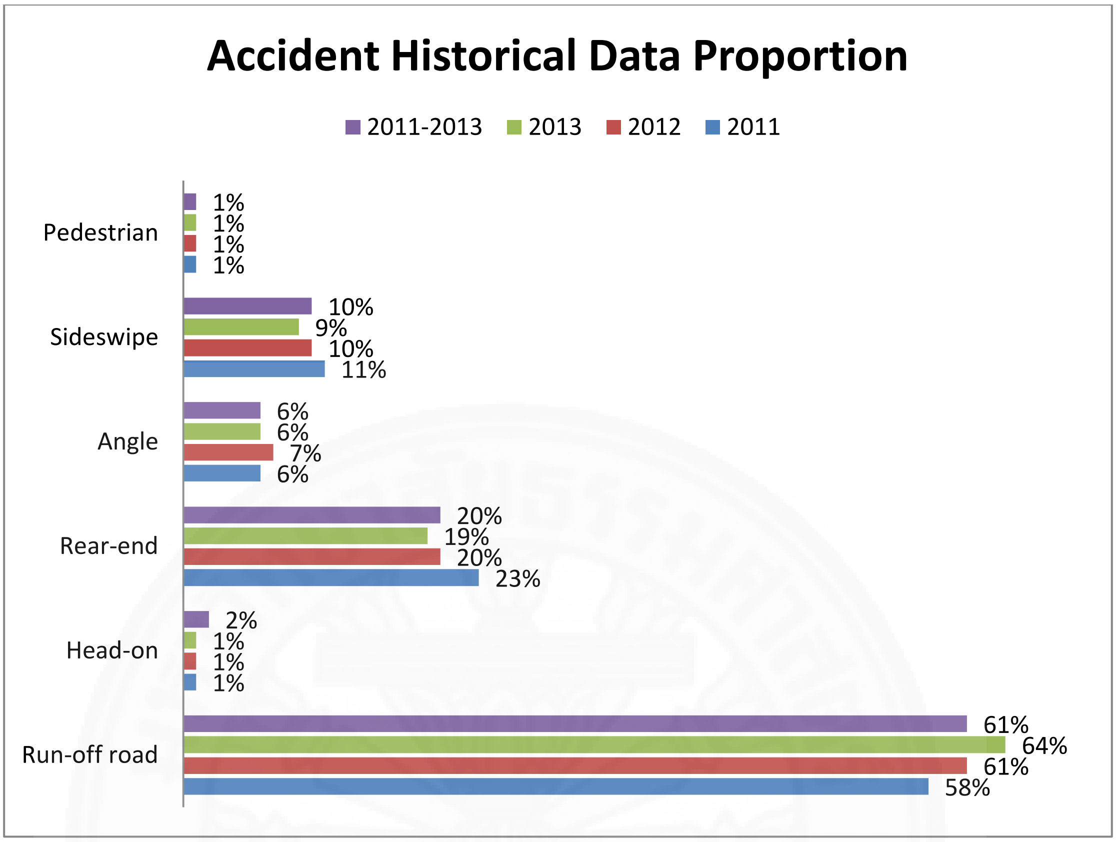

Figure 3.1 Historical data of accidents proportion for each crash types.

According to previous studies, it is explicit that there are differences in crash types due to different driving styles, road conditions, and environment. Each study considers only crash types which cause the serious injuries and fatalities in the study areas. In this research, the proportions of rear-end collision, sideswipe collision, and angle collision in 2011 – 2013 combined together are 36% (as in figure 3.2) which is quite high.

Moreover, the proportions of head-on collision and pedestrian collision are relatively few within the context of the entire collision population. For example, Figure 3.2 indicated that there are only 1% of pedestrian collision and 2% of head-on collision in 2011 - 2013. It is noted however, that head-on collision and pedestrian collision are typically very severe.

Therefore, this research considers 6 crash types as the ARFs which consist of the following:

1. Run-off road collision
2. Head-on collision
3. Rear-end collision
4. Angle collision
5. Sideswipe collision, and
6. Pedestrian collision

Due to the historical data of accidents proportion for each crash types in year 2011, 2012, and 2013 are not too much different (as in figure 3.2). Hence, table 3.2 shows the ARFs for each crash type which is calculated from the average of 3-year historical data of accidents in Thailand.

Table 3.2 Accident Risk Factors (ARFs)

Crash Type	ARFs
Run-off road	0.61
Head-on	0.02
Rear-end	0.20
Angle	0.06
Sideswipe	0.10
Pedestrian	0.01
Total	**1.00**

3.2 Crash modification factors (CMFs)

Multi-lane highways in this study indicate all divided-highways that have more than two lanes. Almost no research studies have indicated the formulas for CMFs calculation (Agent et al., 1996, New South Wales Roads and Traffic Authority, 2004, Bahar et al., 2008, James et al., 2010, Elvik and Vaa, 2004). These studies just show the CMFs or CRFs value if there are any safety improvements. The CMFs calculation in this study applies the formula from the “Collision Modification Factors For British Columbia” study (Sayed and de Leur, 2008), “Roadway Safety Design Synthesis” workbook (Bonneson et al., 2005), and “Prediction of Expected Safety Performance of Rural Two-Lane Highways” report (Harwood et al., 2000) adjusted with the road element characteristics in Thailand. CMFs for multi-lane highways are divided in to 4 categories:

3.2.1 Cross-sectional design elements

Any design element that is related to vertical plane of the roadway and roadside area. This part consists of 8 elements, including:

3.2.1.1 Lane width (Sayed and de Leur, 2008)

$$\mathrm{CMF_{LW}} = e^{-0.047\,(3.28\,\mathrm{W_L} - 12)}$$

Where,

CMF_{LW} = Collision modification factor for lane width

W_L = Lane width (m)

3.2.1.2 Outside shoulder width (Sayed & de Leur, 2008)

$$\mathrm{CMF_{SW(O)}} = \mathrm{e}^{-0.021\,(3.28\,\mathrm{W_{S(O)}} - 10)}$$

Where,

$CMF_{SW(O)}$ = Collision modification factor for shoulder width

$W_{S(o)}$ = Outside shoulder width (m)

3.2.1.3 Inside shoulder width (Sayed & de Leur, 2008)

$\mathrm{CMF_{SW(I)}} = e^{-0.021(3.28\,\mathrm{W_{S(I)}} - 4)}$, For highways with 4 lanes

$\mathrm{CMF_{SW(I)}} = e^{-0.021(3.28\,\mathrm{W_{S(I)}} - 10)}$, For highways with 6+ lanes

Where,

$CMF_{SW(I)}$ = Collision modification factor for inside shoulder width

$W_{S(I)}$ = Inside shoulder width (m) (measured from the lane edge to base of the median barrier)

3.2.1.4 Median width (Sayed & de Leur, 2008)

(1) Median width without barrier

$$\mathrm{CMF_{mw}} = e^{-0.0296\left([3.28084W_m - 6.56168W_{is}]^{0.5} - [56 - 6.56168W_{isb}]^{0.5}\right)}$$

(2) Median width with barrier

- For 4 lanes:

$$CMF_{mw} = e^{0.2713/W_{icb} - 0.0296([6.5617W_{icb}]^{0.5} - 5.29)}$$

- For 6 and more lanes:

$$CMF_{mw} = e^{0.2713/W_{icb} - 0.0296([6.5617W_{icb}]^{0.5} - 2.45)}$$

Where,

CMFMW	=	Collision modification factor for median width
Wm	=	Median width (m)
Wis	=	Inside shoulder width (m)
Wisb	=	Base inside shoulder width (m)
Wicb	=	Width from edge of shoulder to barrier face (m)

3.2.1.5 Roadside clear-zone (Sayed & de Leur, 2008)

$$CMF_{cz} = e^{-0.0137\,(3.28\,(W_{CZ} - S_{CZ}))}$$

Where,

CMF_{CZ}	=	Collision modification factor for clear zone
W_{CZ}	=	Clear zone width (m)
S_{CZ}	=	Required (standard) clear zone width (m)

3.2.1.6 Roadside utility pole density & offset (Bonneson, Zimmerman, & Fitzpatrick, 2005)

$$CMF_{UP} = (f_p - 1.0)P_S + 1$$

Where,

$$f_p = \frac{(0.0000984ADT + 0.022D_P)(3.28W_O)^{-0.6} - 0.04}{0.0000128ADT + 0.075}$$

CMF_{UP}	=	Collision modification factor for utility pole density
ADT	=	Average daily traffic (vehicle per day)
D_P	=	Utility pole density (two-way total), poles per km
W_O	=	Average pole offset from edge of pavement (m)
Ps	=	Subset proportion

Table 3.3 Crash distribution for utility pole density CMF

Area Type	Crash Type Subset	Through Lanes	Subset Proportion
Rural	Single-vehicle collision with pole	4	0.030
		6	0.038
Urban	Single-vehicle collision with pole	4	0.046
		6	0.029
		8	0.016
		10	0.012

3.2.1.7 Shoulder Rumble Strips (Sayed and de Leur, 2008)

If available, $CMF_{SRS} = 0.86$

If not available, $CMF_{SRS} = 1$

3.2.1.8 Median/Centreline Rumble Strips (Sayed and de Leur, 2008)

If available, $CMF_{CRS} = 0.90$

If not available, $CMF_{CRS} = 1$

3.2.2 Longitudinal design elements

Any design element that is along the direction of the road. This part consists of 3 elements, including:

3.2.2.1 Horizontal Alignment (Sayed & de Leur, 2008)

If the curve is presented applied the following equation,

$$CMF_{HC} = \frac{0.92L_c + \frac{80.2}{3.28R} - 0.012S}{0.962L_c}$$

If the curve is not presented, then CMF is equal to 1.

Where,

CMF_{HC} = Collision modification factor for horizontal curve

LC = Horizontal curve length including spiral transitions (km)

R = Radius of curvature (m)

S = Spiral indicator: 1 if spirals used, or 0 if spirals is absent

3.2.2.2 Super-Elevation

(Harwood, Council, Hauer, Hughes, & A., 2000)

If the curve is presented applied the following equation,

CMFSE = 1.00	Curves with SD < 1.00%
CMFSE = 1.00 + 6(SD – 0.01)	Curves with SD ≥ 1.00% and < 2.00%
CMFSE = 1.06 + 3(SD – 0.02)	Curves with SD ≥ 2.00%

If the curve is not presented, then CMF is equal to 1.

Where,

SD = Super-elevation deficiency in decimal; the difference between the actual super-elevation on the curve and the super-elevation that is required by AASHTO – A Policy on Geometric Design of Highways and Streets.

According to Design Quality Assurance Bureau (2003), super elevation that is required by American Association of State Highway and Transportation Officials (AASHTO) are listed below:

6% maximum in urban area.

12% maximum in rural areas and expressway.

3.2.2.3 Vertical Alignment (Sayed & de Leur, 2008)

$$\mathrm{CMF_G} = e^{0.019\mathrm{P_G}}$$

Where,

CMFG = Collision modification factor for roadway grade

PG = Percent grade (absolute value) in %

3.2.3 Signs and Delineation

This part consists of 5 elements, including:

3.2.3.1 Install Warning Signs (Sayed & de Leur, 2008)

If available, CMF_{WS} = 0.93

If not available, CMF_{WS} = 1

3.2.3.2 Install Post-Mounted Delineators

(Sayed & de Leur, 2008)

If available, CMF_{PMD} = 0.92

If not available, CMF_{PMD} = 1

3.2.3.3 Install Standard Edge-line Marking

(Sayed & de Leur, 2008)

If available, CMF_{SEM} = 0.97

If not available, CMF_{SEM} = 1

3.2.3.4 Pavement Mounted Delineators/Cat-Eyes

(Sayed & de Leur, 2008)

If available, $CMF_{PMD/CE}$ = 0.92

If not available, $CMF_{PMD/CE}$ = 1

3.2.3.5 Flashing Beacons (Sayed & de Leur, 2008)

If available, CMF_{FB}= 0.90

If not available, CMF_{FB}= 1

3.2.4 Miscellaneous Design Features

This part consists of 4 elements, including:

3.2.4.1 Illumination (Sayed & de Leur, 2008)

If available, CMF_{I}= 0.79

If not available, CMF_{I}= 1

3.2.4.2 Road Surface Treatments: Improved drainage

(Sayed & de Leur, 2008)

If available, CMF_{RST}= 0.92

If not available, CMF_{RST}= 1

3.2.4.3 Traverse Rumble Strips (Sayed & de Leur, 2008)

If available, CMF_{TRS}= 0.67

If not available, CMF_{TRS}= 1

3.2.4.4 Bridge Narrowing (Sayed & de Leur, 2008)

If available, $CMF_{BW} = e^{-0.135\,(3.28w_B - 12.0)}$

Where,

CMF_{BW} = Bridge width Collision modification factor

W_B = Relative bridge width

(= bridge width – the approach traveled-way width) (m)

All of these elements are categorized to the target collisions or crash types by the road safety experts from Department of Highways including Mr.Sujin Mungnimit (Deputy Director, Bureau of Highway Safety) and Asst. Prof. Dr. Bhanitiz Aursudkij (Highway Safety Expert). In addition, the CMFs will be calculated from the equation of each element presented above.

Table 3.4 Categorized road attributes involved in target collisions

Crash Types / Road Attributes	Run-off road	Head-on	Rear-end	Angle	Sideswipe	Pedestrian
Cross-Sectional Elements						
Lane Width	●		●		●	
Outside Shoulder Width	●					●
Inside Shoulder Width	●					
Median Width	●	●				
Clear-Zone	●					●
Utility Pole Density & Offset	●					
Shoulder Rumble Strips	●					●
Centreline Rumble Strips	●					
Longitudinal Elements						
Horizontal Alignment	●				●	

Crash Types / Road Attributes	Run-off road	Head-on	Rear-end	Angle	Sideswipe	Pedestrian
Super-Elevation	●				●	
Vertical Alignment			●		●	
Signs and Delineation						
Install Warning Signs	●					
Install Post-Mounted Delineators	●					
Install Standard Edge-line Markings	●					
Pavement Mounted Delineators / Cat-Eyes	●	●		●	●	
Flashing Beacons	●			●		
Miscellaneous Design Features						
Illumination	●	●	●	●	●	●
Road Surface Treatments	●	●	●	●	●	
Traverse Rumble Strips	●					
Bridge Narrowing	●		●		●	
Crash Types / Road Attributes	**Run-off road**	**Head-on**	**Rear-end**	**Angle**	**Sideswipe**	**Pedestrian**
Cross-Sectional Elements						
Lane Width	●		●		●	
Outside Shoulder Width	●					●
Inside Shoulder Width	●					
Median Width	●	●				
Clear-Zone	●					●
Utility Pole Density & Offset	●					
Shoulder Rumble Strips	●					●
Centreline Rumble Strips	●					
Longitudinal Elements						
Horizontal Alignment	●				●	
Super-Elevation	●				●	
Vertical Alignment			●		●	
Signs and Delineation						
Install Warning Signs	●					

Crash Types / Road Attributes	Run-off road	Head-on	Rear-end	Angle	Sideswipe	Pedestrian
Install Post-Mounted Delineators	●					
Install Standard Edge-line Markings	●					
Pavement Mounted Delineators / Cat-Eyes	●	●		●	●	
Flashing Beacons	●			●		
Miscellaneous Design Features						
Illumination	●	●	●	●	●	●
Road Surface Treatments	●	●	●	●	●	
Traverse Rumble Strips	●					
Bridge Narrowing	●		●		●	

3.3 Road Safety Index (RSI)

Road Safety Index (RSI) is a composite index and a significant measurement in comparing, ranking and determining road safety levels. It is a result from a comprehensive set of the exposure and risk indicators which includes ARFs and CMFs. According to International Road Assessment Programme (iRAP) (2014), the equation of RSI is typically written as equation 3.1:

$$RSI_{Total} = RSI_{Run\text{-}off\ road} + RSI_{Head\text{-}on} + RSI_{Rear\text{-}end} + RSI_{Angle} + RSI_{Sideswipe} + RSI_{Pedestrian}$$

According to Sayed and de Leur (2008), if the proportion of accident statistics for each crash type is presented, then it can be simultaneously combined with CMFs for each crash type to generate the safety index that can be applied to all crashes.

$$CMF_{Total} = (CMF_{Target} - 1)P_{Target} + 1$$

Where,

CMF_{Total} = Collision modification factor for the collision

CMF_{Target} = CMF for the target collision

P_{Target}	=	Proportion of target collision to total collisions

CMF_{Total} Equation can be applied to this study due to the P_{Target} can be substituted by ARF due to the same concept in accident statistics proportion. Moreover, the concept of CMF_{Total} in this equation is in accordance with the concept of RSI as they are results from the combination of CMFs and accident statistics proportion. Namely, the ARFs are the value carried the importance (weight) of the CMFs.

$$RSI_i = (CMF_i - 1)ARF_i + 1$$

Where,

RSI_i	=	Road safety index for the target collision i.
CMF_i	=	CMF for the target collision i.
ARF_i	=	Proportion of target collision i to total collisions.

According to Lacy (2001), the following equation creates a single CRF for the multiple elements applied at the single crash type.

$$CRF_i = 1\text{-}(1\text{-}CRF_{1i})(1\text{-}CRF_{2i})(1\text{-}CRF_{3i}) \ldots (1\text{-}CRF_{ni})$$

Where,

CRF_i	=	Total crash reduction factors for the crash type i in decimal format.
CRF_{ni}	=	The crash reduction factors for the nth element for the crash type i in decimal format.

And according to Sayed and de Leur (2008), CRF can be converted to CMF by the following equation:

$$CMF = 1 - CRF$$

$$\therefore \quad CRF = 1 - CMF$$

So, $$(1 - CMF)_i = 1\text{-}[(CMF_{1i})(CMF_{2i})(CMF_{3i}) \ldots (CMF_{ni})]$$

Then, $CMF_i = (CMF_{1i})(CMF_{2i})(CMF_{3i}) \ldots (CMF_{ni})$

Where,

CMF_i = Total crash modification factors for crash type i in decimal format.

CMF_{ni} = The crash modification factors for the nth element for the crash type i in decimal format.

Figure 3.2 shows summary of RSI calculation equations. The calculation begins from CMF_i equation and RSI_i equation for each crash type, and then the RSITotal equation is calculated respectively.

$CMF_i =$	$(CMF_{1i})(CMF_{2i})(CMF_{3i}) \ldots (CMF_{ni})$
$RSI_i =$	$(CMF_i - 1)ARF_i + 1$
$RSI_{Total} =$	$RSI_{Run\text{-}off\ road} + RSI_{Head\text{-}on} + RSI_{Rear\text{-}end} + RSI_{Angle} + RSI_{Sideswipe} + RSI_{Pedestrian}$

Figure 3.2 RSI calculation spreadsheet.

RSI will be calculated for each road by inserting the road attribute value in the Microsoft Excel spreadsheet (Table 3.5). The higher RSI leads to the higher risks due to both ARFs and CMFs value are involved in number of accidents. To classify the level of road safety, this research uses the iRAP Star Ratings method (Table 3.6) as a reference. However, due to the differences in some criteria, the Star Ratings method will be accordingly adjusted to this research method.

Table 3.5 Microsoft Excel spreadsheet for RSI calculation.

Road Safety Index Evaluation Form						
Road name:						
Cross-Sectional Design Elements		**Longitudinal Design Elements**		**Results**		
1. Lane Width		**1. Horizontal Alignment (Y/N)**		**Crash Types**	**CMF**	**RSI**
Lane width (m)		Horizontal curve length including spiral transitions (km)		Run-off road		
CMF-LW				Head-on		
2. Outside Shoulder Width		Radius of curvature (m)		Rear-end		
Outside shoulder width (m)		Spiral (Y/N)		Angle		
CMF-SW(O)		**CMF-HC**		Sideswipe		
3. Inside Shoulder Width		**2. Super-Elevation (Y/N)**		Pedestrian		
Inside shoulder width (m)		Urban area or Rural area/Express way		**Total**		
CMF-SW(I)		Actual super-elevation (%)				
4. Median Width		Super-elevation Deficiency (SD)				
Barrier available		**CMF-SE**				
If yes, please input		**3. Vertical Allignment**				
Number of lane		Percent grade (absolute value) in %				
Width from edge of shoulder to barrier face (m)		**CMF-G**				
If no, please input		**Signs and Delineation (Y/N)**		**CMF**		
Median width (m)		1. Install Warning Signs				
Inside shoulder width (m)		2. Install Post-Mounted Delineators				
Base inside shoulder width (m)		3. Install Standard Edge-line Markings				
CMF-MW		4. Pavement Mounted Delineators / Cat-Eyes				
5. Roadside Clear-Zone		5. Flashing Beacons				
Clear zone width (m)		**Miscellaneous Design Features (Y/N)**		**CMF**		
Standard clear zone width (m)		1. Illumination				
CMF-CZ		2. Road Surface Treatments: Improved drainage				
6. Roadside Utility Pole Density & Offset		3. Traverse Rumble Strips				
Average daily traffic (vehicles/day)		4. Bridge Narrowing				
Utility pole density (two-way), (poles/km)		If Yes -> Relative bridge width (m)				
Average pole offset from edge of pavement (m)						
Subset proportion						
fp						
CMF-UP						
7. Shoulder Rumble Strips (Y/N)						
CMF-SRS						
8. Median/Centreline Rumble Strips (Y/N)						
CMF-CRS						

Table 3.6 iRAP star rating bands and colors

Star Rating	Star Rating Score		
	Vehicle occupants and motorcyclists	Pedestrians	Bicyclists
5	0 to < 2.5	0 to < 5	0 to < 5
4	2.5 to < 5	5 to < 15	5 to < 10
3	5 to < 12.5	15 to < 40	10 to < 30
2	12.5 to < 22.5	40 to < 100	30 to < 60
1	22.5 +	100 +	60+

Source: International Road Assessment Programme (iRAP) (2014)

Since RSI calculation for this model differs from iRAP, RSI star rating will be adjusted mathematically by linear interpolation using iRAP star rating as reference. For each class, upper limit and lower limit can be determined using following equation,

$$\frac{UL_{iRAP} - LL_{iRAP}}{R_{iRAP}} = \frac{UL_{RSI} - LL_{RSI}}{R_{RSI}}$$

Where,

UL_{iRAP}	=	Upper limit of a class in iRAP rating
LL_{iRAP}	=	Lower limit of a class in iRAP rating
UL_{RSI}	=	Upper limit of a class in RSI rating
LL_{RSI}	=	Lower limit of a class in RSI rating
R_{iRAP}	=	Range of iRAP rating, (Upper limit of last class – Lower limit of first class)
R_{RSI}	=	Range of RSI rating, (Upper limit of last class – Lower limit of first class)

iRAP score starts from 0 to 22.5. Values exceeding 22.5 will be classified into the 5th class (1-star). Thus, range of iRAP rating (RiRAP) equals 22.5-0 = 22.5.

To determine range of RSI score, lower limit of the first class and upper limit of the last class are determined by best and worst case scenarios assumption. The best case scenario is constructed under the assumption of wide lane, wide outside and inside shoulder width, separation of opposing traffic by a wide median or barrier, wide clear zone, good line-marking, and so on. RSI for best case scenario is equal to 5.57.

The worst case scenario is constructed under the assumption of narrow lane, narrow outside and inside shoulder width, steep curve is presented, lack of warning sign and illumination, no median width, and so on. RSI for worst case scenario is equal to 11.17. Though, it is merely impossible for a road to be in such condition. To make star rating more applicable, the upper limit of RSI is rounded down to 10.

From here, we can calculate RRSI which equals to 10-5.57 = 4.43. Obtaining all variable, upper and lower limit of each class can be calculated as shown below:

★★★★★ (Risk Category Color: Green),

From,
$$\frac{UL_{iRAP}-LL_{iRAP}}{R_{iRAP}}=\frac{UL_{RSI}-LL_{RSI}}{R_{RSI}}$$
$$\frac{2.5-0}{22.5}=\frac{UL_{RSI}-5.57}{4.43}$$
$$UL_{RSI}=6.06$$

★★★★ (Risk Category Color: Yellow),

From,
$$\frac{UL_{iRAP}-LL_{iRAP}}{R_{iRAP}}=\frac{UL_{RSI}-LL_{RSI}}{R_{RSI}}$$
$$\frac{5-2.5}{22.5}=\frac{UL_{RSI}-6.06}{4.43}$$
$$UL_{RSI}=6.55$$

★★★ (Risk Category Color: Orange),

From,
$$\frac{UL_{iRAP}-LL_{iRAP}}{R_{iRAP}}=\frac{UL_{RSI}-LL_{RSI}}{R_{RSI}}$$
$$\frac{12.5-5}{22.5}=\frac{UL_{RSI}-6.55}{4.43}$$
$$UL_{RSI}=8.03$$

★★(Risk Category Color: Red),

From
$$\frac{UL_{iRAP}-LL_{iRAP}}{R_{iRAP}}=\frac{UL_{RSI}-LL_{RSI}}{R_{RSI}}$$
$$\frac{22.5-12.5}{22.5}=\frac{UL_{RSI}-8.03}{4.43}$$
$$UL_{RSI}=10$$

Thus, RSI = 10 is also a lower limit of ★ (Risk Category Color: Black). RSI star rating for this model can be summarized by table 3.7.

Table 3.7 Comparison between iRAP and RSI star rating

STARS	iRAP Scores	RSI	Safety Level
★★★★★	0 to < 2.5	5.57 to < 6.06	**Safest**
★★★★	2.5 to < 5	6.06 to < 6.55	
★★★	5 to < 12.5	6.55 to < 8.03	
★★	12.5 to < 22.5	8.03 to < 10	
★	More than 22.5	More than 10	**Least Safe**

The RSI values are adjusted again to make the RSI value smooth and to be simple for recognizing. Table 3.8 shows the adjusted value of RSI.

Table 3.8 Comparison between RSI and adjusted RSI.

STARS	RSI	Safety Level	Adjusted RSI
★★★★★	5.57 to < 6.06	**Safest**	**0 to 10**
★★★★	6.06 to < 6.55		**10 to 20**
★★★	6.55 to < 8.03		**20 to 50**
★★	8.03 to < 10		**50 to 90**
★	More than 10	**Least Safe**	**more than 90**

This RSI calculation method will be applied to 3 multi-lane highways with high traffic volume to prioritize the improvement of the roads. Moreover, high traffic volume road is the road with Annual Average Daily Traffic (AADT) greater than

25,000 vehicles per day (Peshkin et al., 2011). Figure 3.3 shows the summarized steps for this study. The results of RSI calculation and road improvement ranking will be explained in the next chapter.

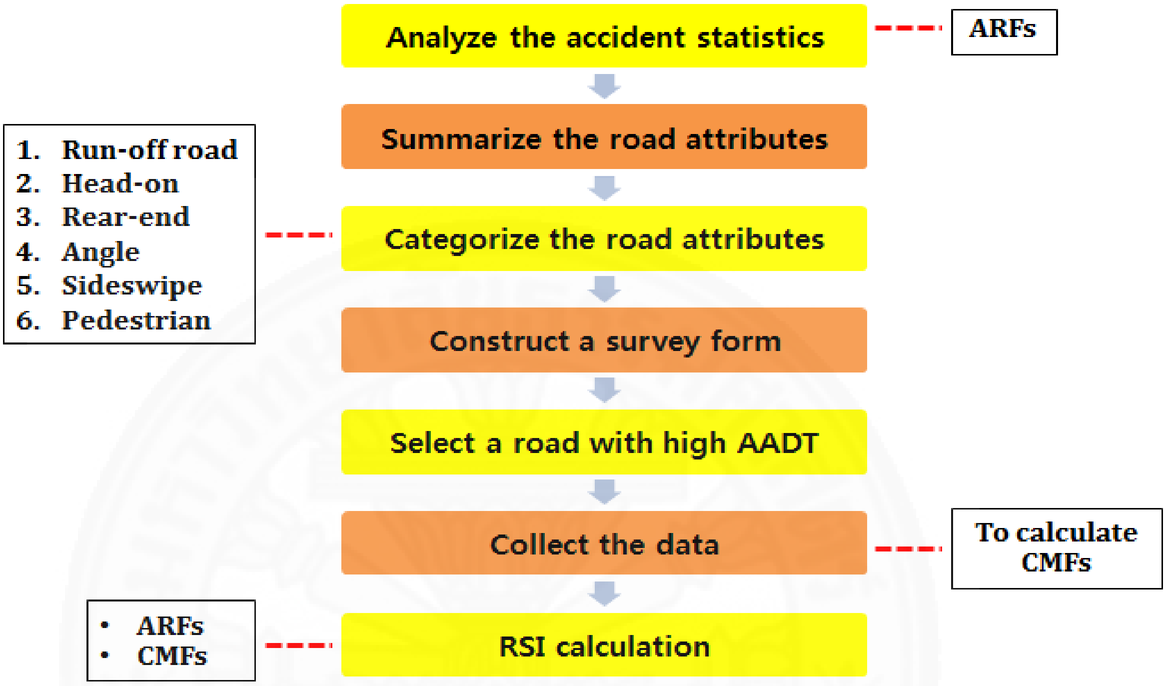

Figure 3.3 Summarized steps for road improvement ranking.

Chapter 4
Results and Discussion

4.1 Case study area

In this study, 3 multi-lane highways with high traffic volume were selected to evaluate the road safety level and prioritize the improvement of the roads. Case study roads included:

(1) Highway route 301 from Km.5+119 to Km.7+559 with AADT of 99,915 vehicles per day (Department of Highways (DOH), 2015).
(2) Highway route 304 from Km.2+329.700 to Km.10+130 with AADT of 116,013 vehicles per day (Department of Highways (DOH), 2015).
(3) Highway route 306 from Km.7+909 to Km.20+601 with AADT of 41,911 vehicles per day (Department of Highways (DOH), 2015).
(4) Even though these roads are not the highest traffic volume roads in Thailand due to the limitation of data source, these roads still have high traffic volume according to Peshkin et al. (2011).

4.2 Results and discussion

The road attribute characteristics data were collected and inserted to the RSI calculation tool in Microsoft Excel to calculate RSI score of each road. Table 4.1 – Table 4.3 show results of RSI calculation of highway route 301, 304, and 306 respectively.

Table 4.1 Result of RSI Calculation of Highway Route 301**.**

Road Safety Index Evaluation Form						
Road name: Highway Route 301 (Km.5+119 to Km.7+559)						
Cross-Sectional Design Elements		**Longitudinal Design Elements**		**Results**		
1. Lane Width		**1. Horizontal Alignment (Y/N)**	No	**Crash Types**	**CMF**	**RSI**
Lane width (m)	3.5	Horizontal curve length including spiral transitions (km)		Run-off road	4.367911	3.054426
CMF-LW	1.024741			Head-on	1.596439	1.011929
2. Outside Shoulder Width		Radius of curvature (m)		Rear-end	0.751891	0.950378
Outside shoulder width (m)	0	Spiral (Y/N)		Angle	0.7268	0.983608
CMF-SW(O)	1.233678	**CMF-HC**	1	Sideswipe	2.568081	1.156808
3. Inside Shoulder Width		**2. Super-Elevation (Y/N)**	No	Pedestrian	1.22013	1.002201
Inside shoulder width (m)	0.4	Urban area or Rural area/Express way	Urban	**Total**	35.98917	**8.15935**
CMF-SW(I)	1.058072	Actual super-elevation (%)				
4. Median Width		Super-elevation Deficiency (SD)				
Barrier available	Yes	**CMF-SE**	1			
If yes, please input		**3. Vertical Allignment**				
Number of lane	4	Percent grade (absolute value) in %	0.5			
Width from edge of shoulder to barrier face (m)	0.4	**CMF-G**	1.009545			
If no, please input		**Signs and Delineation (Y/N)**		**CMF**		
Median width (m)		1. Install Warning Signs	No	1		
Inside shoulder width (m)		2. Install Post-Mounted Delineators	No	1		
Base inside shoulder width (m)		3. Install Standard Edge-line Markings	No	1		
CMF-MW	2.196531	4. Pavement Mounted Delineators / Cat-Eyes	No	1		
5. Roadside Clear-Zone		5. Flashing Beacons	No	1		
Clear zone width (m)	0	**Miscellaneous Design Features (Y/N)**		**CMF**		
Standard clear zone width (m)	5	1. Illumination	Yes	0.79		
CMF-CZ	1.251922	2. Road Surface Treatments: Improved drainage	Yes	0.92		
6. Roadside Utility Pole Density & Offset		3. Traverse Rumble Strips	No	1		
Average daily traffic (vehicles/day)	99915	4. Bridge Narrowing	No	1		
Utility pole density (two-way), (poles/km)	20	If Yes -> Relative bridge width (m)				
Average pole offset from edge of pavement (m)	0.1					
Subset proportion	0.046					
fp	*14.77943*					
CMF-UP	1.633854					
7. Shoulder Rumble Strips (Y/N)	No					
CMF-SRS	1					
8. Median/Centreline Rumble Strips (Y/N)	No					
CMF-CRS	1					

Table 4.2 Result of RSI Calculation of Highway Route 304**.**

Road Safety Index Evaluation Form						
Road name: Highway Route 304 (Km.2+329.700 to Km.10+130)						
Cross-Sectional Design Elements		**Longitudinal Design Elements**		**Results**		
1. Lane Width		**1. Horizontal Alignment (Y/N)**	No	**Crash Types**	**CMF**	**RSI**
Lane width (m)	3.5	Horizontal curve length including spiral transitions (km)		Run-off road	2.009982	1.616089
CMF-LW	1.024741			Head-on	1.851914	1.017038
2. Outside Shoulder Width		Radius of curvature (m)		Rear-end	0.751891	0.950378
Outside shoulder width (m)	0.3	Spiral (Y/N)		Angle	0.7268	0.983608
CMF-SW(O)	1.208447	**CMF-HC**	1	Sideswipe	2.568081	1.156808
3. Inside Shoulder Width		**2. Super-Elevation (Y/N)**	No	Pedestrian	1.195176	1.001952
Inside shoulder width (m)	0.3	Urban area or Rural area/Express way	Urban	**Total**	12.09789	**6.725873**
CMF-SW(I)	1.065385	Actual super-elevation (%)				
4. Median Width		Super-elevation Deficiency (SD)				
Barrier available	Yes	**CMF-SE**	1			
If yes, please input		**3. Vertical Allignment**				
Number of lane	8	Percent grade (absolute value) in %	0.5			
Width from edge of shoulder to barrier face (m)	0.3	**CMF-G**	1.009545			
If no, please input		**Signs and Delineation (Y/N)**		**CMF**		
Median width (m)		1. Install Warning Signs	Yes	0.93		
Inside shoulder width (m)		2. Install Post-Mounted Delineators	No	1		
Base inside shoulder width (m)		3. Install Standard Edge-line Markings	Yes	0.97		
CMF-MW	2.548038	4. Pavement Mounted Delineators / Cat-Eyes	No	1		
5. Roadside Clear-Zone		5. Flashing Beacons	No	1		
Clear zone width (m)	0	**Miscellaneous Design Features (Y/N)**		**CMF**		
Standard clear zone width (m)	5	1. Illumination	Yes	0.79		
CMF-CZ	1.251922	2. Road Surface Treatments: Improved drainage	Yes	0.92		
6. Roadside Utility Pole Density & Offset		3. Traverse Rumble Strips	Yes	0.67		
Average daily traffic (vehicles/day)	116013	4. Bridge Narrowing	No	1		
Utility pole density (two-way), (poles/km)	20	If Yes -> Relative bridge width (m)				
Average pole offset from edge of pavement (m)	1.5					
Subset proportion	0.046					
fp	*2.896035*					
CMF-UP	1.087218					
7. Shoulder Rumble Strips (Y/N)	No					
CMF-SRS	1					
8. Median/Centreline Rumble Strips (Y/N)	No					
CMF-CRS	1					

Road Safety Index Evaluation Form						
Road name: Highway Route 306 (Km.7+909 to Km.20+601)						
Cross-Sectional Design Elements		**Longitudinal Design Elements**		**Results**		
1. Lane Width		**1. Horizontal Alignment (Y/N)**	No	**Crash Types**	**CMF**	**RSI**
Lane width (m)	3.5	Horizontal curve length including spiral transitions (km)		Run-off road	3.780598	2.696165
CMF-LW	1.024741			Head-on	1.851914	1.017038
2. Outside Shoulder Width		Radius of curvature (m)		Rear-end	0.751891	0.950378
Outside shoulder width (m)	0.2	Spiral (Y/N)		Angle	0.7268	0.983608
CMF-SW(O)	1.216799	**CMF-HC**	1	Sideswipe	2.568081	1.156808
3. Inside Shoulder Width		**2. Super-Elevation (Y/N)**	No	Pedestrian	1.203437	1.002034
Inside shoulder width (m)	0.2	Urban area or Rural area/Express way	Urban	**Total**	30.10053	**7.806032**
CMF-SW(I)	1.072748	Actual super-elevation (%)				
4. Median Width		Super-elevation Deficiency (SD)				
Barrier available	Yes	**CMF-SE**	1			
If yes, please input		**3. Vertical Allignment**				
Number of lane	6	Percent grade (absolute value) in %	0.5			
Width from edge of shoulder to barrier face (m)	0.3	**CMF-G**	1.009545			
If no, please input		**Signs and Delineation (Y/N)**		**CMF**		
Median width (m)		1. Install Warning Signs	No	1		
Inside shoulder width (m)		2. Install Post-Mounted Delineators	No	1		
Base inside shoulder width (m)		3. Install Standard Edge-line Markings	Yes	0.97		
CMF-MW	2.548038	4. Pavement Mounted Delineators / Cat-Eyes	No	1		
5. Roadside Clear-Zone		5. Flashing Beacons	No	1		
Clear zone width (m)	0	**Miscellaneous Design Features (Y/N)**		**CMF**		
Standard clear zone width (m)	5	1. Illumination	Yes	0.79		
CMF-CZ	1.251922	2. Road Surface Treatments: Improved drainage	Yes	0.92		
6. Roadside Utility Pole Density & Offset		3. Traverse Rumble Strips	No	1		
Average daily traffic (vehicles/day)	41911	4. Bridge Narrowing	No	1		
Utility pole density (two-way), (poles/km)	30	If Yes -> Relative bridge width (m)				
Average pole offset from edge of pavement (m)	0.4					
Subset proportion	0.046					
fp	*6.582202*					
CMF-UP	1.256781					
7. Shoulder Rumble Strips (Y/N)	No					
CMF-SRS	1					
8. Median/Centreline Rumble Strips (Y/N)	No					
CMF-CRS	1					

Table 4.3 Result of RSI Calculation of Highway Route 306

RSI of highway route 301, 304, and 306 are approximately 8.16, 6.73, and 7.81 respectively. The adjusted RSI of highway route 301, 304, and 306 are 52.62, 23.57, and 45.51 respectively. According to table 3.7 and table 3.8, highway route 301 star rating is at 2-star level. Moreover, highway route 304 and 306 star ratings are at 3-star level.

Figure 4.1 shows the road characteristics of highway route 301. There is a wide median to separate opposing lanes of traffic. However, there is no clear zone to prevent the serious injury from the run-off road accident. Moreover, there are narrow inside shoulder width and outside shoulder width.

Figure 4.1 Road Characteristics of Highway Route 301

Figure 4.2 shows the road characteristics of highway route 304. There are road safety warning sign, median width, and streetlights. However, there are some road attributes that seems to be unsafe. Inside shoulder width and outside shoulder width is narrow. Besides, there is junction between normal lane and bridge narrowing lane that some time effect to the driver’s decision in choosing the lane.

Figure 4.2 Road Characteristics of Highway Route 304

Figure 4.3 shows the road characteristics of highway route 306. There are road safety median width, standard edge-line marking and streetlights. However, there is no clear zone to prevent the serious injury from the run-off road accident. Moreover, there are narrow inside shoulder width and outside shoulder width.

Figure 4.3 Road Characteristics of Highway Route 306

Afterward, RSI calculation results were ranked from the highest RSI to the lowest RSI to prioritize which road will be improved first because of the limited budget, workforce, and time. The ranking of RSI value from lowest to highest is presented in table 4.4.

Table 4.4 RSI Ranking of highway route 301, 304, and 306.

Rank	Highway Route	RSI	RSI Adjusted	Star Rating
1	301	8.16	52.62	2-star
2	306	7.81	23.57	3-star
3	304	6.73	45.51	3-star

Since the road improvement is limited by the budget provided, highway route 301 has to be considered first for the road improvement then highway 306 and 304 will be considered accordingly adjusted with the remaining budget.

The expected significance of this study is to provide further evidence of the contributions to the fields of road safety evaluation. In addition, it is anticipated that the results will provide government and relevant agencies with reliable and objective information and solutions adapted to the conditions in Thailand for future investments in road safety measures and strategies. Likewise, the study makes a contribution through its use of mixed indicators which results in a more effective explanation of road safety level.

Since this research is originally conducted in Thailand, the results and review of this research could play an important role as a pilot study for further research studies. The research objectives and framework could be broadened to be implemented in other countries to construct their own road safety assessment tools. The benefits of this study envisioned with better understanding of the interrelationship of road safety indicators and eventually could be followed in other developing countries in Asia.

Chapter 5
Conclusions and Further Study

5.1 Conclusion

The review of road safety problem worldwide indicated that road safety is a serious issue that need to be solved urgently. The main question addressed in this study was: how do we integrate several road safety attributes together in one simple and summarized index?

Before constructing the Road Safety Index (RSI) evaluation tool, the road assessment programs were studied about the factors and indicators involved in the road safety evaluation as well as a method for classifying the road safety scores into star rating levels. In this study, iRAP star rating method is considered as a reference for constructing the RSI star rating to determine the number of safety star(s) of each road.

In the construction of RSI evaluation tool, the road accident data and road characteristics were considered to construct a road safety evaluation tool that suits for Thailand. Road accident statistics were converted to Crash Modification Factors (CMFs) and road attribute conditions were converted to Accident Risk Factors (ARFs). Besides, RSI is calculated from the combination of ARFs and CMFs involved in each crash type.

The methodology and approach that is used in the construction of RSI were stated. The star ratings methodology has been developed and proven to classify RSI. RSI is a summarized index and can be a government interest since it shows the scale of the road safety problem. RSI evaluation method is a unique way of assessing the road safety level in different countries. Moreover, RSI helps prioritize the highways improvement project. This index is a key indicator in road safety that provided a broad picture compared to the traditional models in road safety. The study provides further evidence of the contributions to the fields of road safety evaluation.

5.2 Further study

There are a number of scopes to further study this research in a wider scale. The recommendations are proposed for further study relating to this study topic. More extensive analysis will be conducted in the future work.

RSI results seem very promising and worth testing further applications with more roads from different provinces in Thailand. This index needs to be tested further and revised. The revision of RSI may search more comprehensive data for a larger number of dimensions and indicators, such as consider more road attributes involved in each crash type or improve the accuracy and reduce the uncertainty of the final RSI results. This means that there always need to improve the road attributes data and the assessment of road accident weights. In addition, RSI needs to be tested on a larger sample of highways from different parts in Thailand.

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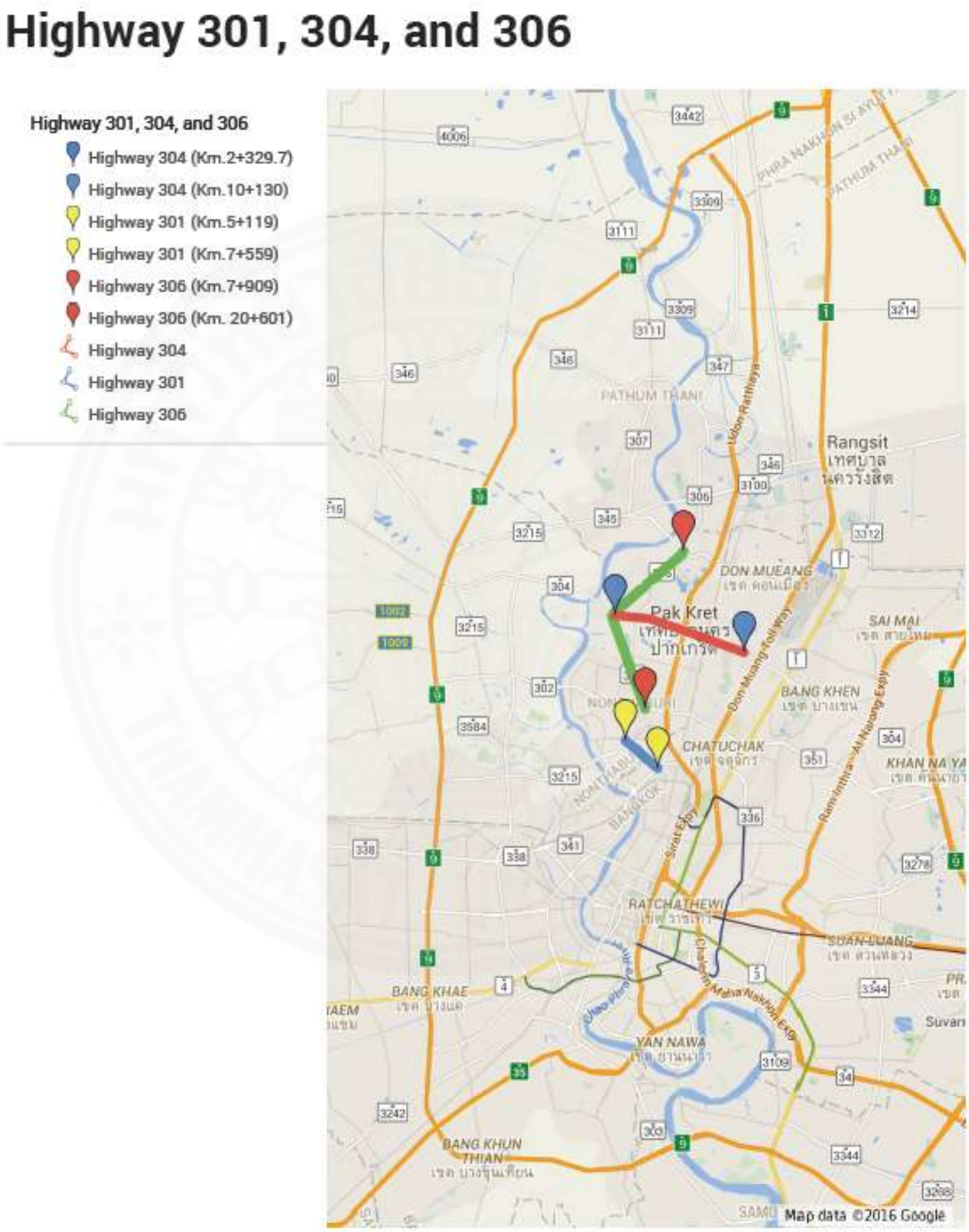
Appendices

Appendix A

Map of Highway Route 301, 304, and 306



Appendix B

Pictures of Highway Route 301, 304, and 306

Highway Route 301

Highway Route 304

Highway Route 306