UNIVERSITY OF BIRMINGHAM

DEVELOPMENT OF A HOLISTIC INDEX FOR SAFER ROADS

By

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ABSTRACT

Generally, road safety is an important issue. Some global and national organisations have recognised the size of this problem and introduced the "safe system approach " approach as a successful guide for road safety management. The concept of this approach considers road safety as a system compiled of the elements of road infrastructure, mobility, and vehicles; which all should be designed to accommodate the vulnerability of the road users. This corrected the traditional view which considered road-user behaviour as the main contributing factor to the road safety problem.

The question raised in this research is to what extent the safe system approach contributes to the national road safety strategic plans? To answer this question, an assessment of road safety performance is needed. For this, the research aims to develop a holistic and understandable index of road safety to use as a tool of assessment. This index can be used to rate and rank countries according to the effectiveness of the national road safety strategic plan; to monitor the progress of these plans towards a set target; warn of weaknesses early; and suggest solutions.

To develop the road safety assessment index (RSAI), its thematic indicators are identified based on the components of the safe system approach which cover safer road infrastructure and mobility, safer vehicles, and safer road-user behaviour. A sub model is developed for each thematic indicator, along with their individual indicators that can give a full reflection.

The road assessment programme (RAP) is considered in this research to identify the indicators of safer road infrastructure and mobility, as it is the most valid methodology

recommended by the global organisations to assess the features of road design. A procedure for extending the RAP methodology is developed and evaluated for this purpose.

The new car assessment programme (NCAP) of rating cars according to the safety requirements is chosen to identify the most comprehensive indicator of the safer vehicle sub model. While seven indicators are selected to form the sub model of safer road-user behaviour.

The chosen indicators are weighted through investigating two methods, equal and unequal weightings, to identify the weights that reflect the rational importance of each indicator in saving road users' lives. Then the indicators are aggregated using the simple linear additive aggregation method to form the RSAI's preliminary models. These models are evaluated through comparing their results with the rate of road fatalities, to test their validity in achieving their purpose and decide the final form of the RSAI model. The results show the suitability of the RSAI model in assessing the road safety level, and in replacing the crash data for benchmarking and ranking countries.

The usage of the RSAI in rating countries according to the effectiveness of their strategic plan of road safety and the level of road severity is investigated through developing a specific methodology. The usage of the RSAI in identifying the rate of progress of the national road safety plans towards a set target is also investigated. In addition, a methodology for suggesting solutions is developed, based on the results of a sensitivity analysis conducted to measure the change in the RSAI resulting from an individual improvement in one indicator or multiple improvements in two or more indicators. The multi-usage of the proposed RSAI enhances its value as a strategic decision-making tool.

DEDICATION

To

My parents,

My teachers,

My sisters and brothers in law

My nieces and nephews

All my family and friends

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LIST OF ABBREVIATIONS

AADT	Annual Average Daily Traffic
ABS	Anti-brake system
AHP	The analytic hierarchy process
ALsc	The aggregated larger score of each ASR band
ASR	Aggregated star rating
ASRS	Aggregated star rating scores
ASsc	The aggregated smaller score of the ASR band
AusNCAP	Australian new car assessment programme
AusRAP	Australian road assessment methodology
BA	The budget allocation
BAC	Blood alcohol content
CI	Composite aggregated
DARS	Decade of Actions on Road Safety
DEA	Data envelopment analysis
DFT	Department for Transport in the UK
ECHRS	The effectiveness score on using child restraints' enforcement
ECMT	European Conference of Ministers of Transport
EDDS	The effectiveness score on drink-driver enforcement
EDGS	The effectiveness score on drug-driver enforcement
EHS	The effectiveness score on wearing helmets' enforcement
EMPS	The effectiveness score on mobile usage while driving enforcement
ESBS	The effectiveness score on wearing seat belts' enforcement

ESS	The effectiveness score on speeding enforcement
EU	The European Union
EuroNCAP	European new car assessment programme
EuroRAP	European road assessment programme
EUROSTAT	The statistics agency of the European Union
FA	Factor analysis
GA	Geometric Method
GNP	Gross National Product
HDI	Human Development Index
HSM	Highway Safety Manual
iRAP	International road assessment programme
IRF	The International Road Federation
IRTAD	International Road Traffic and Accident Database
JTRC OECD/ECMT	the Joint Transport Research Centre of the Organisation for Economic Co-operation and Development and the European Conference of Ministers of Transport
K1	The road section number that is awarded an aggregated three stars or more
k2	The vehicle models that were awarded five stars
KiwiRAP	New Zealand' road assessment methodology
L(≥3stars)	The length of a sample of roads which is assessed by iRAP and awarded minimum 3 star for all the road user groups
Lk1	The length of the road section k1
Lsc	The larger score of a star rating band
Lt	The total length of the roads' network
LT	The total length of selected sample of the road network.

MAAP	Microcomputer Accident Analysis Package
MAX	Maximum function
MIN	Minimum function
NCAP	New car assessment programme
OECD	The Organisation for Economic Co-operation and Development
OSGR	Ordnance Survey Grid Reference
PCA	The principal components analysis
R^2	Coefficient of determination
RAP	Road assessment programme
RSAI	Road safety assessment index
RSRM™	Road Safety Risk Manager
SDG	Sustainable Development Goal
SLAA	The simple linear additive aggregation method
SR	Star rating
SRb	The star rating of bicyclists
SRIM	Safer road infrastructure and mobility
SRmt	The star rating of motorcyclists
SRp	The star rating of pedestrians
SRS	Star rating scores
SRSb	The star rating scores of bicyclists
SRSmt	The star rating scores of motorcyclists
SRSp	The star rating scores of pedestrians
SRSv	The star rating scores of vehicle occupants
SRUB	Safer road user behaviour
SRv	The star rating of vehicle occupants

Ssc	The smaller score of a star rating band
SV	Safer vehicle
UN	United Nations
UNECE	The United Nations Economic Commission for Europe
usRAP	United states' road assessment methodology
Vi	Variable of the indicator i
VIDA	which is online software developed to process the RAP methodology
ViWi	The term form of a mathematical model
Vk2	volume of vehicles of model k2
Vt	The total volume of all vehicle models
W_1SRIM	The term of the safer road infrastructure and mobility sub model
W_2SRUB	The term of the safer road user behaviour sub model
W_3SV	The term of the safer vehicle sub model
WHO	World Health Organisation
Wi	the weight of the indicator i

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Globally, road safety is a considerable problem. It results in increasing the rate of mortality and raising concerns for health, social and economic issues. The World Health Organisation (WHO) (Peden et al. 2004; WHO 2009; 2013a; 2015) reports that road safety is one of the leading causes of deaths worldwide and the first cause of deaths among young people. Its published documents stated that road crashes produce annually over one million fatalities and about 20 to 50 million injuries. Half of the crash injuries are considered severe, which cause an increasing disability rate worldwide; in turn this leads to an increase in some social issues such as stigma and discrimination, especially among disabled children (Peden et al. 2004; WHO 2009). Moreover, the road safety issue can create poverty problems when the survivors have long-term consequences, which require high-cost medical care in addition to losing the main source of income for the family due to injury or death (Peden et al. 2004; WHO 2009; 2013a; 2015). Furthermore, road traffic fatalities and injuries result in national financial implications, especially in developing countries. Their cost is estimated at about 2-5% of the global Gross National Product (GNP) and about 1-2% of the GNP in low and middle-income countries, where it reaches to about $500 billion, more than the total amount that these countries receive in development assistance (Al-Haji 2007; WHO 2009; UN and WHO 2011; WHO 2013a).

Some global organisations, such as the WHO and the United Nations (UN), have recognised this serious problem and have taken actions to solve it. The WHO has been publishing reports since 2004 (Peden et al. 2004; WHO 2009; 2013a; 2015) to raise warnings of road safety issues and assess the road safety performance on a national and international scale, as shown in Figure 1.1. It has been discussed that the main reason behind the increase in the rate of road and traffic risk level is the rapid raise in motorization without sufficient improvement in road safety strategies, which have resulted from a lack of a poor road safety management system (Elvik 2008). The WHO has supported the resolution of a Decade of Action for Road Safety 2011–2020 by the United Nations General Assembly in 2010, which aimed at saving 5 million lives by 2020 (UN and WHO 2011; Bliss and Breen 2012). It has also referred to the targets set by the 2030 sustainable development agenda (UN 2015), in which reduction of road fatalities by half by 2030 is set as a target, to improve the sustainable health and transportation sectors (WHO 2015).

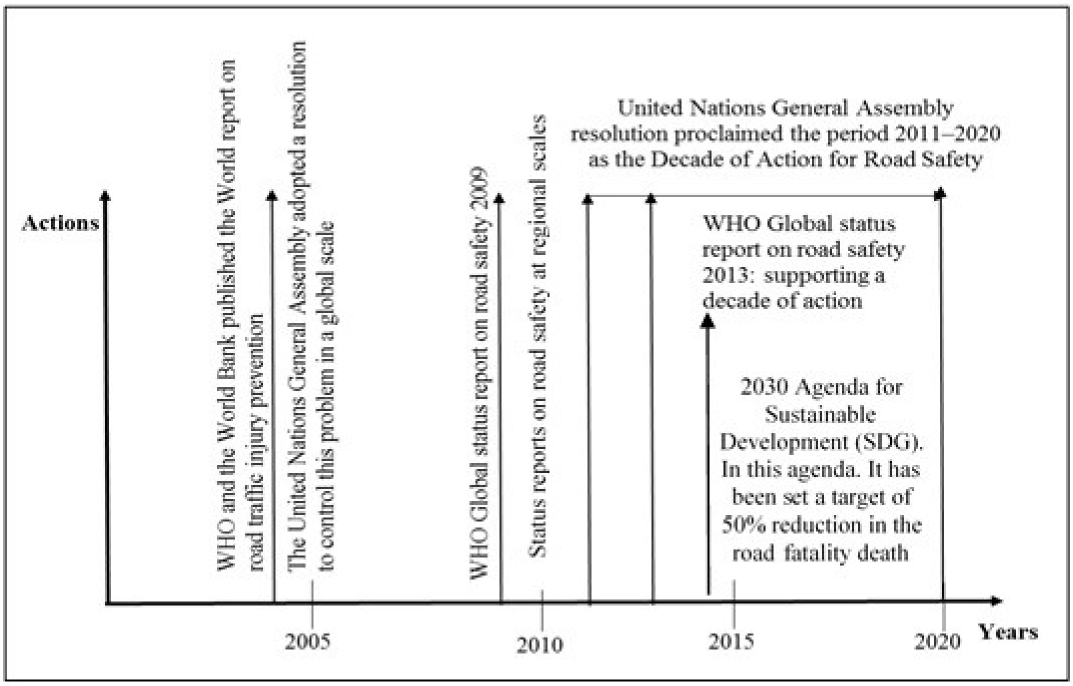

Figure 1.1 The Actions Taken by the WHO, the World Bank and the United Nations from 2004 to 2013 (Peden et al. 2004; WHO 2009; 2013a; 2015)

he WHO's reports show also the change in the traditional view of the characteristics of the road safety problem, from a random event to a predictable and preventable event. This new vision which is called the "safe system approach " considers road safety as a system compiled of elements which all should be considered in the new strategies of improving road safety. This means that the roads' environment and the vehicles should be designed to accommodate the limitations and vulnerability of the road users' bodies. This vision is produced from the successful practices that some developed countries have implemented, such as Sweden (Belin et al. 2012), the Netherlands (van Vliet and Schermers 2000), the United Kingdom, and Australia (Corben et al. 2010), where a significant decline in road fatalities has been achieved. The safe system approach has been produced as the effective guide of successful road safety management, through a process of continual improvement in road safety performance towards the set targets of no road fatalities and injuries (Peden et al. 2004).

Therefore, it is recommended to take lessons from the leading strategies in road safety. To measure the size of the problem and the extent to which the safe system approach contributes to the national road safety strategies, it is recommended that the road safety performance is assessed. It is also important to monitor the progress of the operation system towards a set target and to warn early about any weakness of a strategy. In order to achieve that, it is necessary to define tools can be used to interpret and indicate the performance of the road safety system or its parameters (ETSC 2001; Al-Haji 2007; WHO 2013a). Indices are the most used tools in assessment and benchmarking which are used in different types as will be shown in the next section.

1.2 Road Safety Performance Indices

Indices are tools of reflecting and expressing scientific knowledge in an understandable and applicable way (Singh et al. 2009). The ETSC (2001) defines a safety performance index as "any measurement that is related to accidents and casualties and used to count accidents and casualties, indicate the safety performance or understand the process that leads to accidents". The road safety performance index can reflect the final outcome or the intermediate outcome of the road safety strategies.

The final-outcome indices measure the reported and estimated crash rate. It can be in different terms such as registered road crash fatalities or exposure fatalities per population, per vehicle fleet, or per kilometre travelled (JRC-EC 2008; Hermans 2009; Wegman and Oppe 2010; Shen et al. 2012; Oluwole et al. 2013; Aarts and Houwing 2015). Despite the fact that this type of indices can capture an overall picture of road safety (Al-Haji 2007), it is considered ineffective by system assessors and managers for several reasons. The measurement of these types of indices may be subject to random fluctuations. For example, the cash reporting is subjected to short-term change which gives a wrong indication of the long-term change of the trend of road crashes. In addition, the final-outcome index is not an effective measure of the process and factors producing crashes; which means that it does not indicate the likelihood of crashes occurring and their predicted severity level. It also does not indicate what kind of countermeasures can be applied to prevent a crash occurring and reduce the consequent severity (Hermans et al. 2009a). Moreover, the final outcome is not effective where there is lack of crash data especially in the developing countries where the majority of road fatalities occur. Therefore, it is necessary to identify different kinds of indices to measure the road safety problem in a better way.

The intermediate-outcome indices are used to measure the operational performance of the road safety system (Hakkert et al. 2007; Papadimitriou and Yannis 2013). These indices reflect the variables that measure the progress of implementing interventions, such as the percentage of using seat belts and the percentage of roads designed according to standards of road safety (Wegman et al. 2008b; Hermans 2009; Wegman and Oppe 2010; Shen 2012; Aarts and Houwing 2015). These kinds of indices are used in many studies in different domains: such as the Human Development Index (HDI) developed by the United Nations, the Technology Achievement Index and the Environmental Sustainability Index (Hermans et al. 2009a). Therefore, this research will focus on using the intermediate outcome indicators.

1.3 Problem Statement

Many separate indices do not give an understandable or meaningful idea of the broader picture (Saisana et al. 2005; Shen et al. 2012; Chen et al. 2015). In addition, assessment by each index separately ignores the contribution weight of each indicator on the overall system. Furthermore, policy makers desire one indicator to set targets and priorities which are essential in making strategic decisions. Moreover, for the requirement of comparison and benchmarking, one index is the most suitable and correct style of measurement (Wegman et al. 2008b). Therefore, there is a need to aggregate the intermediate-outcome indices into one overall index.

An aggregated index is integrating or compiling mathematically individual indicators into easily understood formats (Freudenberg 2003; Saisana et al. 2005; JRC-EC 2008). It is recognised as a useful tool in summarizing, interpreting and highlighting the characteristics of complex or multi-dimensional systems. It is used to avoid troubles resulting from finding a trend in many separate indicators and to reduce the size of a list of indicators (Saisana et al. 2005; JRC-EC 2008).

There have been attempts to construct aggregated road safety indices in the last two decades, as will be shown in Chapter Three. Various indicators are considered in these attempts and some of them are related to the components of the safe system approach : safer road infrastructure, safer speed, safer vehicles and safer road-user behaviour. The indicators of safer road-user behaviour were the most considered in the previous studies because they were based on the traditional vision of road safety issues, where road-user behaviour is the main factor. Safer vehicles are also considered by most of these studies, as the vehicles' development has been investigated and addressed since the 1990s. The (EuroNCAP 2017), which is the new car assessment programme for European countries, is used widely to indicate and assess vehicle safety.

However, not all the measures related to the safe system approach are fully reflected by the selected indicators. In addition, safer road infrastructure and safer speed limits are not considered effectively. This may result from the lack of valid methodologies, at the time of conducting the research, to measure the impact of the multiple factors of road infrastructures and mobility on the overall level of road safety. It also may result from a lack of necessary data, especially for new programmes that have been considered recently, such as protecting pedestrians and cyclists by separated roads and using a mobile phone while driving.

1.4 The Scope of the Study

This research addresses the gap in defining comprehensive, measurable, independent and valid indicators of safer road infrastructure and safer speed management, and aggregates them with the indicators of safer road-user behaviour and safer vehicles, including the most common and the newly considered indicators, to construct an overall road safety index. The tools of road safety assessment at the disaggregating level will be reviewed to select the one that meets the aim and objectives of this research. The most valid and the only methodology of road infrastructure assessment based on the safe system approach concept, which is the road assessment program (RAP) (iRAP 2017), is investigated in this research for use in indicating the road infrastructure and mobility safety. The methodologies of assessing the vehicle safety and finding the vehicles safety index are also reviewed and investigated. The factors of road user behaviour are reviewed also to consider the factors that have more impact on the road safety system in developing the suggested index. The selection of indicators and aggregating them are evaluated to assess the achieving of the developed index in achieving its purpose. The purposes of developing this index is assessments of the national strategic plan of road safety and comparing them with other strategic plans of other countries. This index also may be sued in rating countries, monitoring progress towards a set target and suggesting solutions to improve the road safety level.

1.5 The Aim and Objectives of the Research

The question raised in this research is to what extent the safe system approach contributes to the national road safety strategies. To answer this question, an assessment of road safety performance is needed. Since the index is the tool used in assessing the road safety performance, it is necessary to develop an index that may reflect the safe system approach concept and assess the road safety performance on a national scale.

Hence, the main aim of the research is to develop a simple to use and understandable index of road safety, to assess whether road safety at a national or regional scale are in accordance with the safe system approach, to rate and rank countries and to monitor the strategic plan progress towards a set target and to suggest strategic road safety plan. Achieving these aims may lead to improve the road safety level at country and sub-domain level. To achieve this aim, the following objectives should be considered:

- To identify the components of the Road Safety Assessment Index (RSAI) based on the safe system approach principles, which cover safer road infrastructure and mobility, safer vehicles, and safer road-user behaviour.
- To extend the ability of using the RAP methodology to produce a thematic index of safer road infrastructure and mobility and integrate it with indices that concern vehicles and road users.
- To develop and test a model to aggregate the selected indicators of road infrastructure and mobility with the vehicle and road-user behaviour indicators, to find the values of the RSAI.
- To evaluate the developed model of the RSAI in terms of achieving its purposes as an index for strategic studies and plans to improve road safety.

1.6 Thesis Structure

To meet the main aim and objectives of this study, this thesis is structured as follows:

1. Chapter Two describes the concept of the safe system approach . This theory is the base of the theoretical framework of the developed index in this study. It is focused on the main principles of the safe system approach , which are safe road infrastructure, safer speed limits, safer vehicles and safer road-user behaviour. The risk factors of road-user behaviour are reviewed: including the consuming of psychoactive substances, using protective systems, speeding, and using a mobile phone while driving.

2. Chapter Three reviews the previously developed indices in the assessment of the performance of road safety. Two points are considered in this chapter: the indictors selected to construct the developed index and the method of weighting and aggregating indicators.

3. Chapter Four describes the overall methodology of this research in developing the proposed index of road safety assessment (RSAI). It outlines the development of the theoretical framework and the setting of the structure of the thematic and individual indices; weighting and aggregating of the indicators to develop the RSAI main model and its sub models; evaluation of the developed model; and the application of the developed model in ranking, rating and monitoring progress of current strategies.

4. Chapter Five presents the methodology of selecting the indicators of the RSAI. It illustrates the selected thematic indicators; then the setting of the candidate set of individual indicators. The evaluating process of the candidate indicators and the criteria that they are based on in the evaluation process are presented in this chapter. The final set of indicators are also presented.

5. Chapter Six illustrates the process of developing the RSAI main model and its sub models. The sub models represent the thematic indicators which are the road infrastructure and mobility, safer vehicles and safer road user behaviour. The terms of each model, including the variables and their weights, are shown in this chapter. It also explains the aggregating process of the models' terms to produce the preliminary forms of the proposed models.

6. The index of the safer road infrastructure sub model needs to extend the RAP methodology and find an aggregated RAP star rating. The process of developing this methodology is shown in Chapter Seven. Two approaches are proposed in the chapter to produce preliminary aggregated star ratings.

7. In Chapter Eight, the developed preliminary aggregated star ratings in Chapter Seven are evaluated. The method of evaluation is discussed and decided in this chapter. Then, the processes of selecting roads and gathering the necessary data are presented, and the results of the evaluation are analysed to select the final model for identifying the variable of the safer road infrastructure sub model.

8. The developed sub models are aggregated to produce preliminary main RSAI models, which are evaluated in Chapter Nine. The method of evaluation is discussed and decided in this chapter. Then, the procedure of selecting countries for applying the RSAI is shown. The results of the evaluation are discussed to select the most suitable RSAI that achieves its particular purposes.

9. Chapter Ten presents an investigation of using the RSAI model in ranking and rating countries according to their level of road safety and the effectiveness of the road safety strategic plan.

10. Using the RSAI model in monitoring progress of road safety strategic plan towards a set target and setting options of a strategic solution is investigated also in Chapter Eleven.

11. The results of this study are discussed in Chapter Twelve; while the conclusions obtained from this investigation, and suggestions for future works are presented in Chapter Thirteen.

CHAPTER TWO

SAFE SYSTEM APPROACH

2.1 Introduction

The safe system approach is highly recommended by the WHO and the UN to be considered in the national road safety strategies as it is the most effective guide offer successful road safety management through a process of continual improvement in road safety performance, towards the set targets of no road fatalities and injuries (Peden et al. 2004). A significant change in the rate of road fatalities is achieved in some countries, such as Sweden and the Netherlands a result of applying the concept of the safe system approach. It is also considered in the global strategic plan such as the resolution of the Decade of Actions in Road safety (2011-2020) which is proclaimed by the UN and supported by the WHO and the World bank (UN and WHO 2011; WHO 2015).

To understand deeply the principles of the safe system approach and its components, this chapter illustrates the concept of the safe system approach . The components of the safe system approach and their impact on the road safety level are explained in this chapter.

2.2 The Concept of the "Safe system Approach "

The safe system approach aims to develop a proactive and preventable road safety system aimed at no crashes or at least no road deaths and injuries. Its concept is based on two main points. The first point is that road safety is a multi-dimensional system where all its dimensions have roles in this system; while the traditional concept considers the road user's behaviour as the sole causes of the road crashes (Larsson et al. 2010). The second point is that the road user is the weakest element, the victim not the criminal in this system and the other components should accommodate the physical limitations and vulnerability of humans. This means that the impact forces in the crash event should not exceed the physical limits of the human body (Peden et al. 2004; WHO 2009; UN and WHO 2011; ITF2016; Woolley et al. 2018). This has been achieved by improving the design standards of roads and vehicles, managing speed limits, and producing innovative interventions in which the elements of the safe system approach are incorporated (OECD 2008; Turner 2013; WHO 2015; Turner and Jurewicz 2016; Woolley et al. 2018). Figure 2.1 shows the concept and the components of the road safety system approach. It is shown that the main components of the safe system approach are safer road infrastructures, safer speeds, safer vehicles, and safer road user behaviour. In the further sections, the elements of the safe system approach will be explained.

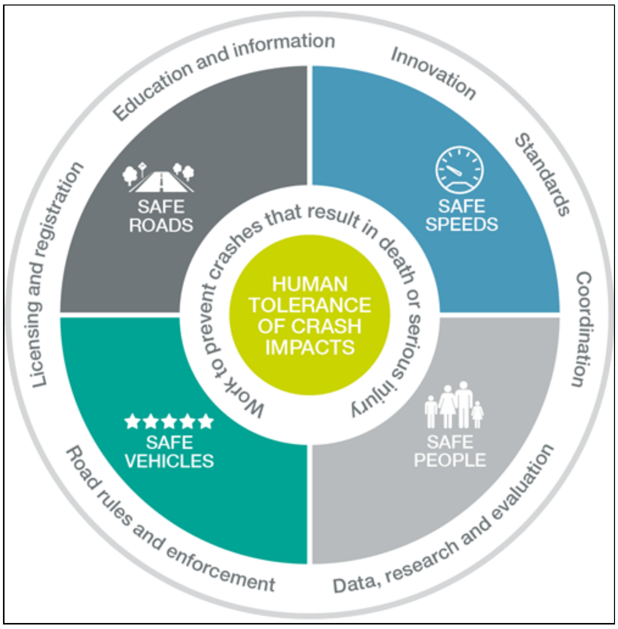

Figure 2.1 Safe system approach diagram (Department of Transport and Main Roads 2015)

2.3 Safer Road Infrastructure

Planning and designing of the roads' infrastructure according to the needs of all road user groups is essential in providing a safer environment for road users (Robinson and Thagesen 2004; Larsson and Tingvall 2013; Woolley et al. 2018). Reducing road crashes and fatalities is also achieved through treating existing roads with a high rate of road crashes (Robinson and Thagesen 2004; ITF 2016).

Preventing road crashes and fatalities is considered through the road safety impact assessment of road design alternatives and through road safety inspections. In these stages, the standards for safer roads should be checked. These standards might be modified in most of the high-income countries to ensure the elimination of the probabilities of conflicting points between vehicles and between vehicles and vulnerable road users. They were modified also to keep the impact energy in the crash event below levels that will cause fatal or serious injury (Robinson and Thagesen 2004; McInerney and Smith 2009; ITF 2016).

The safe system approach standards consider the safe-explaining and forgiving roads (Bekiaris and Gaitanidou 2011; Mackie et al. 2013) which produce a 30% reduction of road fatalities in Europe (Stigson et al. 2008). Self-explaining design considers the needs of all road users through clear communication and interaction between road and driver. Drivers should be able to predict the mass and speed of the used roads to behave appropriately and use the roads effectively with less distraction. The classes of roads network should be clearly defined and distinctive not only with their layout or with adequate markings and signing but also with the set speed for each class of road and the expected mass of traffic using the roads (Miller and Zaloshnja 2009; Bekiaris and Gaitanidou 2011). This should also consider the need of cycling and walking and identify the priority of using the road through setting safer speed and providing road class with less motorists traffic (Wegman et al. 2012; Mackie et al. 2013). The self-explaining standards reflect three out of the four key principles of sustainable safety which are functionality, homogeneity, and predictability (van Vliet and Schermers 2000; Wegman et al. 2005). The fourth key principle is reflected by forgiving standards. Forgiving road environments considers driver errors through designing and treatment. For example, lane separation devices are provided to correct unintentional lane departure errors which is a significant factor of road crashes (Wegman et al. 2005; Bekiaris and Gaitanidou 2011).

Road assessment and inspection (ETSC 2001) are highly recommended by the WHO and the UN since it is proved to be factor in reducing the rate of road collisions. For example, the road safety audit in Surrey in the UK has resulted in reducing the average number of casualties by 1.25 per year which is a drop of more than 80% compared to the average reduction in the number of road casualties in unaudited sites. In addition, the audit of a road project at the design stage saved about an average of GBP 11,373 more than the project audited at the construction stage. Therefore, it is considered a cost-effective approach (OECD 2008).

The existing road should be investigated to identify section with high rate of road fatalities and serious injuries, which indicates the need for treatment. Turner et al. (2013) classified road safety treatments into “primary” and “supportive”. Primary treatments contribute more to the Safe system approach principles while supportive treatments provide improvement at the level of road safety, but not to a level that would create a safe system approach . A median barrier is an example of a primary safe system approach treatment as it is proved to reduce the number of fatal head-on crashes about 90%. Well-designed roundabouts, grade-separated pedestrian crossings, and wire-rope barriers are other examples of primary safe system approach treatments. A wide centreline and rumble strips are examples of supportive treatments that lead to less likely reduction (ITF 2016; iRAP 2017; Woolley et al. 2018).

Many road authorities in the world tend to redesign the traditional road policy instruments in ways consistent with a safe system approach . The next section presents a review some of the tools of road safety assessment which are used by road safety experts in the assessment stage of road design and construction.

2.3.1 Road safety assessment tools

Table 2.1 shows a brief review of some models and software which have been used by some world safety agencies to study, evaluate, predict, or improve the level of road safety and to address its factors. It can be found that most of these models aim to quantify the road risk problem, identify the high risk roads, and suggest infrastructure treatments to control this issue. However most of these models can be used in a local area with their local specification and characteristics. The MAAP (Microcomputer Accident Analysis Package) and SafetyNet (Hills and Baguley 1993; TRL 2017) and the Guidelines for Safety Analysis of Road Networks (ESN) models (Brannolte et al. 2009) are based on crash data as inputs to assess the road safety level which are not available le in most of low and middle income countries. The International Road Assessment Programme (iRAP) (iRAP 2017), Highway Safety Manual (HSM) (National Research Council 2010) and the Road Safety Risk Manager (RSRM™) (ARRB 2017) were developed to assess road safety standards and suggest the required treatment, which are based on an economical investment plan without need to historical crash data. The iRAP is recommended more by the WHO and the UN; and it is also recommended by the local road safety agencies in many developed countries because the iRAP methodology is refined to consider the concept of the safe system approach and the responsiveness to emerging road safety treatments (Gitelman et al. 2014). Furthermore, the iRAP assessment score, which is in terms of a star rating, is incorporated as a quantified global target to achieve the goals of the Decade of Actions on Road Safety (DARS 2011-2020) and the sustainable Development goal (SDG) (UN and WHO 2011; WHO 2015). Three stars is considered the target that can save half of road users' lives. The iRAP is also widespread worldwide; it is produced in many local versions such as the European Road Assessment Programme EuroRAP, the Australian Road Assessment Programme AusRAP, the New Zealand Road Assessment Programme KiwiRAP, and the United States Road Assessment Programme usRAP (iRAP 2017). More details about iRAP are shown in Appendix I.

Table 2.1 Review of some road safety models and software

Model Name	Use	Inputs	Outputs	Area of Application	Features
iRAP different developed versions (AusRAP, EuoRAP, UsRAP) (iRAP 2017)	• Assessing the new and existing road safety standards • Suggesting treatments and countermeasures • Producing an investment plan	• Road attributes • Vehicle composition flow • Speed	• Road safety class in terms of star rating for four different road user groups • List of suggested countermeasures with its investment plan	More than 80 countries	Refined the risk models to provide improved responsiveness to emerging road safety treatments
HSM Highway Safety Manual (National Research Council 2010)	• High risk site identification • Safety factors and countermeasures addressed • Economic analysis • Treatment suggestion • Policy decision.	• For predictive model: traffic flow, geometric characteristics of roads, and time period. • For descriptive model: crash detail data and severity	• Crash frequency • Crash modify factor (CMFs) to quantify the forecasted change which resulted from geometric or operational modifications.	USA	• Limited to the standards of the US roads • Risk factors should be determined by users (Nye et al. 2017) • More complicated process • Expensive
MAAP (iMAAP new version) Microcomputer Accident Analysis Package (TRL 2017)	• Road accidents reporting • Road accidents analysis • Road accidents factors identification • Data storage • Black spot Identification	• Location • Accident type and severity • Vehicle type • Length of the road	• Accidents rate can be presented by tables and graphs • They can be analysed by location using digital GIS maps	UK as well as places such as Jamaica, Saudi Arabia, and Indonesia.	• It is based on road crash data • Less comprehensive • Expensive

Model Name	Use	Inputs	Outputs	Area of Application	Features
	• Economic Evaluation				
RSRM™ The Road Safety Risk Manager (ARRB 2017)	• Road safety assessment • Local safety condition management • Road ranking • Providing treatment alternatives • Economic evaluation	• Road Geometric characteristics • pavement surface • parking • environment and weather • vehicle and traffic characteristics	• Risk Score • Relative risk • Budget analysis	Australia	Reflect the findings of an extensive Austroads research project
SafeNET 2 (TRL 2017)	• Software for Accident Frequency Estimation for Networks • Urban and rural road planning and design	• Accident data • Traffic flow • road geometric characteristics	Forecasted accident frequency	The UK	• It is based on accidents' data • Less comprehensive • Not well approved
ESN, Guidelines for Safety Analysis of Road Networks (Brannolte et al. 2009)	• Crash evaluation in term of "accident cost rate" • Risk potential • Safety improvement criteria	• Accident data • Traffic flow •	• Accident-cost density /km • ESN-mapping	Germany	• It is based on accident data • Limited to the standards of German roads

2.4 Safer Speed

Managing speed is essential through setting speed limits to manage the interactions between vehicles and valuable road users (OECD 2008; WHO 2008; Larsson and Tingvall 2013). It is considered a complementary cost effective intervention to create a safer road system in the short term (Woolley et al. 2018). Managing the speed limit achieves a reduction in fatal and serious injury crashes by 30% (Wegman et al. 2008a; Corben et al. 2010; Turner 2013; Gitelman et al. 2014). ETSC (2001) shows the demonstrations of studies which present a reduction of 3% in the number of accidents and 5% in the number of fatalities as a result of a reduction of 1 km/h in the vehicle speed.

Road safety experts and researchers have indicated that the speed limit should be identified according to the type, class and function of the road, in addition to the road user group (OECD 2008; Turner and Jurewicz 2016). May et al. (2008), Belin et al. (2012), WHO (2013b) and Turner and Jurewicz (2016) show that vehicle speed more than 30km/hr leads to more serious injuries and fatal collisions within pedestrian group and speed over 60km/hr leads to increase the likelihood of severe injury or death within all road user groups. In Australia 30 km/hr is the safer speed limit for vulnerable road users, which is recommended by the WHO (2013b). While 50 km/h is considered the safer speed to reduce the consequences of a car side impact on motorways and at intersections; and 70 km/h to prevent head-on car crashes (Turner 2013; Woolley et al. 2018).

Speed management is considered in the RAP methodology by identifying the risk factor according to the speed limit and the road type, as shown in Figure 2.2. The RAP methodology also considers the setting of road countermeasures to limit the negative effect of excessive speed, such as using speed humps and raised platforms (OECD 2008; Harwood and Mclnerney 2011). This is supported with providing vehicles with speed assistance system to warn drivers when the speed is above the set limit (Chorlton and Conner 2012; EuroNCAP 2017).

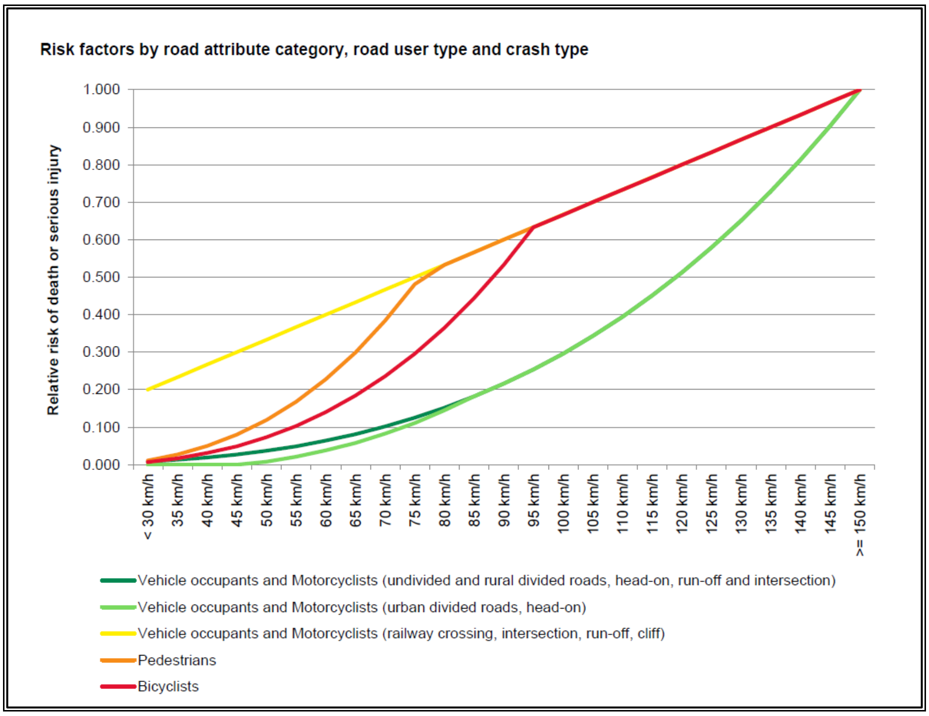

Figure 2.2 Speed factor effect on the road risk by road attribute category, road user type, and crash type (iRAP 2017)

2.5 Safer Vehicles

Vehicle safety has a role in the reduction of the crash rates and severity (Pei et al. 2012; Jackisch et al. 2015). The WHO expected that 50% of disability injuries resulting from road crashes would not occur if safer standards of vehicles were applied in all countries (OECD 2008).

Safer vehicles are achieved at two levels: improving the active safety and passive safety standards. Active safety measures the requirements for the technologies provided in the design of the vehicles which are more likely to prevent vehicles crashes; such as stability control, an anti-brake system (ABS), and speed limiters. Passive safety measures the requirements for protecting the cars' occupants in the crash event from serious consequences; such as air cushion technology, padded dashboard and seat-belts (Wegman et al. 2005; OECD 2008; Corben et al. 2010; Jackisch et al. 2015; Woolley et al. 2018).

There was a need to consider the requirements for safer vehicles. Therefore, a test was developed about three decades ago to conduct standardised crash barrier tests under laboratory-controlled conditions, tests of the safety standards of the design layout of vehicles; and assessment of the availability of the supporting technologies (Wegman et al. 2005; Jackisch et al. 2015; Woolley et al. 2018). This is called the New Car Assessment Programme (NCAP). It is considered a successful, and may be the only provided test, designed to consider the combinations of the demand and supply of vehicles, and to encourage the consumers to consider safety criteria in choosing their cars. It also encouraged vehicle manufacturers to produce five-star vehicles (NHTSA 2007; EuroNCAP 2017). The NCAP is highly recommended by the WHO and the UN as a tool for assessing the safety requirements of vehicles and as an indicator of the crashworthiness (UN and WHO 2011; Gitelman et al. 2014).

This crash testing programme was first applied in Europe and then Australia, Japan, Korea and China (Hobbs and McDonough 1998; NHTSA 2007; OECD 2008; ITF 2016). It has published the assessment rating of about 500 models of vehicles (van Ratingen 2017). It is reported that in Europe the road fatalities have been reduced by about 25% within 10 years because of the contribution of EuroNCAP, which is the European version of NACP, with use of the assessment tools of the road safety requirements (Jost et al. 2011).

The NCAP star rating is used in setting the targets for improving the safe vehicle pillar and in conducting the impact of improving the safety standards of vehicles on overall level of road safety system. For example, Gitelman et al. (2014) refers to studies demonstrating that the risk of being killed in a one-star vehicle is double that of a five-star vehicle and the reported three and four star ratings are 30% safer. More details about NCAP are shown in Appendix II.

2.6 Safer Road User Behaviour

The behaviour of the road user must be improved to follow the rules of the road safety system and avoid deliberate errors which are the reasons behind about 30% of road crashes in the pioneer countries; these are countries that have achieved a significant decline in road fatalities and serious injuries, such as Sweden and the Netherlands (Wegman et al. 2005; ITF 2016). The WHO (2015) shows that establishing laws that meet best practice is one way of improving road user behaviour. Practises in the pioneer countries have shown that adopting and enforcing road safety laws is effective in improving road user behaviour (Wegman et al. 2008a; Larsson et al. 2010; WHO 2015). It has been shown that there are five factors which are important to be considered in road safety laws' legislation. They are: speeding, drunk–driving, using helmets, wearing seat belts and using child restraints (WHO 2013b). Two risk factors, using a mobile phone and drug-driver have emerged later to add to the five factors from the WHO (2015) because of their impact on driver behaviour. The WHO (2015) shows that 17 countries have changed their road safety laws to bring in legislation on one or more of these risk factors. The previous studies on defining the road safety performance indicators considers these risk factors as the main indicators (ETSC 2001).

The practises also demonstrated that the most noticeable improvement in road user behaviour happen when road safety legislation is supported by a strong and sustained enforcement (Wegman et al. 2008a; UN and WHO 2011; Larsson and Tingvall 2013; WHO 2013b; Jackisch et al. 2015). This can be achieved by setting penalties ranging from driving license demerit to administrative fines, licence withdrawal, vehicle impoundment and even imprisonment (WHO 2013b).

The effect of the seven main risk factors of road user behaviour on the road safety level will be explained in the next sub sections.

2.6.1 Speeding

Excessive speed is one of the major factors of severe road crashes because of its direct impact on the probability of a crash occurrence and its severity (Papadimitriou 2018). It is considered a main contributing factor to 10% of the total number of accidents and to about 30% of fatal crashes worldwide (Wegman et al. 2008b; WHO 2013b). Enhancing the use of the decided speed limits by drivers is essential to get the benefit of setting speed limit intervention (Wegman and Goldenbeld 2006; OECD 2008). The enforcement of speed limits is highly recommended to ensure safer road usage (WHO 2013b). Figure 2.3 shows the effect of the speed limit law and enforcement on the road deaths' rate.

Many methods of enforcement are employed to facilitate speed management. Innovative technologies are used, such as speed camera, which have a role in reducing speeding offences by 70% and saving 32% of road fatalities (Wegman et al. 2008b).

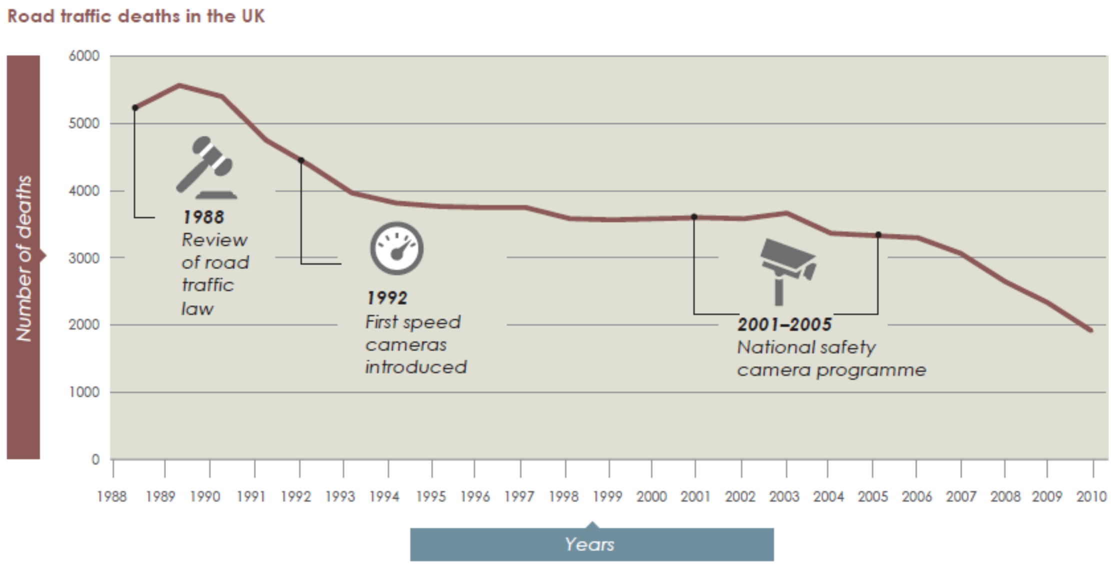

Figure 2.3 The improvement in road safety via speed law legislation and enforcement (Achterberg 2007)

2.6.2 Psychoactive substances

Consuming psychoactive substances including alcohol and illegal drugs have a significant effect on the behaviour of road users, as will be explained in the next sub-sections.

2.6.2.1 Drunk-Drivers

Drinking alcohol is one of the most important factors that has direct impact on the increasing of risk on roads (ETSC 2001; Ramstedt 2008; Wegman et al. 2008b; Hermans 2009; Assum and Sørensen 2010). Drinking alcohol produces deficits in the ability of humans to operate a motor vehicle (Martin et al. 2013). It is attributed to about 32% of fatal crashes in the world (Peden et al. 2004). Blood alcohol content (BAC) is the variable used to measure the effect of alcohol drinking on road safety (Wegman et al. 2008b). Hakkert et al. (2007) referred to the results of some studies which stated that the rate of road fatalities increases with the increase in the BAC. For single-vehicle crashes, each 0.02% increase in the BAC level approximately doubles the risk of ending up in a fatal crash (Peden et al. 2004). The drinking-driving law was passed in the best practices based on a maximum BAC of 0.05 g/dl for the general population and ≤0.02 g/dl for novice and commercial drivers. It is reduced to 0.02 g/dl for all drivers in some countries such as the Netherlands, which has produced a noticeable improvement in the level of road safety (Wegman et al. 2008b; WHO 2013b; Jackisch et al. 2015).

The introduction of drunk-driving laws reduces fatal accidents by 26% (Hakkert et al. 2007; Wegman et al. 2008a). Drunk-driving enforcement may save 9% more of road users (Elvik and Vaa 2004 adapted by (Hakkert et al. 2007)). Enforcement is applied to ensure more effective drink-driving laws via strict penalties and fines. Breath testing is used to check the BAC of drivers to monitor on a systematic basis (ETSC 2001; Hakkert et al. 2007; Bax et al. 2012; Jackisch et al. 2015). Figure 2.4 shows the evolution of drinking-driving regulations in Sweden, where there was a significant improvement in the rate of drinking drivers' behaviour.

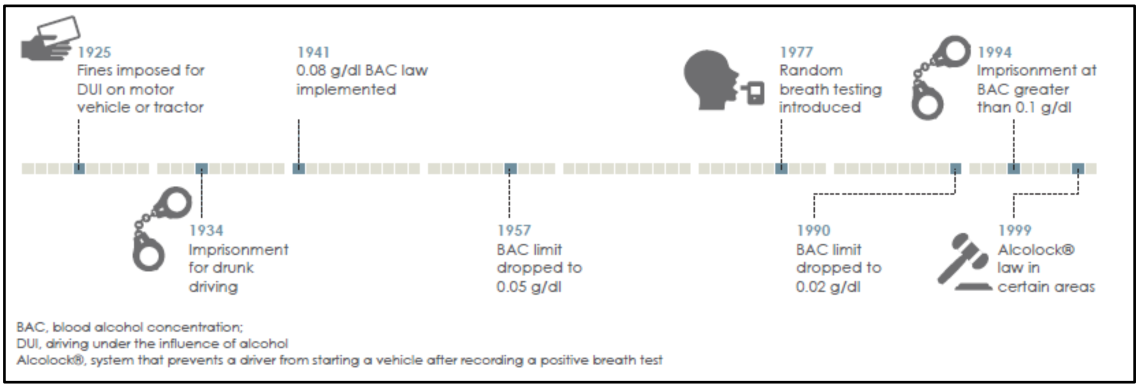

Figure 2.4 Evolution of drinking-driving laws and regulations in Sweden (WHO 2013b)

2.6.2.2 Consuming drugs

The effect of drugs' intake was considered recently in the legislation of road safety laws. It is considered as less known and most complicated for testing because of the different types of drugs in different countries (WHO 2015). Therefore drugs are categorised into two types: legal and illegal drugs. The legal drugs include the medical drugs prescribed by doctors while illegal drugs are the medical drugs in abusive doses (Hakkert et al. 2007). Studies referred to by Hakkert et al. (2007) stated that the intake of morphine or heroin increases the probability of a crash occurring 32 times. Wegman et al. (2008b) showed that 50% of the alcohol and drug-related crashes in the Netherlands resulted from alcohol only, 25% resulted from consuming drugs, and the remaining 25% from a combination of alcohol and drug consumption. However, enforcement of drug laws remains a challenge even in best practice countries because there is no proved method of measuring the drugs' concentrate (Jackisch et al. 2015).

2.6.3 Using protecting systems

2.6.3.1 Using seat belts

The use of seat belts is one of the effective means of reducing the severity of traffic and road crashes. It is stated that improving seatbelt wearing results in saving the lives of 40%-65% of car occupants (ETSC 2001; WHO 2013b; Gitelman et al. 2014). It reduces the risk of a fatality among front-seat passengers by 40–50% and of rear-seat passengers by between 25–65% (Achterberg 2007). This is achieved by seat belt law legislation with firm police enforcement (WHO 2013b). The recent use of seatbelt reminder technology and seat belt ignition interlock, that prevents a vehicle from operating if there is an unrestrained occupant (OECD 2008), enhances the increase in using a seat belt by car riders. According to the safe system approach, it is recommended that wearing seatbelts should be required in all motor vehicles in both front and rear seats (WHO 2013b).

2.6.3.2 Child restraints

Child restraints seats are developed for children shorter than 1.35 m in Europe or under 12 years or 9 years of age in different countries, in the front or in the back of the car (Bax et al. 2012; Brubacher et al. 2016). Using child restraint has reduced fatal injuries among infants by around 70% and among children under the age of 5 by about 54% (ETSC 2001; Peden et al. 2004; WHO 2013b; Gitelman et al. 2014). It also reduced the serious injuries by about 90% (ETSC 2001). Ekman et al. (2001) referred to some studies in Sweden in which it was stated that when the using of child restraints' level was raised to 97%, the child fatalities on the roads reduced to 2.8 per year and to 76 over 26 years. Brubacher et al. (2016) concluded that using child restraint laws together with public education and awareness campaigns produces better results (Jackisch et al. 2015).

2.6.3.3 Motorcycle helmets

The use of helmets for motorcyclists is included in the national law of road safety which should be applied for all motorcycle drivers and riders. This includes the safety design requirement of the helmet to be fastened. Wearing helmets has been shown to have a clear impact on reducing fatal and serious injuries by between 20% to 45% for motorcyclists and 60% to 80% for bicyclists (Peden et al. 2004; Al-Haji 2007; Hakkert et al. 2007). It is also demonstrated that using motorcycle helmets can reduce the risk of head injury by almost 70% (ETSC 2001; Bambach et al. 2013; WHO 2013b; Gitelman et al. 2014) and bicycle helmets reduce the risk of head and brain injuries by 63% to 88% (Shen 2012; Høye 2018).

2.6.4 Using mobile phones during driving

Using mobile phones during driving is a major cause of distracted driving, which is a growing concern for road safety and driver performance (WHO 2015; Gariazzo et al. 2018; Rahman et al. 2018). This is because the usage of mobile phone results in higher speed variation and longer reaction time (Papadimitriou 2018). Rahman et al. (2018) referred to the studies of Caird and Scialfa (2005), Schreiner et al. (2004) and Strayer et al. (2001). These studies show the response time of drivers using mobile phones to a sudden event and taking emergency action may be later than undistracted drivers by more than a half second and a longer distance to recover speed is needed. Rahman et al (2018) also referred to Brace et al.'s (2007) research which demonstrated that both hand-held and hands-free mobile phones have a negative effect on the driver's performance but, the hand-held phone affects the physical performance in addition to the cognitive performance.

The risk of road crash increases when using mobile phones by approximately 17% to 54%, depending on the period length of the call and the number of text messages and people connected according to Gariazzo et al. (2018). The danger of mobile phone distraction is more at intersections because of the challenge that the drivers face in decision making (Rahman et al. 2018). Therefore, recently, the road safety laws in most countries prohibits the using of hand-held phones and hand-free phones while driving (Jackisch et al. 2015). Despite that, the recent studies showed that the rate of road fatalities involved using mobile phone is raised. Therefore, it is necessary to investigate this issue effectively (He et al. 2014).

2.7 Summary

This chapter presented an overview of the concept of the "safe system" approach. This approach considers that the road users' behaviour is not the main cause of road crashes, but road infrastructure with effective speed management and vehicles' design should be improved to accommodate the vulnerability of humans. Models and programmes of assessing the safety requirements of safer road infrastructures are reviewed and it is concluded that the RAP is the most comprehensive and relevant to the concept of the safe system approach . The NCAP is also considered in this review as the only tool provided and well proved by previous studies for assessing the requirements of safer vehicles. In addition, the traditional action of improving the behaviour of the road user should be enhanced with new measures of the risk factors related to road user behaviour. These factors are categorised into four groups: speeding, consuming psychoactive substances (alcohol and drugs), using protective systems (seat belts, child restraints, and helmets), and distracting by using a mobile phone while driving. This chapter covered details regarding the effect of these factors on overall road safety.

The next chapter will review the literature that considers the factors of the safe system approach in constructing road safety indices.

CHAPTER THREE

REVIEW OF THE ROAD SAFETY INDICATORS AND METHOD OF AGGREGATION

3.1 Introduction

To construct an index in a correct and scientific manner, it is important to review the methods and techniques which are used in the development of previous indices. Therefore, the most recent road safety indices are reviewed in this chapter. Two main points are considered in this review. The first point concerns the criteria used to decide the final set of indicators and the selected indicators with regard to the main components of the safe system approach. The second point covers the methods and techniques used in the weighting and aggregating of the developed indices.

3.2 Selecting Indicators

In this section, the selected indicators in previous studies and attempts of developing road safety indices are reviewed. It is focused on the indicators that are related to the four main components of the safe system approach : safer road infrastructure, safer speed, safer vehicle and safer road user behaviour. It is focused also on the criteria that the selection of the indicators are based on. Summary of this review is shown in Table 3.1.

Table 3.1 Summary of the reviewed literature in terms of the criteria of indicators selection and the selected indicators

The index	The author	The criteria of selection indicators	The selected indicators		
			Road infrastructure and mobility	**Vehicles**	**Road user behaviour**
Transport safety performance index	(ETSC 2001)	• Relevancy to the best practice in Europe • Data availability	• % of roads meeting design standards • %of roads fitting in road network hierarchy	EuroNCAP 4 score	• % above legal limit speed • % above max. BAC • % wearing seat belts • % of using child restraints
The European SafetyNet project	• (Vis 2005) • (Hakkert et al. 2007) • (Vis and van Gent 2007) • (Gitelman et al. 2014)	• Experiences • Data availability	EuroRAP scores	EuroNCAP score/ vehicle age	• % fatalities resulted from drinking alcohol and consuming drugs • % of speed limit offenders • rate of wearing seat belts in front and rear seats • rate of wearing helmets by two-wheels riders
Road Safety Development Index (RSDI)	(Al-Haji 2007)	• Data availability • Quality • Measurability • Clarity and simplicity • Reliability	% of the paved roads per total network	%vehicles in the total vehicle fleet	• % of seat belt use • % of helmet use
SUNflower and SUNflowerNext studies	• (Wegman et al. 2008b) • (Wegman and Oppe 2010)	• Quality aspects • Sensitivity in time • Relevancy to policy		• EuroNCAP score • Vehicle fleet composition • Median age of the passenger car fleet	• % fatalities resulted from drinking alcohol • wearing rates of seatbelts in the front seats • wearing rates of seatbelts in the rear seats

The index	The author	The criteria of selection indicators	The selected indicators		
			Road infrastructure and mobility	Vehicles	Road user behaviour
		• Recognisability and clarity			
Road safety performance index	• (Hermans et al. 2008) • (Hermans 2009) • (Hermans et al. 2009b)	• Relevancy • Measurability • Interpretability • Specificity • Sensitivity • data availability • Comparability • Reliability	Infrastructure network density	% cars < 6 years	• % road users < speed limit • % road users < BAC • % seatbelt wearing
Composite indicator for road safety	(Gitelman et al. 2010)	Data availability		• crash worthiness • composition of vehicle fleet	• wearing rates of seat belts • alcohol-impaired driving
The DaCoTA study on Road Safety Index	(Bax et al. 2012)	Data availability		• % score of pedestrian protection for new cars sold • Average renewal rate of passenger cars	• Road-side police alcohol tests per 1,000 population • % of drivers above legal alcohol limit • Daytime seat belt wearing rates on front seats • Daytime wearing rates of seat belts on rear seats of cars
International benchmarking of road safety performance	(Shen 2012)	Data availability	• Motorway density • % of motorways	• % of vehicles > 6 years • % of old vehicles > 10 years • % of heavy vehicles • % of two-wheeled vehicles	• % of drivers > max BAC limit • % of fatalities attributed to alcohol • % of drivers > max speed limit on urban, rural, and motorway roads

The index	The author	The criteria of selection indicators	The selected indicators		
			Road infrastructure and mobility	Vehicles	Road user behaviour
				• % of cars awarded 5 stars on car occupants • % of cars awarded 4 stars on child restraints • % of cars awarded 3 stars on pedestrian protection	• % of wearing seat belt in front and rear seats • % of using child restraints
Global status report on road safety (GSRRS)	(WHO 2015)	Relevancy to safe system approach Policy	• Is speed limit set according to the road class? • Is the protection of vulnerable road users and separation their infrastructure considered by national road policy? • Is the Public transport promoted as an alternative to car travel by national policy? • Is the cycling and walking promoted as alternative to car travel by national policy? • Are roads regularly assessed for safety?	Are the following technologies promoted in the standards design of vehicle? - seat belts - anchorages - child restraint systems - frontal and side impact protection -pedestrian protection - electronic stability control - anti-lock braking systems	• % of road deaths involving alcohol • % wearing seat belts in front and rear seats • % of drivers and riders using helmets • % children using child restraints • Enforcement score on speeding, drinking alcohol, wearing seat belt, wearing helmet, using child restraints, using mobile phone, drug-driver • Is drug-driver law legislated? • Is the using mobile phone while driving is legislated?

The index	The author	The criteria of selection indicators	The selected indicators		
			Road infrastructure and mobility	Vehicles	Road user behaviour
Road Safety Development Index (RSDI)	(Chen et al. 2017)	Data availability	• % of paved roads • Enforcement scores on road safety audits	• % of vehicles not motorcycles • Enforcement score on vehicle standard applied	• % fatalities involving alcohol, • % of seat belt use front seat, • % of using helmets
	(Tesic et al. 2018)		• density of motorways	• % of cars < 6 years	• of surveyed car drivers < max BAC • % of surveyed car drivers< speed limit • Seat belt wearing rate at front seats

3.2.1 The criteria for the selection of individual indicators

In most of the reviewed research which is shown in Table 3.1 (Vis 2005; Al-Haji 2007; Hermans 2009) and in other studies which developed indices in other domains (Ledoux et al. 2005; Farchi et al. 2006; Litman 2007), the indicators are selected through at least two stages. In the first stage, the first set of candidate indicators are suggested. Then in the second stage, the suggested indicators are refined based on specific criteria. In general, the criteria for selecting indicators are:

1. Relevancy to the phenomena of the index or the policy that the index is used to assess (Booysen 2002).
2. Measurability (Ledoux et al. 2005): indicators should be quantifiable on objective or subjective terms, or in ordinal or numerical forms (Booysen 2002).
3. Comprehensiveness (Al-Haji 2007): indicators should measure all or most of the factors related to the domain of the index.
4. Simplicity (Booysen 2002; Farchi et al. 2006; Litman 2007): they should be understandable.
5. Comparability (Booysen 2002; Ledoux et al. 2005; Farchi et al. 2006; Litman 2007): the indicators should enable comparison to be made of cases.
6. Independency: two or more indicators (Booysen 2002) should not refer to the same factor.

7. Achieving target (Booysen 2002): indicators should address both the means and ends. For example, to reduce the rate of road crashes resulting from the factor of drinking alcohol, setting enforcement breath tests points is recommended as an action. In this case, the rate of road fatalities involving alcohol drinking is the end and the rate of enforcement points per 10 km is the mean.

8. Validity (Booysen 2002). Any change in the variables' values of the indicators should have a clear impact on the overall index.

9. Data availability: this is considered as the most critical criterion of almost all the reviewed studies. The source of data should be decided according to the purpose of the index. In the case of using an index for an international comparison, the data should be collected from a universal source. The data should be coherent in terms of interpreting the same definition, same unit, and the same time of collection or estimation. The difference in the cultures and social factors should also be considered (Booysen 2002; Tešić et al. 2018). To get the sufficient data set, various data sources are reviewed as it is shown in the next sub section.

3.2.1.1 Data sources

Various sources of data are used by the reviewed studies (Yannis et al. 2018). The most used is the International Road Traffic and Accident Database (IRTAD) (ITF-OECD 2018), which is considered as one of the most important, reliable, widely used and perspective crash databases (Hermans 2009; Gitelman et al. 2010). It operates in the frame of the Joint Transport Research Centre of the Organisation for Economic Co-operation and Development (OECD) and the European Conference of Ministers of Transport (ECMT)

(JTRC OECD/ECMT) and it is used as a source for both final and intermediate outcomes data.

Other sources used to collect data in European countries are the statistics agency of the European Union (Eurostat 2018) and The United Nations Economic Commission for Europe (UNECE) (Gitelman et al. 2010; Tesic et al. 2018; UNECE 2018).

The World Bank also provides some supporting data such as the population size and land area (Al-Haji 2007).

The International Road Federation's (IRF) database provides data related to the road length, classes, surface conditions, and traffic compositions (Al-Haji 2007; IRF 2018).

The World Health Organisation's (WHO 2015) database provides data regarding, road safety management systems, strategies of safer roads, strategies of safer vehicles, strategies of safer road user behaviour implemented by the members of the WHO, the speed limit for each road class, the intermediate outcome and the final outcome (Hermans 2009; Gitelman et al. 2010; Tesic et al. 2018). Hakkert et al. (2007) and Vis and van Gent (2007) also established a database in the SafetyNet study which is used by further studies, such as that of (Bax et al. 2012).

3.2.2 The selected indicators

This section focuses on the indicators representing the intermediate outcome which were selected in the reviewed studies with regards to the safer road infrastructure, safer speed, safer vehicles, and safer road user behaviour. The results of reviewing is shown in Table 3.1.

It may be noticed that the indicators of road user behaviour were the most considered in the reviewed studies. Consuming alcohol, using protective systems (wearing seat belt and helmet) and vehicles exceeding speed limit were the most indicators used to indicate the road user behaviour.

Vehicle indicators were also considered by most of the reviewed studies since they contribute to improvement in vehicle design and technologies that assist drivers to behave in safer fashions. The EuroNCAP score, age of the vehicle and the composition of vehicles were the most used indicators of vehicle safety.

The road infrastructure indicators were the most challengeable to identify as they were not incorporated in some studies such as Wegman et al. (2008b), Wegman and Oppe (2010), Gitelman et al. (2010), and Bax (2012); and they were considered in various forms in other studies such as ETSC (2001), Vis (2005), Al-Haji (2007), Hermans et al. (2008) and Shen (2012). The ETSC (2001), which might be considered as the first attempt of defining road safety indicators and the basis of other studies, selected more comprehensive indicators which reflect the safety standards of road infrastructure and the hierarchy of road classes. These indicators may be effective if they reflect the forgiving and self-explaining standards on which the safe system approach is based, as shown in Chapter Two. The SafetyNet study

(Hakkert et al. 2007; Vis and van Gent 2007; Gitelman et al. 2014) selected the EuroRAP score as the indicator of road infrastructure, which may be considered the most comprehensive and relevant to the safe system approach principles. Other studies used indicators which were less comprehensive and based mainly on the data availability in the area of the study, such as those by Al-Haji (2007) and Shen (2012).

A safer speed limit were considered in one study (WHO 2015) because it was based on the recommended actions which are based on the safe system approach concept.

There are other individual indicators which were selected by some studies but are not relevant to the scope of the proposed road safety index. These cover trauma management, weather and geographical factors.

3.2.2.1 The NCAP and the RAP indicators

As shown in Chapter Two, the NCAP and the RAP are highly recommended as tools for vehicle and road infrastructure assessments respectively. The EuroNCAP was used in some research to indicate the vehicle safety. The EuroRAP was also used in one study (Vis 2005) to indicate the road infrastructures safety. Therefore, there is a need to review the indicators on which both these tools are based.

- The EuroNCAP (EuroNCAP 2017) was established in 1990s to assess the passive safety of vehicles which represents the standards that help in protecting car occupants in the event of the crash, and reduce the severity level of the crash consequences. Then, the requirements of active safety, which helps in preventing crash occurrence, were incorporated in 2009. The indicators of the EuroNCAP are shown in Appendix II. They are categorised into four groups: adult occupant, child occupant, pedestrian protection and safety assistant system. The output of the EuroNCAP is represented by star rating forms. Five stars means that all the passive and active safety requirements are fit while one star means that the vehicle is less safe as not all the requirements are fit.

- The EuroRAP (iRAP 2017) is the first version of the RAP which was developed to assess the passive safety of road infrastructure. The EuroRAP was developed as a sister of the EuroNCAP to rate road infrastructure in terms of star ratings. The AusRAP was then developed in Australia based on the concept of the EuroRAP, which is then developed to consider crash avoidance by assessing the likelihood of crashes. After demonstrating the validity of the EuroRAP and the other versions such as the KiwiRAP, the usRAP as well as the AusRAP, the iRAP was developed to be used at international scale. The iRAP version considers the low income levels in some countries where there are high rates of road fatalities, by developing an investment plan for safer roads. The iRAP also considers the high rate of vulnerable road users fatalities by adding three assessing rates for motorcyclists, bicyclists, and pedestrians. The indicators that the iRAP is based on are shown in Appendix I. For each road user group, they are categorised according to the crash type. The road attributes are the main indicators that measure the safety requirements of the road design elements and protect the road users in the event of the crash. The requirements of preventing crashes are considered in terms of providing technologies that help drivers to avoid mistakes leads to crashes such as lane separation device and speed humps (iRAP/EuroRAP 2011; iRAP 2017).

3.3 Weighting and Aggregation Methods

In order to develop an index, weighting and aggregation of indicators techniques are needed. They are considered as important stages which directly affect the quality of the developed indices (JRC-EC 2008; Zhou et al. 2010). This section presents a review of techniques which are used in constructing previous indices.

3.3.1 Weighting methods

The weighting methods used in previous studies may be classified into five methods: equal weighting method, statistical method, optimisation method, expert opinion method and theoretical method. These may be elaborated as follow.

3.3.1.1 Equal weighting method

It is widely used in previous studies (Nardo et al. 2005; Al-Haji 2007; Hermans et al. 2008; JRC-EC 2008; Wegman et al. 2008b; Hermans 2009; Hermans et al. 2009a; Hermans et al. 2009b; Gitelman et al. 2010; Wegman and Oppe 2010; Oluwole et al. 2013). Although this method does not reflect the deep understanding of the impact of each indicator on the overall index (Oluwole et al. 2013), it is considered the most simple (Gan et al. 2017), less subjective (Chen et al. 2015), and the most explicit method (Maggino and Ruviglioni 2009; Chen et al. 2015). Gan et al. (2017) reviewed the literature of weighting methods and concluded that equal weights is used by about half of the developers of the indices in various domains. This method is preferable when the structure of the selected indicators is more complicated

(Sharpe 2004; Maggino and Ruviglioni 2009); or there is insufficient knowledge regarding each indicator (Nardo et al. 2005).

3.3.1.2 Statistical methods

The principal components analysis (PCA) and factor analysis (FA) are techniques used to cluster the indicators and define the weights (Nardo et al. 2005; Al-Haji 2007; JRC-EC 2008; Wegman et al. 2008b; Gitelman et al. 2010; Wegman and Oppe 2010; Shen et al. 2011; Bax et al. 2012; Shen 2012). They are used to reduce a set of correlated indicators to a smaller set of uncorrelated indicators. However, the weights obtained from these methods are based on the correlation and variance between variables. (Dharmawardena et al. 2016) argued against the use of PCA and FA in weighting indicators because the correlation matrix produced by the process of PCA and FA represents coefficients of standardized variables. In addition, the indicator with more available data will have weight more than other indicators despite it is less important in reducing the road fatalities than others (Hermans et al. 2008). Therefore, it is less easy to interpret directly the real value of the variables.

3.3.1.3 Experts' opinions

Two well-known techniques are based on expert opinions in weighting indicators: the analytic hierarchy process (AHP) and the budget allocation (BA) (Nardo et al. 2005; Hermans et al. 2008; JRC-EC 2008; Hermans 2009). The selection of experts are time consuming and more suitable for a small number of indicators (Hermans et al. 2010). In addition, the choice of experts should be according to criteria to ensure reliable results. Having a wide range of knowledge and experience in all the dimensions of the road safety system and not specialising in only some of these dimensions is an important criterion to avoid inconsistency and biases of assigning weights. The experts should have an international view on the risk factors of the road safety not only on those in their own countries (Hermans et al. 2008; Chen et al. 2015).

3.3.1.4 Optimization models (non-statistical method)

Data envelopment analysis (DEA) has been used recently (Shen 2012; Oluwole et al. 2013) to weight indicators by finding the efficiency of each country in terms of the rate of output (the final outcome) to the input (the indictors). It is also referred to as frontier analysis. However, this method derives different weights for each case (country) (Shen 2012). This makes it unsuitable for assessing national strategies and operational performance according to the same set of indicators with same weighting (Nardo et al. 2005; JRC-EC 2008). This means that same weighting of indicators for all countries is more likely to give right indication of ranking and benchmarking countries.

3.3.1.5 Theoretical method

This may be the only method which is used to endow the meaning and the real contribution of indicators in measuring the overall index (Al-Haji 2007; Maggino and Ruviglioni 2009; Oluwole et al. 2013). Maggino and Ruviglioni (2009) shows that to use this method, criteria related to psychometric properties should be identified through reviewing literatures and evaluation studies. Al-Haji (2007) considered the role of each indicator in increasing the rate of road risk as a criterion of weighting. For example, he assumed that 25% of the total weight should be assigned to the indicators for road user behaviour, as they were higher than the weight of other indicators because of their higher influence on the overall road safety level based on statistics. This kind of weighting is flexible in terms of changing by the developer according to particular considerations concerning each indicator (Maggino and Ruviglioni 2009).

3.3.2 Aggregation methods

To combine all the values of the indicators, various methods are used. This section presents the methods of aggregation used in the reviewed studies.

3.3.2.1 The simple linear additive aggregation method (SLAA)

It is used by most of the indices developer to aggregate indicators (Al-Haji 2007; JRC-EC 2008; Hermans et al. 2009a; Miller et al. 2013; Oluwole et al. 2013; Abdullah and Adawiyah 2014; Chen et al. 2016). Gan et al. (2017) shows that about 86% of the developed indices used the SLAA method in aggregating indicators. This method employs the function of summation, to sum up the value of indicators. It can be also in the form of the arithmetic mean (Munda and Nardo 2003; 2005a; 2005b; JRC-EC 2008).

The general form of the SLAA method is (Forman and Peniwati 1998; Freudenberg 2003; Munda and Nardo 2003; Munda and Nardo 2005a; JRC-EC 2008):

$$CIj = \sum_{i=1}^{n} W_i V_i \qquad \dots\dots\dots (3.1)$$

where:

CIj = the composite aggregated indicator of case j

j= 1, 2…,m,= case number,   m= number of cases

Wi = the weight of indicator i, $0 \leq Wi \leq 1$, $\sum_{i=1}^{n} Wi = 1$

Vi= the variable of indicator i

i = 1, 2…n = indicator number,   n= number of indicators

The main strengths of this method are three. Firstly, it is the simplicity of defining the terms of the model and the form of the model. Secondly, it is the effective interpretation of the individual indicators' variables and their weights. Thirdly, that this method assumes that all the indicators should be independent. This means that any change in the value of any indicators' variables does not affect the values of the other indicators' variables. Therefore, it can test the sensitivity of the model to a change of one indicator (JRC-EC 2008; Pollesch and Dale 2015).

The main weakness of the SLAA method is that the aggregated results from this method are subjected to compensation, which is rewarding the poor performance in an indicator the equivalent score of the better performance. This means that the aggregated score neglects the performance of cases according to each indicator separately, which make the results of the ranking unfair (Munda and Nardo 2003; JRC-EC 2008). For example, a case is assessed by four indicators, three of them have a very high score but one has a very low score which refers to a significant poor performance. The overall score of this case will be high but does not refer to the low performance indicator. Therefore, this weakness should be checked when using this method.

3.3.2.2 Geometric aggregation method (GA)

This is also called the weighted product method or multiplicative method (Nardo et al. 2005; Al-Haji 2007; Hermans et al. 2008; JRC-EC 2008; Wegman et al. 2008b; Zhou et al. 2010). Its form is shown in Equation 3.2 (Forman and Peniwati 1998; Chang and Yeh 2001; Nardo et al. 2005; JRC-EC 2008).

$$CIj = \prod_{i=1}^{n} V_i^{W_i} \qquad \text{…….. (3.2)}$$

where:

CIj = the composite aggregated indicator of case

J= 1, 2…m= case number,   m-= number of cases

Wi =the weight of indicator I, $0 \leq Wi \leq 1$, $\sum_{i=1}^{n} Wi = 1$

Vi=the variable of indicator i

i = 1, 2…n = indicator number,   n= number of indicators

This method is developed to solve the fully compensatory problem of the linear additives aggregation method by limiting the ability of the marginal effect of indicators with very low scores to be fully compensated for by indicators with high scores (OECD and JRC 2008). However, the aggregation models derived by the geometric aggregation method have limited ability to reflect the sensitivity analysis (Gan et al. 2017). In addition, since this method is based on multiplication, it is not suitable where zero values is used as values of indicators.

3.3.2.3 Other methods

- Data envelopment analysis (DEA)

  This was used recently to develop a ranking method based on the efficiency rate' which is the rate of output indicators to input indicators (Shen et al. 2011; Bax et al. 2012; Shen 2012; Rosic et al. 2017). This method is more suitable when the aim to rank countries only. However, there is no valid model and method to use the DEA in constructing road safety indices. Therefore, it will not consider in this research.

- Multi Criteria analysis

  This is used to aggregate the orders of countries rather than aggregating numerical scores (Nardo et al. 2005; JRC-EC 2008; Chen et al. 2015). Therefore it is not considered deeply in the reviewing of literature since the aim of the research is to find an index in terms of score and not rank only.

3.4 Summary

This chapter presents a review of the main steps in the process of constructing aggregated indices.

- The first main step is selecting the indicators which are based on the theoretical framework of the index. This step is based on different criteria which are presented in this chapter. The main criteria are relevancy to the phenomena, comprehensiveness, simplicity, comparability, independence, able to achieve target, and validity. Data availability is considered a critical criteria of deciding the indicators, since it is based on finding a source of reliable and coherent data. A list of the most significant sources of road safety data used in the reviewed studies are presented in this chapter.

- The indicators selected in the reviewed studies are presented in Table 3.1. It can be concluded that the road user behaviour indicators are considered by almost all the studies; possibly because these indicators were already identified and addressed in many studies which discussed road safety from the traditional view. Thus, the road user behaviour is the main factor.

- In the studies that consider road infrastructure indicators, different indicators were considered by each study. Some studies did not consider these indicators. This is because of reasons related to the difficulty in identifying comprehensive and measurable indicators or because of the lack of data.

- Regarding the vehicle indicators, the EuroNCAP score was used by most of the European studies as indicator of a safer vehicle. This may result from the fact that the validity of EuroNCAP has been proved.

- The indicators of a safer speed limit are considered only by the WHO assessment; since this assessment is based on the new vision of a road safety policy, which was founded on the safe system approach principles.

- Regarding the weighting of indicators, several methods were used in previous studies. Statistical and optimisation methods are used recently, but they are criticized since they are based on the values of indicators not on the interpretation of the importance and the real influence of the indicators. Use of expert opinion is closer to interpreting the importance of the indicators, if the selected experts have sufficient knowledge in all dimensions of the index on an international scale. Equal weighting is widespread used by the developers of the most valid indices despite it neglects the difference in the indicators' importance. Weighting on a theoretical base is used rarely, since there is not sufficient information that can be used to weight the indicators at the time of constructing the reviewed indicators. However, with increasing the attention on road safety issues and growth in the size of the conducted studies, more information can now be found. Therefore, this method needs to be considered.

Regarding the aggregation methods, a simple linear additive method is widely used. Other methods have been developed but all of them are based on the rank of countries rather than on aggregating the scores. The aggregated score is objective in this research for use in assessing road safety strategies. Therefore, this will be considered in choosing the method of aggregation in the further chapters.

The next chapter will present the general methodology of the research to achieve the aim and objectives of the research.

CHAPTER FOUR

METHODOLOGY OF THE RESEARCH

4.1 The Overall Aim

The overall aim of this research is to develop an aggregated road safety assessment index (RSAI) based on the safe system approach principles. This index may be used as a meaningful measure to assess the whole safety system rather than assessing each of its elements or dimensions individually (WHO 2013a; 2015). It may also be used to monitor the progress of road safety strategies at national level towards targets defined by polices such as that of the Decade of Action (2011-2020) and the Sustainable Development Goals (SDG) (UN and WHO 2011; UN 2015). In addition, this index could be used in assessing the extent to which a new vision, such as the safe system approach , contributes to a national strategy of road safety; and furthermore to compare the performance of such a strategy against actual crash rates and against best practices. Moreover, the suggested index could be used to rank and rate countries according to their road safety performance.

There have been attempts to construct road safety indices in the last two decades as shown in Chapter Three. Various indicators are considered in these attempts and some of them are related to the components of the safe system approach . The indicators of safer road user behaviour were the most considered in the previous studies because they were based on the traditional vision of road safety issues, where road user behaviour is the main factor. Safer vehicles are considered also by most of these studies as their developments have been investigated and addressed, and valid assessment methodologies of vehicle safety are developed since the 1990s.

However, most of them do not fully reflect the safe system approach concept, especially those related to the road infrastructure and mobility. In addition, there seems to be a lack of methodologies capable of measuring the impact of each component of the safe system approach on the overall level of road safety. It also may result from lacking of needed data associated with the efficiency of new road safety approach, such as those related to walking and cycling.

This research addresses the above gap by defining comprehensive, measurable, independent and valid indicators for safer road infrastructure mobility, and aggregates them with the indicators for safer road user behaviour and safer vehicles including the most common and the new considered indicators.

The general methodology of developing the RSAI is presented in this chapter and shown in Figure 4.1. It broadly consists of four main steps. The first step is identifying and selecting the indicators of the RSAI, based on the theoretical framework of the RSAI from the safe system approach concept. These indicators are classified into thematic and individual indicators. The second step is developing the preliminary RSAI models by weighting and aggregating the selected indicators. Thirdly, the preliminary models of the RSAI are evaluated in terms of achieving it particular purpose of assessing the road safety level by comparing with crash data to choose the final RSAI model. Finally, using the developed model in ranking and rating countries, in monitoring progress towards a set target, and in suggesting solutions are investigated.

Inputs	Steps	Outputs
- The purpose - The domain - The theory	**Developing the theoretical framework based on safe system approach principles**	Defining the RSAI indicators
- The RSAI indicators - Weighting methods - Aggregation methods	**Aggregating the weighted RSAI indicators**	The preliminary RSAI models and sub models
- The existing RAP methodology of road infrastructure assessment - The outputs of the RAP assessment methodology - Weighting methods - Aggregation methods	**Extending the RAP methodology by aggregating its output**	The road infrastructure sub model
-The needed data -The available and accessed data sources - the criteria of selecting the study area - The sample size	**Collecting data**	Providing the necessary data for evaluation process
- The necessary data - Methods of evaluation	**Evaluation of the preliminary RSAI models**	Selection of the most appropriate model
The RSAI model	**The sensitivity analysis**	The change in the RSAI score resulting from the individual and multiple change in the indicator score
- The necessary data - The RSAI model	**Application of the RSAI**	Ranking countries
- The necessary data - The RSAI model		Rating countries
- The necessary data - The RSAI model		Monitoring Progress
- The necessary data - The results of the sensitivity analysis - The RSAI model		Suggesting Solutions

Figure 4.1 The general approach of the research methodology

4.2 Developing the Theoretical Framework

In this step, the context of the RSAI is defined. The main inputs needed (Freudenberg 2003; Sharpe 2004) are: the purpose of the index, which is illustrated in section 4.1; the domain of the index which is the road safety system; and the theory on which the concept of the index is based. The theory is the safe system approach which is illustrated in Chapter Two. The output of this step is the definition of the RSAI indicators.

The indicators of the RSAI are categorised into thematic indicators and individual indicators. The thematic indicators represent the main groups of indicators which concern the main components of the safe system approach : safer road infrastructures, safer speed, safer vehicles, and safer road user behaviour.

To understand each component and its effect on the overall road safety (Sharpe 2004; Saltelli 2007; JRC-EC 2008), a set of individual indicators making up each of the thematic indicators should be identified (Freudenberg 2003). The selection of the individual indicators is based on a comprehensive literature review. These suggested indicators will be then evaluated according to specific criteria to form the final structure of the indicators. This step will be shown in Chapter Five.

However, there is a need to develop an appropriate methodology for aggregation of the selected indicators that may ultimately facilitate the integration of all the themes of road safety into a single index which will represent the state of the road safety based on the safe system approach. This is achieved in the next step.

4.3 Developing the RSAI Model

The process of aggregating the selected indicators and developing the model of the road safety assessment index (RSAI) contains two steps which are:

- Defining the terms of the RSAI model. Each term is compiled of a variable and its weight. The variables of the RSAI's terms represent the thematic indicators. Since each thematic indicator is reflected by individual indicators, sub models are developed to incorporate the individual indicators into the RSAI model.

  The weightings of the variables reflect the relative importance of the indicators. Suitable weightings may be identified through appropriate methods of weighting based on the practical importance of each indicator and its impact on the overall road safety level (ETSC 2001).

  Based on the strengths and weakness of the weighting methods which are mentioned in Chapter three, the method of computing weightings will be selected. The expert opinions method may be appropriate but it is difficult to get sufficient numbers of experts with experience of all of the safe system approach components. Therefore, the theoretical method of weighting which based on theories and literatures may be the best alternate method. Equal weighting is also considered since it is widely used and may reflect the concept of the safe system approach of sharing the safety system's components the responsibilities of providing safer roads.

- Aggregating terms: The linear aggregation method will be considered in aggregating the terms of the model because it seems to be widely used in previous studies and it is considered simple and effective in interpreting the independence and importance of the individual indicators (JRC-EC 2008; Pollesch and Dale 2015).

The main model of the RSAI is developed to aggregate the thematic indicators. Then the individual indicators are aggregated in separated sub models as shown in Figure 4.2. The first sub model is the safer road mobility model, which aggregates the indicators of road infrastructure and safer speed limits. The second sub model is the safer road user behaviour model which its indicators are subdivided into four sub groups based on the concept of the safer road user behaviour. The third sub model is the safer vehicle model.

Different weighting methods investigated in this step will produce more than one preliminary RSAI models. To select the most proper model, the preliminary models will be evaluated as will be shown in the next section.

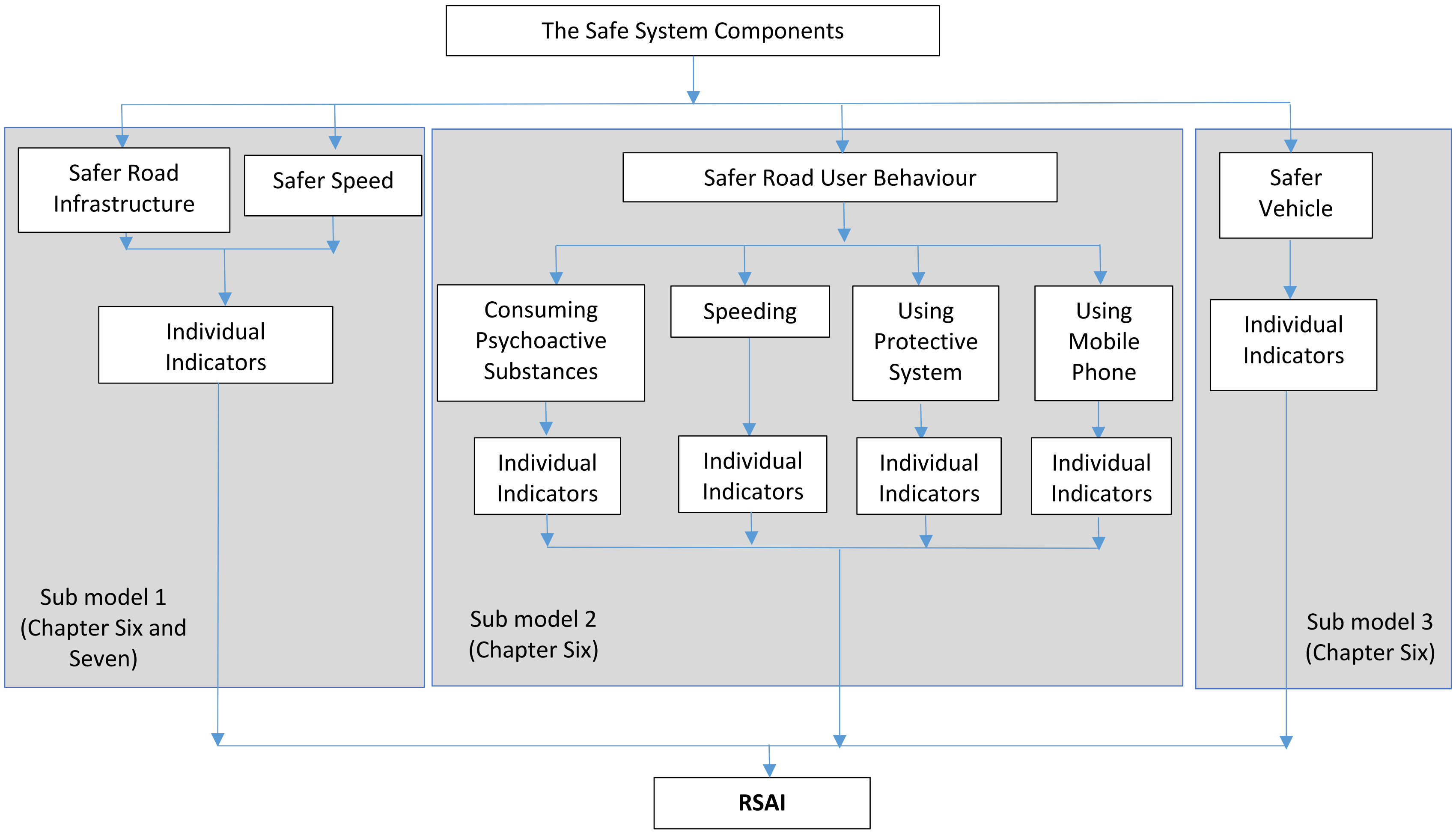

Figure 4.2 The developed aggregation model of RSAI

4.4 Data collection

The data are needed to evaluate the preliminary developed models and select the most appropriate model.

The necessary data are identified based on what input data are needed for using the developed models and sub models and what data are needed to compare with preliminary developed models. Two groups of data are collected in this research. The first group is for evaluating the models developed in Chapter seven to aggregate the RAP assessment methodology outputs as will be shown in Chapter Eight. The second group is the data needed to evaluate the preliminary RSAI models as will be shown in Chapter Nine.

Different sources of data are used to gather the necessary data. Most of them are available and free accessed for most the world countries, especially those for road user behaviour data. The WHO reports (WHO 2015) and the European Transport Safety Council reports (ETSC 2016) are examples of these sources. However, the data needed for road infrastructure and mobility model and for vehicle safety models are not available for all countries and not available for all the road sections in the same country. Therefore, the availability of free accessed data is considered in selecting the sample size.

The homogeneity of the collected data is another common factor considered in identifying the sample size. For example, the selection of road sections to evaluate the models developed for extending RAP methodology and finding the aggregated RAP outputs are based on road type in terms of the design feature of the roads and the type of the road-user groups using the road as will be shown in Chapter Eight.

To demonstrate that the selected samples of data is statistically a representative sample of population, the sample size is justified using t test method as will be shown in details in chapters Eight and Ten.

4.5 Sensitivity Analysis

The sensitivity analysis of the RSAI's indicators is conducted to investigate the change in the overall RSAI score resulted from the change in each indicator individually or multiple change in two indicators or more. For example, the improvement in the road infrastructure will be investigated. The improvement in the road infrastructure and vehicle safety together will be investigated also. The results of this step is used in suggesting individual and multiple solutions of the road safety system based on the RSAI model. The results of this analysis will enhances the contribution of the safe system approach concept in the developed model if improvement in multiple indicators achieves better improvements than individual solutions.

4.6 Evaluation of the Preliminary RSAI's Models

In this step, the ability of the developed models in achieving the particular purposes of the RSAI is evaluated. Since the main purpose of the RSAI is assessing the road safety level at country scale, the RSAI scores resulted from developed models will be compared with the real crash data for selected countries. The relationship between the RSAI scores and the real crash data is measured by coefficient of correlation. Since two weighting methods are used in developing the model, two preliminary RSAI models are produced (Saisana and Tarantola

2002; JRC-EC 2008). The model that produce RSAI scores more correlated with crash data is the most appropriate model of finding the RSAI score.

4.7 Application of the RSAI Model

1. The use of the RSAI in ranking countries is investigated in this study. The rank of the countries according to the RSAI scores is compared with the rank of the same countries according to real crash data. The rank is compared also with the rank according to the scores of the road safety indices developed in previous studies to assess to what extent the developed RSAI has the ability to use in ranking countries.

2. The use of the RSAI in rating countries by developing star rating bands based on specific criteria. Five levels of ratings are used to classify the range between the minimum and the maximum RSAI score. Each star rating reflect a level of road severity and effectiveness of the strategic road safety plans in terms of the considered indicators.

3. The use of the RSAI in monitoring the progress towards a set target is also investigated by developing a methodology of identifying the rate of progress using the RSAI score. Based on that, solutions may be suggested.

4. The methodology of suggesting solutions through using the RSAI scores is developed in this research. Two kinds of solutions are suggested, individual solution and multiple solutions. Individual solutions means improving one element of the road safety such as road infrastructure or vehicles safety. While multiple solutions

means improving two or more elements together. The impact of the change in the indicator scores on the RSAI scores, which are identified by sensitivity analysis, are used to suggest the kind of solutions.

CHAPTER FIVE

THE THEORETICAL FRAMEWORK OF THE RSAI

5.1 Introduction

The theoretical framework of the RSAI is developed in this chapter based on the concept of the safe system approach . The methodology of developing the theoretical framework starts with the suggestion of the preliminary thematic indicators to interpret the four components of the safe system approach : safer road infrastructure, safer speed, safer road user behaviour, and safer vehicles. To measure each of these indicators, the set of individual indicators is suggested based on the reviewed studies which are shown in Chapter Three, and the measures of the safe system approach components which are shown in Chapter Two. These candidate indicators are evaluated according to specific criteria to select the final set of indicators. The final structure of the thematic and individual indicators is produced as a result of the methodology of this chapter. This methodology is shown in Figure 5.1.

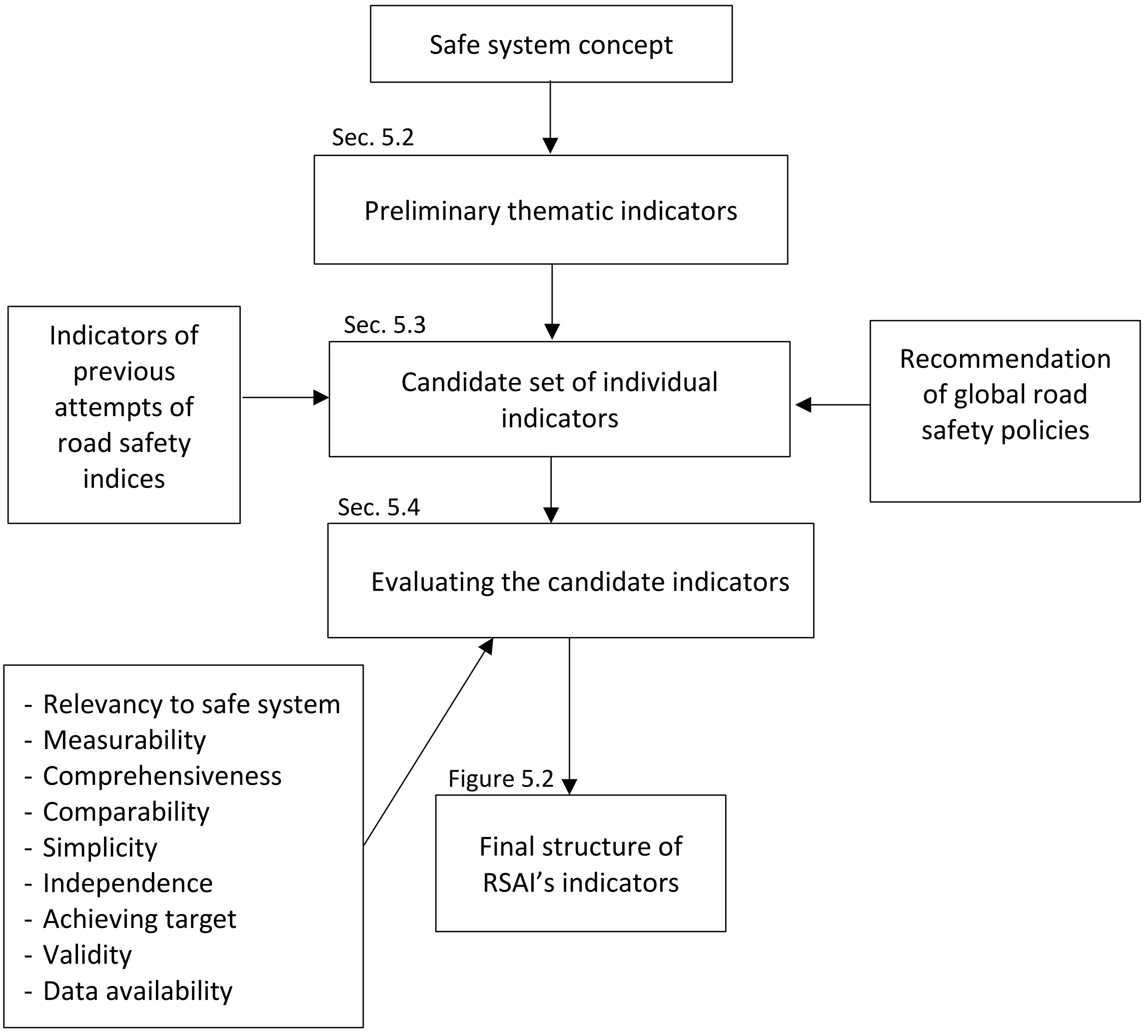

Figure 5.1 Methodology of defining the final structure of the RSAI's indicators

5.2 The Thematic Indicators of the RSAI

As the safe system approach is the theory on which the RSAI is based, the RSAI thematic indicators are identified accordingly. These indicators reflect the four main components of the safe system approach ; safer road infrastructure, safer speed, safer road user behaviour and safer vehicles.

To define the components of the four thematic indicators, a wide literature review was conducted. Based on its findings, it was felt appropriate that the RSAI should be built on the following basis.

- Based on the concept of the safe system approach regarding safer road infrastructure, the forgiving road design is considered to correct the mistakes in road users' behaviour when designing and treating roads. The self-explaining design is also considered to accommodate the needs of the road user for homogenous roads in terms of speed and traffic mass; predictable roads in terms of predicting the speed and traffic mass using roads; and functional roads in terms of the real road class fitting with the requirements of land use and road users' density (Vis 2005; Vis and van Gent 2007). Accordingly, two subgroups are suggested for this research. The first subgroup is safer road design elements, which contains indicators related to the forgiving standard of road design and treatment. The second subgroup is safer road networking, which indicates the self-explaining design of road infrastructure.

  Two more subgroups of indicators are suggested on the recommendation of policies that are based on the safe system approach. These subgroups are providing an effective road audit and safer public transportation (WHO 2013a; 2015).

- Regarding the indicator for safer speed management, two subgroups are suggested. The first one concerns managing speed by setting a maximum speed limit based on the road class, as shown in section 2.4. The second subgroup is speed management through road and vehicle technologies (Litman 2007; EuroNCAP 2017; iRAP 2017).

- The factors of safer road user behaviour mentioned in Chapter Two (section 2.6) are investigated to be considered in terms of four items: speeding; consuming psychoactive substances, including alcohol and illegal drugs; using protective systems including seat belts and helmets, as well as child restraints; and distracted while driving, through using a mobile phone.

- The factors of safer vehicles may be considered in terms of passive safety, active safety, age of vehicle, and vehicle compatibility which is reflected by the vehicle composition as was shown in section 2.5.

A set of individual indicators is suggested in the next step and allocated to the suggested subgroups.

5.3 The Candidate Set of Individual Indicators

Further to the definition of the components of the four thematic indicators, a more in-depth analysis enabled the detailed description of each of the components in terms of individual indicators. The sources of information are given in Table 5.1 and the indicators are described in the following sub sections.

Table 5.1 The preliminary set of individual indicators of the RSAI

The thematic indicators	Subgroups of thematic indicators	The individual indicators	The authors										
			ETSC 2001	SafetyNet study (Vis 2005; Hakkert et al. 2007)	(Al-Haji 2007)	SUNflower study (Wegman et al. 2008b)	(Hermans 2009)	(Gitelman et al.	(Bax et al. 2012)	(Shen 2012)	(WHO 2015)	(Chen et al. 2017)	(Tešić et al. 2018)
1. Safer road infrastructure	**1.1 Safer road design elements**	1.1.1 % of roads meeting design standards	X										
		1.1.2 % of paved roads per total network			X							X	
		1.1.3 EuroRAP scores		X									
		1.1.4 % of roads with RAP star rating ≥ 3 star*											
	1.2 Safer road network classification	1.2.1 % of roads fitting in road network hierarchy	X										
		1.2.2 % of motorways in total length and density								X			X
		1.2.3 Infrastructure network density					X						
		1.2.4 % of separated walking and cycling infrastructure*											
		1.2.5 % of roads with RAP star rating ≥ 3 stars*											
	1.3 Road audit inspections	1.3.1 Road audit and inspection effectiveness score										X	
		1.3.2 Is RAP methodology applied?*											
2. Safer speed	**2.1 Setting max. speed limit per road class**	2.1.1 % of urban roads with max speed limit < safer speed*											
		2.1.2 % of rural roads with max speed limit < safer speed*											
		2.1.3 % of motorways with max speed limit < safer speed*											
		2.1.4 % of roads with RAP star rating ≥ 3 stars*											

The thematic indicators	Subgroups of thematic indicators	The individual indicators	The authors										
			ETSC 2001	SafetyNet study (Vis 2005; Hakkert et al. 2007)	(Al-Haji 2007)	SUNflower study (Wegman et al. 2008b)	(Hermans 2009)	(Gitelman et al.	(Bax et al. 2012)	(Shen 2012)	(WHO 2015)	(Chen et al. 2017)	(Tešić et al. 2018)
	2.2 Speed management technologies	2.2.1 % of roads with RAP star rating ≥ 3 stars*											
		2.2.2 % of vehicles awarded 5 stars*											
3.Safer road user behaviour	**3.1 Speeding**	3.1.1 % drivers driving above legal limit	X	X			X		X	X			X
		3.1.2 Effective score of speeding enforcement									X		
	3.2 Consuming psychoactive substances	3.2.1 % > BAC limit (0.05 for general drivers and 0.02 for young/novice and commercial drivers)*	X				X	X		X			X
		3.2.2 % of fatalities involving alcohol and drug consumption		X		X				X	X	X	
		3.2.3 Roadside police alcohol tests per 1,000 population							X				
		3.2.4 Effective score of drinking-driver enforcement									X		
		3.2.5 Effective score of drug enforcement									X		
	3.3 Using protective system (seat belt, child restraints, and helmets	3.3.1 % wearing seat belts	X		X		X	X					X
		% wearing seat belt by drivers and front seat occupants, % wearing seat belt by rear seat occupants		X		X			X	X	X	X	
		3.3.2 % of children using child restraints in front and rear seats	X							X	X		
		3.3.3 Rate of wearing helmets by two-wheeled vehicle occupants (drivers and passengers)		X	X						X	X	

The thematic indicators	Subgroups of thematic indicators	The individual indicators	The authors										
			ETSC 2001	SafetyNet study (Vis 2005; Hakkert et al. 2007)	(Al-Haji 2007)	SUNflower study (Wegman et al. 2008b)	(Hermans 2009)	(Gitelman et al.	(Bax et al. 2012)	(Shen 2012)	(WHO 2015)	(Chen et al. 2017)	(Tešić et al. 2018)
		3.3.4 Effective reinforcement score of wearing seat belt									X		
		3.3.5 Effective reinforcement score of child restraints									X		
		3.3.6 Effective reinforcement score of using helmets									X		
	3.4 Distraction during driving	3.4.1 % of drivers using mobile phone while driving (hand-held and hands-free)*											
		3.4.2 Effective reinforcement score of using mobile phone*									X		
4. Safer vehicles	**4.1 Vehicle age**	4.1.1 % cars < 6 years					X			X			X
		4.1.2. % of old vehicles > 10 years								X			
		4.1.3 renewal rate of passenger cars							X				
		4.1.4 Median age of the passenger car fleet		X		X							
	4.2Passive safety requirements	4.2.1 Passive safety score (EuroNCAP score)	X	X		X		X					
		4.2.2 % score of pedestrian protection for new cars sold							X				
		4.2.3 Enforcement score on vehicle standard applied										X	
		4.2.4 % of cars awarded 5stars on car occupants								X			
		4.2.5 % of cars awarded 4 stars on child restraints								X			

The thematic indicators	Subgroups of thematic indicators	The individual indicators	The authors										
			ETSC 2001	SafetyNet study (Vis 2005; Hakkert et al. 2007)	(Al-Haji 2007)	SUNflower study (Wegman et al. 2008b)	(Hermans 2009)	(Gitelman et al.	(Bax et al. 2012)	(Shen 2012)	(WHO 2015)	(Chen et al. 2017)	(Tešić et al. 2018)
		4.2.6 % of cars awarded 3 stars on pedestrian protection								X			
		4.2.7 % of vehicles with effective seat belt*											
		4.2.8 % of vehicles with anchorages*											
		4.2.9 % of vehicles with child restraint systems*											
		4.2.10 % of vehicles with safer frontal and side impact standards*											
		4.2.11 % of cars awarded overall 5 stars*											
	4.3 Active safety requirements	4.3.1 Enforcement score on vehicle standard applied										X	
		4.3.2 % of vehicles with effective electronic stability control*											
		4.3.3 % of vehicles with anti-lock braking systems*											
		4.3.4 % of cars awarded overall 5 stars*											
	4.4 Vehicle composition	4.4.1 % of heavy vehicles								X			
		4.4.2 % of two-wheeled vehicles								X			
		4.4.3 % of vehicles in the total vehicle fleet			X								
		4.4.4Vehicle fleet composition				X		X					
		4.4.5 % of vehicles not motorcycles										X	

* These indicators are not considered in previous attempts of developing road safety indices and are suggested in this research based on the recommendation of best practises of road safety, which is based on the safe system approach concept.

5.3.1 The individual indicators for the safer road infrastructure

The individual indicators for safer road infrastructure are included in group (1) and consist of four subgroups:

1 The subgroup 1.1: the safer road design elements. Three different individual indicators are used in three different studies as shown in Table 5.1.

- The indicator 1.1.1. of the percentage of roads meeting the safety standards is selected by the ETSC (2001) study to consider all the standards that are related to road design safety. This indicator is suggested in this research to indicate the standards that are based on the safe system approach (forgiving and self-explaining design). However, it is necessary to find a valid methodology to measure this indicator which is suggested in this research.
- The indicator 1.1.2 that is related to the paved road designates the road surface condition. It was selected in the work of Al-Haji (2007) and Chen et al. (2017) based on the data availability and not on the full reflection of road design elements.
- The indicator 1.1.3 which is the EuroRAP score is used in the SafetyNet study (Vis 2005; Hakkert et al. 2007) to interpret the crashworthiness factors: the factors for protecting road users in the event of a crash and reducing the severity level of a road crash. However, EuroRAP is the first version of the RAP which was developed recently to include the factors of preventing crashes. Therefore, this should be taken in account in deciding the indicators of the RSAI.

The review of RAP methodology shown in Appendix (I) shows that the RAP is developed to consider the safe system approach concept (Lynam 2012). It produces a comprehensive, systematic, and valid methodology of assessing roads based on indicators which are identified by the forgiving and self-explaining roads' concept (Turner et al. 2009; iRAP/EuroRAP 2011; Lynam 2012). The RAP score is used to set the target at global and national scales by the UN and the WHO, in addition to the national road safety agencies. It is also pioneered by the World Bank as a criterion and target for safer roads. A target of three stars is set as the minimum rating of a safer road infrastructure and as an objective of achieving the target of the SDG and the Decade of Action for Road Safety (2011-2020) (UN and WHO 2011; UN 2015; Mclnerney 2016; iRAP 2017). Therefore, an indicator 1.1.4 of the percentage of roads with a star rating equal to or greater than 3 is suggested in this research.

2 The subgroup 1.2 of safer road network classification. It contains the following indicators.

- The indicator 1.2.1 is identified by ETSC (2001) which is the percentage of roads fitting in the road network hierarchy. There has been no valid methodology to measure this indicator.
- The indicator 1.2.2 which is the motorway length and density (Shen 2012; Tešić et al. 2018) and the indicator 1.2.3 which is the Infrastructure network density (Hermans 2009) were selected based on the available data and not on the full reflection of the road network classification.
- The indicator 1.2.4 of walking and cycling road separation is suggested based on the recommendation of promoting walking and cycling modes of transportation (UN and WHO 2011; WHO 2015) which is considered because of the high

percentage of road non-motorised road fatalities as shown in the latest report of WHO (2015) especially in the developing countries. Therefore, it is considered in the candidate list of individual indicators.

- The indicator 1.2.5 which is related to RAP is suggested also in this group to evaluate its relevance to self-explaining standards of road infrastructures.

3 The subgroup 1.3 which is the road safety audit indicators. The suggested indicators within this sub group are:

- The indicator 1.3.1 is the effectiveness score of road audits. It is selected by Chen et al. (2017) and suggested in this research. However, the methodology of obtaining this score was not shown clearly.
- The indicator 1.3.2. Since the validity of the RAP as a tool of road assessment is proved practically (Castle et al. 2007; Lynam et al. 2007; iRAP/EuroRAP 2011), the usage of RAP in assessing roads is suggested as an indicator of the effectiveness of a road audit score.

5.3.2 The individual indicators for safer speed behaviour

Two groups of indicators are suggested and included in group (2) as shown in Table (5.1)

1. The subgroup 2.1 is the setting maximum speed limits. The percentage of road types with a maximum speed limit less than the safer speed limit is suggested to reflect the recommendation of the safe system approach policies. Since the RAP rating considered the speed limit as a critical indicator (Harwood and Mclnerney 2011), the indicator of the percentage of roads awarded 3 stars or more is suggested as an alternative indicator of speed limits.

2. The subgroup 2.2 is using road and vehicular technologies. The provision of technologies which are used to help drivers control the speed of their driving are considered in this research. According to the review of the RAP and NCAP methodologies, these tools consider these technologies in assessing road infrastructure and vehicles. Therefore, two indicators related to the RAP and NCAP are suggested in this research to measure the speed indictors.

5.3.3 The individual indicators for safer road user

The indicators in groups (3) are classified in this research: speeding, consuming psychoactive substances, using protective systems, and distraction by using a mobile phone (Jameel and Evdorides 2018b; c).

1. The subgroup 3.1 which is speeding indicators
    - The indicator 3.3.1 is the percentage of drivers exceeding the maximum speed limit. It is the indicator that most of the previous studies have used because of the related data availability. Therefore, this is suggested as the indicator of speeding in this research (UN and WHO 2011; WHO 2015).
    - The indicator 3.3.2 which is the effective score of speeding enforcement is also suggested based on best practice recommendations research (UN and WHO 2011; WHO 2015).

2. The subgroup 3.2 is consuming psychoactive substances, including alcohol and illegal drugs;

- The indicator 3.2.1 is setting a maximum BAC limit of 0.05 g/dl for general drivers and of 0.02 g/dl for novice and commercial drivers has been recommended by best practices on road safety, as shown Chapter Two research (UN and WHO 2011; WHO 2015). Therefore, the percentage of drivers with a BAC greater than the maximum BAC limit was selected in previous studies and is considered in this research as an indicator.
- The indicator 3.2.2 is the percentage of road fatalities involving alcohol and drug consumption. It is also used in some studies as an alternative indicator because of the data restraints.
- The indicator 3.2.3 is the roadside police alcohol test which is used as an indicator of the enforcement's effectiveness by Bax et al. (2012).
- The indicators 3.2.4 and 3.2.5 are the effective enforcement score of drinking alcohol and consuming drugs are also considered based on the requirement of the safe system approach policy research (UN and WHO 2011; WHO 2015).

3. The subgroup 3.3 is using protective systems including
    - The indicator 3.3.1 is the most common indicator used in previous studies is the percentage of vehicle occupants wearing seat belts. This is used by some studies with disaggregation of the front and rear seats.
    - The indicator 3.3.2 is the percentage of vehicle occupants using child restraints
    - The indicator 3.3.3 is The percentage of two-wheeled vehicle occupants wearing helmets
    - The indicators 3.3.3-3.3.6 are the effective enforcement score regarding using these protective systems. They are suggested in this research to reflect the enforcement system.

4. The subgroup 3.4 is distraction while driving through using a mobile phone; the percentage of drivers using a mobile phone and the effective enforcement score. These indicators are suggested in this group because of the recent attention paid to the increasing number of road crashes resulting from using a mobile phone while driving, as shown in Chapter two research (UN and WHO 2011; WHO 2015).

There are other important factors relating to the road user behaviour such as stress, fatigue and driver health are not considered in this research because of two reasons. Firstly, there is not sufficient available free access data related to these factors. Secondly, there is not effective enforcement system to force the driver avoiding driving when he has healthy issue such as fatigue and stress.

5.3.4 The individual indicators of safer vehicles

The fourth group of indicators is the individual indicators of safer vehicles which are considered in terms of four subgroups as shown below:

1. Indicators 4.1 is the vehicle age: different forms of indicators were used in previous based on the available data and on the national targets of road policies.

2. Indicators 4.2 of vehicle passive safety which contains:
   - The EuroNCAP score is the most common indicator of passive safety, since the validity of its methodology has been proved (Hobbs and McDonough 1998; Lie and Tingvall 2002; Kullgren et al. 2010; Strandroth et al. 2011).

- The indicator related to the pedestrian protection is selected in one study (Bax et al. 2012) but the indicators related to the other factors are suggested in this research.
- The enforcement score on vehicle standards is used in one study (Chen et al. 2017) with reference to a methodology of determining the value of this indicator by using expert questionnaires.
- Shen (2012) used the indicators that are related to a minimum target of car occupants, child restraints, and pedestrian protection. However, these are not based on a set global target.
- The indicators of availability of technologies of crash worthiness represent the minimum requirement recommended in the WHO (2015) and UN and WHO (2011). The focus is on pedestrian protection, frontal and side impact, and seat belts.
- The minimum requirements of the UN in the Decade of Actions on Road Safety (UN and WHO 2011) focuses on providing crash avoidance and crash worthiness technologies (UN and WHO 2011; Gaylor et al. 2016; van Ratingen et al. 2016). Through reviewing the national road safety targets, a minimum of 4 to 5 stars is used in some countries, such as Norway, and 5 stars in Sweden and New Zealand (DaCoTA 2012; Forum 2016). Four stars and five stars reflect overall good performance of passive safety, but four stars reflect partially equipped with robust crash avoidance (EuroNCAP 2017). Therefore, five stars is suggested in this research to be the minimum standard of vehicle safety, and the percentage of vehicles awarded five stars is suggested as an indicator of vehicle passive and active safety.

3. The subgroup 4.3 is Indicators of vehicle active safety: the percentages of vehicles with effective electronic stability control and anti-lock braking systems are

recommended by recent policies (UN and WHO 2011; WHO 2015); therefore, they are suggested in this research, in addition to the indicator of the percentage of vehicles awarded five stars.

4. Indicators of vehicle compatibility. This is reflected by the difference in the vehicle mass within one fleet (Gitelman et al. 2007). The composition of vehicles is an indicator used to reflect this factor. Since two-wheeled vehicles have a lower mass than other vehicles, then the percentage of bicycles and motorcycles are considered in some research (Hakkert and Gitelman 2007) to reflect the unsafe part of a vehicle fleet (Abdel-Aty and Abdelwahab 2004; Fredette et al. 2008). Heavy vehicles represent a larger mass and have different impacts on road safety (Shen et al. 2012). Therefore, the percentage of heavy vehicles is also suggested.

The suggested indicators in this step are evaluated to form the final set of the RSAI's indicators as will be shown in the next section.

5.4 Evaluating the Individual Candidate Indicators of the RSAI

The candidate indicators for inclusion in the RSAI are then evaluated based on a set of criteria which are used in previous studies and shown in Chapter Three (section 3.2.1). These criteria are: relevant to the safe system approach concept, measurability, comprehensiveness, simplicity, comparability, independency, achieving targets, validity and data availability.

The results of the evaluation are shown in Table 5.2.

Table 5.2 The evaluation of the suggested individual indicators of the RSAI

The thematic indicators	**Subgroups of thematic indicators**	**The individual indicators**	**The criteria of selecting indicators**								
			Relevant to Safe System	Measurable	Comprehensive	Simple	Comparable	Independent	Achieving Targets	Valid	Data Available
1. Safer road infrastructure	**1.1 Safer road design elements**	1.1.1 % of roads meeting design standards	X	X	X	X	X		X	X	
		1.1.2 % of the paved roads per total network	X	X		X	X		X	X	X
		1.1.3 EuroRAP scores	X		X	X	X		X	X	
		1.1.4 % of roads with RAP star rating ≥ 3 star**	X	X	X	X	X	X	X	X	X
	1.2 Safer road network classification	1.2.1 % of roads fitting in road network hierarchy	X		X	X	X		X	X	
		1.2.2 % of motorways in total length and density		X		X	X			X	X
		1.2.3 Infrastructure network density		X		X	X			X	X
		1.2.4 % of separated walking and cycling infrastructure	X	X		X	X		X	X	
		1.2.5 % of roads with RAP star rating ≥ 3 stars	X	X	X	X	X		X	X	X
	1.3 Road audit inspections	1.3.1 Road audit and inspection effectiveness score	X	X	X	X	X		X	X	
		1.3.2 Is RAP methodology applied?	X	X	X	X	X		X	X	X
2. Safer speed	**2.1 Setting max. speed limit per road class**	2.1.1 % of urban roads with max speed limit < safer speed	X	X		X	X		X	X	X
		2.1.2 % of rural roads with max speed limit < safer speed	X	X		X	X		X	X	X
		2.1.3 % of motorways roads with max speed limit < safer speed	X	X		X	X		X	X	X
		2.1.4 % of roads with RAP star rating ≥ 3 stars	X	X	X	X	X		X	X	X
	2.2Speed management technologies	2.2.1 % of roads with RAP star rating ≥ 3 stars	X	X	X	X	X		X	X	X
		2.2.2 % of vehicle awarded 5 stars	X	X	X	X	X		X	X	X

The thematic indicators	Subgroups of thematic indicators	The individual indicators	The criteria of selecting indicators								
			Relevant to Safe system	Measurable	Comprehensive	Simple	Comparable	Independent	Achieving Targets	Valid	Data Available
3. Safer road user behaviour	3.1 Speeding	3.1.1 % drivers driving above legal limit	X	X	X	X	X	X	X	X	
		3.1.2 Effective score of speeding enforcement**	X	X	X	X	X	X	X	X	X
	3.2 Consuming psychoactive substances	3.2.1 % > BAC limits which are 0.05 for general drivers and 0.02 for young/novice and commercial drivers	X	X	X	X	X		X	X	
		3.2.2 % of fatalities involving alcohol and drug consumption	X	X	X	X	X		X	X	
		3.2.3 Road-side police alcohol tests per 1,000 population	X	X		X	X		X	X	
		3.2.4 Effective score of drinking-driver enforcement**	X	X	X	X	X	X	X	X	X
		3.2.5 Effective score of drug enforcement**	X	X	X	X	X	X	X	X	X
	3.3 Using protective System (seat belt, child restraints, and helmets)	3.3.1 % wearing seat belts, % wearing seat belt by drivers and front seats occupants, % wearing seats by rear seat occupants	X	X		X	X	X	X	X	
		3.3.2 Effective reinforcement score of wearing seat belt**	X	X		X	X	X	X	X	X
		3.3.3 % of children using child restraints in front and rear seats	X	X		X	X	X	X	X	
		3.3.4 Effective reinforcement score of child restraints**	X	X		X	X	X	X	X	X
		3.3.5 Rate of wearing helmets by two-wheeled vehicle occupants (drivers, passengers, or all)	X	X		X	X	X	X	X	
		3.3.6 Effective reinforcement score of using helmets**	X	X		X	X	X	X	X	X
	3.4 Distraction during driving	3.4.1 % of drivers using mobile phones while driving (hand-held and hands-free)	X	X	X	X	X	X	X	X	
		3.4.2 Effective reinforcement score of using mobile phones**	X	X	X	X	X	X	X	X	X
	4.1 Vehicle age	4.1.1 % cars < 6 years		X	X	X	X			X	X
		4.1.2 % of old vehicles > 10 years		X	X	X	X			X	X
		4.1.3 Renewal rate of passenger cars,		X	X	X	X			X	X
		4.1.4 Median age of the passenger car fleet		X	X	X	X			X	X
		4.2.1 Passive safety score (EuroNCAP score)	X	X	X	X	X	X	X	X	X

The thematic indicators	Subgroups of thematic indicators	The individual indicators	The criteria of selecting indicators								
			Relevant to Safe system	Measurable	Comprehensive	Simple	Comparable	Independent	Achieving Targets	Valid	Data Available
4. Safer Vehicle	**4.2 Passive safety requirements**	4.2.2 % score of pedestrian protection for new cars sold	X	X		X	X		X	X	X
		4.2.3 Enforcement score on vehicle standard applied	X	X		X	X		X	X	X
		4.2.4 % of cars awarded 5stars on car occupants	X	X		X	X			X	X
		4.2.5 % of cars awarded 4 stars on child restraints	X	X		X	X			X	X
		4.2.6 % of cars awarded 3 stars on pedestrian protection	X	X		X	X		X	X	X
		4.2.7 % of vehicles with effective seat belts	X	X		X	X		X	X	X
		4.2.8 % of vehicles with anchorages	X	X	X	X	X		X	X	X
		4.2.9 % of vehicles with child restraint systems	X	X		X	X		X	X	X
		4.2.10 % of vehicles with safer frontal and side impact standards	X	X	X	X	X		X	X	
		4.2.11 % of cars awarded overall 5 stars**	X	X		X	X		X	X	X
	4.3 Active safety requirements	4.3.1 Enforcement score on vehicle standard applied	X	X		X	X		X	X	X
		4.3.2 % of vehicles with effective electronic stability control	X	X		X	X		X	X	X
		4.3.3 % of vehicles with anti-lock braking systems	X	X		X	X		X	X	X
		4.3.4 % of cars awarded overall 5 stars	X	X	X	X	X		X	X	X
	4.4 Vehicle composition	4.4.1 % of heavy vehicles		X		X	X	X		X	X
		4.4.2 % of two-wheeled vehicles		X		X	X			X	X
		4.4.3 % of vehicles in the total vehicle fleet		X	X	X	X			X	X
		4.4.4 Vehicle fleet composition		X	X	X	X			X	X
		4.4.5 % of vehicles not motorcycles		X		X	X			X	X

** The selected indicators for developing the RSAI

5.4.1 Evaluating the suggested individual indicators of safer road infrastructure

Each group of indicators are evaluated according to the above criteria as will be shown in the following sub sections.

Almost all the suggested indicators are simple and understandable, comparable, and valid. The criteria of comprehensiveness, independency, data availability, measurability and achieving set targets are more critical in evaluating the suggested indicators .

5.4.1.1 Evaluating the suggested individual indicators of the safer road design elements' subgroup

- Regarding the indicator 1.1.1, there is no data available related to the results of the percentage of roads fitting the safety standards. Therefore, there is a need to measure this indicator by valid methodology. The methodology of the RAP can be used to measure this indicator. Therefore, it is considered dependant on the indicator related to the RAP rating.

- Regarding the indicator 1.1.2, the selection of the percentage of paved road length indicator in previous studies was based mainly on the available data, with a reference to a limitation regarding its incomprehensive reflection of the road infrastructure indicators (Al-Haji 2007; Chen et al. 2017). Therefore, it is considered incomprehensive. In addition, the surface quality of roads is considered as one of the input indicators of the RAP methodology, therefore, it is considered dependant on the indicator of the RAP.

- Regarding the indicators 1.13 and 1.1.4, the RAP methodology produces ratings of road sections which are aggregated by a smoothing process (iRAP 2017). However, there is no clear and valid methodology to aggregate the RAP score of a whole network. Therefore, the EuroRAP is considered not measurable and substituted with the indicator of the percentage of roads awarded three stars or more; which can be measured through a methodology developed in this research and will be presented in Chapter Seven.

To this end, the percentage of roads awarded three stars or more is selected as the indicator of the safer road design.

5.4.1.2 Evaluating the suggested individual indicators of the safer road network subgroup

- Regarding the indicator 1.2.1, there is no data available related the percentage of roads fitting in the road network hierarchy and there is no valid methodology to measure this indicator. Therefore, it is considered immeasurable. In addition, it may depend on the RAP indicator this point is considered in the RAP methodology as will be shown at the end of this section.

- The indicators 1.2.2 and 1.2.3 which are the percentage of the motorway length, motorway density, and the density of the network are considered incomprehensive, since the selection of these indicators is based mainly on the data availability and not on the reflection of the factors of road classification. They are also not related to the principles of the safe system approach .

- The indicator 1.2.4 of the separation walking and cycling paths/roads is considered incomprehensive because it measures the factors related to the class of roads that are used by vulnerable road users only. In addition there is not available open access data regarding this indicator.

To this end, there is no comprehensive indicator in this subgroup. Therefore, it is suggested in this research to review the methodology of the RAP to evaluate its ability to consider the road network hierarchy as follow.

The ITF study (2016) refers to some road features that create a self-explaining environment; such as a cross-section, i.e. number of lanes and lane width, frequency of junctions, presence of bends (Lynam 2012), line marking, signage and functional design, which are considered by the iRAP (2017). The input indicators of the RAP, which are 60 road attributes, include: road type (divided or undivided); area type (urban, semi-urban, and rural); land use (residential, educational, industrial and manufacturing, farming and agricultural, undeveloped areas, and commercial); and property access points (Lynam 2012; iRAP 2017). These criteria are taken into account in the classification of roads by functions and types (Weijermars 2008; Arsénio et al. 2009). Furthermore, the road network hierarchy is considered in generating countermeasures through the RAP methodology, such as the countermeasures related to sidewalk/footpath segregation (Weijermars 2008; Arsénio et al. 2009; iRAP 2013d; Yannis et al. 2013; iRAP 2015). These criteria may reflect the homogeneity and functionality of roads (Yannis et al. 2013).

The latest version of the RAP is developed with greater attention to the requirements of safer road users, including pedestrians and cyclists. The vulnerable users' needs are considered by some indicators: such as the number of lanes (iRAP 2013e); segregation lanes and the roadside (iRAP 2013a; 2014b); intersection type (iRAP 2013c); pedestrian crossing facilities (iRAP 2014a); and pedestrian fencing (iRAP 2013b). The separation of walking and cycling is greatly considered in scoring the safety level of road sections by RAP methodology. Therefore, the indicator of RAP is suggested to reflect the indicator related to the protection of vulnerable road users and provide a separated area from the high-speed roads.

Hence, the RAP is an alternative, more comprehensive indicator suggested in this research to reflect the road network classification. The percentage of roads awarded three stars is suggested as the form of the indicator. Since this indicator is already selected in the first subgroup, the two groups are merged.

5.4.1.3 Evaluating the suggested individual indicators of road audit and inspection

Regarding the action of road audits, indicator group 1.3, the applicability of the RAP is selected to assess the audit effectiveness because there is no data reflecting the effectiveness of this indicator. However, to measure this indicator, yes/no question is needed which may produce different form of variable than the other selected indicator. In addition, this indicator may overlap with the indicator of the percentage of roads awarded three stars or more. Therefore, the latter indicator is considered in this group as the roads that are not assessed is rated by one star.

To this end, the percentage of roads awarded three stars or more is selected to reflect all groups of the road infrastructure indicators.

5.4.2 Evaluating the suggested individual indicators of safer speed

- The three individual indicators 2.1.1, 2.1.2, and 2.1.3 which measure the percentage of roads with a speed limit higher than the safer speed should be selected together to achieve the target of the comprehensiveness indicator. Since the speed limit is already considered in the RAP methodology and the indicator related to the RAP is already selected, the indicator 2.1.4 is likely to be best alternative in countries where the RAP is applicable in terms of comprehensiveness and independency.

- Regarding the technologies of speed management which are reflected by the indicator 2.2.1 and 2.2.2, they are already considered in the methodology of the RAP when suggesting countermeasures where the speed limit is higher than the safer speed. Therefore, the indicator of the RAP rating is most likely to selected here to avoid overlapping with the indicators of safer road infrastructure. This means that the groups of safer road infrastructure and safer speed limit might be merged into one thematic indicator under the name safer road infrastructure and mobility.

  Other technologies have been created to manage speed in vehicle design and are assessed by the EuroNCAP. These may increase the comprehensiveness of the EuroNCAP which will be evaluated in Section 5.4.4.

5.4.3 Evaluating the suggested individual indicators for safer road user behaviour

- The indicator 3.1.1 of the speeding factor is fit in terms of most the selected criteria. However, it is not fit in terms of data availability in some countries. The WHO (2013a; 2015) established a methodology to measure the effective score on enforcement subjectively. This score is measured by most of the countries. Therefore, it is considered the best alternate if the data regarding the indicator 3.1.1 are not available for the group of assessed countries.

- To measure the indicator 3.2.1, the data needed should reflect that the setting of the maximum BAC is fitting with the requirements of the recent policies, which are 0.05 g/ml for general drivers and 0.02 g/ml for novice and commercial drivers. However, not all countries have set the maximum BAC according to the safer limit (WHO 2015). Therefore, it will be difficult to measure this indicator.

- The indicator 3.2.2 of the percentage of road fatalities involving alcohol consumption is easier to measure but the data needed is not available for all countries. Therefore, it is better to considered other indicators which may their data is more available and can be measured easily. The same issue is related to the indicator 3.2.3 since not all countries have open access dataset regarding enforcing drinking-drivers.

- The indicators 3.2.4 and 3.2.5 which are related to the enforcement score on drinking-drivers and drug drivers respectively, are easier to measure by the methodology of the WHO (2013a; 2015) which is based on questionnaire methods. This makes them more fitted regarding the data availability criteria and best alternates when the data of other indicators are not available for the group of countries that needs assessment by the developed model.

- The indicators 3.3.1, 3.3.2, and 3.3.3 of using protective systems are not considered comprehensive unless they are selected together. This is because each indicator reflects a measure of the use of the protective system. For example, the rate of wearing seat belt measure the factor of wearing seat belt only while the indicator of using helmet measure the related factor only. If the data needed top measure these indicators are available, they are considered the selection of these three indicator may be considered the best choice. However, there are many countries still have issues regarding the related data. Therefore, the suggested alternative which are the effective score of enforcement are again considered here since the enforcement is a mean to achieve the aim of reducing the rate of drivers' offenders.

- The same thing with the indicator of using mobile phone in group 3.4. the indicator 3.4.2 is preferred because of the simplicity in measuring the indicator and data availability.

5.4.4 Evaluating the suggested individual indicators of safer vehicles

The evaluation of these indicators is shown below.

- The selection of the vehicle age as an indicator of vehicle safety is based on old studies (Hägg et al. 1999 and Frampton et al. 2002 adapted by Gitelman et al. 2007), which demonstrated that the newer vehicles are less likely to be involved in severe road crashes. Some more recent studies demonstrated that newer vehicles are much more likely to be equipped with protection and crash avoidance technologies (Hermans et al. 2009b). Therefore, the year of the vehicle is made is the suitable indicator and not its age. This is assessed by the EuroNCAP rating which is selected as indicator of passive and active safety, as will be shown in the following points.

- Most of the suggested indicators of the passive and active safety standards are not comprehensive except the indicators related to EuroNCAP and effective enforcement of vehicle standards. The latest version of EuroNCAP, as reviewed in Appendix II, considers the passive and active safety requirements. Therefore, it is more comprehensive than other indicators. The enforcement score is an important indicator but there is no data found in the reviewed sources and also there is a valid and clear methodology to measure this indicator. Therefore, the EuroNCAP score is the decided indicator of active and passive safety.

- Regarding the traffic composition, there is no related set target but it may reflect the homogeneity of roads. However, the percentage of two-wheeled vehicles and vulnerable road users are already considered by the RAP. The percentage of light vehicles is already considered by EuroNCAP. The percentage of heavy vehicles is not considered by any other indicators. However, to consider this indictor, a valid methodology is needed. However, a few studies conducted to consider the heavy vehicle safety and effect of traffic composition on road safety. Therefore, this group of indicators is not considered in this study and it is recommended to considered in further studies.

To this end, the final structure of the RSAI indicators is decided as shown in Figure 5.2.

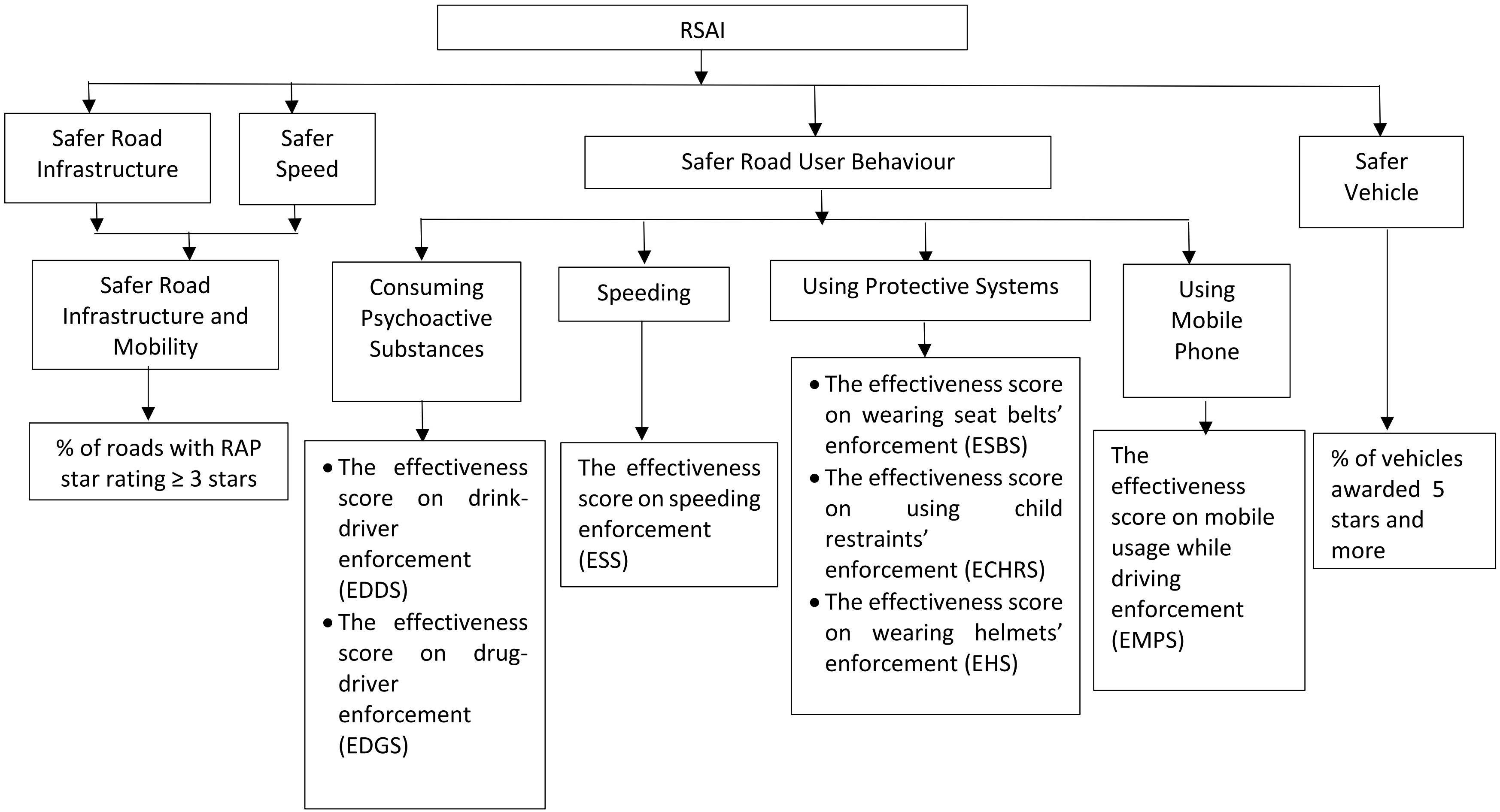

Figure 5.2 The final structure of the RSAI's indicators

5.5 Summary

In this chapter, the thematic indicators of the RSAI are identified based on the theory of the safe system approach . Then, individual indicators are suggested based on the reviewed studies to form a candidate list of individual indicators. These indicators are further refined based on specific criteria. The comprehensiveness, independence, measurability, data availability and achievement of targets are the most critical criteria affecting the selection of the most needed indicators.

The percentage of roads awarded three stars or more is the indicator selected to measure the safer road infrastructure and safer speed. To avoid overlapping, these two indicators are merged to become the safer road mobility indicator.

The indicators of the percentage of vehicle occupants wearing seat belts, using child restraints and wearing helmets, the percentage of drivers exceeding the maximum legal speed, the percentage of road fatalities involving drinking alcohol and consuming drugs, and the percentage of drivers using mobile phones while driving are best choice as individual indicators of the safer road user in terms of all the criteria. However, there are some countries still have issues regarding the availability of related data. Therefore, an alternate is suggested based on the indicators used in the WHO assessment methodology which are the effective scores on enforcement of these factors which are measured by expert questionnaire method.

The percentage of vehicles awarded five stars or more is the indicator of safer vehicles.
The final structure of the indicators has been developed. These indicators are weighted and aggregated to develop the RSAI model as will be shown in the next chapter.

CHAPTER SIX

DEVELOPING THE RSAI MODEL FORMS

6.1 Introduction

To compute the RSAI values, an aggregation model should be build. The methodology of building the RSAI model is shown in this chapter, see Figure 6.1. It starts with creating the form of the main model of the RSAI to aggregate the selected thematic indicators. Then three sub models are developed to incorporate the selected individual indicator into the RSAI model. These sub models are a safer road infrastructure and mobility model (SRIM), a safer road user behaviour model (SRUB) and a safer vehicle model (SV).

For each model, the terms of ViWi should be defined; where Vi is the variable of the indicator i, and Wi is the weight of the indicator i. The defined terms of each sub model are aggregated; then the sub models are aggregated to find the RSAI.

In this chapter, the main model of the RSAI is formulated in the next section. The sections 6.3, 6.4, and 6.5 will show the formulating of the SRIM, SRUB, and SV sub models respectively.

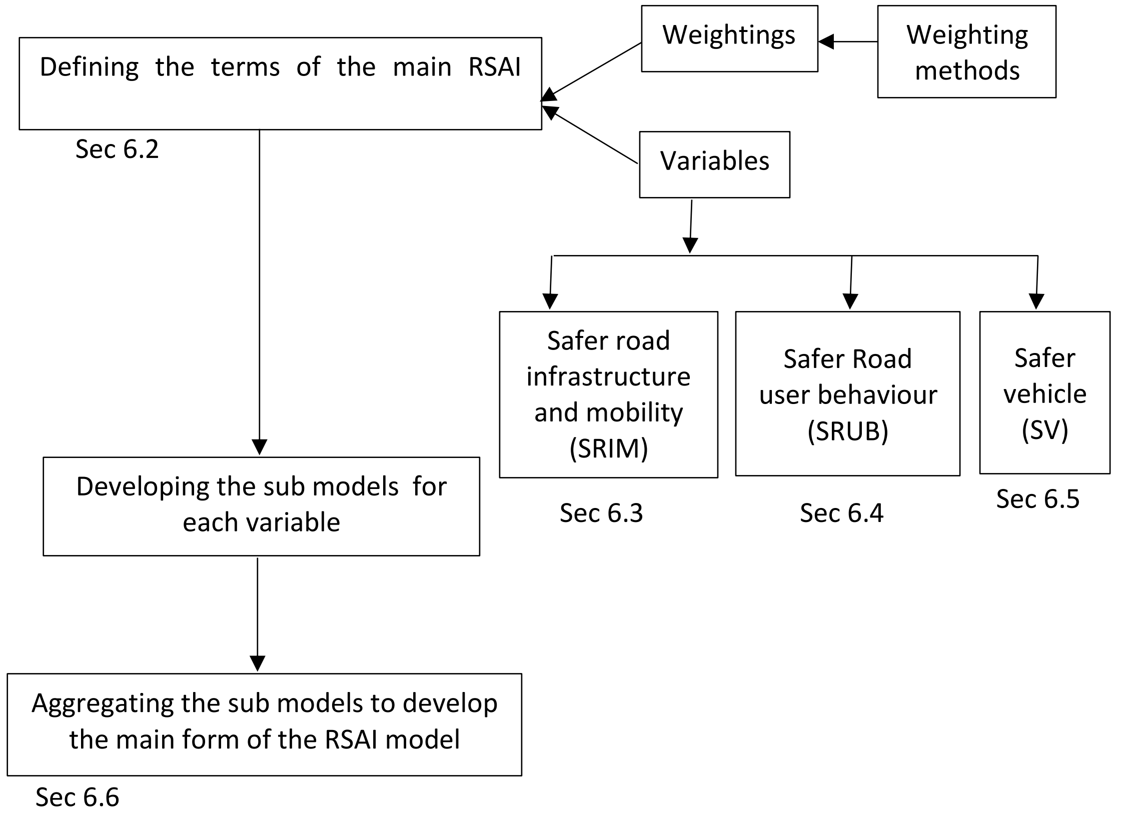

Figure 6.1 The methodology of developing the RSAI model

6.2 Formulating the Main Model of the RSAI

To formulate the main model of the RSAI, the main terms of the models should be defined. Each term contains variables (Vi) and the weights of the variables (Wi). The Vi represents the variables of thematic indicator i. The weight of the variables represents the relative importance of the indicator's impact on the overall developed RSAI. These terms are aggregated to develop the preliminary form of the RSAI model.

6.2.1 The main terms of the RSAI's model

The main model of the RSAI contains three main terms. These terms are (W_1SRIM), (W_2SRUB) and (W_3SV).

6.2.1.1 The variables of the RSAI's model

The variables SRIM, SRUB and SV represent the thematic indicators of safer road infrastructure and mobility, safer road user behaviour, and safer vehicles, respectively. A sub model will be developed for each variable in the following sections.

6.2.1.2 The weighting of the variables

Regarding the weights of these variables (Wi), the relative importance of each indicator is the criterion on which the selection of the weighting method is based. The ETSC (2001) identified the measure of the importance of the indictors:

"A useful way to show the importance of a safety performance indicator is to measure the change in accident or injury risk attributable to a certain change in the value of the indicator)" (ETSC 2001).

Research studies have been conducted to measure the impact of actions decided and implemented based on the safe system approach . These studies show that the programmes of road infrastructure improvement using speed management, vehicle safety improvements and road user behaviour improvements have resulted in the same range of reduction in the rate of road fatalities and injuries, which is about 30% (OECD 2008; Stigson et al. 2008;

Jost et al. 2011; Turner 2013; Woolley et al. 2018). This means that these programmes have the same relative importance. This also proves the concept of the safe system approach approach, where all components have a mutual responsibility in improving the road safety level.

Based on that, equal weights will be assigned to the main terms of the RSAI model. This means $W_1 = W_2 = W_3$.

6.2.2 The aggregation of the RSAI's terms

To aggregate the main terms of the RSAI, a method of aggregation should be decided. The simple linear additives aggregation (SLAA) method is selected because it is the most widely used method of aggregation as shown in Chapter three.

Equations 3.1, which is the general form of the SLAA method, is developed to Equations 6.1 to form the general RSAI model.

$$RSAI_j = SRIM + SRUB + SV \quad \text{... (6.1)}$$

where:

RSAIj = the road safety assessment index for country j

j= 1, 2…m, = country number; m = number of countries

To find the values of the SRIM, SRUB, and SV, three sub models are formulated. In these sub models the individual indicators which are selected in Chapter Five are incorporated, as will be shown in the following sections.

6.3 Formulating the Safer Road Infrastructure and Mobility Sub model

The percentage of road lengths awarded at least three-star rating is the individual indicator selected to interpret the road user infrastructure and mobility (SRIM). This indicator is the only term of the SRIM sub model as shown in equation 6.1.1.

$$SRIM_j = \frac{\sum_{k1}^{a} L_{k1}}{Lt} * 100 \qquad \text{...(6.1.1)}$$

where:

K1 = the road section number that is awarded an aggregated three stars or more= 1, 2,.....a

a = the number of the road sections subjected to RAP assessment and awarded an aggregated three stars or more

L_{k1} = the length of the road section k1

Lt = the total length of the roads' network

The RAP methodology is followed to rate road sections using VIDA (VIDA-iRAP 2018), which is online software developed to process the RAP methodology to rate road sections. This methodology is shown in Appendix I. The outputs of this methodology are in terms of a star rating classified into five levels; one star is the worst level and five stars is the safest level.

Four ratings are produced for four road user groups: vehicle occupants, motorcyclists, bicyclists, and pedestrians. Therefore, there is a need to aggregate them into one star rating. Specific methodology is developed in this research to find the aggregated RAP star rating per road section. This methodology will be shown in chapters Seven and Eight.

6.4 Formulating the Safer Road User Behaviour Sub model

The terms of the safer road user behaviour (SRUB) sub model should be defined; they are then aggregated to formulate the sub model.

6.4.1 The terms of the SRUB sub model

The variables and the weightings of the variables are determined as shown in the following sub-sections.

6.4.1.1 Variables of the SRUB's terms

The variables of the SRUB terms represent the individual indicators of safer road user behaviour. They are:

- The effectiveness score on speeding enforcement (ESS)
- The effectiveness score on wearing seat belts' enforcement (ESBS)
- The effectiveness score on using child restraints' enforcement (ECHRS)
- The effectiveness score on wearing helmets' enforcement (EHS)
- The effectiveness score on drink-driver enforcement (EDDS)
- The effectiveness score on drug-driver enforcement (EDGS)

- The effectiveness score on mobile usage while driving enforcement (EMPS)

6.4.1.2 Weighting of the SRUB's variables

Two methods of weighting are investigated to use in weighting the SRUB's. they are equal weighting and theoretical weighting.

1. The equal weighting is used assuming that each factor of the road user behaviour have the same impact on the road safety level. In this case, the weight of the SRUB variable which equals one is divided by the number of the SRUB's individual indicators which is 7. So, each variable's weight equal 0.143.

2. The theoretical method (Jameel and Evdorides 2018c) is suggested to estimate the importance of each individual indicator based on the rate of reduction of road fatalities and injuries resulting from enforcement countermeasures related to each indicator. The report published by the WHO (2013b) on strengthening road safety laws with more effective measures related to the risk factors of the road user's behaviour, and also other studies, have shown that:

    - Enhancing road safety laws with a new BAC limit of 0.02 g/ml, supported by effective enforcement, resulted in saving the lives of about 25-35% of road users (Hakkert et al. 2007; Elvik et al. 2009)

    - Speed enforcement leads to reducing road fatalities and injuries by about 30-35% (WHO 2013b).

- Seat belt enforcement resulted in saving the lives of 40-65% of road users (ETSC 2001; WHO 2013b; Gitelman et al. 2014).

- Enforcing the use of child restraints leads to saving the lives of about 54% of children aged under 5 years; which is equivalent to 5% of all road users' lives (Peden et al. 2004; WHO 2013b).

- Using helmets leads to saving about 20-45% of motorcyclists' lives and 60-80% of bicyclists' lives (Peden et al. 2004; Al-Haji 2007; Hakkert et al. 2007). This is equivalent of about 3-8% of all road users' lives.

There is a little information regarding the effectiveness of interventions to reduce the rate of road fatalities resulting from distraction by using a mobile phone (WHO 2015, Rac 2018). Studies have reported that the scale of this issue has been increasing and there is no evidence that the rate of using mobile phone while driving is reduced with the recent introduction of penalties (He et al. 2014, RAC 2018). In this case, the rate of road fatalities' reduction resulting from interventions related to using mobile phones is assumed equal to the minimum which is zero score.

There is also a little information regarding the effect of the interventions related to using drugs prior to driving, because of the various kinds of drugs with no valid method of measuring their concentration in the blood. (Wegman et al. 2008a) refers to studies which showed that the rate of road fatalities resulting from consuming drugs prior to driving is about half that of the road fatalities resulting from drinking alcohol prior to driving. Based on that, the rate of the related road fatalities' reduction assumed in this research is 12.5% to 17.5%.

These rates of reduction in road fatalities are standardised with regards to a maximum rate of fatalities' reduction, as shown in Table 6.1, to find the final weights of the SRUB's variables.

It is necessary to mention here that these weights do not reflect the size of the issue related to each indicator, but reflect the impact of the implemented interventions regarding legislation and enforcing road safety laws. For example, the role of speed management is significant and it is reflected by interventions related to road infrastructure and supported by vehicle technologies. The indicators of speeding in the SRUB sub model reflect the enforcement programme by installing cameras or setting penalties.

Table 6.1 Finding the weights of the SRUB's variables

Indicators	The rate of road fatalities' reduction	The standardised rate	The final weight
Drinking-drivers	0.3	0.58	0.21
Speeding	0.33	0.63	0.23
Wearing seat belts	0.52	1.00	0.36
Drug-drivers	0.15	0.29	0.10
Using helmets	0.05	0.10	0.03
Using child restraints	0.05	0.10	0.03
Using mobile phones	0.05	0.10	0.03
Total		2.79	1.00

6.4.2 The aggregation of the SRUB's terms

The sub model used to find the aggregated SRUBs is developed based on the general forms of the SLAA method. Equations 3.1 is developed by incorporating the terms of the SRUB to Equation 6.1.2a assuming equal weighting and to Equation 6.1.2b assuming unequal weighting as shown below.

$$SRUB_j\ (1) = \big(0.143\ (ESS) + 0.143(ESBS) + 0.143(ECHRS) + 0.143(EHS) + 0.143(EDDS) + 0.143(EDGS) + \ 0.143(EMPS)\big) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(6.1.2a)$$

$$SRUB_j\ (2) = \big(0.23\ (ESS) + 0.36(ESBS) + 0.03(ECHRS) + 0.03(EHS) + 0.21(EDDS) + 0.10(EDGS) + \ 0.03(EMPS)\big) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(6.1.2b)$$

Where $SRUB_j$ (1) and $SRUB_j$ (2) are the first and the second proposed safer road user behaviour score of country j producing from using equal weighting and unequal weighting method respectively.

ESPS, ESBS, ECHRS, EHES, EDDS, EDGDS, and EMPS are in percentage form (%).

6.5 Formulating the Safer Vehicle Sub model

The percentage of vehicles awarded five stars is the selected indicators for safer vehicles (SV). This indicator represent the term of the SV sub model. The variable of this term is obtained through the methodology of EuroNCAP. The vehicles that were awarded five stars are reported by EuroNCAP and, therefore, to get the aggregated value of this indicator, the vehicles' size per country classified by make and model is needed.

Then the developed sub model represented by equation 6.1.3 is used:

$$SV = Percentage\ of\ vehicles\ awarded\ five\ stars = \left(\frac{\sum_{k2=1}^{p} V_{k2}}{Vt}\right) * 100 \qquad \ldots\ldots\ldots(6.1.3)$$

where:

k2 = the vehicle models that were awarded five stars number = I, 2 ....p

p = the number of available models awarded five stars

V_{k2} = volume of vehicles of model k2

Vt= the total volume of all vehicle models

6.6 The Aggregated RSAI Model

By substituting the developed sub models including the two preliminary SRUBs in Equations 6.1, two preliminary RSAI models are generated as shown equations 6.1.a and 6.1.b.

$$RSAI_j\,(1) = SRIM + SRUB(1) + SV \quad \text{.................................} \; (6.1.a)$$

$$= \frac{\sum_{k1}^{a} L_{k1}}{Lt} * 100 + \big(0.143\,(ESS) + 0.143(ESBS) + 0.143(ECHRS) + 0.143(EHS) + 0.143(EDDS) + 0.143(EDGS) + 0.143(EMPS)\big) + \left(\frac{\sum_{k2=1}^{p} V_{k2}}{Vt}\right) * 100$$

$$RSAI_j\,(2) = SRIM + SRUB(2) + SV \quad \text{.................................} \; (6.1.b)$$

$$= \frac{\sum_{k1}^{a} L_{k1}}{Lt} * 100 + \big(0.23\,(ESS) + 0.36(ESBS) + 0.03(ECHRS) + 0.03(EHS) + 0.21(EDDS) + 0.10(EDGS) + 0.03(EMPS)\big) + \left(\frac{\sum_{k2=1}^{p} V_{k2}}{Vt}\right) * 100$$

These preliminary models will be evaluated to choose the most appropriate one in achieving the purposes of the RSAI as will be shown in Chapters Nine and Ten.

6.7 Summary

This chapter presented the process of developing the preliminary forms of the RSAI model. These models are produced using the simple linear additive aggregation method. The terms of the main preliminary RSAI models are defined. The variables of these terms represent the thematic indicators of the RSAI, which are SRIM, SRUB, and SV. The weights of these variables are assumed equal because of the same relative importance. The relative importance is measured by the rate of road fatalities reduced by implemented programmes regarding the thematic indicators.

The variables of the main terms of the RSAI are found using three developed sub models, which are SRIM, SRUB, and SV sub models.

The SRIM sub model contains one term which represents the presence of road lengths awarded three stars and more. The methodology of computing the aggregated stars is developed in the next chapter, based on the methodology of the RAP.

The SRUB model is developed by aggregating seven variables which are weighted using two methods: equal and unequal method which is based on the relative importance of each variable. Thus, two preliminary SRUBs are produced.

The SV model is developed by computing the percentage of light vehicles awarded five stars using the EuroNCAP methodology.

Two preliminary RSAI models are derived as a result of the methodology of this chapter. These models will be evaluated in Chapter Nine to choose the final RSAI model which may be used to achieve its purposes.

In the next chapters, Seven and Eight, a methodology of aggregating the RAP methodology output will be developed to investigate the method that may be used in aggregating the RAP star ratings. The aggregated output is needed to use as variable of the road infrastructure and mobility sub model as was shown in section 6.3.

CHAPTER SEVEN

DEVELOPING A METHODOLOGY OF AGGREGATING THE RAP STAR RATINGS

7.1 Introduction

As shown in Chapter Five and Chapter Six, the percentage of road lengths awarded three stars and more is the suggested indicator of safer road infrastructure and mobility (SRIM). The RAP's methodology of assessing road infrastructures (iRAP 2017), which is shown in Appendix I, is used in this research to rate roads because it the most valid available methodology. However, the outputs of this methodology are in terms of four star ratings (SRs) for each assessed section of road, which is 100 m in length. Each of these SRs is for an individual road user group, i.e. vehicle occupants, motorcyclists, bicyclists, and pedestrians (iRAP 2015). The SR is determined by computing the star rating score (SRS) using models shown in Appendix I (iRAP 2017). These SRSs then are assigned to a SR band developed by the RAP to identify the SR.

To find the overall indicator of the SRIM, a single value of a road's rating is needed. Therefore, the four star ratings resulting from the RAP methodology should be aggregated for each section of road. For this, a methodology of aggregating the RAP star rating is developed in this research (Jameel and Evdorides 2016). Figure 7.1 shows the suggested methodology to develop preliminary models of aggregating the SRs.

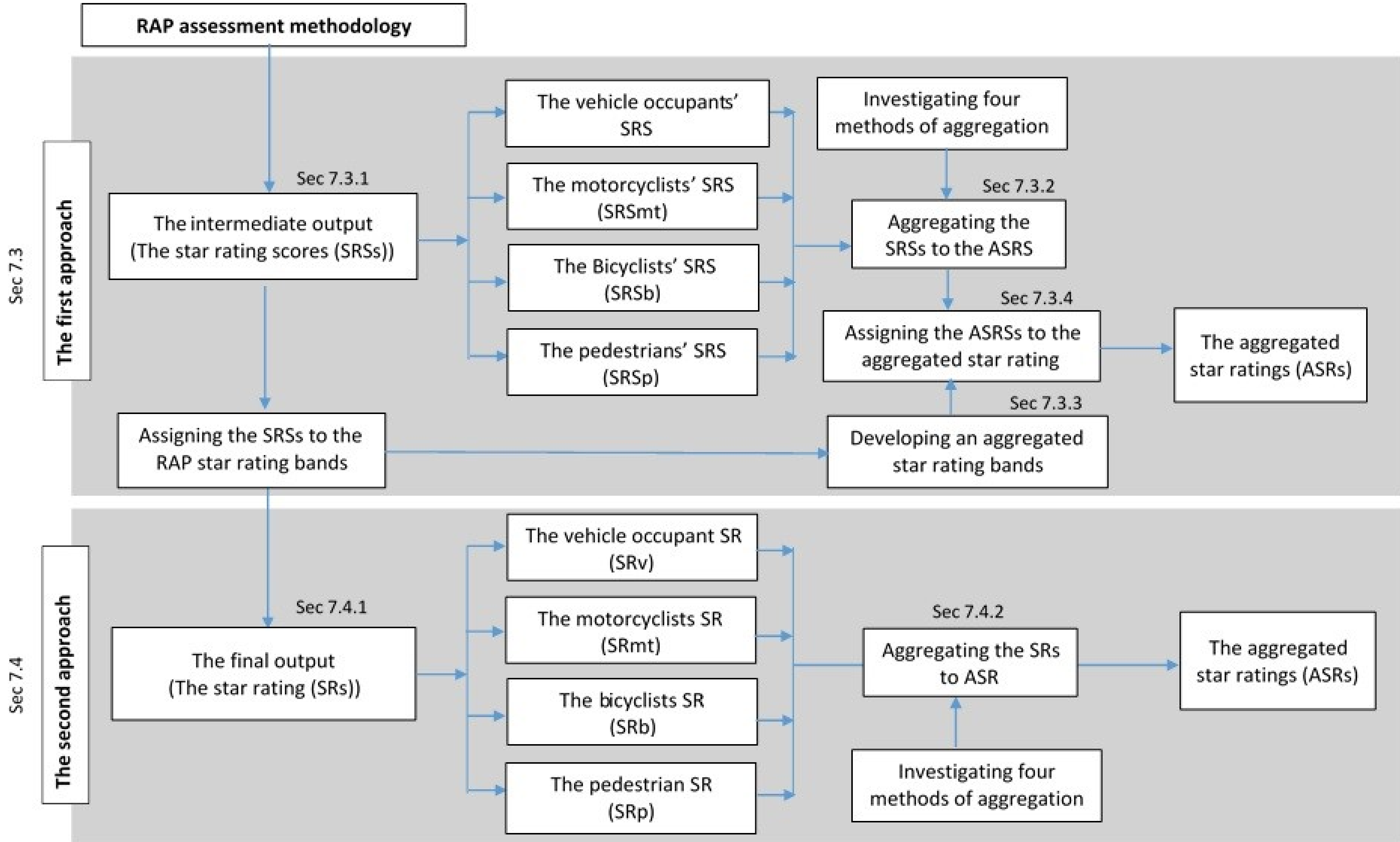

Figure 7.1 The methodology of investigating the aggregated star ratings assuming two approaches

7.2 The Suggested Approaches of Aggregating the RAP's Star Ratings

To formulate the models of aggregating the RAP star ratings, the methodology of the RAP's rating of roads is reviewed. This methodology may be divided into three phases:

- The first phase is identifying the input data for the four road-user groups' models.

- The second phase is calculating the star rating scores (SRSs) of the four road-user groups per each 100 m length of road section. These are the vehicle occupants' SRS (SRSv), the motorcyclists' SRS (SRSmt), the bicyclists' SRS (SRSb) and the pedestrians' SRS (SRSp).

- The third phase is assigning the SRSs to a SR band to identify the SR per each 100 m length of road section for the four road-user groups. These are the vehicle occupants' SR (SRv), the motorcyclists' SR (SRmt), the bicyclists' SR (SRb) and the pedestrians' SR (SRp).

If it is assumed that the same input data of the RAP's methodology is used to find the aggregated star rating (ASR), the aggregation may concern either the results of the SRSs' models or the SRs. To investigate these assumptions, two approaches are suggested in this chapter:

- The first approach is to aggregate the star rating scores (SRSs) per each 100 m length of road section, which are the intermediate results of the RAP's methodology, to produce an aggregated star rating score (ASRS). Then, to develop aggregated star rating bands to find the overall aggregated star rating (ASR).

- The second approach is to aggregate the star ratings (SRs) of each 100 m length of road section, which are produced from the RAP's methodology, in order to produce the overall aggregated star rating (ASR).

To find the ASR using both approaches, preliminary models are developed in this research. The processes of developing the models are shown in the next sections.

7.3 The First Approach

The main steps in developing the ASR model in the first approach are: identifying the terms, aggregating them, assigning the aggregated score to a developed star rating bands, and finding the ASR. The process in this approach is more complicated since it is based on aggregating intermediate results which needs following steps to find the ASR.

7.3.1 Identifying the terms of the model

To formulate the models for aggregating, the terms of the models should be identified, these models contain variables and the weights of these variables.

The variables of the terms are the star rating scores of the four road-user groups of each 100 m length of the road sections, which are SRSv, SRSmt, SRSb, and SRSp.

Regarding the weighting of the variables, it is assumed that the weight of each variable reflects the relative ratio of the level of the road safety for each of the road-user groups to the overall road safety level. Since the road safety level of each of the four road-user groups is measured by the SRS (iRAP 2017), the ratio of the SRS of each group of road users to the total SRSs of the assessed section is used to weight the variables. This weight is different for each section of road because it is based on the volume of road users and the indicators of the roads' infrastructure safety that are related to each road-user group on each road section (iRAP 2017). Therefore, this weight should be computed for each road section.

To interpret this assumption to a mathematical form, the weight of the ASR and ASRS models is computed by dividing the star rating score (SRS) of a 100 m length of road section, produced from the RAP methodology for a specific group of road user, into the summation of the SRSs for all road users, as shown in equation 7.1:

$$Wr = \frac{SRSr}{\sum_{r=1}^{4} SRSr} \quad \dots\dots\dots (7.1)$$

where:

Wr = Weight of variable r

r = the road user group: vehicle occupants, motorcyclists, bicyclists and pedestrians

SRSr = the star rating score for road user group r

For example, the weight of the variable related to the vehicle occupant is computed as below:

$$W\ of\ vehicle\ occupant\ variable = \frac{SRSv}{SRSv + SRSmt + SRSb + SRSp} \quad \dots\dots\dots (7.1.1)$$

The identified variables and their weights are aggregated as shown in the next section.

7.3.2 Aggregating the terms

The aggregation methods which are reviewed in Chapter Three are investigated in this chapter to choose the method that produces the final ASR. These methods are the simple linear additive aggregation method (SLAA) and the geometric aggregation method (GA). Two more aggregation functions are investigated also, which are the maximum function (MAX) and the minimum function (MIN), to interpret the logical concept of aggregation (Jayram et al. 2008; Grabisch et al. 2009). This concept is based on the particular purpose of aggregation, which is quantifying the level of road safety of the road section for all road-user groups, based on the road design features. This means that the road design features should be qualified with the needs of all road users. Therefore, it is a concern that the SLAA method might not interpret this concept. When the design features are fully match with the safety requirements of three of the road-user groups, then it is expected that the aggregated star rating will be high, even in case the fourth road-user group is fully in an unsafe condition in this section of road. Based on this concern, the four suggested methods of aggregation are investigated to develop the aggregation models and produce the preliminary aggregated star rating scores (ASRSs), as shown in equations 7.2 to 7.5.

$$ASRS\ (1) = W1(\mathrm{SRSv}) + \mathrm{W2\ (SRSmt)} + \mathrm{W3\ (SRSb)} + \mathrm{W4\ (SRSp)} \qquad \ldots\ldots\ldots (7.2)$$

$$ASRS\ (2) = (SRSv)^{W1}(SRSmt)^{W2}(SRSb)^{W3}(SRSp)^{W4} \qquad \ldots\ldots\ldots (7.3)$$

$$ASRS\ (3) = Max\ [(SRSv), (SRSmt), (SRSb), (SRSp)] \qquad \ldots\ldots\ldots (7.4)$$

$$ASRS\ (4) = Min\ [(SRSv), (SRSmt), (SRSb), (SRSp)] \qquad \ldots\ldots\ldots (7.5)$$

where:

ASRS (1), ASRS (2), ASRS (3), and ASRS (4) = the preliminary aggregated star rating scores resulting from aggregating the RAP's SRSs using the SLAA method, the GA method, the maximum function, and the minimum function respectively;

W1, W2, W3, and W4 = the weights of SRSv, SRSmt, SRSb, and SRSp respectively.

The ASRSs resulting from this step will be assigned to a developed star rating bands to find the ASR, as shown in the next section.

7.3.3 Developing an aggregated star rating bands

Assigning the star rating scores to star rating bands is based on the RAP methodology assessment in identifying the SR (iRAP 2017). The RAP's bands are shown in Figure 7.2. However, these bands are categorised into four bands each for a road user group (iRAP 2017). Therefore, there is a need to develop an aggregated star rating bands to use in the methodology of aggregating star ratings.

Figure 7.2 shows that ranges of star rating scores are allocated for each star rating. Each range contains a smaller score (Ssc) and a larger score (Lsc). These bands are identified and evaluated based on some points of which the safe system approach concept is their core (iRAP 2017), as shown in Appendix I. Therefore, these scores are considered in this research as the best choice for a starting point in developing the new aggregated star rating bands, which may be used in finding the final ASR, without neglecting the safe system approach principles.

Star Rating	Star Rating Score		
	Vehicle occupants and motorcyclists	Bicyclists	Pedestrians
			Total
5	0 to < 2.5	0 to < 5	0 to < 5
4	2.5 to < 5	5 to < 10	5 to < 15
3	5 to < 12.5	10 to < 30	15 to < 40
2	12.5 to < 22.5	30 to < 60	40 to < 90
1	22.5 +	60+	90 +

Figure 7.2 The RAP star rating bands and colours (iRAP 2017)

The aggregating of the Ssc and the Lsc of each range is investigated to find the aggregated bands. Since there are four preliminary ASRSs produced from the equations 7.2 to 7.5, where each is developed by a different method of aggregation, it is suggested here to develop an aggregated star rating band for each preliminary ASRS using the same methods of aggregation that used to find that ASRS. This means that the star rating band which is for the ASRS1 is developed using the SLAA method and for the ASRS2 is developed using the GA method, and so on.

Equations 7.2a to 7.5a are developed in this chapter to aggregate the Ssc and Lsc values of the aggregated star ratting bands for the four ASRSs.

$$ASsc\ (1) = \sum_{r=1}^{4} Ssc(r) \qquad \dots \dots \dots (7.2a)$$

$$ASsc\ (2) = \prod\nolimits_{r=1}^{4} \mathrm{Ssc(r)} \qquad \dots \dots \dots (7.3a)$$

$$ASsc\ (3) = \mathrm{Max}[Ssc1, Ssc2, Ssc3, Ssc4] \qquad \dots \dots \dots (7.4a)$$

$$ASsc\ (4) = \mathrm{Min}\ [Ssc1, Ssc2, Ssc3, Ssc4] \qquad \dots \dots \dots (7.5a)$$

$$ALsc\ (1) = \sum_{r=1}^{4} Lsc(r) \qquad \ldots\ldots\ldots (7.2b)$$

$$ALsc\ (2) = \prod\nolimits_{\mathrm{r}=1}^{4} \mathrm{Lsc(r)} \qquad \ldots\ldots\ldots (7.3b)$$

$$ALsc\ (3) = \mathrm{Max}[Lsc1, Lsc2, Lsc3, Lsc4] \qquad \ldots\ldots\ldots (7.4b)$$

$$ALsc\ (4) = \mathrm{Min}\ [Lsc1, Lsc2, Lsc3, Lsc4] \qquad \ldots\ldots\ldots (7.5b)$$

Where:

ASsc (1), ASsc (2), ASsc (3), and ASsc (4) are the aggregated smaller score of each ASR band for ASRS1, ASRS2, ASRS3, and ASRs4 respectively, using SLAA method, GA method, maximum function, and minimum function respectively.

ALsc (1), ALc (2), ALsc (3), and ALsc (4) are the aggregated larger score of each ASR band for ASRS1, ASRS2, ASRS3, and ASRs4 respectively, using SLAA method, GA method, maximum function, and minimum function respectively.

Ssc (1), Ssc (2), Ssc (3), and Ssc (4) are the smaller score of the SR of vehicle occupants, the SR of motorcyclists, the SR of bicyclists and the SR of pedestrians respectively.

Lsc (1), Lsc (2), Lsc (3), and Lsc (4) are the larger score of the SR bands of vehicle occupants, the SR bands of motorcyclists, the SR bands of bicyclists and the SR bands of pedestrians respectively.

Table 7.1 shows the application of the equations 7.2a to 7.5a and equations 7.2b to 7.5b in finding the ASsc and ALsc of each ASR. The results of this application are shown in Figure 7.3.

Table 7.1 Developing the aggregated star rating bands

The proposed ASRS	**ASRS1**		**ASRS2**	
The developed model of aggregation	Equation (7.2a)	Equation (7.2b)	Equation (7.3a)	Equation (7.3b)
5	0+0+0+0=0	2.5+2.5+5+5=15	0×0×0×0=0	2.5×2.5×5×5=156.25
4	2.5+2.5+5+5=15	5+5+10+15=35	2.5×2.5×5×5=156.25	5×5×10×15=3750
3	5+5+10+15=35	12.5+12.5+30+40=95	5×5×10×15=3750	12.5×12.5×30×40=187500
2	12.5+12.5+30+40=95	22.5+22.5+60+90=195	12.5×12.5×30×40=187500	22.5×22.5×60×90=2733750
1	22.5+22.5+60+90=195	+	22.5×22.5×60×90=2733750	+
The proposed ASRS	**ASRS3**		**ASRS4**	
The developed model of aggregation	Equation (7.4a)	Equation (7.4b)	Equation (7.5a)	Equation (7.5b)
5	MAX[0,0,0,0]=0	MAX[2.5,2.5,5,5]=5	MIN [0,0,0,0]=0	MIN[2.5,2.5,5,5]=2.5
4	MAX[2.5,2.5,5,5]=5	MAX [5,5,10,15]=15	MIN[2.5,2.5,5,5]=2.5	MIN [5,5,10,15]=5
3	MAX [5,5,10,15]=15	MAX[12.5,12.5,30,40]=40	MIN [5,5,10,15]=5	MIN [12.5,12.5,30,40]=12.5
2	MAX[12.5,12.5,30,40]=40	MAX[22.5,22.5,60,90]=90	MIN [12.5,12.5,30,40]=12.5	MIN [22.5,22.5,60,90]=22.5
1	MAX[22.5,22.5,60,90]=90	+	MIN [22.5,22.5,60,90]=22.5	+

Aggregated Star Ratings (ASRs) \ Aggregation methods	Aggregated star rating scores (ASRSs)			
	ASRS1 $(ASsc(1)\ to < ALsc(1))$	**ASRS2** $(ASsc(2)\ to < ALsc(2))$	**ASRS3** $(ASsc(3)\ to < ALsc(3))]$	**ASRS4** $(ASsc(4)\ to < ALsc(4))$
5	0 to < 15	0 to < 156.25	0 to < 5	0 to < 2.5
4	15 to < 35	156.25 to < 3750	5 to < 15	2.5 to < 5
3	35 to < 95	3750 to < 187500	15 to < 40	5 to < 12.5
2	95 to < 195	187500 to < 2733750	40 to < 90	12.5 to < 22.5
1	195 +	2733750 +	90 +	22.5 +

Figure 7.3 The developed aggregated star rating bands and colours using four aggregation methods

7.3.4 Finding the ASRs

The aggregated ASRSs are assigned to the aggregated star rating bands that resulted from using the same method of aggregation to find the aggregated ASRs. For example, the ASRS1 which is identified using the SLAA method is assigned to the ASRS band which is developed also using the SLAA method. The other ASRSs are assigned to the developed aggregated bands in the same way.

The results of this step, which are the output of the first approach, are ASR1, ASR2, ASR3, and ASR4. These will be evaluated with the output of the second approach to select the most appropriate ASR.

7.4 The Second Approach

The process of developing the ASR model in the second approach is simpler than the first approach since it is based on aggregating the final results, which are the star ratings. Two steps only are followed: identifying the terms of the developed model, and aggregating them.

7.4.1 Identifying the terms of the model

The variables of the terms are the star ratings of the four road-user groups of each 100 m length of the road sections, which are SRv, SRmt, SRb, and SRp. These variables are weighted by the same method of weighting illustrated in the first approach.

7.4.2 Aggregating the terms

The four methods of aggregation suggested in the first approach are investigated also in aggregating the terms in this approach, to develop the preliminary aggregation models and find preliminary ASRs. Equations 7.6 to 7.9 are developed for this purpose.

$$ASR\ (5) = W1(\text{SRv}) + \text{W2 (SRmt)} + \text{W3 (SRb)} + \text{W4 (SRp)} \quad \text{… … … (7.6)}$$

$$ASR\ (6) = (SRv)^{W1}(SRmt)^{W2}(SRb)^{W3}(SRp)^{W4} \quad \text{… … … (7.7)}$$

$$ASR\ (7) = Max\ [(SRv), (SRmt), (SRb), (SRp)] \quad \text{… … … (7.8)}$$

$$ASR\ (8) = Min\ [(SRv), (SRmt), (SRb), (SRp)] \quad \text{… … … (7.9)}$$

Where:

ASR (5), ASR (6), ASR (7), and ASR (8) = the preliminary aggregated star ratings resulting from aggregating the RAP’s SR using the SLAA method, the GA method, the maximum function, and the minimum function respectively.

These four equations produce the output of the second approach.

The output of the first and the second approaches are evaluated to choose the final ASR, which is the most appropriate one in terms of interpreting the level of the road infrastructure and mobility safety. The process of the evaluation is shown in Chapter Eight.

7.5 Summary

In this chapter, a methodology for developing models to produce preliminary ASRs is developed. The ASR is needed to find the variable of the SRIM model which is developed in Chapter Six. The proposed methodology in this chapter is based on the RAP methodology of assessing and rating roads. Assuming that the input data is the same input data of the RAP methodology, the main two phases of the RAP methodology are considered in developing the ASR models by assuming two approaches.

The first approach is based on the first phase of the RAP methodology which produces the intermediate output in terms of the RAP star rating scores (SRS). In this approach, the RAP's SRSs are aggregated by investigating four methods of aggregation: the SLAA, the GA, the maximum function, and the minimum function. To obtain the ASRs from the preliminary ASRSs, an aggregated star rating band is developed. This step is suggested based on the RAP methodology in assigning the RAP's SRS to the RAP's SR bands. The aggregated SR bands are developed starting from the RAP's SR bands, by aggregating the smaller and the larger score of each range of SRSs. Since there are four ASRSs produced from the four models of aggregation in the first approach, therefore four aggregated SR bands are developed using the same four methods of aggregation. The developed aggregated SR bands are used to assign the ASRSs and identify ASR1, ASR2, ASR3, and ASR4.

The second approach is based on the second phase of the RAP methodology which is the final output in terms of the RAP's SR. In this approach, the RAP's SRs are aggregated using the same methods of aggregation which are used in the first approach. Four preliminary ASRs are produced from this approach: ASR5, ASR6, ASR7, and ASR8.

To select the final ASR model, the eight preliminary ASRs are evaluated. The methodology of the evaluation is shown in the next chapter.

CHAPTER EIGHT

EVALUATION OF THE PRELIMINARY ASR MODELS

8.1 Introduction

As shown in Chapter Seven, eight preliminary aggregated star ratings (ASRs) are produced. In order to select the final ASR that indicates the road risk based on the observed road design features, the preliminary ASRs are evaluated. This chapter presents the method of evaluation which is based on comparing each of the preliminary ASRs with actual crash data.

The procedures of the evaluation are shown in this chapter. It starts with deciding the form of the crash data and the terms of comparison, through reviewing the previous evaluation studies of the RAP methodology, as shown in section 8.2. Based on that, the necessary data with their sources are defined, and the road sections in the UK are selected as a case study to apply the proposed methodology of aggregation, as shown in sections 8.3 and 8.4. The results of the evaluation are presented in section 8.6 and the selection of the final ASR is shown in section 8.7.

8.2 The Methods of the ASRS Evaluation

To decide the method of evaluation, a review is carried out of the evaluations of the original RAP's star ratings in previous studies. The RAP's studies are based on the comparison of the RAP's results with reported or estimated crash data in testing the validation of the iRAP models (Lynam et al. 2007; McInerney et al. 2008; iRAP/EuroRAP 2011). Hence, this kind of comparison is used to evaluate the preliminary ASRs. For this, there is a need to decide the form of the crash data and the terms of comparison.

8.2.1 The form of the crash data

The crash data were used in the evaluation studies in different forms, such as average crash rates per section of road, crash severity, or crash cost. McInerney et al. (2008) argued that crash cost per vehicle kilometre (VKT) travelled is the most appropriate means of testing because it accounts for the number and severity of crashes, and brings in how many vehicles are using the road. Therefore, the estimated crash cost per VKT is the form used in this step to compare with the ASRs. It is also important to consider isolating the fatal and serious injury accidents that only involve cars that are rated as the highest level of the NCAP star ratings, and where no traffic violation factors such as speeding or drinking alcohol have contributed, as recommended in the previous RAP studies (Lynam et al. 2007; McInerney et al. 2008; iRAP/EuroRAP 2011).

8.2.2 The terms of the comparison

Regarding the terms of comparison between the preliminary ASRs and the estimated crash cost, three were used in previous investigations of the RAP validation. These are:

1. Investigating the trend in the real crash rates or crash costs and comparing it with the trend of the SRs: the decreasing of the average crash rates or crash cost with increasing SRs means a valid indication of the real road risk by the SRs. Thus, the road sections rated the highest have lower crash costs (Castle et al. 2007; McInerney et al. 2008; iRAP/EuroRAP 2011).

2. Measuring the average crash rates' change from one SR band to the next: it was shown that the reduction of average crash rates when moving from two-star to three-star roads is higher than when moving from three-star to four-star or from four-star to five-star banding (McInerney et al. 2008; iRAP/EuroRAP 2011).

3. Investigating the roads that are awarded the highest SR: these roads, in principle, should have no fatal crashes (Lynam et al. 2007; McInerney et al. 2008; iRAP/EuroRAP 2011).

To process the evaluation of the preliminary ASRs, data is needed and should be identified and gathered for the selected roads under study. The next section shows the selected roads, the types of data needed, and the source of the data.

8.3 The Selected Roads

The selection of road sections is based on the road type, the availability of the needed data, and the statistical confidence level of the sample size.

1. The road type is considered in the selection of the roads to be studied to ensure the homogeneity of the gathered data, in terms of the design feature of the roads and the type of the road-user groups using the road. The roads in the UK are classified by the Department for Transport (DFT) (DfT 2017) as motorways, A roads, and B roads.

2. Some of the main data needed are the RAP star rating results. Since the purpose of this step is the evaluation of the preliminary developed model of aggregating the RAP star

ratings, then the selected road should be the type that can be used by the four road-user groups, which are considered by the RAP methodology, or at least by three of them to enlarge the sample size. Therefore, the motorway roads are not selected in the evaluation because they are used by only two road-user types, which are vehicle occupants and motorcyclists. The B-type roads may be the most suitable for this study because they are used by all the road-user types. However, it was difficult to get access to the result of RAP assessment results of the B-type roads; hence, the A-type roads are selected for the evaluation step. Access was granted to the results of the RAP assessment results of some of the A-type road sections in the UK (VIDA-iRAP 2018). The sections shown in Table 8.1 are selected for the evaluation of the ASR models since these sections are used by at least three road-user types. These roads are divided into 100 m sections as per the RAP methodology (iRAP/EuroRAP 2011; iRAP 2017).

Table 8.1 The road sections selected for evaluation of the ASR models

Road Name	**Section**	**Length (km)**
A21	From A229 to A259	22.7
A5	From A458 to Felton Butler roundabout	06.6
A5	From Wolfshead roundabout to A484	21.5
A616	From A628 to M1 excluding 1.9 km.	14.9
A453	From A42 to A52	12.4
A303	From Hayes End roundabout to A30	26.4
Total		104.5
Total number of 100m sections		1045

3. The selected section is subjected to statistical analysis using t test to identify the sample size with minimum confidence level of 95% which represent the sufficiently of selected number of road sections to choose the most appropriate model (Limpert and Stahel, 2011; Cowles and Davis, 1982; Zar, 1984; Allison, 1999). Equation 8.1 is used to compute the maximum rate using t test method (Kennedy and Neville, 1986).

$$MaxRError=(SD/mean)*t/N^{0.5} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8.1)$$

Where

MaxRError=maximum rate of error resulting from the rate of variation of the set of data

SD= standard deviation

t= t value corresponding to 95% confidence level and sample size greater than 1000= 1.96

N=optimum sample size

The results show that the standard deviation and the mean of the 1045 road sections selected in this study equals to 300375.6 and 53893.18 respectively. This results in maximum rate of error equal to 3.4%. This means that the selected sample size is sufficient in evaluating the preliminary models and selecting the most appropriate model.

Table 8.2 shows an example of division of a segment of the A5 road.

Table 8.2 The gathered RAP's SRSs and SR data for the four road-user groups per 100 m length of road section for a 2 km length section of the A21 road (VIDA-iRAP 2018)

Section number	Road name	The star rating scores				The star ratings			
		Vehicle star rating score (SRSv)	Motorcyclist star rating score (SRSmt)	Bicyclist star rating score (SRSb)	Pedestrian star rating score (SRSp)	Vehicle star Rating (SRv)	Motorcyclist star rating (SRmt)	Bicyclist star rating (SRb)	Pedestrian star rating (SRp)
1	A21	4.431235	5.983594	31.87979	10.9999	4	3	2	4
2	A21	8.61629	10.41483	68.69608	12.39295	3	3	1	4
3	A21	9.553674	12.40242	27.69019	25.62444	3	3	3	3
4	A21	8.789488	11.07454	37.92779	25.73149	3	3	2	3
5	A21	6.423362	7.483362	23.15419	22.79819	3	3	3	3
6	A21	11.37038	13.91746	37.92779	49.40135	3	2	2	2
7	A21	3.931434	4.991434	14.76259	27.03139	4	4	3	3
8	A21	12.4344	16.74452	36.54878	17.0202	3	2	2	3
9	A21	3.831489	4.891489	17.71013	32.4109	4	4	3	3
10	A21	9.970002	11.78128	21.749	47.59809	3	3	3	2
11	A21	7.537554	9.499084	20.20579	39.05253	3	3	3	3
12	A21	6.890543	8.852073	22.11367	43.26873	3	3	3	2
13	A21	10.50255	13.3513	31.77661	54.62002	3	2	2	2
14	A21	7.012123	8.826514	31.87979	32.51796	3	3	2	3
15	A21	17.1123	20.26976	47.99234	53.87049	2	2	2	2
16	A21	9.893934	12.44456	26.02699	49.2943	3	3	3	2
17	A21	3.669752	4.729752	14.76259	12.33809	4	4	3	4
18	A21	13.45487	15.75706	31.15099	53.76343	2	2	2	2
19	A21	3.931434	4.991434	17.71099	6.155663	4	4	3	4
20	A21	14.0535	17.64402	36.55187	41.20794	2	2	2	2

8.4 The Necessary Data

The necessary data for the evaluation step are gathered per each 100 m road section and concerned a period of five years (2010-2014) to ensure a sufficient data set. This data may be categorised into two main types as shown below:

1. The data needed to find the preliminary aggregated star ratings (ASRs); these data are:
    - The RAP's star rating scores (SRSs) of the four road-user groups: SRSv, SRSmt, SRSb and SRSp. These data are used to find the variables' weight of the proposed models of aggregation, using equation 7.1. They are also used as the variables of the aggregation models in the first approach, which are shown in equations 7.2 to 7.5.

    - The RAP's star rating (SRs) of the four-road user groups: SRv, SRmt, SRb and SRp. These data are used as the variables of the aggregation models in the second approach, which are shown in equations 7.6 to 7.9.

    The source of the RAP data is the VIDA website, which is the RAP online road safety platform (VIDA-iRAP 2018). A sample of the gathered data is shown in Table 8.2. All the gathered data are shown in Appendix III, Table III.1.

2. The data needed to estimate the crash cost of fatal and serious injury crashes (FSI) per vehicle kilometres (VKT); which are:

- The estimated cost of fatal and serious crashes. Table 8.3 shows the average value of prevention per reported road accident for the years 2010-2014, which are gathered from the DFT (DFT 2017).

Table 8.3 Average value of prevention per reported road accident for the years 2010-2014 (DFT 2017)

Accident type	Cost per accident				
	2014	**2013**	**2012**	**2011**	**2010**
Fatal	2,066,732	1,953,783	1,917,766	1,877,583	1,838,057
Serious	235,791	223,870	219,043	216,203	210,902

- The reported crashes caused by the road design features categorised by the severity level to fatal and serious crashes per year (CrashMap 2017; DfT 2017). However, this data needs to be estimated based on what data is available data. The available data is number of road fatalities and serious injuries (FSI) involved with 5-stars vehicles per section of road and the FSI resulted from human risk factors such as speeding and drinking alcohol. The available FSIs are subtracted from the total FSI to find the FSI involved with road design features. This data is obtained as a result of some steps which are shown in Appendix IV. Samples of the results are shown in Table 8.4.

Table 8.4 The total number of fatal and serious injury road accidents caused by road design features occurring in the sample of sections of the A21 in 2010-2014

Section number	Total accidents caused by road design features				
	2010	**2011**	**2012**	**2013**	**2014**
1	0	2	0	0	0
2	0	0	0	0	0
30	1	0	0	0	0
34	0	0	1	0	0
45	0	1	0	0	0
46	0	0	0	1	0
49	0	0	0	0	1
50	0	0	0	0	0
51	0	0	0	0	0

8.5 The Results

The collected data regarding the RAP star ratings are used to find the eight proposed ASRS per each 100 m road section using the developed equations 7.2-7.9. Samples of the results are shown in Table 8.5. All of the results are shown in Table III.2. The first aggregated star ratings (ASRs) resulted from the proposed first approach; while the second ASRs resulted from the second approach.

Table 8.5 The results of computing the weights of the variables of the preliminary ASRSs and ASRs' models and the ASRs produced from these models

Section number	The first approach of aggregation				The second approach of aggregation			
	ASR 1	**ASR2**	**ASR 3**	**ASR 4**	**ASR 5**	**ASR 6**	**ASR 7**	**ASR 8**
1	4	5	3	4	3	3	4	2
2	3	5	2	3	2	1	4	1
30	4	5	3	3	3	3	3	2
34	4	5	3	4	3	3	4	3
45	4	5	3	4	3	3	4	3
49	4	5	3	3	3	3	3	2
51	4	5	3	3	3	3	3	2
52	4	5	3	3	3	3	3	3

These results are compared with the estimated crash cost per VKT, which are shown in Table IV.7. Samples of the results are shown in Table 8.6. It can be seen that the total cost is computed for the years 2010-2014 by multiplying the average value of crash prevention of each year by the total number of crashes in that year. For example, the total number of crashes in year 2010 in section 30 equals one crash only; this crash resulted in seriously injured casualties, as shown in the details of crashes in Appendix IV. So, the cost of this crash is £216,203. The obtained number is added to the estimated cost of crashes occurred in years 2011-2014 to find the total cost of £210902.5, which is divided by the AADT to get the total cost per VKT which is equal to 152.65.

Table 8.6 The results of the estimation of the crash cost per VKT for each 100 m length of road sections of some sections of the A21 road

Section number	Road name	Total cost for five years (2010-2014)	Vehicle flow (AADT)	Total cost per VKT
1	A21	3971369	21680	2874.471
2	A21	0	21680	0
30	A21	210902.5	21680	152.6509
34	A21	219,043	21680	317.086
45	A21	216203.5	21680	156.4877
46	A21	1,953,783	21680	2828.291
49	A21	235790.5	21680	170.6648
52	A21	223870	21680	162.0368

Figure 8.1 shows the results of the comparison between the proposed ASRs and the estimated crash cost per VKT.

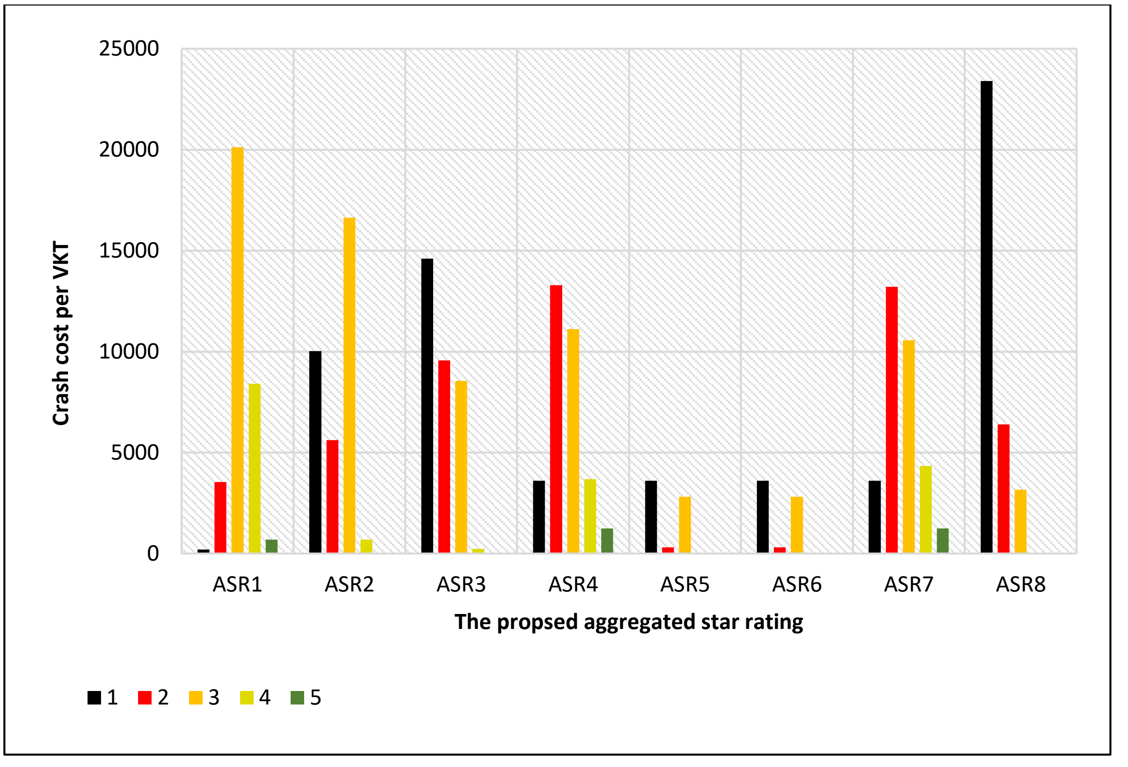

Figure 8.1 Comparing the total cost of fatal and serious injury crashes per VKT for each 100 m road section with the proposed aggregated star rating ASRs for single roads

Figures 8.2a-8.2h show the correlation between the preliminary ASRs and the crash cost per VKT. The correlation is measured by the bivariate Pearson correlation R which is the degree of the relationship between a pair of variables. It can vary between -1 and 1; where 1 indicates that the two variables rise and fall together with perfect correlation, while -1 means that the two variables are perfect opposites (Wilcox and Austin 1979; Eisinga et al. 2013; Kumar et al. 2018). The IBM SPSS statistics 24 are used to identify R, assuming a linear relationship between the crash cost per VKT and each proposed ASR.

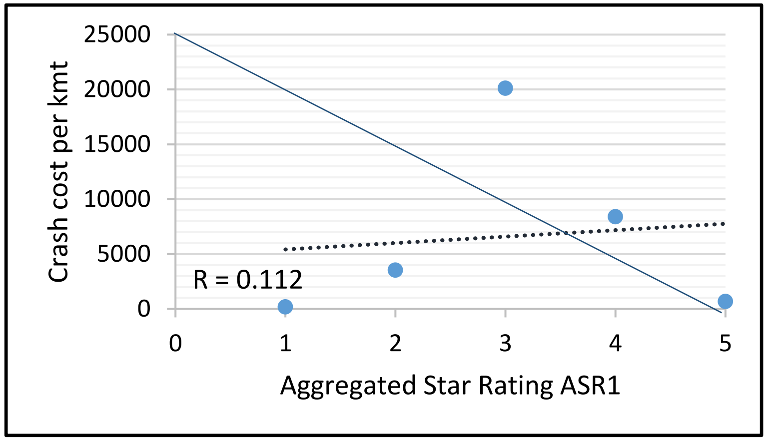

Figure 8.2aThe relationship between the crash cost per VKT and ASR1

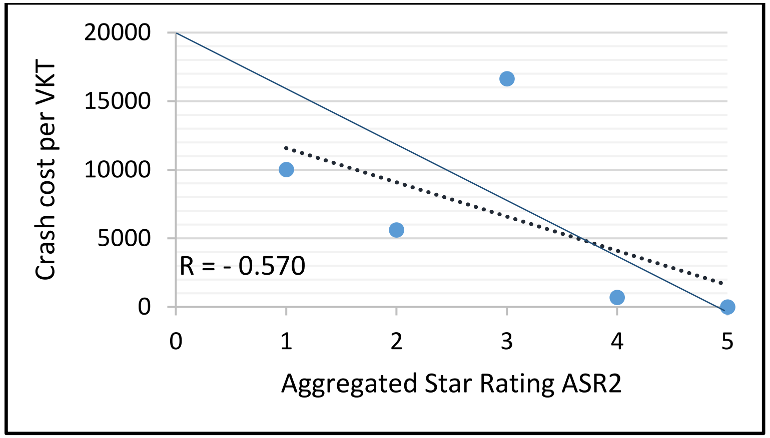

Figure 8.2bThe relationship between the crash cost per VKT and ASR2

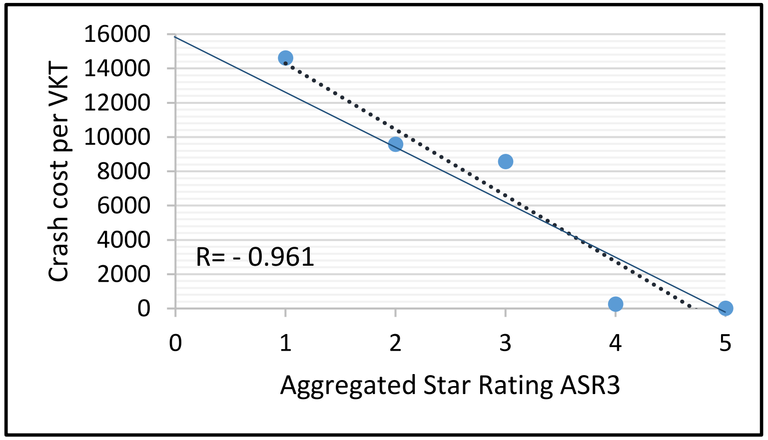

Figure 8.2cThe relationship between the crash cost per VKT and ASR3

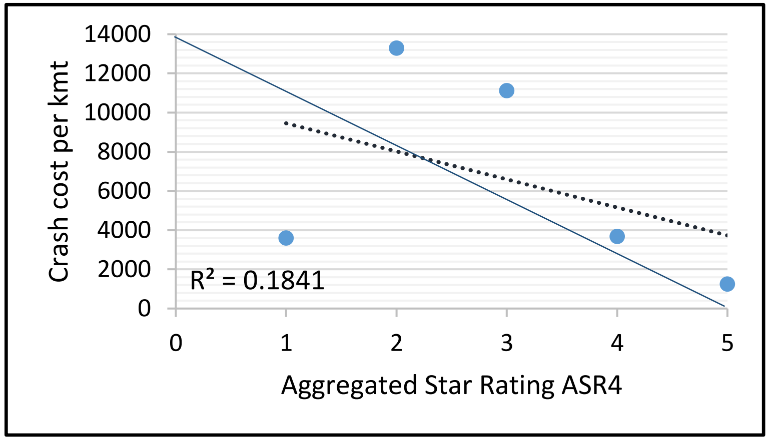

Figure 8.2d The relationship between the crash cost per VKT and ASR4

Figure 8.2 The correlation between the crash cost per VKT and the proposed aggregated star ratings

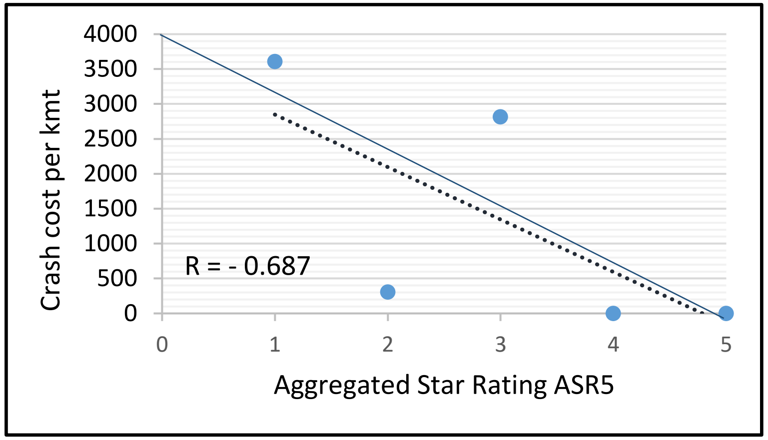

Figure 8.2eThe relationship between the crash cost per VKT and ASR5

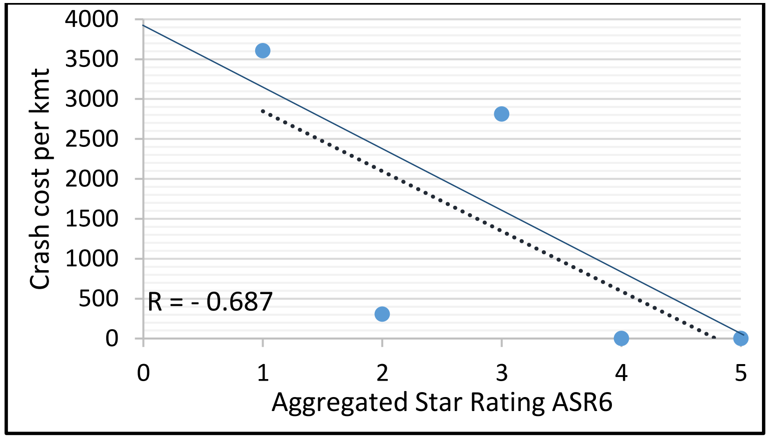

Figure 8.3f The relationship between the crash cost per VKT and ASR6

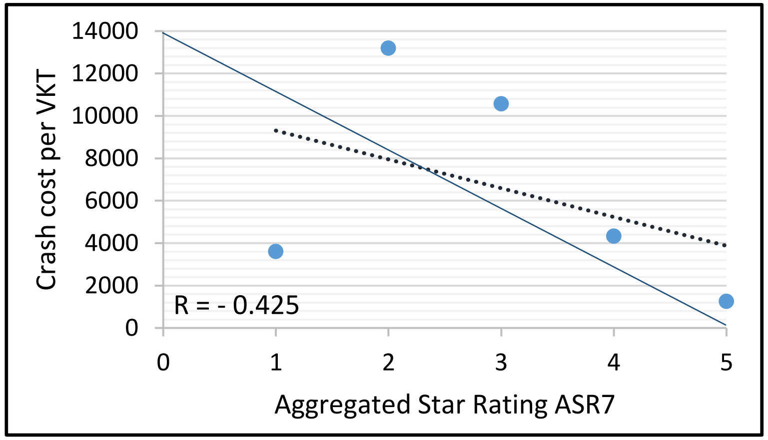

Figure 8.2hThe relationship between the crash cost per VKT and ASR7

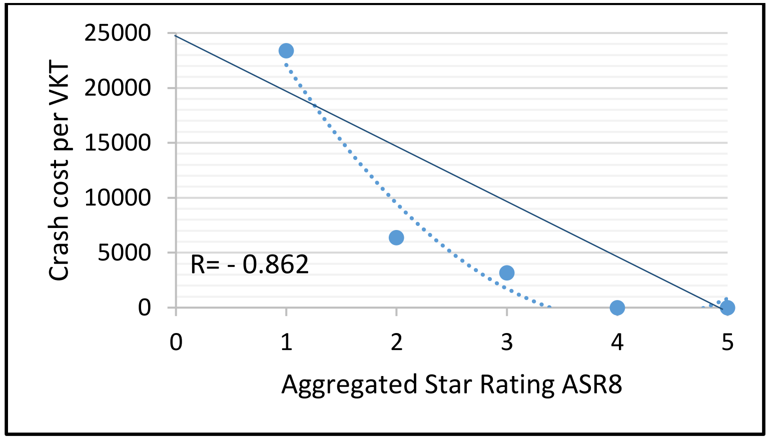

Figure 8.3i The relationship between the crash cost per VKT and ASR8

Figure 8.2 (continued) The correlation between the crash cost per VKT and the proposed ASR

8.6 Selection of the Most Appropriate ASR

The results of testing the validation of the proposed ASRs are summarised in Table 8.7.

Table 8.7 The evaluation of the proposed ARSs

Criteria of selection / The alternatives of the aggregated star ratings	Pearson correlation R	Crash cost at five ASR = 0	Variance of crash cost from ASR to ASR	The most appropriate
ASR1	0.112	-	-	
ASR2	- 0.570	-	-	
ASR3	- 0.961	√	- crash cost at one ASR3- crash cost at two ASR3 = 5030 - crash cost at two ASR3- crash cost at three ASR3 = 1013 - crash cost at three ASR3- crash cost at four ASR3 = 8315 - crash cost at four ASR3- crash cost at five ASR3 = 237 - not qualified	-
ASR4	- 0.429	-	-	
ASR5	- 0.687	-	-	
ASR6	- 0.687	-	-	
ASR7	- 0.425	-	-	
ASR8	- 0.862	√	- crash cost at one ASR3- crash cost at two ASR3 = 17002 - crash cost at two ASR3- crash cost at three ASR3 = 3227 - crash cost at three ASR3- crash cost at four ASR3 = 3165 - crash cost at four ASR3- crash cost at five ASR3 = 0 - More qualified	√

According to these results, it is concluded that:

1. All the proposed ASRs have a negative relation with the crash cost per VKT except the ASR1. However, not all of them have a perfect negative relationship because the measured R is not close to 1, except for the ASR3 and ASR8. Therefore, the ASR3 and ASR8 are selected in the evaluation according to the first criterion.

2. According to Figure 8.1, both ASR3 and ASR8 produced zero crash cost at a five-star rating. Therefore, both of them fit with this criterion.

3. The variation of the crash cost when moving from one ASR3 to two ASR3 and when moving from two ASR3 to three ASR3 are less than the variation of the crash cost when moving from three ASR3 to four ASR3. This means that ASR3 does not qualify with criterion related to this point. The variation of the crash cost when moving from one ASR8 to two ASR8 and when moving from two ASR8 to three ASR8 are greater than the variation of the crash cost when moving from three ASR8 to four ASR8. This makes ASR8 more qualified with this criterion.

4. Both ASR3 and ASR8 give logical concepts of the aggregated risk of roads. The ASR3 is resulted from identifying the star rating based on the maximum star rating score of all road-user groups assessed by the RAP methodology. The higher star rating scores mean a higher risk. While the ASR8 is the minimum star rating of all road-user groups assessed by the RAP methodology. A lower star rating means a higher risk. This means that if one of the road-user groups is assessed with a high risk, the road is considered a risk even if the remaining road-user groups are safe.

5. The simplicity of the method of identifying the ASR8, which is the minimum of the RAP star ratings of the road-user groups, in comparison with the methodology of identifying the ASR, enhances the selection of this method in identifying the aggregated star ratings.

   Therefore, the final selected method of aggregating the RAP star rating is the minimum of the star ratings of the vehicle occupant star rating, motorcyclists' star rating, bicyclists' star rating, and the pedestrians' star rating. This aggregated star rating is used to identify the indicator of the safer road infrastructure sub model (SRU), which is aggregated with other indicators to develop the road safety assessment index (RSAI).

8.7 Summary

In this chapter, the ASRs' models developed in Chapter Seven are evaluated by comparing with the crash cost per VKT. Road sections are selected for the evaluation processes which start with collecting the necessary data. This data is categorised into the RAP's SR and SRS data which is gathered from VIDA and the crash data which is gathered from the DFT.

Subtracting the crash data that are caused by reasons other than the road design features has been considered. For this, a methodology of estimation of the number of road crashes caused by road design features is developed in Appendix IV. Then the crash cost is estimated using the preventing crash values gathered from the DFT (DFT 2017) to estimate the crash cost per VKT.

Three terms of comparison are used to evaluate the preliminary ASR model, as used in the previous RAP studies: investigating the trend of the ASR valued with the trend of the crash cost; investigating the crash cost when the ASR is equal to the highest; and investigating the difference of the crash cost when moving from one star rating to the next star rating.

The results show that the ASR3 and the ASR8 are selected as the most appropriate according to the first and the second investigation. The ASR8 is more qualified with the third investigation. The simpler process of estimating ASR8 makes this model the most suitable as the selected model for aggregating the RAP star ratings and then finding the percentage of the road lengths awarded three stars or more.

CHAPTER NINE

EVALUATION OF THE RSAI MODELS

9.1 Introduction

The evaluation of the developed model of the RSAI is necessary to measure its robustness, to test and demonstrate its suitability and validity, and to allow the selection of alternative models. The model is considered valid if it accomplishes its particular purpose (Urbina et al. 2005; Tedeschi 2006; Hermans et al. 2009b; Sargent 2009; Akaateba 2012). The main purpose of developing the RSAI is to assess the road safety level on a national scale. Therefore, the results of the RSAI scores will be compared with other real indicators used in assessing road safety levels, which are the real crash data (WHO 2015). The correlation of the RSAI scores with the rate of road fatalities is measured to test how the RSAI correlates to the actual road safety level.

From the two methods of the indicators' weighting, the indicators of the safer road user produced two preliminary RSAI models, which are shown in equations 6.1.a and 6.1.b; the evaluation of these models will assist in selecting the one that is closer to achieving its particular purpose. A higher correlation with real crash data means the RSAI model is more valid in assessing the actual road safety level.

The methodology of this chapter is shown in Figure 9.1. The first step is the selection of the countries that can apply the RSAI preliminary models. Then, the necessary data is collected to use in finding the RSAIs for each country. After that, the preliminary RSAI scores are computed and compared with the real road fatalities' rate to select the final RSAI.

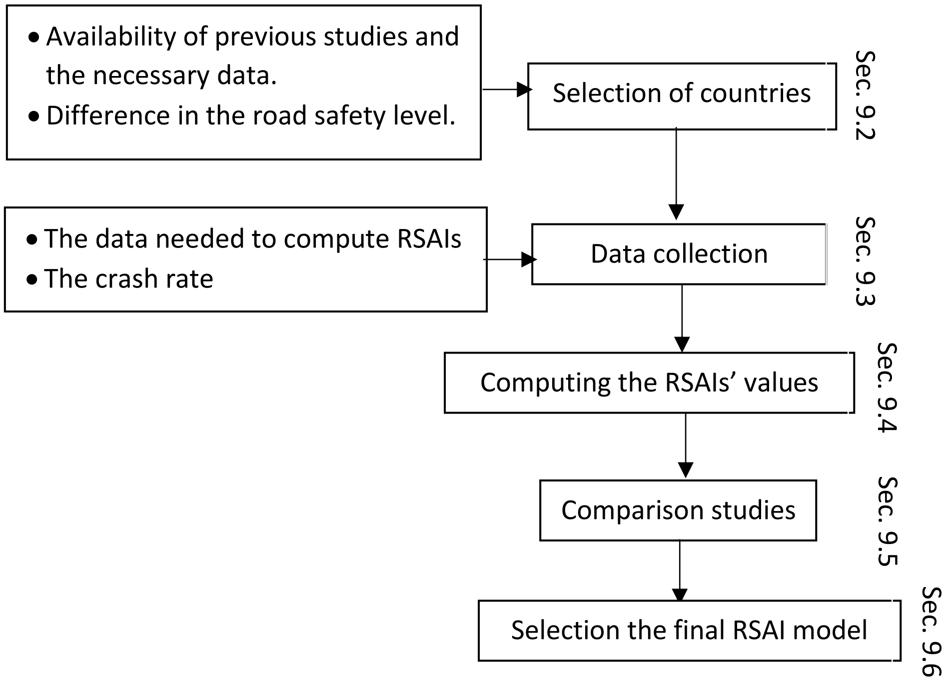

Figure 9.1 The procedure of evaluating the RSAI models

9.2 The Selected Countries for Comparison Studies

The selection of the countries is based on the following criteria:

- Criterion (A): the availability of previous studies which considered these countries in benchmarking road safety.
- Criterion (B): the availability of the necessary data to find the RSAI.

- Criterion (C): the clear difference in the level of road safety, which is identified by the rank of the selected countries according to the actual crash rate, to avoid the slight difference in the rank and make the comparison more sensible.
- Criterion (D): the statistical confidence level of the selected sample size.

Based on criterion (A), the reviewed studies in Chapter Three show that most of the studies in constructing road safety indices are conducted for the European region. The European Union (EU) member states that are located primarily in Europe (Data.Gov.UK 2018) has a yearly publication regarding benchmarking EU countries according to the road safety indices; it contains some of the necessary road safety data (WHO 2015; ERF 2016; ETSC 2016; ITF-OECD 2018). However, not all the necessary data for this research are available in these studies, especially the data needed to find the SRIM score. Therefore, other sources of data are reviewed such as the iRAP results (iRAP 2017). In addition, there is missing data which is needed for the SV model for some countries. Therefore; based on criterion (B), the EU countries are refined to seven countries which are shown in Table 9.1. These countries, which are Bulgaria, Hungary, Greece, Romania, Slovakia, Slovenia, and the Netherlands, are evaluated according to criterion (C). As shown in Table 9.1, the rank of the selected countries according to the rate of crashes per 1000000 population indicates that there is clear difference in the road safety level. So, the selected countries are considered qualified with criterion (C).

According to criterion (D), the data of the selected countries are subjected to t test analysis to check the confidence level which should be 95% to demonstrate the sufficiently of the sample size in developing the final RSAI model (Limpert and Stahel 2011; Cowles and Davis 1982; Zar 1984; Allison 1999).

Equation 8.1 is used to find the maximum rate of error and the results show that the standard deviation and the mean of the seven countries selected in this study equals to 1,9474 and 7,1714 respectively. This results in maximum rate of error equal to 2,4% which is less than 5%. This demonstrate that the selected sample size is sufficient in evaluating the preliminary models and selecting the most appropriate model.

Table 9.1 Selection of the countries for the evaluation step (WHO 2015)

Country	**(A)**	**(B)**	**(C)**	**The rank of the countries**
Austria	X	X		
Belgium	X	X		
Bulgaria	X	X	X	17
Croatia	X	X		
Cyprus	X	X		
Czech Republic	X	X		
Denmark	X	X		
Estonia	X	X		
Finland	X	X		
France	X	X		
Germany	X	X		
Greece	X	X	X	23
Hungary	X	X	X	21
Ireland	X	X		
Italy	X	X		
Latvia	X	X		
Lithuania	X	X		
Luxembourg	X	X		
Malta	X	X		
Poland	X	X		
Portugal	X	X		
Romania	X	X	X	
Slovakia	X	X	X	15
Slovenia	X	X	X	9
Spain	X	X		
Sweden	X	X		
The Netherlands	X	X	X	3
The United Kingdom	X	X		

9.3 The Necessary Data

The necessary data are identified based on what input data are needed for the three sub models of the RSAI, and what data are needed to compare with the RSAI to evaluate the preliminary models. The data is gathered for the year 2013 because of the availability of most of the necessary data in this year. This data is categorised into four groups. These are:

1. The data for the safer road infrastructure and mobility (SRIM) sub model; the input of this sub model is the percentage of road length awarded a minimum 3 RAP stars. This is based on the results of finding the aggregated road star rating in Chapters Seven and Eight. The data needed to find the SRIM are:
    - The RAP's star ratings for the road user groups considered by RAP (VIDA-iRAP 2018) to identify the minimum star rating.
    - The length of each section awarded a minimum 3 stars or more and the total length of the road network of each selected country (ERF 2016).

    However, access was only gained for some of the RAP results of the selected countries; therefore, there is a need to impute the missing data based on the available data (Nardo et al. 2005; JRC-EC 2008). The available data is the star rating of the road-user groups per 100m section for a sample of road network which is assessed by the iRAP. It is assumed that the proportion of the length of the roads awarded a minimum 3 stars to the total length of the road sample may be equal to the percentage of the length of all roads with a minimum 3 stars per country, as shown in equation 9.1.

$$\%\ \textit{roads length awarded min 3 stars or more} = L(\geq 3\text{stars})/LT \qquad \textit{......... (9.1)}$$

Where

$L(\geq 3stars)$ = The length of a sample of roads which is assessed by iRAP and awarded minimum 3 stars for all the road user groups

LT = The total length of selected sample of the road network.

For example, the available data of the RAP's assessed roads in the Netherlands is for a road network with a length of about 7322.3 km. The $L(\geq 3stars)$ is about 757.4 km; so, the proportion of roads awarded 3 stars or more for all road user groups is equal to 16.2%. In this case the percentage of roads rated 3 stars or more in the Netherlands is estimated to equal 16.2%. The same method is used to estimate the SRIM values for the selected countries as shown in Table 9.2

Table 9.2 The results of determining the scores of the SRIM for the selected countries

Country	The percentage of road awarded a minimum three stars (%)
Bulgaria	0
Hungary	0.9
Greece	4.87
Romania	0
Slovakia	0
Slovenia	0
The Netherlands	16.2

2. The data for the safer vehicle (SV) sub model; the data needed to find the percentage of registered and licensed vehicles awarded five NCAP stars are:
   - The vehicle models and make that were awarded five NCAP stars, identified using EuroNCAP (EuroNCAP 2017).

- The volume of the vehicles awarded five NCAP stars which can be collected from the official local data set. These data are gathered from ETSC (2016).
- The total volume of all vehicles per country which are gathered from ETSC (2016).

  Since the percentage of vehicles awarded 5-NCAP stars are available in the ETSC report (2016) for the period from 2010 to 2013, these results are used as the values of the SV indicator for the selected countries without the need to collect the data mentioned above. The SV indicator values are shown in Table 9.3.

Table 9.3 The SV values for the selected countries

Country	% of new cars awarded 5 Euro NCAP stars over the period 2010-2013 (ETSC 2016)
Bulgaria	50.3
Greece	47.5
Hungary	53.4
Romania	38.3
Slovakia	55.7
Slovenia	57.6
The Netherlands	57.6

3. The input data for the safer road user behaviour (SRUB) sub model:
   - The effectiveness score on speeding enforcement (ESS)
   - The effectiveness score on wearing seat belts' enforcement (ESBS)
   - The effectiveness score on using child restraints' enforcement (ECHRS)
   - The effectiveness score on wearing helmets' enforcement (EHS)
   - The effectiveness score on drink-driver enforcement (EDDS)
   - The effectiveness score on drug-driver enforcement (EDGS)
   - The effectiveness score on mobile phone usage while driving enforcement (EMPS)

However, not all these data are available to collect from the published reports and online database. There is no enforcement score estimated for the drug-driver and the usage of mobile phones (WHO 2015). Therefore, these indicators are imputed by assuming that they are equal to zero to reflect the unavailability of drug-driver enforcement system and ineffective usage of mobile phone enforcement system. These zero scores means that the overall RSAI scores will be reduced by the amount of the scores of these two indicators in case of existing of full effective enforcement system of drug drivers and usage mobile phone while driving. To investigate the impact of increasing and decreasing in the score of each indicator including zero scores on the overall RSAI score, a sensitivity analysis is conducted in Chapter Eleven.

The available data are gathered from the WHO (2015) and shown in Table 9.4.

Table 9.4 The data of the SRUB model

Country	ESS (WHO 2015)	ESBS (WHO 2015)	ECHRS (WHO 2015)	EHS (WHO 2015)	EDDS WHO 2015)
Bulgaria	70	60	80	70	50
Hungary	80	80	90	80	80
Greece	60	60	60	60	40
Romania	50	80	90	70	70
Slovenia	80	80	70	90	90
Slovakia	70	70	90	80	80
The Netherlands	70	70	70	70	70

4. The actual crash rate; this crash rate in terms of the rate of fatalities per 1000000 population for each selected country is used to compare with the results of the RSAI preliminary models. The form of crash data is chosen because it is used in benchmarking the countries according to the road safety situation by global organisations such as the WHO (2013a; 2015) and the ETSC (2016) and shown in Table 9.5.

Table 9.5 The rate of road fatalities in 2013 for the selected countries

Country	Road fatalities per 1000000 inhabitants 2013 (WHO 2015; ETSC 2016)
Bulgaria	8.3
Hungary	9.1
Greece	7.7
Romania	8.7
Slovakia	6.6
Slovenia	6.4
The Netherlands	3.4

9.4 Computing the Preliminary RSAI Scores

The preliminary RSAI models developed in Chapter Six and shown below are used to find the preliminary RSAIs.

$RSAI_j\,(1) = SRIM + SRUB(1) + SV$ .... *(6.1.a)*

$$= \frac{\sum_{k1}^{a} L_{k1}}{Lt} * 100 + \big(0.143\,(ESS) + 0.143(ESBS) + 0.143(ECHRS) + 0.143(EHS) + 0.143(EDDS) + 0.143(EDGS) + 0.143(EMPS)\big) + \left(\frac{\sum_{k2=1}^{p} V_{k2}}{Vt}\right) * 100$$

$RSAI_j\,(2) = SRIM + SRUB(2) + SV$ .... *(6.1.b)*

$$= \frac{\sum_{k1}^{a} L_{k1}}{Lt} * 100 + \big(0.23\,(ESS) + 0.36(ESBS) + 0.03(ECHRS) + 0.03(EHS) + 0.21(EDDS) + 0.10(EDGS) + 0.03(EMPS)\big) + \left(\frac{\sum_{k2=1}^{p} V_{k2}}{Vt}\right) * 100$$

The two different road-user behaviour scores (SRUBs) are computed using the two different methods of aggregation as shown in Table 9.6. Also, the SRIM and the SV scores are shown in this table. For these different estimated values, two RSAIs are computed.

Table 9.6 The results of computing the RSAI

Country	SRIM	SV	SRUB1 (equal weights)	SRUB2 (unequal weights)	RSAI (1) = SRIM+SV+SRUB1	RSAI (2) = SRIM+SV+SRUB2
Bulgaria	0	50.3	47.14	55.8	97.44	106.1
Greece	0.9	47.5	58.6	73.2	107	121.6
Hungary	4.87	53.4	40	50.2	98.27	108.47
Romania	0	38.3	51.4	64	89.7	102.3
Slovakia	0	55.7	58.6	75	114.3	130.7
Slovenia	0	57.6	55.7	67.1	113.3	124.7
The Netherlands	16.2	57.6	50	63.7	123.8	137.5

9.5 Evaluation of the Preliminary RSAIs

To evaluate the preliminary RSAI models, the preliminary RSAIs are compared with the rate of road fatalities of the selected countries to test how the developed model of assessment can reflect the real road safety situation. This is can be measured by the correlation of the developed models with real road fatalities may. The coefficient of determination R^2 and the bivariate Spearman rank-order correlation are used to measure the correlation coefficient (Tedeschi 2006; Hermans 2009).

The coefficient of determination R^2 is used to measure the variance in the RSAI score to the variance of the real road fatalities. Higher R^2 means less difference between the two values and more closer to give real assessment that the developed index is more likely to use as a replacement of the rate of road fatalities in assessing rod safety level (Ozer 1985; Nagelkerke 1991).

The Spearman rank-order correlation is often used in testing the relationship involving ordinal variables and it is based on the rank of the variables rather than on their raw values. It is used when the variables tend to change together but not necessarily at a constant rate (Wilcox and Austin 1979; Lun et al. 2006; Eisinga et al. 2013; Kumar et al. 2018). This test is necessary to evaluate the use of the RSAI in ranking countries and to test its correlation with the original rank according to the road fatalities' rate.

The results are shown in Figure 9.2 and discussed in the next section.

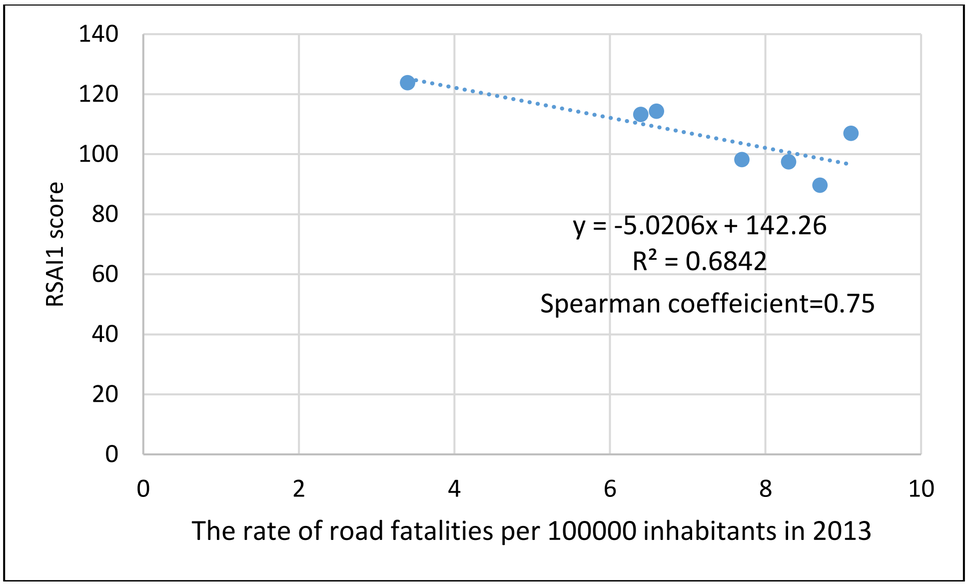

Figure 9.2a The linear relationship between the RSAI (1) and the fatalities rate

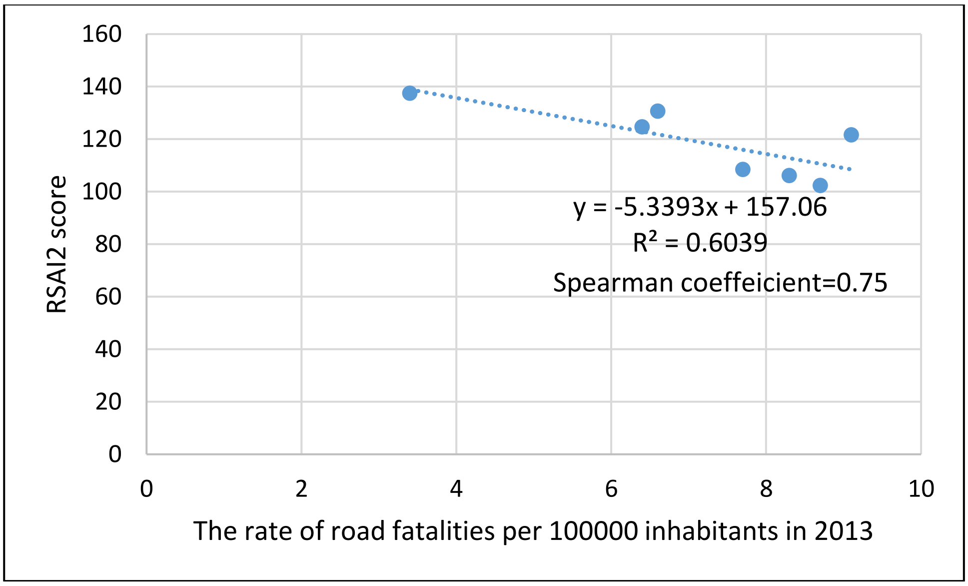

Figure 9.2b The linear relationship between the RSAI (2) and the fatalities rate

Figure 9.2 The comparison of the preliminary RSAI scores with the road fatalities rate

9.6 The Selection of the Final RSAI Model

The results of the comparison are discussed to select the final RSAI based on the correlation coefficient. Table 9.7 summarises the final results.

Table 9.7 The results of evaluating the preliminary RSAIs

The preliminary RSAI	The Spearman coefficient	The coefficient of determination R^2	The selected RSAI
RSAI(1)	-0.75	0.6842	√
RSAI(2)	-0.75	0.6039	

According to the results of the Spearman coefficient, both the RSAI models have the same correlation, which is 0.75. This means that the RSAI scores resulting from using the two methods of weighting the indicators are more likely to be significant in replacing the rate of road fatalities in ranking countries and both may produce the same rank.

According to the coefficient of determination, the equal weighting method produces an RSAI score slightly more correlated to the rate of road fatalities. This means that the RSAI1 may be more significant in reflecting and assessing the real road safety situation. Therefore, the road safety assessment index RSAI computed from the model shown in equation 6.1.a which is developed using equal weighting method is selected to assess the road safety level on a national scale and achieve the other purposes, such as ranking countries and monitoring progress towards set targets.

9.7 Summary

This chapter shows the procedure of evaluating the preliminary RSAI models. The RSAI scores of selected countries are computed and compared with the rate of road fatalities in 2013, which is the year of the collected necessary data.

Seven countries were selected for this purpose based on the availability of the data; availability of previous studies conducted in the countries; and a clear difference in the road safety level, which is measured by the actual rate of road fatalities. These countries are Bulgaria, Greece, Hungary, Romania, Slovakia, Slovenia, and the Netherlands.

The data needed to conduct the evaluation are gathered from different sources. However, the data needed to compute the indicator of safer road infrastructure and mobility (SRIM) is only partially available. Therefore, they are estimated based on the available data. The data of the variables related to the drug-driver and the using of a mobile phone while driving indicators are also not available. They are assumed equal to zero to indicate the issue of the missing data.

The preliminary RSAIs are computed for the selected countries and compared with the rate of road fatalities to find the Spearman correlation coefficient and R^2. The results show that the models of the RSAI when using the equal weighting method have more correlation than the other preliminary RSAIs. Therefore, this model is selected to find the final RSAI and ranking countries. The selected RSAI model will be evaluated in the next chapter according to the purpose of ranking and rating countries.

CHAPTER TEN

APPLICATION OF THE RSAI: RANKING AND RATING COUNTRIES

10.1 Introduction

The RSAI model selected in Chapter Nine is used in this chapter to evaluate its use in achieving the purpose of ranking and rating countries. The methodology of this chapter is shown in Figure 10.1:

- Ranking countries: the selected countries in the previous chapter are used here to identify their rank according to the RSAI and compare with the original rank according to the actual rate of road fatalities. This rank is also compared with the rank according to the road safety scores developed in previous studies. The correlation is measured to assess the suitability of the RSAI model in ranking countries in comparison with other models.

- Rating countries. The process of using the RSAI for rating countries is shown in this chapter. The relationship between the RSAI and the rate of road fatalities is used to establish star rating bands. Then the RSAI scores of the selected countries are assigned to the established bands to rate the countries. The final rating is evaluated by comparing the results of rating the selected countries with the rate of road fatalities and with the effectiveness of the strategic plan measured by the score of the RSAI's indicators

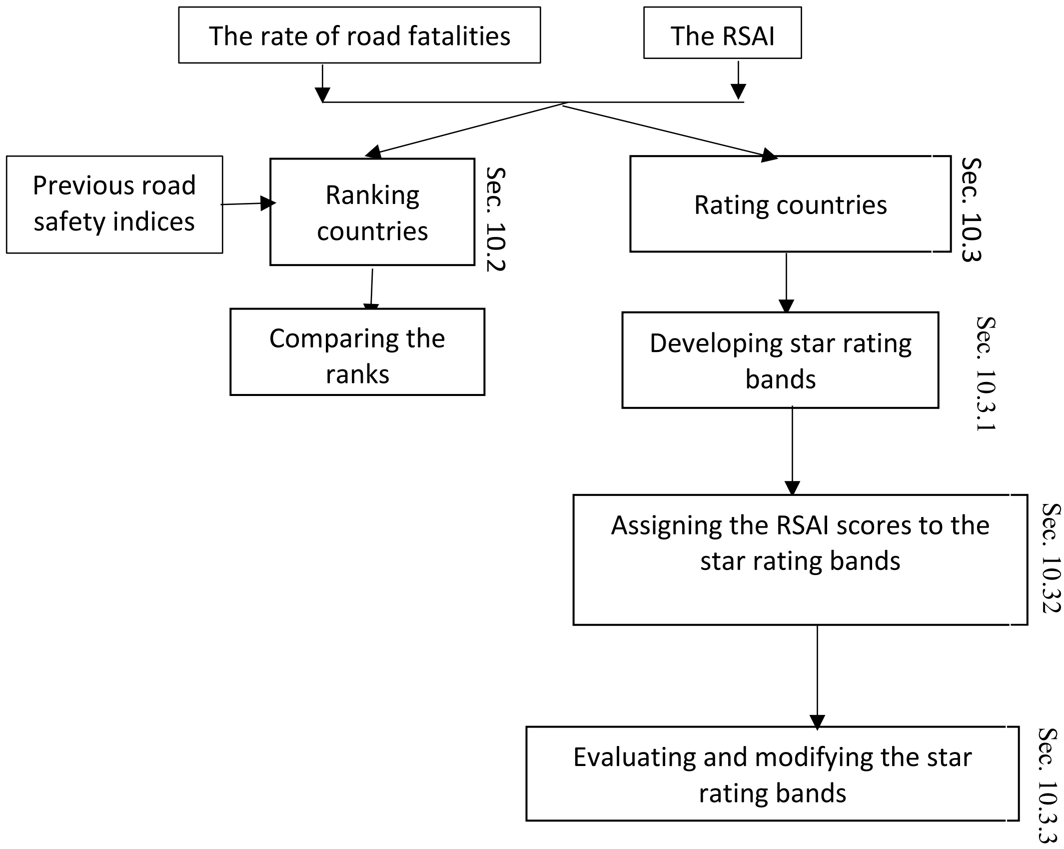

Figure 10.1 The methodology of ranking and rating countries based on the RSAI score

10.2 Ranking Countries

Ranking countries according to the effectiveness of the strategic plan of road safety and the level of rod fatalities is important to identify the countries achieved significant reduction in road fatalities and follow their strategic plan. It is also important to identify the countries with higher rate of road fatalities to apply more successful strategic plan (Munda and Nardo 2003; 2005b; Vis and van Gent 2007; Akaateba 2012; Coll et al. 2013; Adminaite et al. 2017). For this, the developed RSAI is tested to use in ranking countries as an effective replacement of the rate of road fatalities.

To demonstrate the suitability of the RSAI model for use with ranking countries, the ranks of the selected countries according to the RSAI score produced from the selected RSAI model are identified and compared with the ranks according to the road fatalities' rate. They are also compared with the rank of countries according to previously developed road safety indices, as shown in Table 10.1.

Two previously developed road safety indices are selected for comparison based on the year of development. The first index is developed by the project DaCoTA (Bax et al. 2012) in close year to the year of collecting the need data. The second index is developed recently by Tešić et al. (2018) study. However, four countries only out of the six selected countries are ranked by Tešić et al. The details of these studies are shown in Chapter three.

Table 10.1 The results of ranking countries

Country	**The ranking of countries**			
	The selected RSAI	**The road fatalities rate**	**Road safety score of Project DaCoTA (Bax et al. 2012)**	**Road safety score of Tešić et al.'s study (2018)**
Bulgaria	6	5	6	-
Greece	4	7	3	3
Hungary	5	4	4	4
Romania	7	6	7	-
Slovakia	2	3	5	-
Slovenia	3	2	2	2
The Netherlands	1	1	1	1

The results of the comparison are shown in Figure 10.2, and shows that the rank of countries with respect to the RSAI is more correlated to the original rank according to the rate of road fatalities than the other ranks, because it has the highest Spearman correlation coefficient, which is about 0.79 and the highest R^2, which is about 0.6173. This approves the suitability of the RSAI model in ranking countries.

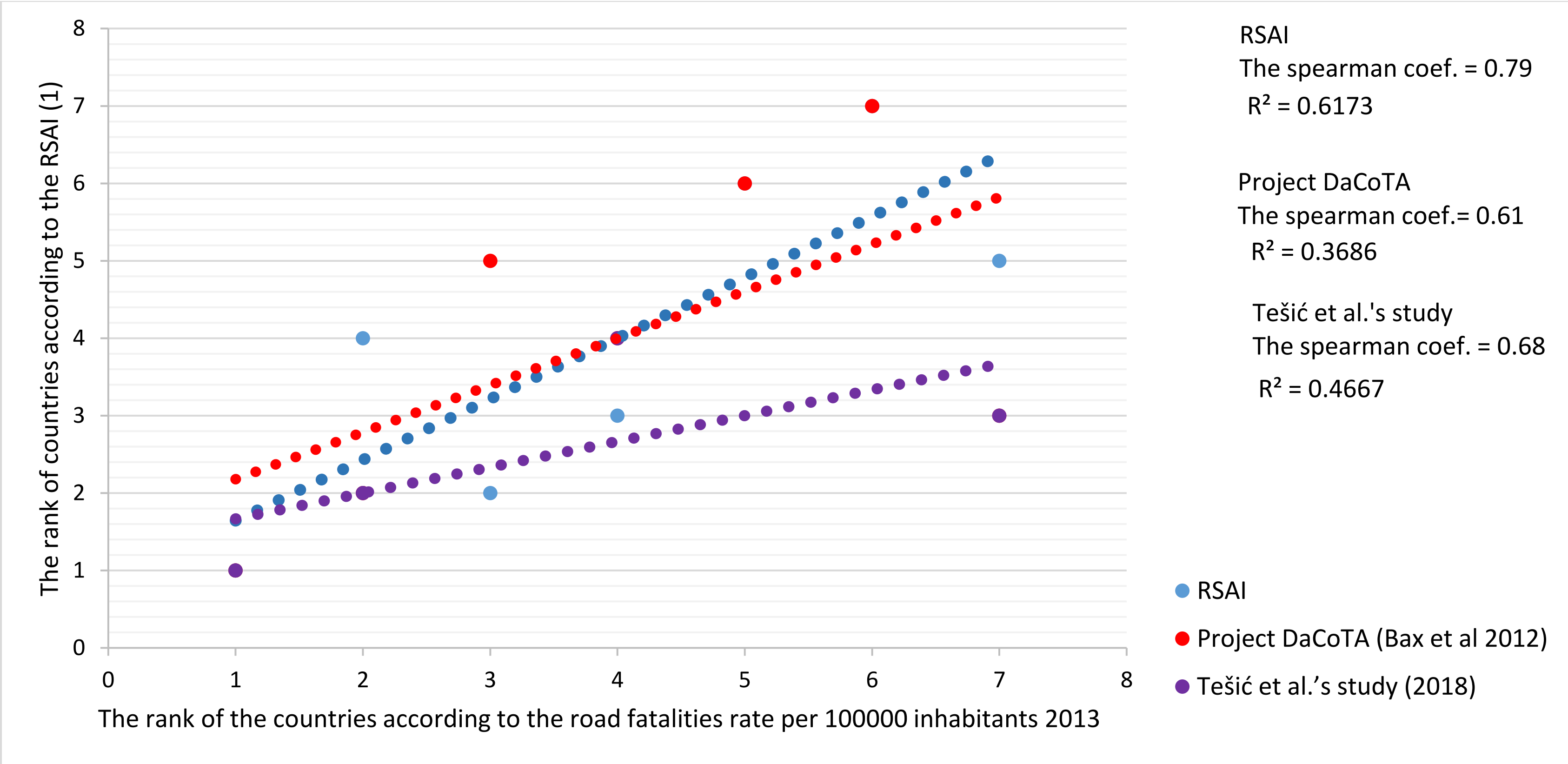

Figure 10.2 The comparison of the rank of countries in respect to the selected RSAI score with the rank according to previously developed road indices

10.3 Rating Countries

Road safety rating is a method of presenting objective information on aspects of road systems' safety (DaCoTA 2012). It has been used recently as a tool of assessment for road infrastructures and mobility (iRAP 2017), and for the assessment of vehicle safety (EuroNCAP 2017). Rating road safety is highly recommended by the UN in their recommendations of the Decade of Actions in Road Safety; as an essential safe system approach tool for benchmarking countries and assessing the quality and potential for improvement, for quantifying targets, and for making strategic decisions (UN and WHO 2011; DaCoTA 2012).

Therefore, this research suggests rating the whole system of road safety based on the RSAI score. The seven European countries selected in Chapter Nine are chosen to assess the methodology of rating suggested in this chapter. The suggested methodology consists of three main steps:

- Identify the star rating bands.
- Assign the RSAI scores of the selected countries to the developed star rating bands.
- Evaluate and modify the star rating bands

10.3.1 Identifying the Star Rating Bands

To identify the star rating bands based on the RSAI score, the rate of road fatalities is considered through using the relationship between the rate of road fatalities per 100000 and the RSAI score, which is shown in Figure 9.2.a and represented by equation 10.1.

$$RSAI = -5.0206\ (\text{rate of road fatalities per 100000 inhabitants}) + 142.26 \quad \text{...... (10.1)}$$

The results of statistical testing this model shows that the coefficient of determination R^2 equals to 0.6842, which means that the rate of variance of the RSAI variable to the variance of the rate of road fatalities equals 68.42%. The statistical significance level (P value) equals to 0.05, which represents the probability of rejection of the model.

Based on this model, the following steps are followed to establish the star rating bands:

1. Determining the maximum limit of the fatal level: it is noticed from equation 10.1 that the maximum RSAI score is equal to 142.26 when the rate of road fatalities is equal to zero. While the maximum RSAI score resulting from using the developed model in equation 6.1.a is equal to 300 when all the recommended strategies of road safety are properly implemented. This means that when the rate of road fatalities is equal to zero, the other road crashes that have resulted in injuries and property damage might occur. This also means that when the RSAI score is less than 142.26, the severity level of the road safety system is less. Therefore, actions are still needed to reduce the rate of all kinds of road crashes. According to this, it may be concluded that if the RSAI score is between zero and less than 142.26, the severity of the road crashes is expected to be high, and high rate of fatalities is expected to result from the occurrence of road crashes.

2. Subdivision of the fatal level into three levels: to subdivide the level of 0-142.26 into more than one level, the estimated rate of road fatalities per 100000 (WHO 2015) for all countries, which is shown in Appendix V, are considered. The range of the road

fatalities rate is between 0 to 36. One country has a very high rate of about 76. This range is categorised into three:

- The first range is the rate of road fatalities of the countries that have a significant reduction in rate of road fatalities and considered as leaders in implementing the safe system approach vision. These countries are Sweden, the Netherlands, the UK, and Australia (WHO 2015). Australia has the highest rate among this group of countries, which is about 5.4; while Sweden has the lowest, which is about 2.8. Therefore, the first rating band is estimated based on the range of road fatalities of zero to 5.4.
- The second range is based on the estimation of the WHO (2015), shown in Figure V.2; where it is shown that the European countries have the lowest rate of road fatalities, lower than the average rate of road fatalities in the world. The average rate of these countries is 9.3. This rate is considered here to estimate the maximum limit of the second rating band of the fatal level.
- The maximum rate of road fatalities for the third range is more than 9.3.

These ranges of the rate of road fatalities are substituted in equation 10.1 to find the RSAI score that might be used to identify the rating bands of the three fatal ratings, which are 1 star, 2 star, and 3 star. These are shown in Table 10.2.

Table 10.2 The estimated RSAI score for the lowest rating bands

Star ratings	The rate of road fatalities per 100000	The estimated RSAI score (using equation 10.1)
3	0	142.26
2	5.4	115.1488
1	9.3	96.07048

3. Subdivision of the range between 142 to 300.

- In the case where the RSAI score is close to 300, the safest situation is expected. This level reflects the full implementation of the strategic plan of road safety, which fully adheres to the safe system approach principles. To identify the minimum limit of this band, it is assumed that two of the three indicators have a 100% score. Then, the score of the third indicator will decide the range length.

The results of the indicators' scores shown in Table 10.3 reveal that the indicator of road infrastructure and mobility has the lowest score for all the assessed countries. If it is assumed that actions will be taken on all elements of road safety, this indicator will still have the lower score. According to the targets set by the UN in the 2030 SDG, 75% of roads rated a minimum of 3 stars is set as a target of safer road infrastructure and mobility (iRAP 2017). Therefore, 75% is the minimum score assumed for the third indicator and the length of the range of this band. According to that, the rating of this band is 275-300, which is the safest level with 5 stars.

Table 10.3 The results of computing the RSAI

Country	SRIM	SV	SRUB	RSAI= SRIM+SV+SRUB
Bulgaria	0	50.3	47.14	97.44
Greece	0.9	47.5	58.6	107
Hungary	4.87	53.4	40	98.27
Romania	0	38.3	51.4	89.7
Slovakia	0	55.7	58.6	114.3
Slovenia	0	57.6	55.7	113.3
The Netherlands	16.2	57.6	50	123.8

- The range of 142 to less than 275 is the rating band of the 4-star rating.

As a result of the above three steps, the identified star rating bands are summarised in Table 10.4. This developed table will be used in the next step to assign the RSAI scores of the selected countries and identify their star ratings.

Table 10.4 The star rating bands based on the RSAI scores

Rating bands (RSAI scores)	Star ratings	Road crashes' severity	Strategic plan
0-<95	*	Extreme fatalities rate is expected (> 9.3 per 100000 population)	Very poor plan, actions are needed instantaneously for all elements of the road safety system
95-<115	**	High fatalities rate is expected (5.4-9.3 per 100000 population)	At least one element of road safety is not considered in the taken actions or all elements need more actions
115-<140	***	Low to moderate fatalities rate is expected (0-5.4 per 100000 population)	At least one element of road safety is not considered in the taken actions or all elements need more actions
140-<275	****	No fatalities, injuries rate is expected	Partially implemented, fully adheres to safe system approach principles
275-300	*****	No fatalities and injuries	Fully implemented, fully adheres to safe system approach principles

10.3.2 Assigning the RSAI scores to the star rating bands

The RSAI scores computed for the selected countries which are shown in Table 10.3 are assigned to the bands shown in Table 10.4. The results is shown in Figure 10.3.

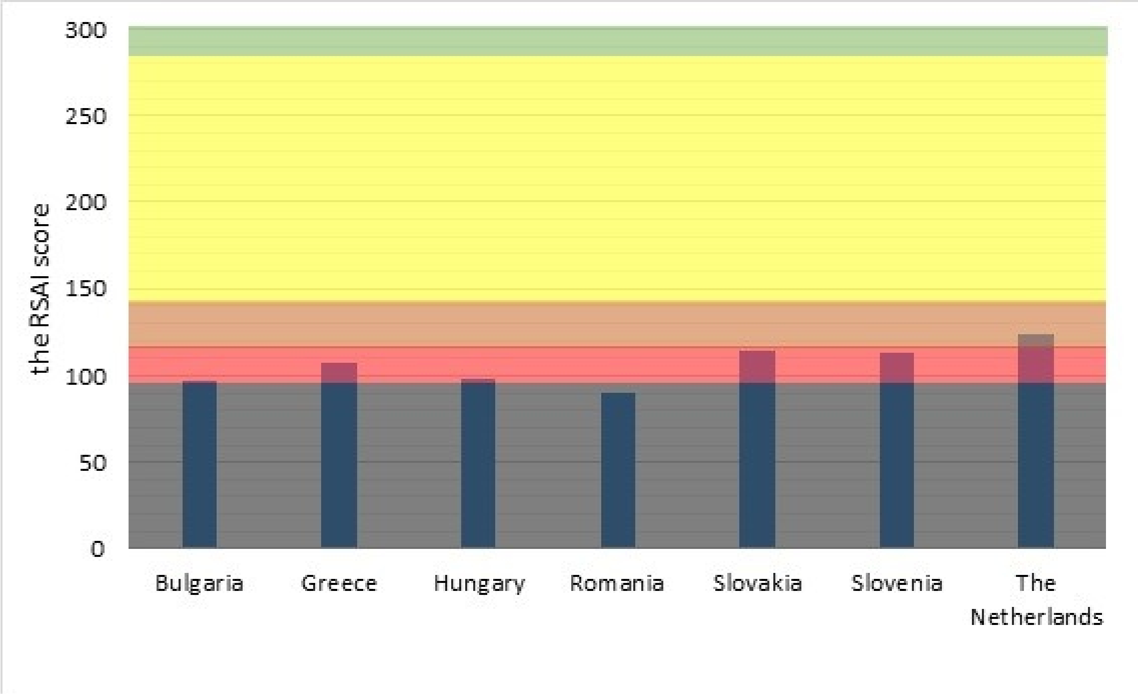

Figure 10.3 The rating results of the assessed countries.

It is shown that the Netherlands is rated as three stars, Romania has one star while the remaining countries have two stars. These results are discussed and evaluated to modify the star rating bands in the next step.

10.3.3 Evaluation of the results of rating countries

By comparing the results of the rating countries with the RSAI scores and each thematic indicator's score which are shown in Table 10.3, the use the developed star rating bands in rating countries is evaluated as follow:

1. The Netherlands has 3 stars, which reflects a slight rate of fatalities. This indicates a real condition since the real rate of road fatalities is 3.4; which is considered low in comparison with the rate of road fatalities of other countries shown in Table V.1.

Regarding the actions taken, the Netherlands has a very poor score for the road infrastructure and mobility, although it is the best among the other countries, and this is interpreted by the level of the strategic plan of 3-stars. This means that fatalities are still expected in the roads of the Netherlands and this is proved by the latest statitiscs which shows that the Netherlands has about 3.4 Road fatalities per 1000000 inhabitants in 2013 (WHO 2015; ETSC 2016) . Therefore, the evaluation indicates the correctness of the star rating band of 3 stars.

2. The remaining countries, except Romania, have 2 stars; which reflects a high rate of fatalities and at least one indicator has a very low score. By comparing these results with the results in Table 10.3, the correctness of the star rating bands of 2 stars is proved.

3. The result for Romania is 1 star which reflects a very poor road safety strategic plan with no successful action. However, the results of Table 10.3 show that there is an action taken regarding enforcement of road safety laws, which gave the road-user behaviour indicator about 51.4%; therefore, the star rating band of 1 star needs modification.

   If an action is taken in one element, the indicator score will be raised to be close to 50%. If no action is taken in other elements, the score will be zero. Therefore, this rating scale is modified to consider the maximum indicator score. If one indicator has a score greater than 50%, as in the case of Romania, the rating is plus1 star. If the maximum indicator score is less than 50%, it means all indicators need significant improvement. So, the rating is minus 1 star, as shown in Table 10.5.

Table 10.5 The modified star rating bands based on the RSAI score

Rating bands (RSAI scores)	Star ratings	Road crashes severity	Strategic plan
0-<95 and the maximum indicator score < 50	*-	Extreme fatalities rate is expected (> 9.3 per 100000 population)	Very poor plan, actions are needed instantaneously for all elements of the road safety system
0-<95 and the maximum indicator score ≥ 50	*+	Extreme fatalities rate is expected (> 9.3 per 100000 population)	Ineffective, at least two elements of road safety are not considered in the taken actions or all elements need more actions
95-<115	**	High fatalities rate is expected (5.4-9.3 per 100000 population)	Ineffective, at least one element of road safety is not considered in the taken actions or all elements need more actions
115-<140	***	Low to moderate fatalities rate is expected (0-5.4 per 100000 population)	Slightly effective, at least one element of road safety is not considered in the taken actions or all elements need more actions
140-<275	****	No fatalities, injuries rate is expected	Effective, partially implemented, fully adhering to safe system approach principles
275-300	*****	No fatalities and injuries	Very effective, fully implemented, fully adhering to safe system approach principles

10.4 Summary

In this chapter, the use of the RSAI in achieving the purpose of ranking and rating countries are assessed.

Regarding ranking countries, the rank of the countries according to the RSAI scores are compared with the rank according to the rate of road fatalities per 100000 inhabitants. This rank is compared also with the rank according to road safety scores developed in previous studies. The results show that the RSAI score produces more significant results. Therefore, the RSAI is significant replacement of the rate of road fatalities in ranking countries.

Regarding the rating of countries, star rating bands based on the RSAI score are developed. Five star ratings are used to assess countries according to the level of road safety and the significance of their road safety strategic plan. The 5-star rating reflects no crashes or very low severity road crashes. It signifies also a successful road safety plan with full adherence to the safe system approach principles. While a 1-star rating is a sign of very severe road crashes'. This rating is categorised into plus1-star reflecting an ineffective strategic plan where at least two elements of the road safety system are not considered in the taken action; while minus 1-star signifies a very poor plan with no actions taken on the road safety system.

More investigation is needed to use the star rating bands in assessing and rating countries, by applying them to more countries and comparing them with real road safety situations. This would need sufficient data for more countries; the collection of this data was not authorised in this case.

The next chapter will present the investigation of using the RSAI score in monitoring the progress of road safety strategic plan towards set targets and suggesting strategic solutions to improve the overall level of road safety.

CHAPTER ELEVEN

APPLICATION OF THE RSAI: MONOTORING PROGRESS AND SUGGESTING SOLUTIONS

11.1 Introduction

In this chapter, the use of the RSAI score in monitoring the progress of the road safety strategic plan toward a set target is investigated through developing a particular methodology. The relationship between the RSAI and the rate of road fatalities is used to estimate the RSAI score in the target year. Then, a model is developed to estimate the rate of progress. In the case where the rate of progress is low, improvement is needed. Therefore, a methodology of suggesting strategic solution is developed also in this chapter.

The suggestion of a solution is based on the impact analysis of the indicators on the RSAI scores. The individual impact of each indicator and multiple impact of two indicators or more are considered to create alternatives of solutions.

The methodology of this chapter is shown in Figure 11.1

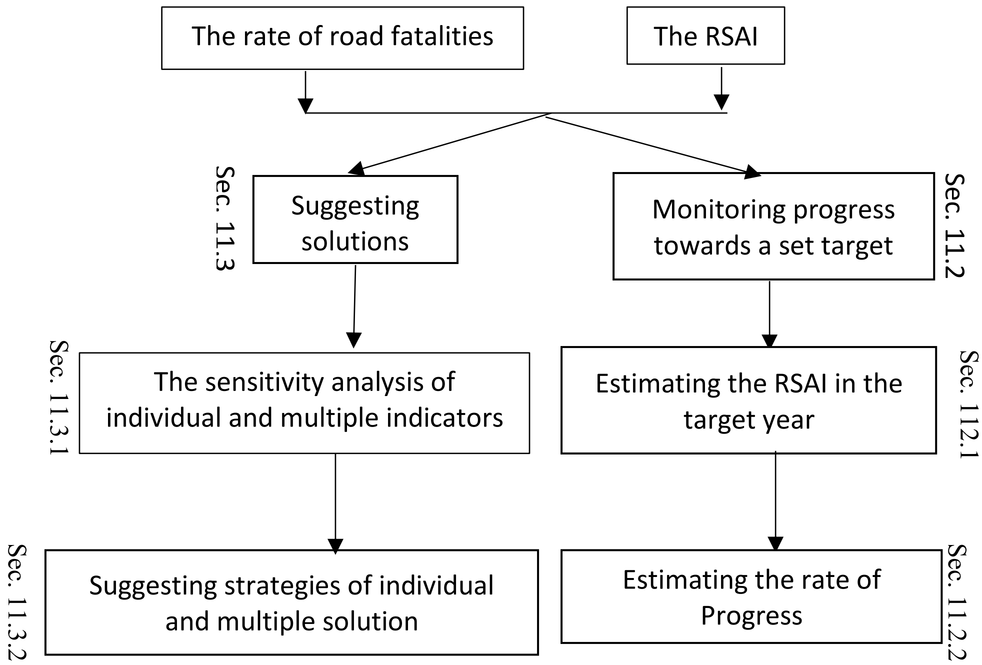

Figure 11.1 The methodology of monitoring progress and suggesting solution based on the RSAI score

11.2 Monitoring Progress and Suggesting Solutions

This section focuses on investigating the usage of the selected RSAI in monitoring the progress of road safety levels towards a set target. The global target of the SDG of reducing the road safety level by half by 2030, compared to the 2010 baseline, is considered by most of the countries as setting a national road safety target (ITF-OECD 2018). Therefore, this global target is considered in this research to measure the progress towards the set targets in the selected countries.

To measure the progress toward the target, a rate of progress should be estimated. For this, the RSAI score in the target year needs estimation as it is shown in the next sub section.

11.2.1 Estimating the RSAI in the target year

The relationship between the RSAI and the rate of road fatalities per 100000 which is represented by equation 10.1 is used to in this chapter to estimate the RSAI score in the target year, which will be used as a replacement of the RSAI that may set by a policy maker and strategic planner as a target of road safety strategic plans. To compare the estimated RSAI score with the existing RSAI score and measure the progress achieved since the base year toward the target year, rate of progress is computed as it is shown in the further sub section.

11.2.2 Estimating the rate of progress

Measuring the progress toward the targeted RSAI by computing the proportion of the difference between the present RSAI and the RSAI in the base year to the difference between the RSAI in the target year and in the base year as it is shown in equation 11.1.

$$\text{The progress rate} = \frac{(\text{Present RSAI} - \text{base RSAI}) * 100}{(\text{targeted RSAI} - \text{base RSAI})} \quad \ldots\ldots. (11.1)$$

Closer progress rate value to %100 means significant progress achieved and the target is almost achieved. When the progress rate is less than 50, it means more effective solutions should be suggested and implemented. The next step is how to use the RSAI in suggesting strategic solutions.

11.3 Suggesting Strategic Solutions

To decide the plan of improvement and which element of the road safety system should have the priority in this plan, an analysis of the impact of each element on the overall road safety level may assist. The next sub section shows the sensitivity analysis of the RSAI's indicators which reflect the road safety elements. The results of this analysis will be used in suggesting a solution in the further steps.

11.3.1 The sensitivity analysis of the RSAI's indicators

Based on the RSAI concept, an improvement in the road safety level may be achieved through improving the road infrastructure and mobility, vehicle safety, or road user behaviour factors. The improvement may consider each of these indicators individually or consider multiple indicators. For example, improving the road infrastructure design or equipping the road infrastructure with road safety technologies may lead to an increase in the percentage of roads rated 3 stars or more. This solution considers the road infrastructure individually. If this solution is supported with increasing the rate of new vehicles rated 5 stars, then it is considered a multiple solution.

11.3.1.1 Individual sensitivity analysis

To suggest solutions regarding each indicator individually, the sensitive impact of the change rate in each indicator on the change rate of the RSAI is analysed. This assists in deciding which indicator has the stronger impact. For this, the relationship between the change in each indicator and the change in the RSAI is estimated based on the RSAI model as shown in Figure 11.2.

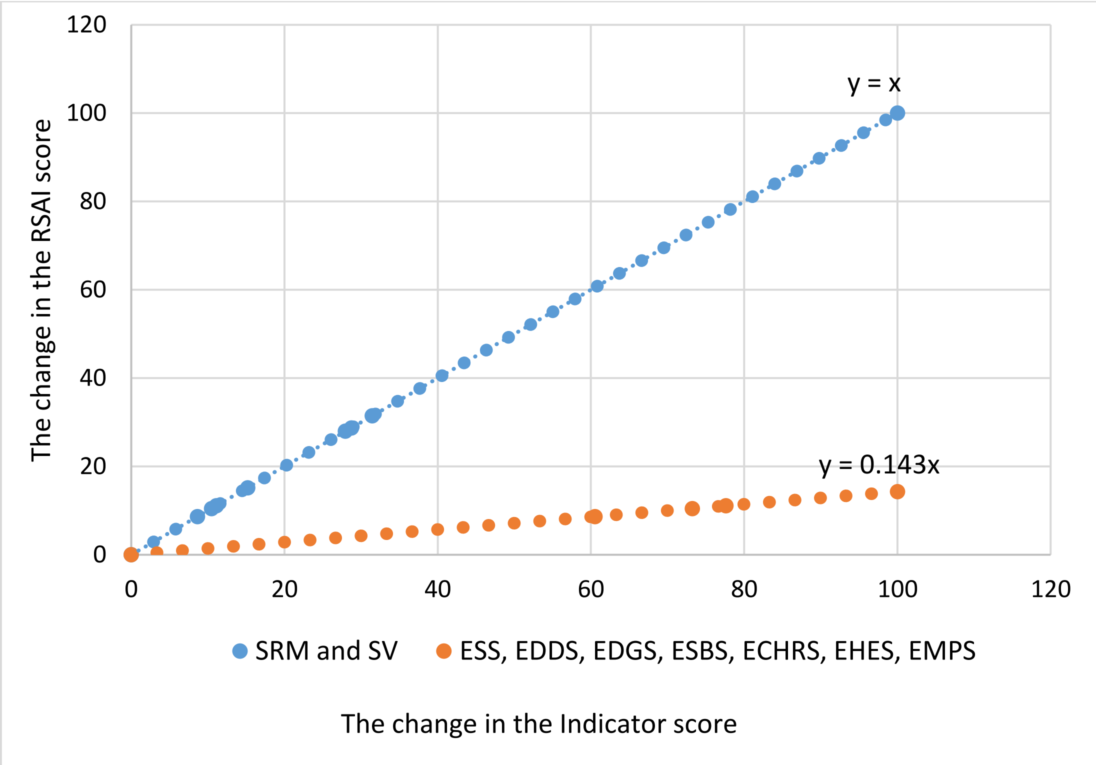

Figure 11.2 The relationship between the change in the indicators' scores and the change in the RSAI,s scores

Based on this relationship, Table 11.1 is developed for use in finding the rate of change in the RSAI in respect to the change in each indicator individually.

Table 11.1 The change in the RSAI score resulting from the change in the indicator score

The change in the indicator score	The change in the RSAI score resulting from the change in each indicator		
	The rate of roads rated minimum 3 stars	The rate of vehicles rated 5 stars	The effectiveness score on enforcement policy*
1	1	1	0.143
10	10	10	1.43
20	20	20	2.86
30	30	30	4.29
40	40	40	5.72
50	50	50	7.15
60	60	60	8.58
70	70	70	10.01
80	80	80	11.44
90	90	90	12.87
100	100	100	14.3

*Including speeding, drunk-driver, drug-driver, wearing seat belts, wearing helmets, using child restraints, or using mobile phones

It is shown that the change in the rate indicators of the road infrastructure and mobility (SRIM) and the safer vehicles (SV) has more impact on the change in the RSAI, which is expected to produce a significant change in the rate of road fatalities. While the factors of the road user behaviour have less impact if they are considered individually. If all the factors of the road user behaviour are considered together, then the impact of the change in the road behaviour score will have the same impact as the road infrastructure and the vehicle safety.

For example, if the rate of the road infrastructure rated 3 stars increases by 20%, the score of the RSAI will increase by 20. The same change results if the rate of the new vehicles rated 5 stars is increased by 20%. While if the enforcement interventions of speeding (ESS) are improved to a level that the effectiveness score of enforcement increases by 20, the RSAI score will increase by only 2.86.

11.3.1.2 Multiple sensitivity analysis

In solution planning, the decision maker needs to know the impact of multiple solutions on the overall road safety level. In this section, the use of the RSAI score in analysing multiple solutions is investigated.

Table 11.1 is investigated to use in finding the total change in the RSAI in the case of planning to improve two elements or more of the road safety system. For example, the improvement in the vehicle safety by increasing the rate of the new vehicles rated 5 stars (SV) by 20%, results in increasing the RSAI by 20. If it is supported with increasing the rate of the roads rated 3 stars or more (SRIM) by 10%, the total change in the RSAI score will be 20+10=30. In the case where the enforcement strategies in wearing seat belts (ESBS), child restraints (ECHRS) and wearing helmets (EHS) are improved to a level that the effectiveness score of the enforcement on these interventions increases by 10 for each indicator, about 4.3 (3*1.43) is added to the total RSAI score.

From this concept, a model can be developed to compute the total change in the RSAI score resulted from multiple change in the indicators score as it is shown in equation 11.2. This model is based on the RSAI model which is shown in Equation 6.1.a.

$$Total\ Change\ in\ the\ RSAI_j = change\ in\ SRIM + \big(0.143\ (change\ in\ ESS) + 0.143\ (change\ in\ ESBS) + 0.143(change\ in\ ECHRS) + 0.143(change\ in\ EHS) + 0.143(change\ in\ EDDS) + 0.143(change\ in\ EDGS) + 0.143(change\ in\ EMPS)\big) + change\ in\ SV \quad \text{.......... (11.2)}$$

Figure 11.3 shows examples of analysing the impact of multiple solutions on the RSAI score in the case of an equal change in the scores of the considered indicators. For illustration, when the SRIM, SV and ESS are improved by same rate, the rate of change of the RSAI might equal 2.143 times the change values in each indicator. If each indicator increases by 5%, the RSAI score will increase by 2.143×5.

Based on this analysis, the suggested solution for the selected countries in this study are investigated in the next section.

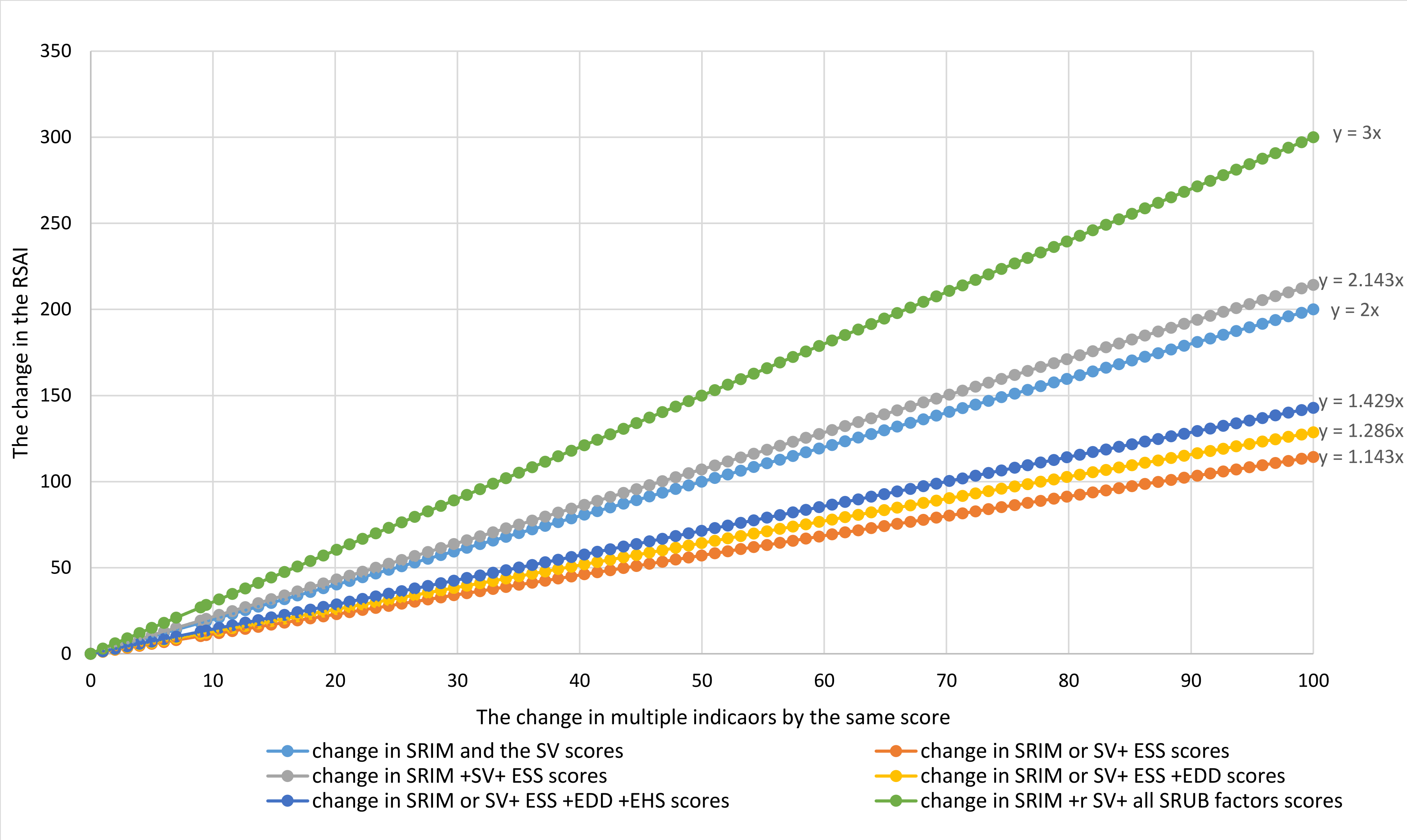

Figure 11.3 The rate of the change of some multiple indicators by equal scores on the RSAI scores

11.3.2 Suggestion of Individual and Multiple Solution

The proposed procedure of monitoring progress and suggesting solutions are applied in the selected cases of this study.

1. The first step is estimating the RSAI in the target year using equation 10.1 as shown in Table 11.2. The rate of road fatalities in the targeted year equals 50% of the rate of road fatalities in 2013 based on the SDG target.

Table 11.2 The targeted rate of road fatalities and the RSAI scores in 2030

Countries	RSAI in 2013	The targeted fatalities rate per 100000 population in 2030 (50% of the rate in 2013)	RSAI scores in 2030 (using equation 10.1)
Bulgaria	97.44	4.15	121.4245
Greece	107	4.55	119.4163
Hungary	98.27	3.85	122.9307
Romania	89.7	4.35	120.4204
Slovakia	114.3	3.3	125.692
Slovenia	113.3	3.2	126.1941
The Netherlands	123.8	1.7	133.725

2. Comparing the RSAI in the target year with the RSAI in the in the year under study. The targeted RSAI is compared with the RSAI in the year under study to decide if an improvement is needed or no. For example, in the case of Bulgaria, the RSAI in 2013 is 97.44. If the percentage of roads rated 3 stars is increased from 0% to be 5% in the in the year under study, the existing RSAI is estimated 102.44. In this case, the estimated rate of road fatalities will decrease from 8.3 to 7.9. However, this rate is still greater than the targeted rate. Therefore, the road safety element needs more improvement. However, access is not available to all the data needed in estimating the

RSAI in the in the year under study. Therefore, it is assumed that they are less than the targeted RSAI and a strategy of improvement should be designed.

3. Measuring the progress toward the targeted RSAI using equation 11.1. For example, if the existing RSAI score in Bulgaria is 120. The progress rate is computed as follows:

$$\text{The progress rate} = (130 - 97.44) * 100/\ (121.4 - 97.44) = 94.16\ \%$$

If the existing RSAI in Hungary equals 120, the rate of progress equals about 88.11%. This means that Hungary achieved less progress than Bulgaria.

4. Suggesting individual solution, based on the results of an individual sensitivity analysis of the RSAI's indicators, the individual indicators are suggested. The base year is assumed as 2013 and the scores of the RSAI indicators in this year are shown in Table 11.3. The suggested individual solutions are shown in Table 11.4. The suggestion is to increase the rate of the roads rated a minimum of 3 stars by about 24% in Bulgaria to reach the targeted RSAI score. The alternative solution is to increase the rate of the new cars rated 5 stars by the same rate of change in the SRIM score by 24% to reach 74.28% in 2013, as shown in Table 11.5.

   It is noticed that the required change in the indicators of the road user behaviour exceeds the maximum limit, which upgrades the effective score to 100%. For example, the enforcement score of wearing seat belts should be increased by 167% which makes this score exceed 100%. Therefore, this indicator is not considered individually and should be supported by other solutions as it is shown in the next step.

Table 11.3 The scores of the RSAI indicators in 2013

Country	The rate of roads rated 3 stars or more (%)	The rate of vehicles rated 5 stars or more (%)	The effectiveness score of enforcement (%)				
			Speeding enforcement score	Wearing seat belts' enforcement score	Child restraints' enforcement score	Using helmets' enforcement scores	Drunk-driver enforcement score
Bulgaria	0	50.3	70	60	80	70	50
Greece	0.9	47.5	80	80	90	80	80
Hungary	4.87	53.4	60	60	60	60	40
Romania	0	38.3	50	80	90	70	70
Slovakia	0	55.7	80	80	70	90	90
Slovenia	0	57.6	70	70	90	80	80
The Netherlands	16.1	57.6	70	70	70	70	70

Table 11.4 The individual increase in the indicators of the RSAI to achieve the 50% reduction target

Country	The increase in the rate of roads rated 3 stars or more (%)	The increase in the rate of vehicles rated 5 stars or more (%)	The change in the effectiveness score of one of the enforcement policies (%)
Bulgaria	23.9845	23.9845	167.7238
Greece	12.4163	12.4163	86.82727
Hungary	24.6607	24.6607	172.4524
Romania	30.7204	30.7204	214.828
Slovakia	11.392	11.392	79.66434
Slovenia	12.8941	12.8941	90.16853
The Netherlands	9.925	9.925	69.40559

Table 11.5 The targeted score for each indicator in the target year

Country	The rate of roads rated 3 stars or more (%)	The rate of vehicles rated 5 stars or more (%)	The effectiveness score of enforcement (%)				
			Speeding enforcement score	Wearing seat belts' enforcement score	Child restraints' enforcement score	Using helmets' enforcement scores	Drunk-driver enforcement score
Bulgaria	23.9845	74.2845	-	-	-	-	-
Greece	13.3163	59.9163	-	-	-	-	-
Hungary	29.5307	78.0607	-	-	-	-	-
Romania	30.7204	69.0204	-	-	-	-	-
Slovakia	11.392	67.092	-	-	-	-	-
Slovenia	12.8941	70.4941	-	-	-	-	-
The Netherlands	26.025	67.525	-	-	-	-	-

5. Suggesting multiple solutions, two options are suggested which are shown in Table 11.6 and Table 11.7 as follows:

- The first option is increasing the scores of the effective enforcement of the interventions related to the road users' behaviour improvement. It is suggested that the effectiveness scores in the drug-driver and use of mobile phone are measured and then the levels of enforcement are improved. This should be supported by increasing the enforcement scores in the other factors of road user behaviour. In our example of Bulgaria, the suggestion is to improve the enforcement system on the wearing of seat belts by 10% and on drunk-driver by 20% as shown in Table 11.6. In addition, increasing the enforcement effectiveness on drug-driver and using mobile phones to reach a score of 70. This multiple solution may lead to an increase in the RSAI scores by 24.31.

- The second option for a solution considers the road infrastructures and vehicles in improving the road safety level with the road user behaviour factors. In this solution, the drug-drivers and using of mobile phone factors are not considered. Table 11.7 shows the suggested multiple solutions for the selected countries. In the case of Bulgaria, improvements in all the elements are suggested to reach the targeted RSAI scores. While in the Netherlands, slight improvements in the road infrastructure and vehicle safety, supported by an improvement in the speeding enforcement system, may upgrade the RSAI score to the targeted level.

Table 11.6 First option: multiple increase in the indicators of the road user behaviour to achieve the 50% reduction target

Country	Speeding enforcement score	Wearing Seat belts' enforcement score	Child restraints' enforcement score	Using helmets' enforcement scores	Drunk-driver enforcement score	Drug-driver enforcement score	Mobile phone use enforcement score	The total increase in the RSAI (%)
Bulgaria	0	10	0	0	20	70	70	24.31
Greece	0	0	0	0	0	50	50	14.3
Hungary	10	10	10	10	10	60	70	25.74
Romania	30	0	0	10	10	80	80	30.03
Slovakia	0	0	0	0	0	40	40	11.44
Slovenia	0	0	0	0	0	40	50	12.87
The Netherlands	0	0	0	0	0	30	40	10.01

Table 11.7 Second option: multiple increase rate in the RSAI indicators to achieve 50% reduction the rate of road fatalities

Country	The increase in the rate of roads rated 3 stars or more	The increase in the rate of vehicles rated 5 stars or more	Speeding enforcement score	Wearing Seat belts' enforcement score	Child restraints' enforcement score	Using helmets' enforcement scores	Drunk-driver enforcement score	The total increase in the RSAI (%)
Bulgaria	7	6.7	10	20	10	10	20	23.71
Greece	5	2	10	10	0	10	10	12.72
Hungary	5	6	20	20	20	10	30	25.3
Romania	10.5	12	30	10	0	10	10	31.08
Slovakia	6	4	0	0	10	0	0	11.43
Slovenia	6	6	0	10	0	0	0	13.43
The Netherlands	4	5	5	0	0	0	0	9.715

11.4 Summary

In this chapter, the use of the RSAI in monitoring progress and suggesting solutions is investigated.

Regarding the progress monitoring, the RSAI is assessed in terms of identifying the targeted RSAI scores and measuring the rate of progress towards the target.

In regards suggesting solutions, the sensitivity analysis of the individual impact of each indicator and the multiple impact of two or more indicators is conducted. A Table is developed to measure the change in the RSAI score resulted from the change in each indicator. This table can be used also to measure the total change in the RSAI score in case of change in multiple indicators. Based on that, solutions can be suggested and decided.

The developed methodology of monitoring progress and suggesting solutions is applied in the selected countries.

It is recommended to contribute more factors in the developed methodologies, such as the cost, to assist the policy maker in planning for more effective, more efficient and safer roads.

CHAPTER TWELVE

DISCUSSION

12.1 Introduction

In this chapter the findings of this study is discussed as follow:

- It starts with discussing the main purposes of the road safety assessment index; which are assessing the road safety level on a national scale, ranking countries, monitoring progress, warning of weakness and suggesting solutions to improve road safety levels.
- The results of reviewing previous attempts at developing road safety indices are also discussed, to define the gaps that are considered in this research, as described in section 12.3.
- Based on this review, the indicators of the developed index are selected as shown in sections 12.4-12.6.
- The selection of the indicator of road infrastructure and mobility is the most challengeable. Therefore, a specific methodology to identify the indicator is developed. The results of this methodology are discussed in section 12.4.1.
- Two weighting methods are investigated to weight the indicators of the developed model. The results of choosing the method of weighting are discussed in section 12.7.
- The aggregating methods used in this work are discussed in section 12.8.
- The results of evaluating the developed model are considered in section 12.9.

- The results of the sensitivity analysis of the indicators of the developed model are discussed in section 12.10.
- The value of the developed model is reflected by its multi-usage. Therefore, the usage of the RSAI model in assessing road safety levels, ranking countries, monitoring progress, and suggesting solutions to improve the road safety level is discussed in section 12.11.
- Other points that enhance the value of the developed model are presented in section 12.12.
- The novelty of the this study is discussed in section 12.13.
- The limitation of the developed model are considered in section 12.14.
- The selection of the case studies and assessing their level of road fatalities and the progress of their strategic plan is discussed in section 12.15.
- The Data Issue is discussed in Section 12.16

12.2 The Need for a Road Safety Assessment Index

The significant importance of road safety issue has been recognised, and global long-term strategic plans with targets for improving road safety levels and reducing the rate of road fatalities have been set. These plans are based on the most successful guide for road safety management, which is the safe system approach. This approach is highly recommended to be considered in the road safety strategic plan on national and regional scales. However, the global rate of road fatalities is still the same and many national rates of road fatalities have been increasing (WHO 2015). Therefore, there is a significant need to assess the road safety situation in terms of the applied and operated programmes, to improve road safety levels. There is also a need to assess the contribution of the safe system approach in the national road safety strategies. In addition, there it is necessary to measure the rate of progress of the strategic plan towards a set target, warn of weaknesses early and suggest the right action to control the increase in road fatalities based on the diagnosed weaknesses.

Currently, the road safety index is in terms of final outcomes; which means the recorded or estimated rate of road casualties or crashes is used to benchmark and rate countries and assess the road safety level. However, it is considered ineffective in reflecting the process and factors producing crashes. In addition, it is an ineffective tool in making strategic decisions regarding the countermeasures and interventions that can be applied to prevent crashes or reduce their severity. Therefore, This study has focused on the other kind of road safety index which is in terms of intermediate outcomes. These kinds of indices have the ability to reflect the implemented programmes aiming to improve the road safety level and measure their progress towards the set target.

Aggregating several indices into one index is also considered important because it is essential to give a meaningful representation of the broader picture of the road safety situation and to set one value for the desired target. In addition, aggregating indices is significant to reflect the rate of importance of each individual index or implemented program on the overall level of road safety. Furthermore, an aggregated index is essential in benchmarking and ranking countries.

From these points, the need to develop a road safety assessment index based on the most recent and successful approaches of road safety, which is the safe system approach , is raised and considered in this research.

12.3 The Previous Attempts at Developing Road Safety Indices

There have been attempts to develop road safety indices in the last two decades. Most of them are for European countries. The principles of the safe system approach are considered in some of these indices through using the components of the safe system approach as thematic indicators. These components are safer road infrastructure and mobility, safer vehicles, and safer road-user behaviour.

However, not all measures are fully reflected, especially the road infrastructure and mobility. The main reason is the lack of comprehensive and valid methodology to assess the road safety infrastructure and mobility according to the safe system approach concept. This gap is mainly considered in this research.

12.4 Selecting Indicators for the Safer Road Infrastructure and Mobility Index

Choosing holistic, measurable, valid, and related to the safe system approach concept indicators for safer road infrastructure and mobility is the most challenging since it not considered properly in previous studies. What might be considered the most comprehensive indicator among those selected in previous studies is the EuroRAP score, which is selected for the European SafetyNet project (Vis 2005; Hakkert et al. 2007; Vis and van Gent 2007). However, the methodology of the EuroRAP version at the time of the SafetyNet study considered the crashworthiness only to reduce the severity of road crashes. This version also considered one road-user type, which is the vehicle occupant.

The latest version of the RAP methodology, which was developed to apply in all countries under the name of the international road assessment programme (iRAP), considers crash avoidance factors to prevent the occurrence of road crashes. It also considers three road-user groups in addition to the vehicle occupants. These are motorcyclists, pedestrians and bicyclists.

The RAP score, which are star rating scores, is used by global organisations interested in the road safety issue to set targets for safer road infrastructure. A minimum of 3 stars is the target set by some national road safety strategic plans; by the UN in the decade of actions on road safety plan (2011-2020); and by the World Bank which uses the RAP rating as a criterion to make decisions regarding funding road infrastructure projects (UN and WHO 2011; WHO 2013a; 2015).

Therefore, the RAP methodology of road infrastructure assessment is considered in this research to decide the indicators of safer road infrastructure. The percentage of roads rated a minimum of 3 stars is the form of the selected indicator. This indicator is also considered in deciding the indicator of safer speed limits, since the speed limit is considered in assessing the road infrastructure by the RAP methodology. Furthermore, choosing this indicator encourages countries to assess road infrastructure and mobility and set periodical road audits and investigations, as it is the globally recommended tool for this action.

However, the outputs of the latest version of RAP methodology, which are grouped into four groups each for an individual road-user group, need aggregation to reflect the overall index of road infrastructure and mobility. Therefore, there was a need to investigate the aggregation method that might produce the aggregated RAP output which is more suitable to use for constructing a holistic index.

12.4.1 Aggregating the RAP Star Ratings

To find the aggregated RAP star rating that indicates the road infrastructure risk based on the road design feature, and at the same time, be more appropriate to use in constructing the holistic road safety index, a methodology of aggregation was developed. In this methodology, two points were considered. They are the level of the RAP output and the method of aggregation.

The RAP methodology produces intermediate outputs in terms of star rating scores for four road-user groups and final output in terms of star rating the same groups of road users. It was not easy to decide which level of outputs might be aggregated. Therefore, aggregation of each star rating score and star ratings were investigated.

Regarding the method of aggregation, four methods of aggregation are investigated to aggregate the RAP output at each level. So, weight aggregation models are produced which are evaluated to choose the most appropriate.

The evaluation is based on three points which are considered in testing the validation of the RAP methodology in previous studies. These are:

1. The trend of the aggregated star rating has a negative relationship with the trend of the crash cost per vehicle kilometre. The crash cost is chosen because it accounts for the frequency and the severity of road crashes (McInerney et al. 2008).
2. The crash cost when the aggregated star rating (ASR) is the highest should be equal to zero to reflect the logical classification of the star ratings.
3. The difference of the crash cost when moving from 1-ASR to 2-ASR and when moving from 2-ASR to 3-ASR is more significant than when moving from 3-ASR to 4-ASR. This is tested to investigate the appropriateness of the set target of a minimum 3-aggregated star rating.
4. The simplicity in identifying the aggregated star rating. This criterion is considered because it seems that the process of aggregating the intermediate outputs is more complicated than aggregating the final outputs.

The results of the evaluation, which is conducted for selected road sections in the UK as the necessary data are available for these sections, show that two models of aggregation were qualified with criteria one and two. The first is the aggregated star rating resulting from assigning the maximum star rating score among the four star ratings of the four road-user groups to a developed aggregated star rating band. The second aggregated star rating is the minimum of the four star ratings of the four road-user groups. The latter aggregated star rating is chosen because it is more qualified with the third and the fourth criteria.

The chosen aggregated star rating model, which is the minimum star rating of the four star ratings, reflects a logical concept because it is not reasonable to rate a road section as safe while it is unsafe for one road-user group. So the selected aggregated star rating means that the road infrastructure is considered overall unsafe if at least one road-user group lacks the safety requirements.

12.5 Selecting Indicators for Safer Vehicles

The new car assessment programme (NCAP) rating is evaluated to choose as the indicator of safer vehicles. Its comprehensiveness, measurability, and validity in indicating the requirements of safer vehicles recommended by the UN and the WHO based on the safe system approach principles are demonstrated (Hobbs and McDonough 1998; Lie and Tingvall 2002; Kullgren et al. 2010; Strandroth et al. 2011). These requirements provide passive and active safety technologies (UN and WHO 2011). In addition, the NCAP might be thought of as a significant replacement for the vehicle age indicator which was considered in previous studies. The reason is that the newer vehicles are safer because they are equipped with protection and crash avoidance technologies (Hermans et al. 2009a) and this is considered in the NCAP assessment. This indicator encourages countries to increase the rate of new cars rated with a high number of stars; this leads to a significant reduction in the rate of road fatalities. Therefore, the selected indicator of vehicle safety is the percentage of vehicles rated 5 stars.

12.6 Selecting Indicators for Safer Road-user Behaviour

Regarding the safer road-user behaviour (SRUB), the selected indicators in the previous studies are mostly related to drunk drivers, to exceeding the speed limit, to wearing seat belts and wearing helmets; few studies have used indictors related to the child restraints and drug drivers, and no study has considered the using of a mobile phone while driving. Despite the importance of these factors, the data unavailability restricted the usage of all of these indicators in reflecting the road-user behaviour indicators. The WHO assessment studies developed a methodology of assessing these factors using an expert questionnaire which produced subjective scores in terms of the effectiveness score of enforcement. These scores are used in this research because they have a uniform unit and they are measured by most of the assessed countries. In addition, using all these scores together can reflect the road user behaviour comprehensively. Therefore, the selected indicators in this study are the effectiveness score of speeding (ESS), drunk driver (EDDS), wearing seat belts (ESBS), wearing helmets (EHS), using child restraints (ECHRS), drug drivers (EDGS), and using a mobile phone (EMPS) enforcements.

12.7 Methods of Weighting Indicators

To aggregate the indicators, weighting is necessary to reflect the relative importance of each indicator in improving the road safety level. Two assumptions are investigated in weighting the indicators: equal weighting and unequal weighting. Equal weighting is based on each indicator having the same impact on the overall road safety level, which is founded on the concept of the safe system approach ; this system focuses on all the road safety components having the same role in reducing the rate of road fatalities. While unequal weighting is based on some indicators having a stronger impact than others. The ETSC (2001) shows that the best interpretation of the importance of the road safety indicators is the reduction in the rate of road fatalities and serious injuries (FSI) caused by factors related to each indicator. For example, the reduction in the rate of road FSIs resulting from the application of interventions related to enforcing the wearing of seat belts, is higher than the rate of reduction resulting from using helmets by two-wheeled vehicle occupants.

The two weighting methods produce two models of the road safety assessment index (RSAI). Both models are evaluated to choose the most appropriate to replace the crash rate in assessing and benchmarking countries according to their level of road safety. The results of the evaluation demonstrated the concept of the safe system approach , as the equal weighting produced the most appropriate model of the RSAI.

12.8 Methods of Aggregating Indicators

The method of aggregation are used in two parts of this work: in aggregating the RSAI's indicators and in aggregating the RAP star ratings

4. The simple linear additive aggregation method is used to aggregated the selected indicator of the RSAI model. The selection of this method is based on the:
   - Simplicity of formulating the model,
   - The effectiveness in interpretation of the independency of the indicators' variables. Therefore, it can test the sensitivity of the RSAI score to a change of one indicator (OECD and JRC 2008; Pollesch and Dale 2015).
   - The effectiveness in interpretation the relative importance of each indicator by weighting them effectively.

   However, the previous studies referred to a weakness of subjection the aggregated scores resulted from this method to compensation, which is neglecting the poor score in one indicator in case the other indicators have high scores (Munda and Nardo 2003; OECD and JRC 2008). Therefore, the rating of the strategic plan based on the

RSAI score considers this point by defining the maximum score of each indicator in developing the star rating bands.

The geometric aggregation method is not used in aggregation of the RSAI indicators because it is based on the multiplication function which is not suitable with scores that equal to zero. The other methods, such as maximum and minimum functions are not considered because the required score of aggregating the indicators should not be based on one score.

2. Four methods of aggregation are investigated to use in deciding the way of aggregating the RAP's star ratings. These methods are the simple linear additive aggregation method, the geometric method, the maximum function and the minimum function.
    - The simple linear method is investigated because of its strength points mentioned above.
    - The geometric method is investigated because the star rating values are always greater than zero.
    - The maximum and the minimum functions are investigated because it is required to refer to the overall safety level of the road infrastructure which may be safe for all groups of road user but unsafe for one group. Therefore, it is not logical to rate a road 3 stars while one road user group, pedestrian for example, is unsafe in using the assessed section of road. The results of the evaluation demonstrate this assumption as the minimum star rating is the most appropriate aggregation method that produce the aggregated star rating that are qualify with the considered criterial of evaluation.

12.9 Evaluating the RSAI model

The different weighting methods produced two preliminary RSAIs which are evaluated by comparing with the rate of road fatalities of seven European countries. The results prove the validity of the selected RSAI model, since the Spearman coefficient is high, which is about 0.75. This indicates the effectiveness of the RSAI in ranking countries. This is enhanced by the results of correlation between the ranking of the selected countries according to the RSAI score with the rank according to the rate of road fatalities, which its spearman coefficients of about 0.79. This rank is compared with the rank according to the road safety indices developed in previous studies. The results show that the RSAI produces the most correlated rank to the real rank.

12.10 The Sensitivity Analysis of the RSAI's Indicators

The results of the sensitivity analysis show that the increase in the rate of each indicator score individually leads to increase the RSAI score. The multiple increase in the scores of two indicators or more leads to a higher upgrade in the RSAI score. Since the indicators of the RSAI's models reflect the elements of the road safety system, the results of the sensitivity analysis prove the theory of the safe system approach , where increasing the efforts in each element of road safety leads to improve the overall road safety level.

The amount of the change in the RSAI score resulting from the amount of change in individual indicators shows that the individual improvement in the road infrastructure improvement, vehicle safety improvement, and safer road-user behaviour leads to the same change in the RSAI score. The safer road-user behaviour may result from much effort in the improvement of the enforcement policy for each factor having an impact on the road-user behaviour, such as speeding, drunk-drivers, and wearing a seat belt.

The increase in the rate of multiple indicators leads to better results if all or most of the elements of road safety are considered in the strategic plan by the same level. For example, improving the road design feature will increase the rate of roads having a minimum of 3 stars. If it is supported with increasing the rate of the new vehicles that are rated 5 stars and improving the enforcement system of road safety laws, the rate of increase in the RSAI score will increase by a higher rate than improving each element individually. This enhances the contribution of the safe system approach concept in the developed model.

12.11 The Usage of the RSAI model

12.11.1 The usage of the RSAI in assessing and rating the road safety level

The evaluation results showed that the RSAI scores are more likely to be used in assessing the level of road safety on a national scale and replacing the rate of road fatalities as an index of assessment.

The RSAI scores are also more likely to be used in rating countries. For this, a methodology is followed to develop star rating bands. The main points considered in developing the star rating bands are:

- The maximum RSAI score is estimated when the rate of road fatalities is equal to zero. This score, which is equal to 142, is considered the maximum limit of the RSAI score for the fatal level, where severe consequences in terms of fatalities and serious injuries are expected when the RSAI score is less than 142.

- The fatal bands of the fatal level are categorised into three: 1-star, 2-star, and 3-star.
  - The 3-star band is identified based on the rate of road fatalities of the leading countries in road safety actions. These countries have effective actions on road safety in more of its components. However, these countries have not reached the target of no fatalities yet. Therefore, they are considered in the safest group within the fatal level.
  - The 2-star band is identified based on the average rate of road fatalities in European countries; as they are the only group of countries that have an average rate of road fatalities less than the average rate of all the world countries, because of the actions taken in this region to improve the road safety level.
  - The 1-star band is the lowest. It is subdivided into plus 1-star and minus 1-star according to a maximum score of the indicators. If it is less than 50%, it means very poor actions in all components of the road safety system. This is reflected by minus 1-star. While plus 1-star interprets actions on one indicator only.
- The non-fatal level is divided into 4-star and 5-star bands. The 5-star band is identified assuming that the strategic plan fully contributes to the safe system approach concept and that all indicators have a full score. Thus the maximum limit of this band is 300. However, the road infrastructure and mobility needs more significant actions to improve and this is interpreted by the very low score of safer road infrastructure indicator. Achieving a full score in this indicator needs significant actions. The RAP agency declared that actions have been taken to achieve a rate of 75% of the roads will have a minimum 3-stars for all road-user groups. This rate is used to identify the lower limit of the 5-star band, assuming that

a full score is achieved in the vehicle and road-user behaviour indicators. Thus, the lower limit of the 5-star bands is 100 + 100 + 75 = 275.

- The range between the maximum limit of the 3-star band which is 142 and the minimum limit of the 5-star which is 275, is the range used as the 4-star band. The countries with effective road safety programmes have the ability to increase their RSAI score to reach the non-fatal level and achieve a 4-star rating.

12.11.2 The usage of the RSAI in ranking countries

Ranking countries is considered a significant tool for policy and decision makers to identify the countries with significant progress and to learn from them; to prioritise the region or the countries for future studies; and to give early warnings. The evaluation of the RSAI model demonstrates the significance of the RSAI score in replacing the rate of road fatalities in ranking and benchmarking countries. Countries with the higher RSAI score have the top positions in the rank; while countries with lower RSAI scores are at the bottom of the rank.

12.11.3 The usage of the RSAI in monitoring progress of strategies

It is possible to use the RSAI to monitor progress towards a set target. For this, a methodology is developed and applied in the selected countries. In the case of setting a target in the form of the RSAI score, the rate of progress is computed by dividing the difference between the RSAI score in the target year and the RSAI in the current year by the difference between the RSAI score in the target year and the RSAI score in the base year. If the rate is less than 100%, the target is not yet achieved. As the rate of progress gets closer to 100%, less efforts are needed to achieve the set target. If the rate of progress is close to 0%, solutions should be suggested. The solutions should be suggested regarding the indicators with lower scores. These indicators represent the weakness of the road safety system.

12.11.4 The usage of the RSAI in suggesting solutions

The methodology of monitoring the progress of the road safety plan towards a set target is enhanced with suggesting solutions considered as individual or multiple indicators. This is achieved through estimating the progress achieved by each suggested solution using the RSAI score. The sensitivity analysis of the indicators of the RSAI is conducted to estimate the change in the RSAI score with the change in each individual indicator and with the changes in multiple indicators. Table 11.1 is developed for this purpose and can be used to suggest strategic solutions to improve the road safety on a national scale. This table shows the following:

- An increase in the rate of roads' infrastructure rated at least 3 stars by improving the design features or equipping the road infrastructure with safety technologies will lead to an increase in the RSAI score by the same rate.
- An increase in the rate of new vehicles rated 5 stars will lead to an increase in the RSAI score by the same rate.
- Enhancing the enforcement policy on speeding will lead to increasing the effectiveness score of enforcement; then the RSAI score will increase by 0.143 of the rate of increase in the effectiveness score. The same rate of increase in the RSAI score will result from enhancing the enforcement policy on the other road-user factors, such as drunk-drivers, wearing seat belts, or using helmets.

- Enhancing the enforcement policy on all the indicators of the road-user behaviour will result in increasing the RSAI score by the sum of 0.143 of each rate of increase in the effectiveness score of each factor.

  The increase in RSAI score = 0.143 (increase in the effectiveness score in speeding) + 0.143 (increase in the effectiveness score in drunk-drivers) …………….. + 0.143 (increase in the effectiveness score on using mobile phones).
- An increase in the rate of the road infrastructures' rate of a minimum 3 stars and supported with an increase in the rate of new vehicles rated 5 stars will lead to an increase in the RSAI score by an amount equal to the summation of the increase in the two indicators. Any increase in the effectiveness score on enforcement on any road-user behaviour factors will be added to the RSAI scores.

12.12 The Value of the RSAI model

The RSAI score may be considered an effective and efficient alternative to assess the road safety level on national scales, to rank and rate countries, to monitor the progress of road safety plans towards a set target, and to suggest solutions to improve the road safety level on a national scale. These factors are enhanced with other points which increase the value of the developed model as shown below:

- It is an effective option because it is constructed based on measuring the availability of the most successful and the most extensive recommended countermeasures that are related to the most of the elements of the road safety system. For example, the rate of roads rated 3 stars or more reflect the rate of roads meeting the minimum design requirement of safer road infrastructure and safer speed limits. When these requirements are applied, the RSAI score is higher and the road is safer. If the safe road is used by safer vehicles in terms of a high rating, then the overall road safety situation is upgraded to a higher level which is represented by a higher RSAI score. The situation is at its best level if the road-user behaviour is improved to safer behaviour by improving the factors affecting the road behaviour through more effective enforcement. The RSAI considers all these factors which make it reflect the safe system approach concept; which is a system of the most successful principles on which the national road safety strategies are based, where a significant reduction in road fatalities is achieved. This assists the policy makers in planning the most effective strategies to improve road safety if the indicators of the RSAI are considered.

- In addition, the RSAI may reflect effectively the integration of the NCAP rating with the RAP rating, which is developed to assess the road safety in the case where all the vehicles are of the highest level of safety. This may assist the developer of both the rating programmes to consider more factors and correct more road users' mistakes which could be addressed by the road infrastructure and the vehicle designers, and measure its aggregated impact on the overall road safety level.

- The RSAI model is considered effective also because of its capability to involve new factors for new countermeasures which may be recommended when assessing the road safety level. The new factors, such as the impact of the heavy vehicle and post crashes' factors, might be added to the model easily if their effect on the road safety is determined and measured.

- Furthermore, the RSAI model is flexible in its unit and the form of the variables used in representing the indicators, on the condition that they have a uniform form and uniform units for all assessed countries. For example, the safer vehicle indicators may be represented by the rate of the new registered vehicles rated 5 stars to the total registered vehicles; or may be represented by the rate of all vehicles' flow rated five stars to the total traffic vehicle volume depending on the available data. Another example is the factors of the road-user behaviour; the rate of car occupants wearing seat belts can be used, if they are available for all countries, as alternate to the effectiveness score of wearing seat belt enforcement.

- Finally, the using of the RSAI model is considered a more efficient and effective alternative in benchmarking than using the real crash data, because it assists in avoiding the problem of unreported and unreliable data. In addition, usage of the RSAI may save the cost of collecting and reporting crash data.

Therefore, it is possible to say' that the RSAI is a valuable measure of assessing the road safety situation and achieving its particular purposes.

12.13 Novelty

The main invaluable innovations achieved in this study are:

1. Developing the ASR model to aggregate the output of the road assessment programme (RAP), which is: the RAP star rating of vehicle occupants (SRv); the RAP star rating of motorcyclists (SRm); the RAP star rating of bicyclists (SRb); and

the RAP star rating of pedestrians (SRp). The ASR model is used in developing the safer road infrastructure and mobility sub model which is aggregated then with the other two sub models to develop the RSAI. This methodology is an extension of the RAP methodology to use in forming the indicator of safer road infrastructure and mobility.

2. Developing the road-user behaviour sub model (SRUB) to consider the five risk factors that have been examined and discussed in previous research; which are speeding, drunk-drivers, wearing seat belts, wearing helmets on two-wheeled vehicles, and using child restraints. Two more factors are aggregated with them, which are drug-drivers and using a mobile phone while driving. These two factors have been described recently in the road assessment reports as important risk factors which need to be taken into account in assessment of road safety performance.

3. Developing the road safety assessment index (RSAI) model to assess the operational performance of road safety by aggregating the developed SRIM sub model and the developed SRUB with the vehicle safety sub model (SV), which has been developed in previous studies. The RSAI model has the ability to assess the application of the highly recommended interventions regarding each indicator. It has other particular purposes which are rating and ranking countries, monitoring progress towards set targets of the road safety strategic plans, and solution planning.

4. Developing a methodology of monitoring the progress of the road safety operation towards a set target. The RSAI score might be used in setting a target, finding the rate of progress towards the set target, and suggesting individual solutions which

consider one element of the road safety system or multiple solutions which consider two elements or more.

5. Developing a methodology of rating countries according to the severity level of the road safety system and the effectiveness of the national strategic plan of road safety in term of their accordance with the safe system approach concept.

12.14 Model Limitations

The limitations of the RSAI models are related to the selected indicators and missing data.

12.14.1 Limitations of the RSAI' indicators

Three points are not considered in the selection indicators of the RSAI model. They are:

1. The selected indicators cover three important elements of the road safety system: road infrastructure and mobility, vehicle safety, and the road-user behaviour factors. Other elements related to post crashes' management, such as medical response time, are not considered in the model. This element is considered by the global organisation in recommending actions for road safety (UN and WHO 2011; WHO 2013a; 2015).

2. The selected indicators for road infrastructure and mobility and vehicle safety are reflected by indicators related to the RAP and NCAP star rating. However, these programmes have not yet considered heavy vehicles, where their weights are greater

than 3.5 ton. Therefore, the RSAI model may be used to assess the operational performance of road safety regarding vehicles of less than 3.5 ton only.

3. For international ranking and comparison, the RSAI should consider the difference in social and cultural characteristics. Some studies used this factor in classifying countries and ranking each group separately. This kind of ranking should be assessed in future studies.

12.14.2 Limitations of data imputation

The missing data which are needed for evaluating the RSAI main model and evaluating the sub models are replaced with substituted values. Three types of data imputation are used in this research.

1. Disaggregating national data into the road sections' level. The data needed to evaluate the aggregated star rating (ASR), which is used to find the indicators of the road infrastructure and mobility (SRIM), includes the number of road crashes resulting from road users' mistakes, such as speeding and using mobile phones while driving, per 100 m section. This number is subtracted from the total number of crashes to find the number of crashes resulting from the road environment only. The number of crashes resulting from road-users' mistakes is available aggregated at a national level. Therefore, it is estimated by disaggregating the available data to road section level. The factor of disaggregation is the rate of the total number of crashes per 100 m road section to the total number of crashes per country. The process and results of disaggregation are shown in Appendix IV.

2. Using the available data; this is used to find the score of the SRIM indicator. The missing data are replaced with the available data, which are the value of the indicator for a part of the road network, not for all the network, as it is only required to find the rate of roads rated at least 3 stars for all the road-user groups. Therefore the proportion of the road length with a minimum of 3 RAP stars or more to the total length of the road network where its data is available, replaces the same proportion, but for the whole network.
3. Replaced with zero values. The data needed to find the score of the indicators related to the drug-drivers and using a mobile phone while driving is replaced with zero values because of the missing information needed to estimate these values.

12.15 The Assessment of Road Safety Level in the Selected Case Studies

The RSAI model is applied in a selected group of countries to assess and rate their level of safety; to rank them according to the level of road safety; and to monitor their progress towards a set target. The RSAI score is used also in suggesting solutions to reduce the rate of road fatalities.

The selection of countries for this study is based on three factors: the availability of previous studies, the availability of needed data, and the clear difference in the level of road safety.

The European countries are selected according to the first criteria, but the necessary data can only be accessed for seven of the countries. They are Bulgaria, Greece, Hungary, Romania, Slovakia, Slovenia, and the Netherlands. These countries have different positions in the rank according to the rate of road fatalities. For example, the Netherlands is at the top because it belongs to the group of countries that achieved a high reduction in the rate of road fatalities. While the rate of road fatalities in Slovakia and Bulgaria positioned them in the middle of the rank, and the rate in Greece and Romania positioned them at the bottom. Therefore, they are considered as qualifying with the three criteria.

1. The Netherlands has the highest rate, which is 3 stars, and the highest position in the rank. Less effort is needed in comparison with the other countries to achieve the set target of reducing the rate of fatalities by 50% by 2030. However, it is still in the fatal level of rating and more actions are needed to improve the safety conditions of the road infrastructure and mobility.
2. Slovakia and Slovenia are rated 2 stars, which reflects that a high rate of road fatalities is expected if no actions are taken. Both countries ranked in the positions following the Netherlands, but effective strategies are needed to increase the rate of roads rated 3 stars or more.
3. Greece is ranked fourth among the seven countries. Actions are needed to increase the rate of new vehicles rated 5 stars and more effective actions are needed to improve the safety level of the roads' infrastructure. The RSAI score and the high rate of road fatalities gave Greece 2 stars.
4. Hungary, and Bulgaria are at the bottom of the list with a very high rate of fatalities expected, because their road safety strategic plan needs to enhance the action of their road infrastructure policy. Hungary needs more action to enforce their road safety law on drunk-drivers..
5. Romania has the lowest star rating because both the road infrastructure and vehicle indicators have very low scores. This enhances the significant effect of these

indicators on the overall road safety level, which is reflected by the weight of their indicators.

6. The road infrastructure and mobility in all countries need more actions.

12.16 Data issue

Data availability is a critical and important criterion that affects various important steps in this research as follows:

1. Data availability was a critical criterion in selecting the indicators of the RSAI.
   - The indicator of safer road infrastructure was not considered properly in previous studies because of a lack of sufficient data regarding all the measures of the road features that have a significant impact on the road safety system. In this research, the results of the RAP assessment methodology (VIDA-iRAP 2018) is considered as a holistic measure of all the factors that are related to road infrastructure and mobility safety. However, the evaluation of the developed model needs to find the percentage of roads that have at least 3 stars for all road-user groups. The type of necessary data is at road section level, while the available data is at aggregated country level. Therefore, there was a need to estimate the necessary data.
   - The indicators of road-user behaviour are selected as alternate indicators. For example, the rate of road users wearing seat belts is the most comprehensive, measurable, and valid measure of the risk factor related to wearing seat belts. However, this rate is not estimated or recorded for all countries. Therefore, the second option is the effectiveness score of the wearing seat belt enforcement programme, which is measured using an expert questionnaire method developed by the WHO (2015); they published their results in accessible reports. The

effectiveness scores may be less comprehensive, but they are used as an alternative indicator because of the lack of data.

- The RSAI model is developed in a way in which the units or forms of the variables can be different from one group of countries to another, but they should in the same form for the same group of countries. For example, a paper has been produced by the author to apply the RSAI in Asian countries (Jameel and Evdorides 2018a). The problem of the lack of the necessary data of the safer vehicle indicator leads to not using the NCAP indicator and substituting it with indicators related to the details of the crash worthiness and avoidance factors.

2. Data availability was a critical criterion in selecting the case studies that are needed to evaluate the developed model.

   - To evaluate the model of the RAP output aggregation, which are four, star ratings for four road-user groups, sufficient data is needed to compare the results of the model with real crash details. Road sections are needed to collect the needed data. These sections should be used by the four road-user groups to test the correctness of the aggregation model. Roads of type B are more qualified for this point, but there was no access allowed to the results of these kinds of roads. The alternative type is roads of type A that are used by the four road-user groups, but the accessible results are not enough to conduct the evaluation study. Therefore, the A-road sections that are used by three of the road-user groups are included in the selected sections to get a sufficient sample size.
   - To select the cases for applying and evaluating the RSAI model, data availability is considered as a main contributing factor in selecting the countries. The European countries are selected because of the availability of the published and

accessible data set. However, there is some missing data for some countries. The availability of accessible RAP results is the most critical criterion that refined the suggested list to only seven countries.

3. Lacking the necessary data made the evaluation of the developed methodologies of monitoring progress and suggesting solutions challenging. Therefore, the methodologies are suggested but it is recommended to contact the agencies that are responsible for providing this data to get grant of access to use it in testing the validity of the developed methodologies.

12.17 Summary

This chapter discussed the main findings of this study. The main finding are developing the RSAI model to assess the operational performance of the road safety system, based on the safe system approach concept. This concept considers the multiple actions of improving the road infrastructure and mobility; improving the vehicle design; and improving the road-user behaviour through an effective enforcement system to improve the overall road safety level. These main strategies are considered in developing the RSAI model. The safer road infrastructure and mobility (SRIM) is reflected by the indicator of the percentage of roads rated 3 stars; while the safer vehicle (SV) is represented by the indicator of the percentage of vehicles rated 5 stars. These indicators interpret the recommendation of the United Nations in their plan of the Decade of Actions of Road Safety (2011-2020). The indicators of safer road-user behaviour (SRUB) consider the main seven risk factors; which are speeding, drunk-drivers, wearing seat belts, wearing helmets, using child restraints, drug-drivers and using a mobile phone while driving.

Three sub models are developed for each of the three elements of the safe system approach ; the road infrastructure and mobility sub model is the most challenging because it is not considered properly in previous studies. The RAP methodology of road assessment is the only one available and is the most valid methodology; its old version was used by only one study. However, the first version was used to rate requirement for safer roads only for one road user group which is the vehicle occupant. The updated version was developed to assess the requirements of other road-user groups, such as pedestrians, bicyclists, and motorcyclists. To use this version, there was a need to aggregate the star ratings' results of the various road-user groups into one star rating. A methodology is developed in this study to aggregate the outputs of the RAP star ratings. The minimum star ratings of the four RAP star ratings is the final model of aggregating the RAP star rating. This model is used to find the SRIM score and aggregate with the SV and SRUB scores. Two different weighting methods are used to aggregate the sub models, and the individual indicators of the SRUB sub model resulted in two preliminary RSAI models.

The final RSAI model is used to rank countries and monitor the progress towards a set target. For this, a methodology is developed in this study to estimate the RSAI score for the target year; find the progress rate; and suggest individual and multiple solutions. This enhances the achievement of the RSAI model for its particular purposes.

At the end of this study, conclusions are drawn, with some recommendations for future works.

CHAPTER THIRTEEN

CONCLUSIONS AND RECOMMENDATIONS

13.1 Introduction

This study developed a road safety assessment index (RSAI) for assessing the operational performance of road safety strategies based on the concept of the safe system approach . The purposes of using the RSAI are to rank countries according to the level of road fatalities; quantify targets; monitor progress towards a set target; and suggest solutions based on the principles of the safe system approach . The innovative features of the RSAI investigate the use of most updated version of the RAP methodology, as it is the most valid methodology in identifying the road infrastructure and mobility indicators. A new methodology is developed to aggregate the outputs of the RAP methodology and the aggregated RAP star rating is used in developing the sub model of the road infrastructure and mobility index (SRIM). This sub model is aggregated with the safer vehicle (SV) sub model and the road-user behaviour (SRUB) sub model to develop the main model of the RSAI. In addition, a methodology to use the RSAI to assess the progress of the road safety strategies towards a set target, and suggest individual and multiple solutions is developed in this research. It is based on the results of the sensitivity analysis of the individual and multiple impacts of the RSAI indicators on the RSAI score.

The developed RSAI model is evaluated through comparing the results of RSAI scores of seven European countries with the rate of their road fatalities per 100000 in 2013. The results of the evaluation demonstrated that the RSAI model is an effective replacement of the crash data in assessing and benchmarking countries.

In this chapter, the key conclusions of the study are summarised and recommendations for further studies are presented.

13.2 The Main Conclusions

The main conclusions of this study are categorised into five groups. They are the selected indicators of the RSAI model; extending the RAP methodology to form the indictor of the road infrastructure and mobility; weighting and aggregation of the RSAI indicators; evaluating the developed RSAI model; and application of the developed RSAI model.

13.2.1 The selected indicators of the RSAI model

1. A new road safety assessment model has been developed to be used for a comprehensive assessment of road safety, by taking into account road infrastructure and mobility, vehicles and road-user behaviour.

2. The model is based on the safe system approach principles.
3. The developed model consists of three sub models. They are the safer road infrastructure and mobility (SRIM), the safer vehicle (SV), and safer road user (SRUB) models.

4. The parameters of each sub model were chosen with regard to their relevancy to the safe system approach concept, comprehensibility, validity, measurability and independency.

5. The indicator of the SRIM sub model is the percentage of roads having a minimum of 3 stars for all road-user groups.

6. The selected indicator for the SV sub model is the percentage of vehicles rated 5 NCAP stars. It reflects the crashworthiness and crash avoidance factors of vehicles.

7. The selected indicators of the SRUB sub model reflect the effectiveness of the enforcement system associated with road-user behaviour in terms of speeding, drunk-drivers, wearing seat belts, wearing helmets, using child restraints, drug-drivers, and using mobile phones while driving

13.2.2 Investigating the usage of RAP star ratings in forming the indicator of safer road infrastructure and mobility

Extending the ability to use the RAP methodology to produce a thematic indicator of safer road infrastructure and mobility is investigated in this study. It is concluded that the minimum vehicle occupants', motorcyclists', bicyclists', and pedestrians' star ratings are the most appropriate to use as the aggregated star rating to reflect the safer road design feature and form the indicator of the safer road infrastructure and mobility. This is selected because it is simple to measure, logic in concept, and more qualified in reflecting the safer conditions of the road design features and the concept of RAP methodology in rating road infrastructures.

13.2.3 Formulating the RSAI Model

The selected indicators of the RSAI model are weighted and aggregated to develop the form of the RSAI model. It is concluded that:

1. The weighting of each of the thematic indicators was equal to 1; these results are from investigating two methods of weighting. This enhances the contribution of the safe system approach concept in the context of the RSAI model.

2. The weighting of each of the SRUB indicators was equal to 0.143. The summation of the weightings of the SRUB's indicators was equal to 1.

3. The simple linear additives aggregation method appeared to be optimum to use in aggregating the thematic indicators and the individual indicators of the SRUB sub model.

4. The minimum score of the RSAI is zero when there is no strategic plan of road safety. While the maximum RSAI score is 300 when all the programmes of the national road safety strategic plan are effective and full implemented and full contributed with the safe system approach.

13.2.4 Evaluating the RSAI model

1. The developed model is evaluated in terms of achieving its purposes, as an index for strategic studies and for plans to improve road safety. The evaluation results prove the significance of the selected RSAI model in replacing the rate of road fatalities in:
   - assessing the road safety level on a national scale, and
   - ranking countries with regards to the level of road safety.

2. A sensitivity analysis is conducted to measure the rate of change in the RSAI score resulting from the change in the scores of each indicator individually, or multiple changes in two or more indicators' scores. The results of this analysis enhance the contribution of the safe system approach concept in the developed model; focusing on sharing the roles of the components of the road safety system in reducing the rate of road fatalities.

13.2.5 Application of the RSAI model

The RSAI scores are more likely to be used to achieve the following:

1. Rating countries according to the level of their road crashes' severity; the contribution of the safe system approach principles in the strategic plan of road safety; and the implementation of the strategic plan. Star rating bands are developed and evaluated to use in rating countries via the RSAI scores. The RSAI scores are categorised into five ranges, each reflecting a star rating:

- The 5-stars indicates the safest conditions when the road safety strategic plan follows fully the safe system approach concept. This is shown when the RSAI score is closer to the maximum of 300.
- The 4-star indicate effective strategic plan of road safety with partial implementing of one of the programs the plan.
- The fatal level is rated by 1-star, 2-star, and 3-star; reflecting different level of severity.
- The most dangerous situation is rated by 1 star, reflecting that the highest rate of road fatalities is expected as a result of a very poor strategic plan for road safety with no actions taken. This situation is measured by the lowest RSAI score.

2. Monitoring the progress towards a set target through developing a model for estimating the rate of progress in the present year. A rate of progress close to 100% means significant progress is achieved. A rate close to zero means no progress is achieved.

3. Suggesting solutions through prioritising alternative solutions based on the results of the sensitivity analysis. Two types of solutions are suggested. First, the individual solution considers the road infrastructure, vehicle, or enforcement system on road-user behaviour risk factors. Second, the multiple solutions consider two of these components or more in deciding the programme of the road safety improvement plan. A table of the change in the RSAI score resulting from individual changes in the indicators is developed; it can be used also to count the change resulting from multiple solutions.

13.3 Suggestions for Future Research

1. Testing the time trend of the RSAI and comparing it with historical crash data to investigate the ability of the RSAI to reflect the trend of a real road safety situation and predict the level of road safety This may assist in setting quantified targets using the RSAI score. This also helps to evaluate and validate the developed methodology of measuring the rate of progress of a strategic plan towards a set target.

2. Aggregating the RSAI score with other recommended indicators related to post crash management; which is recommended highly to reduce the rate of the severe consequences of road crashes.

3. Developing a methodology of spatial aggregating of the RAP results, to find an aggregated RAP star rating on national scale. This may be used to aggregate with the aggregated NCAP score on a national scale and other recommended indicators' scores.

4. Consider heavy vehicles in the RAP methodology and NCAP methodology. This may make the RSAI more comprehensive.

5. Expanding the application of the RAP and NCAP programmes to assess the road infrastructure and vehicles in more countries. This may increase the validity of the RSAI for use in international benchmarking and comparison studies.

6. Investigating the use of the RSAI index in the developing countries where the majority of road safety fatalities are occurred yearly.

7. Investigating other factors related to the road user behaviour such as fatigue, stress , and health issues to use as indicators of road user behaviour index

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APPENDIX I

THE ROAD ASSESSMENT PROGRAMME IRAP

I.1 Introduction

The RAP is developed by a free-of-profit agency for a systematic assessment of road safety. It is used to assess the safety level of roads' infrastructure in terms of star ratings using VIDA which is an online software used to perform all iRAP Star Rating and Safer Roads Investment Plan analyses (VIDA-iRAP 2018). It is used for different road user groups, including vehicle occupants, motorcyclists, pedestrians and cyclists. The RAP assessment considers the crashworthiness factors to provide an estimate of likely fatal and serious injury outcomes when a crash occurs and the crash avoidance factors to include a measure of crash likelihood (iRAP 2017). It considers the vehicle speed and its role in the injury outcome of both vehicle-vehicle impacts and vehicle infrastructure impacts as a key factor in the assessment methodology. It also addresses the main crash types identified by research such as impacts at junctions and head-on impacts with opposing vehicles (DaCoTA 2012; Lynam 2012).

The road assessment programme (RAP) is based on the expectation that the design of the road infrastructure should minimize the risk of predictable mistakes resulting road crashes, and should provide sufficient protection to reduce severity of the road risk (DaCoTA 2012). The RAP assessment programme is applied on over 900000 km of road across 70 countries by using about 60 road attributes. Five to four stars represent the safest conditions produced from well-designed roads that fulfil the requirements of the safe system approach , which is based on the forgiving and self-explaining standards. This includes, for example, physical separation of vulnerable road users, protection from roadside hazards, enhanced intersection design and separation of high-speed oncoming traffic (iRAP/EuroRAP 2011; iRAP 2015).

The iRAP also has a collection of countermeasures that have been proved to be effective treatments to improve road safety levels and result in saving lives for each road user (McInerney and Smith 2009; Turner et al. 2009; iRAP 2015). The iRAP considers the venerable road users: pedestrians and cyclists in the design of the road infrastructure, which is an aim of the safe system approach guide (Jackisch et al. 2015).

The iRAP star ratings are used as benchmarks for setting road standards and targets in most of the road safety strategies. A minimum star rating specification of three is set as a target for new road projects and for existing roads (WHO 2013a; WHO 2015; iRAP 2017)

Research has been conducted on the relation between star rating and real improvements in road safety levels. It was demonstrated that a reduction in road fatalities between 33% to 50% is achieved for each iRAP star awarded (McInerney et al. 2008; iRAP/EuroRAP 2011).

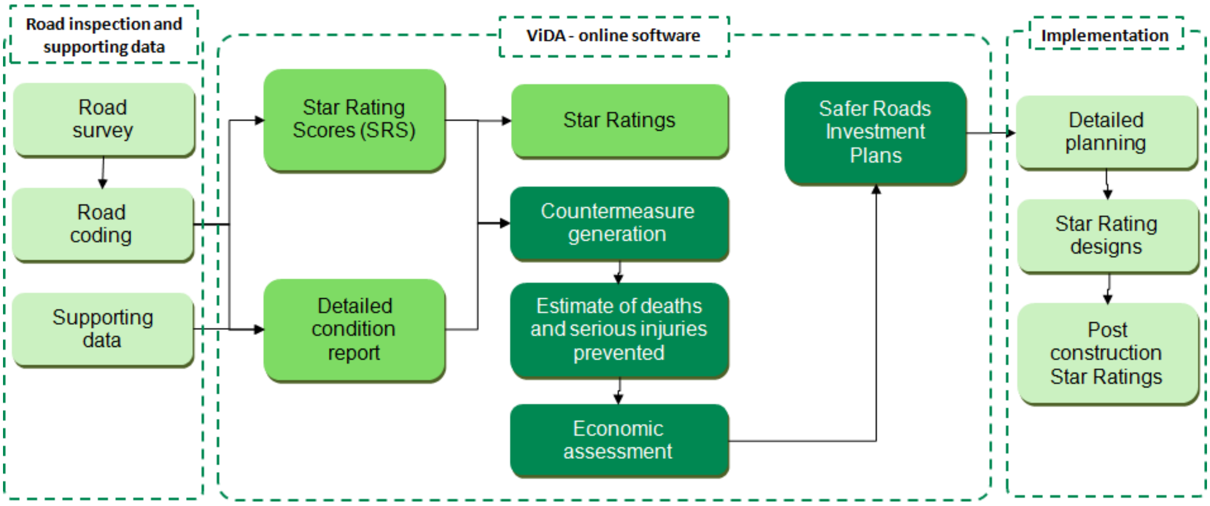

Figure I.1 The protocols of RAP methodology (iRAP 2017)

I.2 The Historical review of developing the iRAP methodology and models.

- The first version of iRAP is the EuroRAP (EuroRAP 2017) which is established in 1999. The EuroRAP model was based on assessments of road attributes that provide crashworthiness to protect car occupants in the event of a crash. The equations and risk factors used in the EuroRAP model were developed by the Swedish National Road Administration, the Dutch Ministry of Transport, National Roads Authority, Republic of Ireland, Transport Research Laboratory (TRL), the English Highways Agency, Germany federal research agency, BASt, European motoring organisations and EuroRAP staff. In addition it is based heavily on some technical works (Elvik et al. 2009; Lynam 2012). The EuroRAP was used since 2004 to assess road infrastructures in some European countries.

- AusRAP is the Australian version of RAP methodology which is developed in 2006 for the Australian Automobile Association (AAA) and ARRB Group and based heavily on the EuroRAP work and research undertaken by ARRB Group. This version considers the crash avoidance factors that related to the road attributes that affect the likelihood that a crash will occur (such as delineation), in addition to the crash worthiness factors (such as safety barriers) (AusRAP 2017; iRAP 2017).

- The iRAP which is the international road assessment programme is developed following the release of the World Report on road traffic injury prevention (Peden et al. 2004) to fulfil the urgent need decision support tools in low and middle-income countries was recognised.

- Other local versions of RAP model are developed such as the usRAP in the United states and KiwiRAP the New Zealand

- The version 2 models significantly expanded on the EuroRAP and AusRAP models. In particular, they enabled extend the assessment of risk to more road user groups such as motorcyclists, pedestrians and bicyclists and cosider the crash avoidance factors.

- The version 2.1 and 2.2 in 2010 to add new road attributes, such as the ability to record the paved shoulder widths on both sides of the road (Turner et al, 2009).

- The version 3 is developed in 2013 to consider more factors of vehicle occupant's safety such as street lighting and skid resistance

- A safer road investment plan is produced as extension of the iRAP assessment methodology to identify economically viable countermeasures that can reduce risk of death and serious injury.

- The iRAP methodology is adapted to meet the trend towards setting Star Rating-based performance targets, such as ‘increase the percentage of road rated 3-stars or better.’

I.3 The Road Attributes

Road attribute data are the attributes that influence the likelihood and severity of the most common types of serious crashes for vehicle occupants, motorcyclists, pedestrians and bicyclists. They collected and recorded for each 100 metre segment of road. In a situation where the condition of an attribute varies within a 100 metre segment, the worst case (from a road safety perspective) is recorded. These attributes are summarised in Table (I.1).

Table I.1 the road attributes considered in the RAP assessment methodology

Road attributes	Item	Category ID	Category
1	Coder name	NA	NA
2	Coding date	NA	NA
3	Road survey date	NA	NA
4	Image reference	NA	NA
5	Road Name	NA	NA
6	Section	NA	NA
7	Distance	NA	NA
8	Length	NA	NA
9	Latitude	NA	NA
10	Longitude	NA	NA
11	Landmark	NA	NA
12	Comments	NA	NA
13	Carriageway	1	Carriageway A of a divided road
		2	Carriageway B of a divided road
		3	Undivided road
		4	Carriageway A of a motorcycle facility
		5	Carriageway B of a motorcycle facility
14	Upgrade cost	3	High
		2	Medium
		1	Low
15	Motorcycle observed flow	1	None
		2	1 motorcycle
		3	2 to 3 motorcycles
		4	4 to 5 motorcycles
		5	6 to 7 motorcycles
		6	8+ motorcycles
16	Bicycle observed flow	6	8+ bicycles
		5	6 to 7 bicycles
		4	4 to 5 bicycles
		3	2 to 3 bicycles
		2	1 bicycle
		1	None
17	Pedestrian observed flow across the road	6	8+ pedestrians across the road
		5	6 to 7 pedestrians across the road
		4	4 to 5 pedestrians across the road
		3	2 to 3 pedestrians across the road
		2	1 pedestrian across the road
		1	None
18	Pedestrian observed flow along the road driver-side	6	8+ pedestrians along driver-side
		5	6 to 7 pedestrians along driver-side
		4	4 to 5 pedestrians along driver-side
		3	2 to 3 pedestrians along driver-side

		2	1 pedestrian along driver-side
		None	
19	Pedestrian observed flow along the road passenger side	6	8+ pedestrians along passenger-side
		5	6 to 7 pedestrians along passenger-side
		4	4 to 5 pedestrians along passenger-side
		3	2 to 3 pedestrians along passenger-side
		2	1 pedestrian along passenger-side
		1	None
20	Land use - drivers side	6	Educational
		4	Commercial
		7	Industrial and manufacturing
		3	Residential
		2	Farming and agricultural
		1	Undeveloped areas
		5	Not Recorded
21	Land use - passenger side	6	Educational
		4	Commercial
		7	Industrial and manufacturing
		3	Residential
		2	Farming and agricultural
		1	Undeveloped areas
		5	Not Recorded
22	Area type	2	Urban
		1	Rural
23	Speed limit	25	>=150km/h
		23	140km/h
		21	130km/h
		19	120km/h
		17	110km/h
		15	100km/h
		13	90km/h
		11	80km/h
		9	70km/h
		7	60km/h
		5	50km/h
		3	40km/h
		1	<30km/h
		45	>=90mph
		43	80mph
		41	70mph
		39	60mph

I.4 Star Rating Scores (SRS)

A Star Rating Score (SRS) is the inetyrmediate output of the rRAP assessment methodology which is calculated to identify the sat rating of the road infrastructure by assigning the SRS to a star rating bands. The SRS is calculated for each 100 metre segment of road and each of the four road users if a flow of the particular road user is recorded, using the following equation:

$$SRS = \Sigma \text{ Crash Type Scores (1)} \qquad \text{.........(I.1)}$$

where:

The SRS represents the relative risk of death and serious injury for an individual road user; and

$$\text{Crash Type Scores} = \text{Likelihood x Severity x Operating speed x External flow influence x Median travers ability} \qquad \text{.........(I.1.1)}$$

where:

- Likelihood refers to road attribute risk factors that account for the chance that a crash will be initiated
- Severity refers to road attribute risk factors that account for the severity of a crash
- Operating speed refers to factors that account for the degree to which risk changes with speed
- External flow influence factors account for the degree to which a person's risk of being involved in a crash is a function of another person's use of the road

- Median traversability factors account for the potential that an errant vehicle will cross a median (only applies to vehicle occupants and motorcyclists run-off and head-on crashes).

The calculated SRS is assigned to the star rating bands to identify the final output which is in term of star ratings (SRs).

x – Factors (to the right) are multiplied

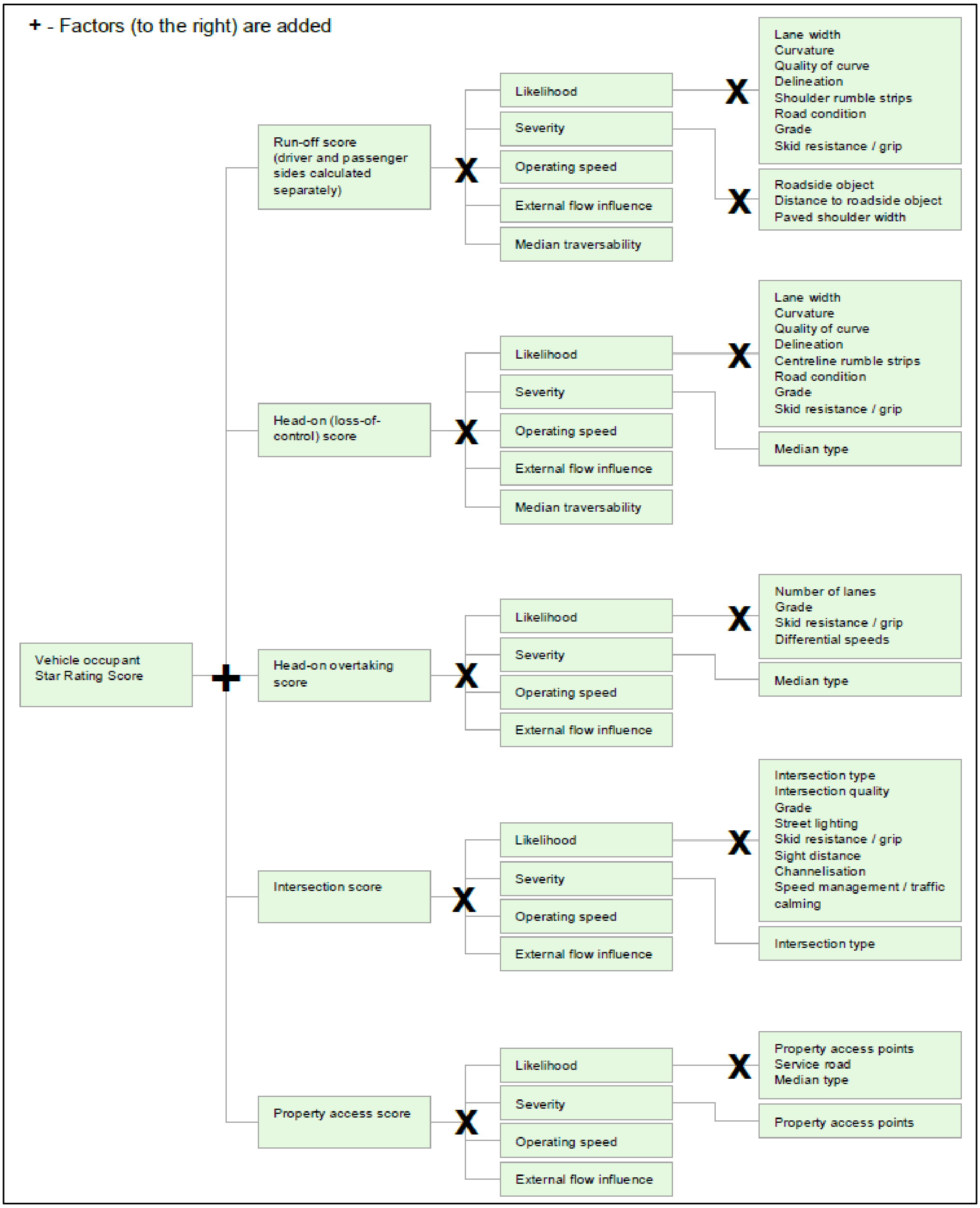

Figure I.2 Vehicle occupant SRS Model

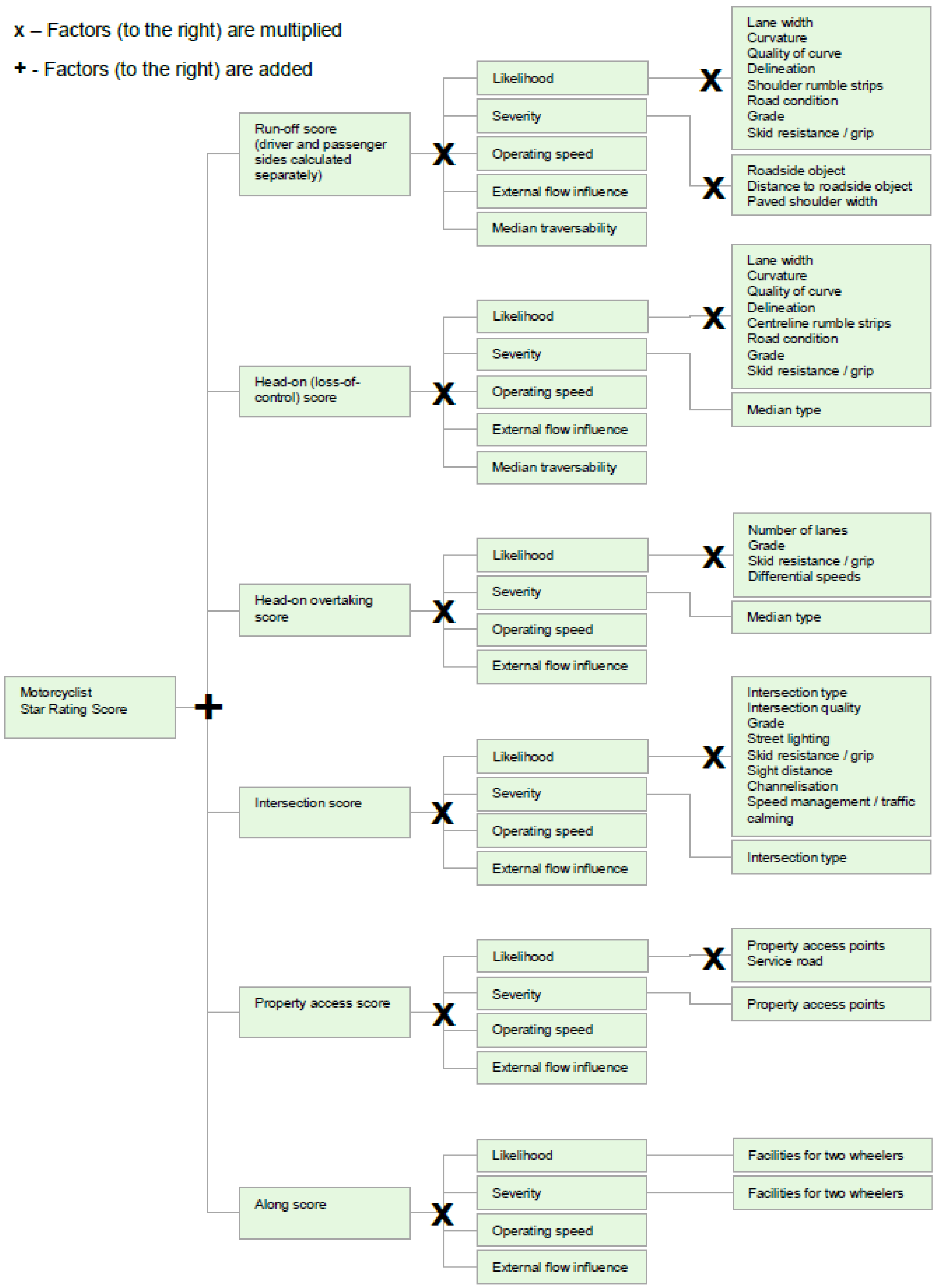

Figure I.3 Motorcyclist SRS models

Bicyclist SRS are calculated using equations in the following form.

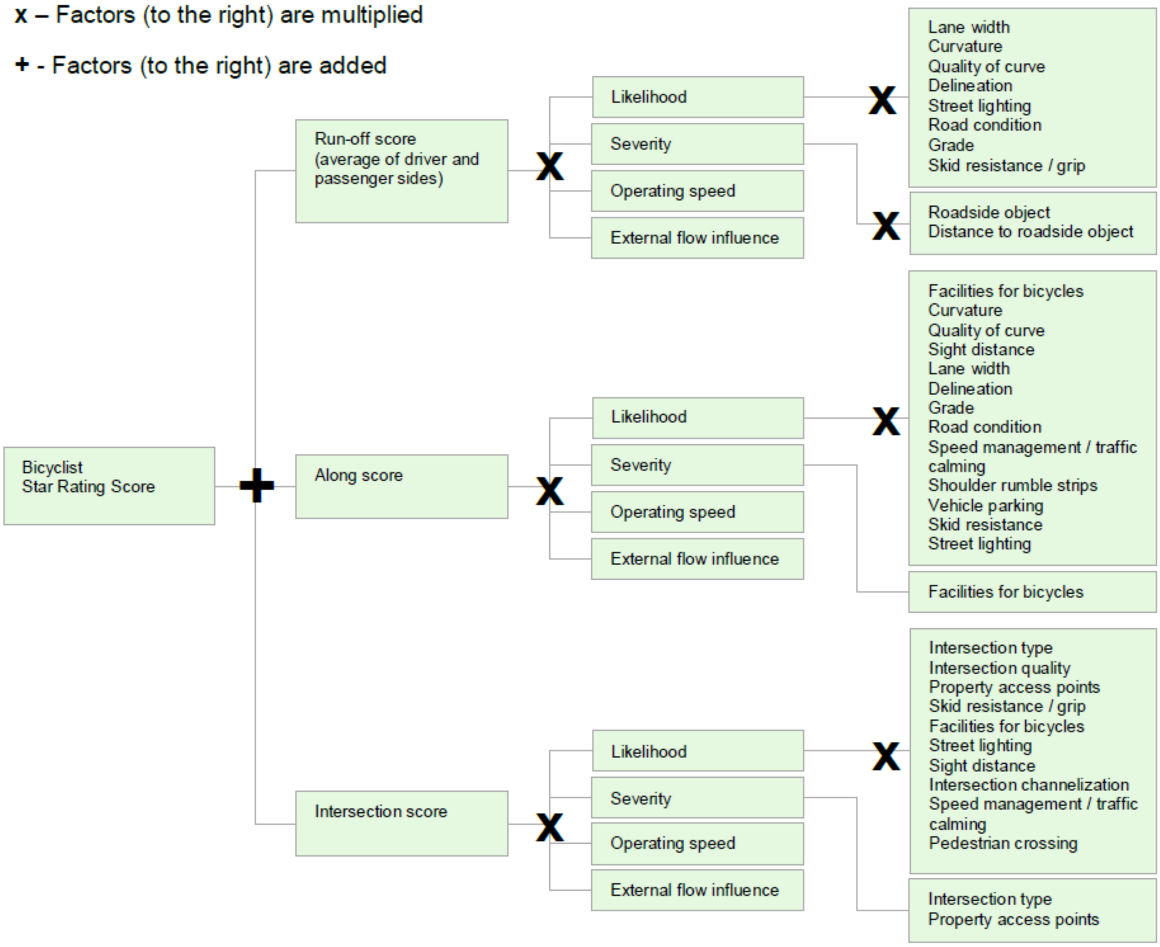

Figure I.4 Bicyclists SRS model

Pedestrian SRS are calculated using equations in the following form.

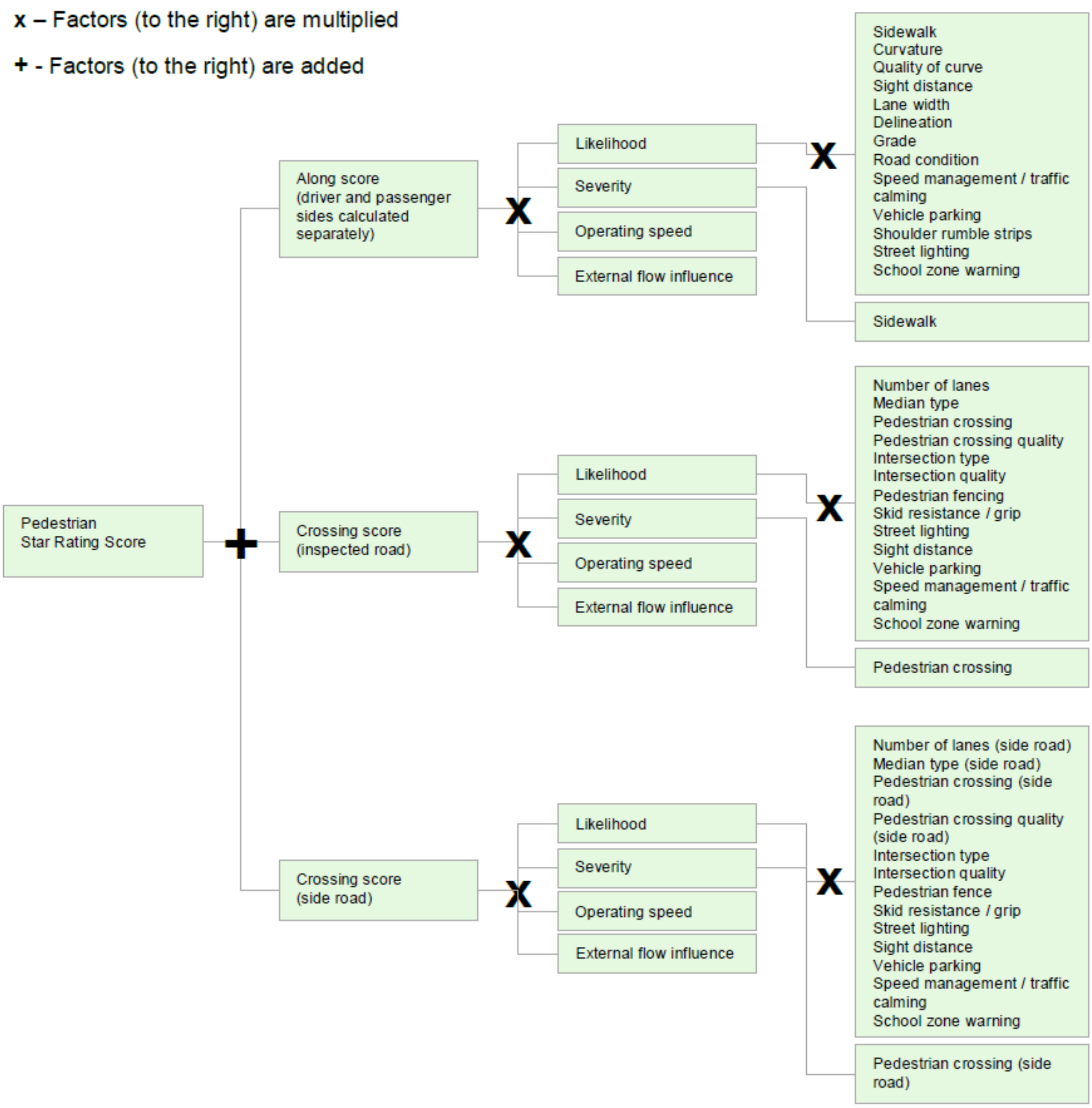

Figure I.5 Pedestrian SRS model

I.3 Star Rating Bands

Separate bands are used for each road user groups because their scores are calculated using different equations. The star bands, which is shown in Figure (I.2), were set after sensitivity testing was performed with a particular focus the safe system approach context and the role of star rating in setting targets. It is also set based on the relationship between Star Ratings and crash rates and the distribution of Star Ratings across a typical road network.

Star Rating bands and colours

Star Rating	Star Rating Score				
	Vehicle occupants and motorcyclists	Bicyclists	Pedestrians		
			Total	Along	Crossing
5	0 to < 2.5	0 to < 5	0 to < 5	0 to < 0.2	0 to < 4.8
4	2.5 to < 5	5 to < 10	5 to < 15	0.2 to < 1	4.8 to < 14
3	5 to < 12.5	10 to < 30	15 to < 40	1 to < 7.5	14 to < 32.5
2	12.5 to < 22.5	30 to < 60	40 to < 90	7.5 to < 15	32.5 to < 75
1	22.5 +	60+	90 +	15 +	75 +

Figure I.I.6 The star rating band developed by RAP

I.4 Countermeasures and Outcomes

The star ratings identified as the final output of assessment methodology are used to suggest countermeasures to improve the level of the safety level of the road infrastructures. The iRAP methodology used about 100 countermeasures which example of them are listed in Table (I.2). . For each countermeasure, there is at least one 'outcome.' This refers to the road attribute code that is applied at the 100 metre segment of road when the countermeasure is 'applied'.

A total of 94 countermeasures can be used in the iRAP model. For each countermeasure, there is at least one 'outcome.' This refers to the road attribute code that is applied at the 100 metre segment of road when the countermeasure is 'applied'. The table below shows an example of the outcome and resultant change in risk factor for the installation of a w-beam safety barrier.

Table I.2 Examples of countermeasures used by iRAP methodology to suggest solutions.

ID	Countermeasures	Outcomes	
		Attribute	**Category**
1	Vertical realignment (major)	Grade	≥ 0% to <4%
2	Realignment (sight distance improvement)	Sight Distance	Adequate
3	Horizontal Realignment	Curvature	Straight or gently curving
4	Duplicate - >20m median	Median Type	Physical median width >=20m
5	Duplicate - 10-20m median	Median Type	Physical median width 10 to <20m
		Number Of Lanes	Two
6	Duplicate - 5-10m median	Median Type	Physical median width 5 to <10m
		Number Of Lanes	Two
7	Duplicate - 1-5 m median	Median Type	Physical median width 1 to <5m
		Number Of Lanes	Two
8	Duplicate - <1m median	Median Type	Physical median width 0 to <1m
		Number Of Lanes	Two
9	Duplication with median barrier	Median Type	Safety barrier - motorcycle friendly
		Number Of Lanes	Two
10	Service road	Property Access Points	Residential Access <3
		Service Road	Present
11	Additional lane (2 + 1 road with barrier)	Median Type	Safety barrier - wire rope
		Number Of Lanes	Two and one
12	Implement one way network	Median Type	One way
13	Overtaking lane	Number Of Lanes	Two and one
14	Grade separation	Intersection Type	Merge lane
15	Central median barrier (no duplication)	Median Type	Safety barrier - wire rope
16	Central turning lane full length	Median Type	Continuous central turning lane
17	Central median barrier (1+1)	Median Type	Safety barrier - wire rope

18	Centreline rumble strip / flexi-post	Median Type	Flexible posts
19	Central hatching	Median Type	Central hatching (>1m)
20	Wide centreline	Median Type	Wide centre line (0.3m to 1m)
21	Motorcycle Lane (Segregated)	Facilities For Motorised Two Wheelers	Exclusive one way motorcycle path without barrier
22	Motorcycle Lane (Construct on-road)	Facilities For Motorised Two Wheelers	Inclusive motorcycle lane on roadway
23	Motorcycle Lane (Painted logos only on-road)	Facilities For Motorised Two Wheelers	Inclusive motorcycle lane on roadway
24	Lane widening (>0.5m)	Lane Width	Wide (≥ 3.25m)
25	Lane widening (up to 0.5m)	Lane Width	Wide (≥ 3.25m)
26	Shoulder sealing passenger side (>1m)	Paved Shoulder - Passenger Side	Wide (≥ 2.4m)
27	Shoulder sealing passenger side (<1m)	Paved Shoulder - Passenger Side	Medium (≥ 1.0m to < 2.4m)
28	Shoulder sealing driver side (>1m)	Paved Shoulder - Driver Side	Wide (≥ 2.4m)
29	Shoulder sealing driver side (<1m)	Paved Shoulder - Driver Side	Medium (≥ 1.0m to < 2.4m)
30	Shoulder rumble strips	Shoulder Rumble Strips	Present
31	Roadside barriers - driver side	Roadside Severity - Driver Side Distance	5 to <10m
		Roadside Severity - Driver Side Object	Safety barrier - motorcycle friendly
32	Roadside barriers - passenger side	Roadside Severity - Passenger Side Distance	5 to <10m
		Roadside Severity - Passenger Side Object	Safety barrier - motorcycle friendly
33	Clear roadside hazards - driver side	Roadside Severity - Driver Side Distance	>=10m
		Roadside Severity - Driver Side Object	Tree >=10cm
34	Clear roadside hazards - passenger side	Roadside Severity - Passenger Side Distance	>=10m
		Roadside Severity - Passenger Side Object	Tree >=10cm
35	Sideslope improvement - driver side	Roadside Severity - Driver Side Distance	>=10m
		Roadside Severity - Driver Side Object	Downwards slope (> -15°)
36	Sideslope improvement - passenger side	Roadside Severity - Passenger Side Distance	>=10m

		Roadside Severity - Passenger Side Object	Downwards slope (> -15°)
37	Roundabout	Intersection Type	Roundabout
38	Pave road surface	Skid Resistance / Grip	Sealed - adequate
39	Road surface rehabilitation	Road Condition	Good
40	Skid Resistance (paved road)	Skid Resistance / Grip	Sealed - adequate
41	Skid Resistance (unpaved road)	Skid Resistance / Grip	Unsealed - adequate
42	Signalise intersection (4-leg)	Intersection Type	4-leg signalised with protected turn lane
43	Protected turn provision at existing signalised site (4-leg)	Intersection Type	4-leg signalised with protected turn lane
44	Protected turn lane (unsignalised 4 leg)	Intersection Type	4-leg unsignalised with protected turn lane
45	Signalise intersection (3-leg)	Intersection Type	3-leg signalised with protected turn lane
46	Protected turn provision at existing signalised site (3-leg)	Intersection Type	3-leg signalised with protected turn lane
47	Protected turn lane (unsignalised 3 leg)	Intersection Type	3-leg unsignalised with protected turn lane
48	Rail crossing upgrade	Intersection Type	Railway Crossing - active (flashing lights / boom gates)
49	Median crossing upgrade	Intersection Type	Median crossing point - formal
		Intersection Quality	Adequate
50	Bicycle Lane (off-road)	Facilities For Bicycles	Off-road path
51	Bicycle Lane (on-road)	Facilities For Bicycles	On-road lane
52	Grade separated pedestrian facility	Pedestrian Crossing - Inspected Road	Grade separated facility
53	Signalised crossing	Pedestrian Crossing - Inspected Road	Signalised with refuge
54	School zone - crossing guard or supervisor	School Zone Crossing Supervisor	School zone - crossing guard or supervisor present at school start and finish times
55	Unsignalised raised crossing	Pedestrian Crossing - Inspected Road	Unsignalised raised marked crossing with refuge
56	Unsignalised crossing	Pedestrian Crossing - Inspected Road	Unsignalised marked crossing with refuge
57	Refuge Island	Pedestrian Crossing - Inspected Road	Refuge only
58	Upgrade pedestrian facility quality	Pedestrian Crossing Quality	Adequate
59	Side road grade separated pedestrian facility	Pedestrian Crossing - Inspected Road	Grade separated facility
60	Side road signalised pedestrian crossing	Pedestrian Crossing - Inspected Road	Signalised with refuge
61	Side road unsignalised pedestrian crossing	Pedestrian Crossing - Inspected Road	Unsignalised marked crossing with refuge
62	Footpath provision passenger side (with barrier)	Sidewalk - Passenger Side	Physical barrier

63	Footpath provision passenger side (>3m from road)	Sidewalk - Passenger Side	Non-physical separation ≥ 3.0m
64	Footpath provision passenger side (adjacent to road)	Sidewalk - Passenger Side	Non-physical separation 0m to <1.0m
65	Footpath provision passenger side (informal path >1m)	Sidewalk - Passenger Side	Informal path ≥ 1.0m
66	Footpath provision driver side (with barrier)	Sidewalk - Driver Side	Physical barrier
67	Footpath provision driver side (>3m from road)	Sidewalk - Driver Side	Non-physical separation ≥ 3.0m
68	Footpath provision driver side (adjacent to road)	Sidewalk - Driver Side	Non-physical separation 0m to <1.0m
69	Footpath provision driver side (informal path >1m)	Sidewalk - Driver Side	Informal path ≥ 1.0m
70	Pedestrian fencing	Pedestrian Fencing	Present
71	Street lighting (intersection)	Street Lighting	Present
72	Street lighting (ped crossing)	Street Lighting	Present
73	Street lighting (mid-block)	Street Lighting	Present
74	Sight distance (obstruction removal)	Sight Distance	Adequate
75	School zone warning - flashing beacon	School Zone Warning	School zone flashing beacon
76	School zone warning - signs and markings	School Zone Warning	School zone static signs or road markings
77	Delineation and signing (intersection)	Intersection Quality	Adequate
78	Improve curve delineation	Quality Of Curve	Adequate
79	Improve Delineation	Delineation	Adequate
80	Restrict/combine direct access points	Property Access Points	None
81	Traffic calming	Speed Management / Traffic Calming	Present
82	Parking improvements	Vehicle Parking	Low
83	Sideslope improvement (bike lane)	Roadside Severity - Passenger Side Distance	5 to <10m
		Roadside Severity - Passenger Side Object	Downwards slope (> -15°)
84	Clear roadside hazards (bike lane)	Roadside Severity - Passenger Side Distance	5 to <10m
		Roadside Severity - Passenger Side Object	Tree >=10cm
85	Roadside barriers (bike lane)	Roadside Severity - Passenger Side Distance	5 to <10m

		Roadside Severity - Passenger Side Object	Safety barrier - motorcycle friendly
86	Central median barrier (MC lane)	Facilities For Motorised Two Wheelers	Exclusive two way motorcycle path with barrier
87	Sideslope improvement (seg MC lane) passenger side	Roadside Severity - Passenger Side Distance	>=10m
		Roadside Severity - Passenger Side Object	Downwards slope (> -15°)
88	Clear roadside hazards (seg MC lane) passenger side	Roadside Severity - Passenger Side Distance	>=10m
		Roadside Severity - Passenger Side Object	Tree >=10cm
89	Roadside barriers (seg MC lane) passenger side	Roadside Severity - Passenger Side Distance	5 to <10m
		Roadside Severity - Passenger Side Object	Safety barrier - motorcycle friendly
90	Sideslope improvement (seg MC lane) driver side	Roadside Severity - Driver Side Distance	>=10m
		Roadside Severity - Driver Side Object	Downwards slope (> -15°)
91	Clear roadside hazards (seg MC lane) driver side	Roadside Severity - Driver Side Distance	>=10m
		Roadside Severity - Driver Side Object	Tree >=10cm
92	Roadside barriers (seg MC lane) driver side	Roadside Severity - Driver Side Distance	5 to <10m
		Roadside Severity - Driver Side Object	Safety barrier - motorcycle friendly
93	Speed management reviews	Operating Speed (85Th Percentile)	<30km/h
94	Speed management reviews (MC Lane)	Motorcycle Speed Limit	<30km/h

APPENDIX II

THE NEW CAR ASSESSMENT PROGRAMME NCAP

II.1 Introduction

The new car assessment programme (NCAP) was established in 1997 to adopt progressive methodologies and protocols for assessing new car safety performance under certain conditions in terms of star ratings. Its first version, which is the EuroNCAP, was developed and sponsored by the European Commission as well as to motoring and consumer organisations in EU countries to provide motoring vehicles consumers with an independent assessment of the safety performance of some of the most popular cars sold in Europe through stringent protocols for vehicle crash testing. This has encouraged the new car designers to enhance significant safety improvements to the newer car design. Figure (II.1) shows The increase in the average score for new cars registered in each successive year from 1994 onwards in some of European countries (Hobbs and McDonough 1998; Haag and Nagel 1999; van Ratingen 2008; Schram et al. 2015; ETSC 2016; Gaylor et al. 2016; EuroNCAP 2017; van Ratingen 2017).

Nine classes of vehicle are included in the EuroNCAP testing and rating from super-minis to large off-road 4x4 vehicles. The rating is comprised of scores in Adult protection, child protection, pedestrian protection and safety assist technologies (EuroNCAP 2017).

The overall score is calculated by weighing the four scores in respect of each other, while ensuring that no one area is underachieving. The validity of the EuroNCAP assessment is proved through consistence correlation between EuroNCAP scoring and risk of serious and fatal. It is also confirmed that a 50% reduction in the risk of serious injury in car crashes has been achieved in new car models within three years of using the EuroNCAP assessment methodology (Lie and Tingvall 2002; Kullgren et al. 2010; Strandroth et al. 2011).

Other local NCAP versions are developed by some countries based on the Euro NCAP protocols such as the Australian New Car Assessment programme (AusNCAP)

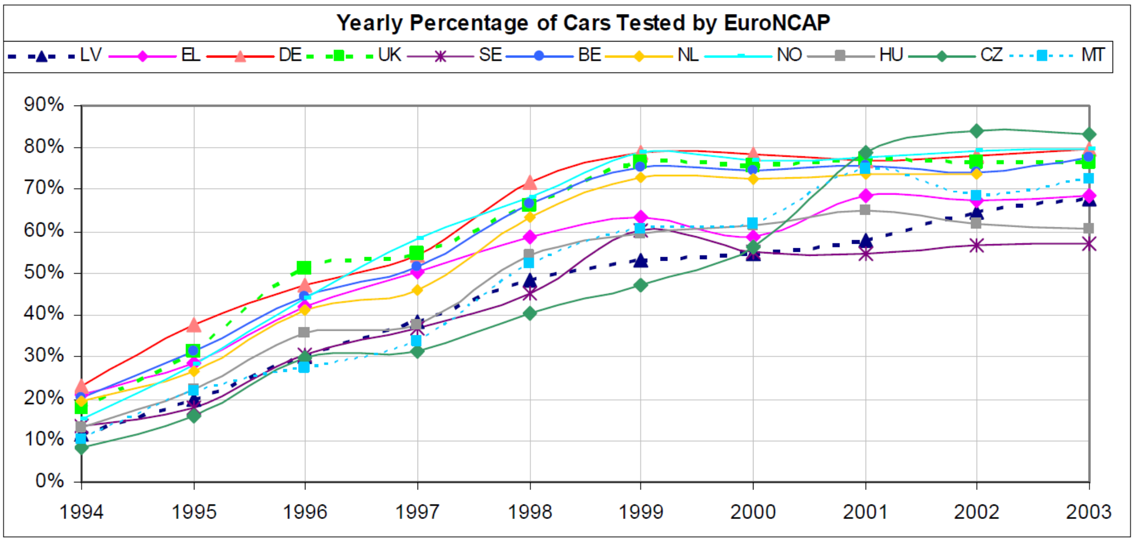

Figure II.1 Percentage of cars tested by the Euro NCAP in some European countries. (Vis 2005; DaCoTa 2012

II.2 The EuroNCAP indicators

Four groups of indicators are considered in the assessment methodology of EuroNCAP as shown in Table (II.1) and as follows:

Table II.1 The indicators of the EuroNCAP assessment methodology (EuroNCAP 2017)

The group of indicators	The indicators
Adult Occupant Protection (for the driver and passenger)	• Offset-Deformable Barrier - ODB • Full Width Rigid Barrier • Side Mobile Barrier • Side Pole • Whiplash • AEB City
Child Occupant Protection;	• CRS Performance • Vehicle Provisions • CRS Installation Check
Pedestrian Protection which has been expanded to include cyclists and is now known as Vulnerable Road User (VRU) protection	• Head impact • Upper Leg Impact • Lower Leg Impact • AEB Pedestrian • AEB Cyclist
Safety Assist, which evaluated driver-assistance and crash-avoidance technologies.	• Electronic Stability Control • Seatbelt Reminders • Speed Assistance Systems • AEB Interurban • Lane Support

1. Adult protection (driver and passenger): The adult drivers and passengers protection is assessed through frontal, side and pole impact tests for different sizes of people and different seats positions. Euro NCAP groups cars into the following structural categories: passenger car, MPV, off-roader, roadster and pickup (Johannsen et al. 2007; DaCoTA 2012).

2. Child protection: The child protection is assessed also by the Euro NCAP assessment. Two sizes are used to test the frontal and side impact of children which are 18 months old and 3 years old. The clarity of instructions and seat installation and airbags warning labels in the vehicle are considered also factors of safety in this group (DaCoTA 2012; Syazwan et al. 2014)
3. Pedestrian protection: The Pedestrians' protection is also integrated in the overall rating of the Euro NCAP assessment methodology. Rating pedestrian protection is based on adult and child head form tests and two leg form tests (Strandroth et al. 2011; DaCoTA 2012).

4. Safety assist technologies: The driver assistance systems and active safety technologies are considered in the Euro NCAP assessment methodology because of the important role of crash avoidance and injury mitigation in the vehicle safety. Euro NCAP currently rewards manufacturers for the fitment of electronic stability control, speed limitation device and intelligent seat belt reminders (NHTSA 2007; van Ratingen 2008; DaCoTA 2012; EuroNCAP 2017).

APPENDIX III

THE GATHERED DATA AND THE RESULTS OF THE RAP STAR RATINGS AGGREGATION METHODOLOGY

Table III.1 The collected RAP's SRSs and SR data for the four road user groups per 100m length of road sections for some of the RAP assessed roads in the UK

Section number	Road name	Vehicle star rating score (SRSv)	Vehicle Star Rating (SRv)	Motorcyclist star rating score (SRSmt)	Motorcyclist Star Rating (SRmt)	Pedestrian star rating score (SRSp)	Pedestrian Star Rating (SRp)	Bicyclist star rating score (SRSb)	Bicyclist Star Rating (SRb)
1	A21	4.431235	4	5.983594	3	10.9999	4	31.87979	2
2	A21	8.61629	3	10.41483	3	12.39295	4	68.69608	1
3	A21	9.553674	3	12.40242	3	25.62444	3	27.69019	3
4	A21	8.789488	3	11.07454	3	25.73149	3	37.92779	2
5	A21	6.423362	3	7.483362	3	22.79819	3	23.15419	3
6	A21	11.37038	3	13.91746	2	49.40135	2	37.92779	2
7	A21	3.931434	4	4.991434	4	27.03139	3	14.76259	3
8	A21	12.4344	3	16.74452	2	17.0202	3	36.54878	2
9	A21	3.831489	4	4.891489	4	32.4109	3	17.71013	3
10	A21	9.970002	3	11.78128	3	47.59809	2	21.749	3
11	A21	7.537554	3	9.499084	3	39.05253	3	20.20579	3
12	A21	6.890543	3	8.852073	3	43.26873	2	22.11367	3
13	A21	10.50255	3	13.3513	2	54.62002	2	31.77661	2
14	A21	7.012123	3	8.826514	3	32.51796	3	31.87979	2

Section number	Road name	Vehicle star rating score (SRSv)	Vehicle Star Rating (SRv)	Motorcyclist star rating score (SRSmt)	Motorcyclist Star Rating (SRmt)	Pedestrian star rating score (SRSp)	Pedestrian Star Rating (SRp)	Bicyclist star rating score (SRSb)	Bicyclist Star Rating (SRb)
15	A21	17.1123	2	20.26976	2	53.87049	2	47.99234	2
16	A21	9.893934	3	12.44456	3	49.2943	2	26.02699	3
17	A21	3.669752	4	4.729752	4	12.33809	4	14.76259	3
18	A21	13.45487	2	15.75706	2	53.76343	2	31.15099	2
19	A21	3.931434	4	4.991434	4	6.155663	4	17.71099	3
20	A21	14.0535	2	17.64402	2	41.20794	2	36.55187	2
21	A21	15.35956	2	17.91018	2	35.67196	3	30.89059	2
22	A21	13.45487	2	15.75706	2	53.76343	2	31.15099	2
23	A21	3.931434	4	4.991434	4	27.03139	3	14.76259	3
24	A21	8.185352	3	9.987087	3	35.18342	3	20.81059	3
25	A21	6.942226	3	8.740416	3	32.53885	3	31.8808	2
26	A21	6.942226	3	8.740416	3	32.53885	3	31.8808	2
27	A21	8.115784	3	9.172207	3	22.25715	3	23.59099	3
28	A21	15.40328	2	17.95033	2	53.76343	2	33.83899	2
29	A21	11.42999	3	14.27517	2	49.2943	2	27.69706	3
30	A21	11.13016	3	13.97533	2	32.71045	3	24.74179	3
31	A21	14.09723	2	17.68417	2	49.40135	2	41.85899	2
32	A21	11.66348	3	12.7199	2	37.22986	3	28.79899	3
33	A21	4.101405	4	5.157828	3	32.4318	3	19.67761	3
34	A21	4.101405	4	5.157828	3	35.93075	3	21.80701	3
35	A21	11.57202	3	14.41719	2	54.62002	2	31.79206	2
36	A21	6.280301	3	12.92657	2	55.998	2	31.52746	2
37	A21	4.155338	4	5.21176	3	21.66929	3	16.40847	3
38	A21	6.018619	3	12.66489	2	40.22077	2	31.52746	2

Section number	Road name	Vehicle star rating score (SRSv)	Vehicle Star Rating (SRv)	Motorcyclist star rating score (SRSmt)	Motorcyclist Star Rating (SRmt)	Pedestrian star rating score (SRSp)	Pedestrian Star Rating (SRp)	Bicyclist star rating score (SRSb)	Bicyclist Star Rating (SRb)
39	A21	3.839723	4	4.896145	4	21.66929	3	16.40161	3
40	A21	11.62595	3	14.47113	2	35.18342	3	26.39352	3
41	A21	9.968775	3	12.81395	2	35.18342	3	24.57226	3
42	A21	3.839723	4	4.896145	4	21.66929	3	16.40161	3
43	A21	3.629313	4	4.685735	4	21.66929	3	16.40275	3
44	A21	9.968775	3	12.81395	2	29.53092	3	24.57226	3
45	A21	3.839723	4	4.896145	4	25.97638	3	19.67761	3
46	A21	7.445843	3	9.403795	3	26.64861	3	18.89539	3
47	A21	6.742347	3	8.668102	3	20.99611	3	16.80379	3
48	A21	7.38272	3	9.340672	3	31.95157	3	20.20579	3
49	A21	8.210326	3	10.61842	3	32.05863	3	34.35296	2
50	A21	5.17468	3	6.744632	3	26.08344	3	31.86845	2
51	A21	7.698273	3	9.360804	3	21.10317	3	30.64889	2
52	A21	7.697593	3	8.757593	3	29.05905	3	19.17602	3
53	A21	4.13718	4	5.161405	3	32.4318	3	19.67761	3
54	A21	8.057405	3	9.94333	3	32.53885	3	31.90551	2
55	A21	7.916888	3	9.842643	3	58.18861	2	20.21266	3
56	A21	5.53948	3	7.066155	3	50.92812	1	31.2635	2
57	A21	5.42098	3	7.00098	3	63.61875	1	39.07735	2
58	A21	9.843531	3	12.71133	2	70.3813	1	42.45371	2
59	A21	10.66305	3	13.74305	2	177.7885	1	73.47249	1
60	A21	11.42341	3	14.50341	2	88.18875	1	61.23137	1
61	A21	11.42341	3	14.50341	2	88.18875	1	61.23137	1
62	A21	11.42341	3	14.50341	2	88.18875	1	61.23137	1

Section number	Road name	Vehicle star rating score (SRSv)	Vehicle Star Rating (SRv)	Motorcyclist star rating score (SRSmt)	Motorcyclist Star Rating (SRmt)	Pedestrian star rating score (SRSp)	Pedestrian Star Rating (SRp)	Bicyclist star rating score (SRSb)	Bicyclist Star Rating (SRb)
63	A21	11.55046	3	14.62007	2	88.25251	1	61.23559	1
64	A21	10.38884	3	13.45845	2	88.25251	1	61.23845	1
65	A21	11.65441	3	14.63046	2	88.25251	1	61.23559	1
66	A21	11.65441	3	14.63046	2	88.25251	1	61.23559	1
67	A21	11.42341	3	14.50341	2	88.18875	1	61.23137	1
68	A21	11.55046	3	14.62007	2	88.25251	1	61.23559	1
69	A21	23.4733	1	29.56577	1	98.60463	1	71.58924	1
70	A21	11.55046	3	14.62007	2			61.23559	1
71	A21	11.42341	3	14.50341	2			61.23137	1
72	A21	6.232414	3	9.312414	3	88.18875	1	61.2079	1
73	A21	6.232414	3	9.312414	3	88.18875	1	61.2079	1
74	A21	30.66975	1	36.26015	1	99.55153	1	77.97137	1
75	A21	11.42341	3	14.50341	2	88.18875	1	61.23137	1
76	A21	10.26179	3	13.34179	2	88.18875	1	61.22708	1
77	A21	9.331168	3	12.30722	3	186.7299	1	61.22701	1
78	A21	11.65441	3	14.63046	2	186.7299	1	61.23559	1
79	A21	30.60646	1	36.18646	1	205.9072	1	77.97137	1
80	A21	11.38322	3	14.43434	2	88.25251	1	61.23559	1
81	A21	11.38322	3	14.43434	2	176.8822	1	61.23559	1
82	A21	10.2216	3	13.27272	2	176.8822	1	61.2313	1
83	A21	10.1985	3	13.2681	2	58.85626	1	61.2313	1
84	A21	11.36012	3	14.42972	2	88.25251	1	61.23559	1
85	A21	20.58063	2	26.66271	1	98.60463	1	69.70599	1
86	A21	10.1985	3	13.2681	2	88.25251	1	61.2313	1

Section number	Road name	Vehicle star rating score (SRSv)	Vehicle Star Rating (SRv)	Motorcyclist star rating score (SRSmt)	Motorcyclist Star Rating (SRmt)	Pedestrian star rating score (SRSp)	Pedestrian Star Rating (SRp)	Bicyclist star rating score (SRSb)	Bicyclist Star Rating (SRb)
87	A21	19.47551	2	24.81551	1	105.7936	1	105.8193	1
88	A21	19.47551	2	24.81551	1	105.7936	1	105.8193	1
89	A21	19.69579	2	25.01777	1	105.8701	1	105.8266	1
90	A21	19.87601	2	25.03579	1	105.8701	1	105.8266	1
91	A21	17.46153	2	22.80153	1	105.7936	1	105.8222	1
92	A21	38.35322	1	48.91614	1	118.2888	1	123.7257	1
93	A21	30.53364	1	39.14167	1	190.4285	1	190.4799	1
94	A21	17.86203	2	23.02181	1	105.8701	1	105.8295	1
95	A21	19.47551	2	24.81551	1	105.7936	1	105.8193	1
96	A21	15.08865	2	20.42865	2	200.3025	1	105.8086	1
97	A21	35.86223	1	46.24493	1	222.2486	1	120.4677	1
98	A21	46.55353	1	60.52931	1	259.7341	1	154.6471	1
99	A21	18.70752	2	24.02949	1	105.8701	1	105.8266	1
100	A21	19.47551	2	24.81551	1	105.7936	1	105.8193	1

Table III.2 The results of computing the weights of the variables of the preliminary ASRSs and ASRs models and the ASRs produced from these models.

Section number	Wv	Wm	Wp	Wb	ASRS 1	ASRS 2	ASRS 3	ASRS 4	ASR 1	ASR2	ASR 3	ASR 4	ASR 5	ASR 6	ASR 7	ASR 8
1	0.08	0.11	0.21	0.60	22.38	18.00	31.88	4.43	4	5	3	4	3	3	4	2
2	0.09	0.10	0.12	0.69	50.49	38.20	68.70	8.62	3	5	2	3	2	1	4	1
3	0.13	0.16	0.34	0.37	22.17	20.64	27.69	9.55	4	5	3	3	3	3	3	3
4	0.11	0.13	0.31	0.45	27.54	24.51	37.93	8.79	4	5	3	3	3	2	3	2
5	0.11	0.13	0.38	0.39	19.26	17.42	23.15	6.42	4	5	3	3	3	3	3	3
6	0.10	0.12	0.44	0.34	37.31	33.32	49.40	11.37	3	5	2	3	2	2	3	2
7	0.08	0.10	0.53	0.29	19.50	16.53	27.03	3.93	4	5	3	4	3	3	4	3
8	0.15	0.20	0.21	0.44	24.90	22.68	36.55	12.43	4	5	3	3	2	2	3	2
9	0.07	0.08	0.55	0.30	23.84	20.09	32.41	3.83	4	5	3	4	3	3	4	3
10	0.11	0.13	0.52	0.24	32.68	27.78	47.60	9.97	4	5	2	3	2	2	3	2
11	0.10	0.12	0.51	0.26	27.27	23.38	39.05	7.54	4	5	3	3	3	3	3	3
12	0.08	0.11	0.53	0.27	30.66	25.93	43.27	6.89	4	5	2	3	2	2	3	2
13	0.10	0.12	0.50	0.29	38.84	33.67	54.62	10.50	3	5	2	3	2	2	3	2
14	0.09	0.11	0.41	0.40	27.43	24.44	32.52	7.01	4	5	3	3	3	3	3	2
15	0.12	0.15	0.39	0.34	42.44	39.00	53.87	17.11	3	5	2	2	2	2	2	2
16	0.10	0.13	0.50	0.27	34.41	29.65	49.29	9.89	4	5	2	3	2	2	3	2
17	0.10	0.13	0.35	0.42	11.44	10.32	14.76	3.67	5	5	4	4	4	4	4	3
18	0.12	0.14	0.47	0.27	37.59	33.21	53.76	13.45	3	5	2	2	2	2	2	2
19	0.12	0.15	0.19	0.54	11.95	10.00	17.71	3.93	5	5	3	4	3	3	4	3
20	0.13	0.16	0.38	0.33	32.37	30.08	41.21	14.05	4	5	2	2	2	2	2	2
21	0.15	0.18	0.36	0.31	27.88	26.49	35.67	15.36	4	5	3	2	2	2	3	2
22	0.12	0.14	0.47	0.27	37.59	33.21	53.76	13.45	3	5	2	2	2	2	2	2
23	0.08	0.10	0.53	0.29	19.50	16.53	27.03	3.93	4	5	3	4	3	3	4	3
24	0.11	0.13	0.47	0.28	24.78	21.82	35.18	8.19	4	5	3	3	3	3	3	3

Section number	Wv	Wm	Wp	Wb	ASRS 1	ASRS 2	ASRS 3	ASRS 4	ASR 1	ASR2	ASR 3	ASR 4	ASR 5	ASR 6	ASR 7	ASR 8
25	0.09	0.11	0.41	0.40	27.46	24.46	32.54	6.94	4	5	3	3	3	3	3	2
26	0.09	0.11	0.41	0.40	27.46	24.46	32.54	6.94	4	5	3	3	3	3	3	2
27	0.13	0.15	0.35	0.37	19.04	17.57	23.59	8.12	4	5	3	3	3	3	3	3
28	0.13	0.15	0.44	0.28	37.99	34.23	53.76	15.40	3	5	2	2	2	2	2	2
29	0.11	0.14	0.48	0.27	34.39	30.19	49.29	11.43	4	5	2	3	2	2	3	2
30	0.13	0.17	0.40	0.30	24.24	22.53	32.71	11.13	4	5	3	3	3	3	3	2
31	0.11	0.14	0.40	0.34	38.23	34.89	49.40	14.10	3	5	2	2	2	2	2	2
32	0.13	0.14	0.41	0.32	27.80	25.39	37.23	11.66	4	5	3	3	3	3	3	2
33	0.07	0.08	0.53	0.32	24.16	20.62	32.43	4.10	4	5	3	4	3	3	4	3
34	0.06	0.08	0.54	0.33	27.02	23.03	35.93	4.10	4	5	3	4	3	3	4	3
35	0.10	0.13	0.49	0.28	38.57	33.67	54.62	11.57	3	5	2	3	2	2	3	2
36	0.06	0.12	0.52	0.30	40.63	34.79	56.00	6.28	3	5	2	3	2	2	3	2
37	0.09	0.11	0.46	0.35	16.51	14.56	21.67	4.16	4	5	3	4	3	3	4	3
38	0.07	0.14	0.44	0.35	31.05	27.69	40.22	6.02	4	5	2	3	2	2	3	2
39	0.08	0.10	0.46	0.35	16.61	14.60	21.67	3.84	4	5	3	4	3	3	4	3
40	0.13	0.17	0.40	0.30	25.99	24.06	35.18	11.63	4	5	3	3	3	3	3	2
41	0.12	0.16	0.43	0.30	25.51	23.21	35.18	9.97	4	5	3	3	3	3	3	2
42	0.08	0.10	0.46	0.35	16.61	14.60	21.67	3.84	4	5	3	4	3	3	4	3
43	0.08	0.10	0.47	0.35	16.68	14.63	21.67	3.63	4	5	3	4	3	3	4	3
44	0.13	0.17	0.38	0.32	22.62	21.05	29.53	9.97	4	5	3	3	3	3	3	2
45	0.07	0.09	0.48	0.36	20.24	17.66	25.98	3.84	4	5	3	4	3	3	4	3
46	0.12	0.15	0.43	0.30	19.41	17.63	26.65	7.45	4	5	3	3	3	3	3	3
47	0.13	0.16	0.39	0.32	15.86	14.67	21.00	6.74	4	5	3	3	3	3	3	3
48	0.11	0.14	0.46	0.29	22.81	20.21	31.95	7.38	4	5	3	3	3	3	3	3
49	0.10	0.12	0.38	0.40	28.02	25.19	34.35	8.21	4	5	3	3	3	3	3	2

Section number	Wv	Wm	Wp	Wb	ASRS 1	ASRS 2	ASRS 3	ASRS 4	ASR 1	ASR2	ASR 3	ASR 4	ASR 5	ASR 6	ASR 7	ASR 8
50	0.07	0.10	0.37	0.46	25.31	22.25	31.87	5.17	4	5	3	3	3	2	3	2
51	0.11	0.14	0.31	0.45	22.26	19.93	30.65	7.70	4	5	3	3	3	3	3	2
52	0.12	0.14	0.45	0.30	20.84	18.65	29.06	7.70	4	5	3	3	3	3	3	3
53	0.07	0.08	0.53	0.32	24.15	20.61	32.43	4.14	4	5	3	4	3	3	4	3
54	0.10	0.12	0.39	0.39	27.18	24.42	32.54	8.06	4	5	3	3	3	3	3	2
55	0.08	0.10	0.61	0.21	41.12	32.96	58.19	7.92	3	5	2	3	2	2	3	2
56	0.06	0.07	0.54	0.33	38.52	32.87	50.93	5.54	3	5	2	3	2	1	3	1
57	0.05	0.06	0.55	0.34	49.10	41.98	63.62	5.42	3	5	2	3	2	1	3	1
58	0.07	0.09	0.52	0.31	51.81	44.33	70.38	9.84	3	5	2	3	2	1	3	1
59	0.04	0.05	0.64	0.27	135.34	110.90	177.79	10.66	2	5	1	3	1	1	3	1
60	0.07	0.08	0.50	0.35	67.68	58.54	88.19	11.42	3	5	2	3	1	1	3	1
61	0.07	0.08	0.50	0.35	67.68	58.54	88.19	11.42	3	5	2	3	1	1	3	1
62	0.07	0.08	0.50	0.35	67.68	58.54	88.19	11.42	3	5	2	3	1	1	3	1
63	0.07	0.08	0.50	0.35	67.66	58.52	88.25	11.55	3	5	2	3	1	1	3	1
64	0.06	0.08	0.51	0.35	68.23	58.96	88.25	10.39	3	5	2	3	1	1	3	1
65	0.07	0.08	0.50	0.35	67.63	58.50	88.25	11.65	3	5	2	3	1	1	3	1
66	0.07	0.08	0.50	0.35	67.63	58.50	88.25	11.65	3	5	2	3	1	1	3	1
67	0.07	0.08	0.50	0.35	67.68	58.54	88.19	11.42	3	5	2	3	1	1	3	1
68	0.07	0.08	0.50	0.35	67.66	58.52	88.25	11.55	3	5	2	3	1	1	3	1
69	0.11	0.13	0.44	0.32	72.90	65.23	98.60	23.47	3	5	1	1	1	1	1	1
70	0.13	0.17	0.00	0.70	46.87	38.66	61.24	11.55	3	5	2	3	1	1	3	1
71	0.13	0.17	0.00	0.70	46.93	38.67	61.23	11.42	3	5	2	3	1	1	3	1
73	0.04	0.06	0.53	0.37	70.63	61.37	88.19	6.23	3	5	2	3	1	1	3	1
74	0.13	0.16	0.38	0.33	69.12	64.14	88.19	30.67	3	5	2	1	1	1	1	1
75	0.06	0.08	0.53	0.33	74.99	64.02	99.55	11.42	3	5	1	3	1	1	3	1

Section number	Wv	Wm	Wp	Wb	ASRS 1	ASRS 2	ASRS 3	ASRS 4	ASR 1	ASR2	ASR 3	ASR 4	ASR 5	ASR 6	ASR 7	ASR 8
76	0.06	0.08	0.51	0.35	68.25	58.98	88.19	10.26	3	5	2	3	1	1	3	1
77	0.05	0.07	0.52	0.36	68.78	59.42	88.19	9.33	3	5	2	3	1	1	3	1
78	0.04	0.05	0.68	0.22	142.09	112.95	186.73	11.65	2	5	1	3	1	1	3	1
79	0.09	0.11	0.56	0.24	130.30	107.57	186.73	30.61	2	5	1	1	1	1	1	1
80	0.04	0.05	0.70	0.21	158.68	125.27	205.91	11.38	2	5	1	3	1	1	3	1
81	0.06	0.08	0.50	0.35	67.75	58.58	88.25	11.38	3	5	2	3	1	1	3	1
82	0.04	0.05	0.68	0.23	135.00	108.25	176.88	10.22	2	5	1	3	1	1	3	1
83	0.04	0.05	0.68	0.23	135.01	108.26	176.88	10.20	2	5	1	3	1	1	3	1
84	0.08	0.10	0.40	0.42	51.76	45.81	61.24	11.36	3	5	2	3	1	1	3	1
85	0.10	0.13	0.43	0.34	67.16	60.25	88.25	20.58	3	5	2	2	1	1	2	1
86	0.06	0.07	0.54	0.33	75.02	64.11	98.60	10.20	3	5	1	3	1	1	3	1
87	0.08	0.10	0.37	0.44	83.83	74.09	105.82	19.48	3	5	1	2	1	1	2	1
88	0.08	0.10	0.41	0.41	91.38	80.82	105.82	19.48	3	5	1	2	1	1	2	1
89	0.08	0.10	0.41	0.41	91.31	80.78	105.83	19.70	3	5	1	2	1	1	2	1
90	0.08	0.10	0.41	0.41	91.30	80.79	105.87	19.88	3	5	1	2	1	1	2	1
91	0.07	0.09	0.42	0.42	92.21	81.30	105.87	17.46	3	5	1	2	1	1	2	1
92	0.12	0.15	0.33	0.39	95.85	88.30	123.73	38.35	2	5	1	1	1	1	1	1
93	0.08	0.10	0.31	0.50	139.36	120.21	190.48	30.53	2	5	1	1	1	1	1	1
94	0.05	0.07	0.56	0.31	143.30	120.93	190.43	17.86	2	5	1	2	1	1	2	1
95	0.08	0.10	0.41	0.41	91.42	80.85	105.87	19.48	3	5	1	2	1	1	2	1
96	0.06	0.08	0.43	0.43	93.20	82.00	105.81	15.09	3	5	1	2	1	1	2	1
97	0.09	0.11	0.50	0.30	144.11	124.76	200.30	35.86	2	5	1	1	1	1	1	1
98	0.10	0.13	0.46	0.32	163.52	144.73	222.25	46.55	2	5	1	1	1	1	1	1
99	0.05	0.06	0.64	0.26	194.93	158.59	259.73	18.71	2	4	1	2	1	1	2	1
100	0.08	0.10	0.41	0.41	91.42	80.85	105.87	19.48	3	5	1	2	1	1	2	1

APPENDIX IV

ESTIMATING THE NUMBER OF CRASHES CAUSED BY ROAD DESIGN FEATURES

IV.1 Introduction

To estimate the average cost of crashes caused by road feature designs, the related number of crashes needs to be estimated based on the available data. The available data is contained in the crashes index, with details of the location, severity, and the date of the accident. Table IV.1 shows the gathered details of crashes which occurred in the year 2014 taken from the accidents' data sheet (DFT 2017). The same data was gathered for the years 2010-2013.

To find the crashes that are caused by road design features, the crashes which have resulted from other causes are subtracted from the total crashes. As the RAP concept is based on the safe system approach principles which seek a balance between road design features, vehicle design and the road users' behaviour, the identification of the crashes caused by road design features is based on this concept. This means that the RAP aims to define what road design standards are needed when the highest NCAP star vehicles are in use, and when drivers comply with traffic laws (Lynam et al. 2007; Lynam 2012). Based on this, the number of crashes caused by road design features is equal to the crashes that involved 5 NCAP vehicles, excluding the crashes caused by road-user behaviour factors, as shown in equation IV.1:

$$No.CRoadDesign = FSI\ involved\ with\ \%NCAP\ stars - No.CRoadUser \quad \ldots\ldots\ldots (IV.1)$$

Where:

No.CRoadDesign = the estimated number of road crashes resulting from road design features.

$FSI\ involved\ with\ \%NCAP\ stars$ = the estimated number of fatal and serious injury road crashes involving cars awarded 5 NCAP stars.

No.CRoadUser = the estimated number of road crashes resulting from road-user behaviour factors.

Table IV.1 The location details for sample of accidents occurred in 2014 in the UK gathered from accidents data sheet (DFT 2017)

Accident Index	**Location_ Easting_OSGR**	**Location_ Northing_OSGR**	**Accident Severity**	**Date**	**Road_ Number**
201401CW10011	527140	181610	2	1/22/2014	5
201401CW10104	527080	181680	2	2/6/2014	5
201401CW10391	527040	181710	2	1/20/2014	5
201401CW10875	526790	181990	2	6/25/2014	5
201401CW11322	526250	182600	2	9/4/2014	5
201401CW11586	526800	181970	2	10/16/2014	5
201401CW11592	527350	181380	2	10/19/2014	5
201401CW11803	527480	181260	2	11/15/2014	5
201401CW11836	527060	181680	2	11/30/2014	5
201401EK40118	524710	184550	2	3/4/2014	5
201401EK40781	524310	185100	2	9/16/2014	5
201401EK41080	525480	183540	2	12/28/2014	5
201401PL60108	537880	174070	2	2/24/2014	21
201401PL60145	537690	173030	2	3/8/2014	21
201401PL60218	538350	175510	2	1/8/2014	21
201401PL60266	537760	173840	2	4/7/2014	21
201401PL60337	537800	173910	2	5/6/2014	21
201401PL60624	538550	171610	2	7/28/2014	21
201401PL60670	537890	174310	2	8/15/2014	21
201401PL60804	538040	174920	2	9/19/2014	21
201401PL60806	538130	175070	2	9/25/2014	21
201401PL60830	537950	174770	2	10/12/2014	21
201401PY20192	540670	168500	2	3/26/2014	21
201401PY20783	539190	170830	2	11/26/2014	21
201401PY20789	540180	169690	2	11/11/2014	21
201401QA10147	520040	190570	2	2/11/2014	5
201401QA10199	519300	191540	2	4/9/2014	5
201401QA10271	518270	192810	2	6/8/2014	5

201401QK50002	521430	185770	2	1/5/2014	453
201401QK50050	520190	190370	2	1/31/2014	5
201401QK50120	523700	185850	2	3/3/2014	5
201401QK50169	525530	183460	2	3/2/2014	5
201401QK50300	525520	183470	2	2/27/2014	5
201401QK50509	523800	185710	2	7/13/2014	5
201401QK50550	521240	189030	2	7/2/2014	5
201401QK50635	523140	186640	2	9/1/2014	5
201401QK50718	524310	185100	2	10/8/2014	5
201401QK50871	525060	184080	2	11/3/2014	5
201401SX20140	520160	190420	2	2/15/2014	5
201401SX20169	520370	190130	2	3/4/2014	5
201401SX20178	523810	185720	2	3/7/2014	5
201401SX20237	523630	185940	2	1/7/2014	5
201401SX20311	521250	189020	2	4/12/2014	5
201401SX20914	521870	188250	2	10/10/2014	5
201401SX20947	521220	189090	2	10/31/2014	5
201401SX20977	522130	187890	2	11/3/2014	5
201401SX21032	522080	187960	2	11/12/2014	5
201401TD00031	538700	171550	1	1/4/2014	21
2014131141205	413720	415084	2	1/4/2014	616
20141314J0428	414196	415883	2	4/19/2014	616
201420H004714	404260	306500	1	3/30/2014	5
201420H007204	403480	306490	2	7/27/2014	5
201420N005884	410400	294650	2	1/25/2014	453
201420N036084	414460	298920	2	7/15/2014	453
201420N041344	408930	293670	2	8/29/2014	453
201420W026194	407080	291270	2	5/12/2014	453
201420W029384	407090	292040	1	6/5/2014	453
201420Z001324	398530	286930	2	3/31/2014	5
201420Z003694	398480	287180	1	11/1/2014	5
2014214000915	418391	302553	2	2/8/2014	453
2014214003611	398102	308500	2	7/10/2014	5
2014214003748	380987	310866	2	7/15/2014	5
2014214004111	396774	309107	2	8/4/2014	5
2014214004757	398496	308370	2	9/9/2014	5
2014214004947	399312	308005	1	9/20/2014	5
2014214005077	422606	302276	2	9/29/2014	5
2014214006211	401875	306984	2	11/25/2014	5
20142140X0036	406388	306503	2	12/22/2014	5
201422D400305	387070	245100	2	1/22/2014	5
201422D400992	388970	241480	2	3/17/2014	5
201422F400130	348710	309680	2	1/13/2014	5
201422F400239	345550	311170	2	1/15/2014	5
201422F401057	330080	332220	2	3/24/2014	5

201422F401410	333800	326870	2	4/18/2014	5
201422F402023	352100	310680	1	6/6/2014	5
201422F403376	352120	310750	2	9/9/2014	5
201422F404761	329990	335070	1	12/17/2014	5
201422F404778	342950	315170	2	12/17/2014	5
201422F500135	352140	310900	2	12/29/2014	5
201422G402091	356910	311540	2	6/6/2014	5
201422G402144	390740	262400	2	6/10/2014	5
201422G402463	390880	263120	2	7/4/2014	5
201422G402495	389970	258190	2	7/6/2014	5
201422G402574	390870	263120	2	6/22/2014	5
201422G402966	372090	310870	2	8/8/2014	5
201423N025747	432309	297204	2	5/25/2014	5
201423N026358	433187	296689	2	9/27/2014	5
201423N026526	431455	297889	1	10/28/2014	5
201423N026680	428497	298934	2	11/20/2014	5
201423N035524	454998	276726	2	4/14/2014	5
201423N036750	453245	279953	2	12/1/2014	5
2014300010594	449530	375970	2	11/21/2014	616
201431B158114	457676	371143	2	7/16/2014	616
201431B235914	468364	365649	2	10/21/2014	616
201431B299614	475966	358479	2	10/7/2014	616
201431C037414	456527	338246	2	3/1/2014	453
201431C271714	455060	335100	2	11/27/2014	453
201431D003614	453633	333386	2	1/15/2014	453
201431D219314	452515	332041	1	10/6/2014	453
2014331400370	447320	288585	1	3/10/2014	5
2014331400412	448000	287750	1	3/16/2014	5
2014331400436	447345	288565	2	2/27/2014	5
2014331400841	443955	290710	2	5/5/2014	5
2014331401553	445105	289995	2	8/22/2014	5
2014331401757	446910	325340	2	5/27/2014	453
2014331405054	440058	293015	2	4/30/2014	5
2014331405082	443817	325382	2	6/29/2014	453
201434WD04684	455663	275508	2	2/27/2014	5
201434WD08904	456607	273637	2	4/13/2014	5
201434WD15604	465365	256657	2	6/27/2014	5
201434WD16814	457190	273038	2	6/30/2014	5
201434WD22724	458074	270279	2	9/13/2014	5
201434WS06104	465678	256019	2	3/15/2014	5
201434WS06234	470399	247617	2	3/16/2014	5
201434WS12754	473820	244750	2	5/25/2014	5
201434WS18044	464961	257289	2	7/25/2014	5
201434WS26094	450803	237123	2	10/17/2014	21
201434WS34134	478355	241428	2	12/2/2014	5

2014350109914	531510	271180	1	7/14/2014	303
2014404BA0484	513434	251619	2	6/1/2014	5
2014404BA0876	515180	251167	2	9/15/2014	5
2014404DA0153	501134	222699	2	2/17/2014	5
2014404DA0366	502197	221545	2	4/15/2014	5
2014404DA0465	496311	227716	2	5/19/2014	5
2014404DA0672	501295	222524	2	7/21/2014	5
2014404DA0684	502397	221351	2	7/24/2014	5
2014404DA0825	502203	221545	2	9/10/2014	5
2014404DA0911	503834	220002	2	9/29/2014	5
2014404DA0933	504652	218908	2	10/6/2014	5
2014404DA0944	505016	217909	2	10/8/2014	5
2014404DA1012	501541	222243	2	10/27/2014	5
20144100D0397	506820	215940	2	7/2/2014	5
20144100D0648	509330	214640	2	11/6/2014	5
20144100D0705	508440	215050	1	12/12/2014	5
20144100F0621	509290	214620	2	9/24/2014	5
201443N088104	482988	212913	2	10/10/2014	21
201443S023064	489292	233571	2	6/7/2014	5
201443S063074	492392	231143	1	7/18/2014	5
201443S076014	489608	233225	2	1/18/2014	5
201443S126114	491519	231925	2	11/21/2014	5
201443S182114	484859	237065	2	11/21/2014	5
2014440024592	438771	144739	2	1/21/2014	303
2014440058125	436380	144057	2	2/18/2014	303
2014440115629	435575	144276	2	4/3/2014	303
2014440176318	438162	144710	2	5/20/2014	303
2014440222866	433529	146033	2	6/24/2014	303
2014440255351	443823	142722	2	7/17/2014	303
2014440310246	433629	145951	2	8/27/2014	303
2014440335924	449556	142556	2	9/16/2014	303
2014440377564	436746	144183	2	10/19/2014	303
2014440377585	437775	144575	2	10/19/2014	303
2014440403625	454971	144598	2	11/9/2014	303
2014440424719	438779	144725	2	11/27/2014	303
2014440452935	432583	146219	2	12/20/2014	303
2014460236867	551250	154320	2	1/11/2014	21
2014460237507	556780	145280	2	1/28/2014	21
2014460238831	551400	154140	2	1/21/2014	21
2014460239164	555240	149510	2	3/9/2014	21
2014460241233	564710	139860	2	5/3/2014	21
2014460241433	561230	142170	2	5/5/2014	21
2014460242617	566640	138030	2	6/8/2014	21
2014460243292	569200	134330	2	6/18/2014	21
2014460244934	563460	140310	2	7/23/2014	21

2014460245486	566310	138130	2	8/11/2014	21
2014460245868	552090	152370	2	8/9/2014	21
2014460246272	564430	140020	2	8/31/2014	21
2014460248499	559670	144820	2	10/17/2014	21
2014460248673	564800	139750	2	10/27/2014	21
2014460249351	552140	152280	2	11/7/2014	21
2014460250121	568900	134580	2	9/23/2014	21
2014460250299	566460	138050	2	11/30/2014	21
2014460251018	552070	152390	2	12/14/2014	21
2014471400109	572987	128522	2	1/8/2014	21
2014471400130	579625	112889	2	1/9/2014	21
2014471400935	580769	109589	2	2/18/2014	21
2014471401938	581680	109400	2	4/11/2014	21
2014471402528	579934	111773	2	5/8/2014	21
2014471402838	579333	114881	1	5/23/2014	21
2014471403767	581467	109399	2	7/4/2014	21
2014471404335	579799	114045	2	7/29/2014	21
2014471404384	573759	126043	2	7/31/2014	21
2014471404554	572634	128819	2	8/7/2014	21
2014471404957	575823	120074	1	8/27/2014	21
2014471405317	579641	112146	2	9/15/2014	21
2014471405397	577612	117524	1	9/19/2014	21
2014471405596	580101	111565	2	9/29/2014	21
2014471405765	573940	123282	2	10/5/2014	21
2014471406081	580177	110192	2	10/16/2014	21
2014471406958	579640	112150	2	11/26/2014	21
2014471407648	576291	119285	2	12/24/2014	21
201450DE2W003	295368	88663	2	6/2/2014	5
201450DE2W004	295365	88661	2	6/5/2014	5
201450KH2A001	325242	110338	2	1/15/2014	303
201450KU2I003	303346	111329	2	5/6/2014	5
201450KU2I012	302962	109846	2	12/27/2014	5
2014520400927	331650	139300	1	1/22/2014	5
2014520401731	350783	121393	2	2/20/2014	303
2014520402211	331525	141321	2	4/2/2014	5
2014520402762	334067	149083	1	4/30/2014	5
2014520402791	359855	125896	2	4/24/2014	303
2014520403652	353485	125076	2	5/26/2014	303
2014520404845	326094	125596	2	7/16/2014	5
2014520405342	331909	142948	1	7/30/2014	5
2014520405390	313340	118440	2	7/8/2014	5
2014520405869	312846	118320	2	5/15/2014	5
2014520406272	334563	115653	2	9/1/2014	303
2014520406388	329648	113434	2	9/12/2014	303
2014520407591	320700	120520	1	11/5/2014	5

2014520407649	352820	124695	2	7/2/2014	303
2014520408774	328221	113161	2	9/23/2014	303
2014520408839	375265	129885	2	10/1/2014	303
2014520408971	348000	118910	2	12/10/2014	303
2014521401863	338060	158570	2	3/6/2014	5
2014521404892	366761	189139	2	7/5/2014	5
2014521405124	352011	176926	2	5/16/2014	5
2014521405747	348191	174240	2	8/4/2014	5
2014521405762	338080	158490	2	7/4/2014	5
2014521407041	352409	177514	2	9/29/2014	5
2014530208746	371566	196432	2	6/28/2014	5
2014530208760	381132	211587	2	4/4/2014	5
2014530208802	389969	224675	1	6/1/2014	5
2014530209013	380429	211303	2	9/25/2014	5
2014530209016	373204	200547	2	9/28/2014	5
2014530209023	375840	203065	2	8/19/2014	5
2014530209182	391185	237736	1	11/6/2014	5
2014530209191	379140	209511	2	12/24/2014	5
2014543609914	389556	134196	2	4/19/2014	303
2014546818414	381830	132882	1	7/27/2014	303
2014547778314	425944	156192	2	8/28/2014	21
2014547838814	412181	141946	1	8/29/2014	303
2014548303814	418945	142430	2	9/14/2014	303
201454B764614	417292	142165	2	12/29/2014	303
2014554D29649	396730	93680	2	7/21/2014	5
201460R029386	263361	364757	2	2/26/2014	5
201460R035260	280591	353837	2	3/9/2014	5
201460R069696	320561	343254	1	5/11/2014	5
201460R088107	329959	338403	2	6/12/2014	5
201460R089159	236536	376922	2	6/14/2014	5
201460R102585	268762	360268	2	7/6/2014	5
201460R103357	290676	350467	2	7/7/2014	5
201460R112373	295972	346637	2	7/22/2014	5
201460R113123	262868	365354	2	7/23/2014	5
201460R115021	296310	346488	2	7/26/2014	5
201460R115163	282880	352480	2	7/26/2014	5
201460R120209	319788	343139	2	8/3/2014	5
201460R132978	328163	340601	2	8/24/2014	5
201460R134211	321799	341880	2	8/26/2014	5
201460R139105	271790	359060	2	9/4/2014	5
201460R150273	243736	374368	2	9/22/2014	5
201460R152682	257623	372146	2	9/26/2014	5
201460R178180	267365	360541	2	11/11/2014	5

Severity: 1 =fatal , 2=serious injuries

IV.2 Estimating the Crashes Involving the Highest NCAP Star Ratings

To isolate the crashes that involved vehicles with 5 NCAP stars, these steps are followed:

1. Gather details of the make and models of the vehicles involved in the accidents which occurred in the selected road sections of the study. Table IV.2 shows the make and model of the vehicles involved in the accidents which occurred in 2014, as an example.

2. The vehicle models that were awarded 5 stars by EuroNCAP (EuroNCAP 2017) are identified as in Figure IV.1; which shows the vehicle models awarded 5 stars in 2014 as an example of the collected data. These models are highlighted in Table IV.2.

3. Tables IV.1 and IV.2 are compounded using the accident index as a reference point to identify the location of each accident involving 5-star vehicles.

4. In the same way the vehicles' makes and models awarded 5 NCAP stars and involved in the crashes which occurred in 2010 to 2013 are isolated. Table IV.3**Error! Reference source not found.** shows the location details of the crashes which occurred in 2010-2014 and involved 5-NCAP-star vehicles.

Table IV.2 Sample of the make and model of vehicles involved in the accidents occurred in the UK in 2014 gathered from the Accidents by vehicle make and model data sheet (DFT 2017)

Accident_Index	Year	Make	Model
201431C270114	2014	VOLKSWAGEN	POLO MODA 60
201431C270114	2014	VAUXHALL	MERIVA ACTIVE CDTI
201431C270314	2014	LEXUS	CT 200H F SPORT CVT
201431C270414	2014	CHEVROLET	CRUZE LT
201431C271114	2014	LEXUS	IS 220D
201431C271114	2014	NISSAN	MICRA E
201431C271514	2014	VAUXHALL	VECTRA SXI 16V AUTO
201431C271514	2014	FORD	MONDEO TITANIUM X
201431C271514	2014	SEAT	TOLEDO ECOMOTIVE S TDI CR
201431C271514	2014	VAUXHALL	ASTRA GTC SRI CDTI S/S
201431C271614	2014	LAND ROVER	110 DEFENDER TURBO DIES
201431C271714	2014	NISSAN	MICRA SHAPE
201431C271914	2014	FORD	TRANSIT 350 LWB
201431C272114	2014	TOYOTA	AVENSIS GS
201431C272914	2014	VOLKSWAGEN	TOURAN S TDI 106
201431C273614	2014	VOLKSWAGEN	TOURAN S TDI
201431C273614	2014	TOYOTA	AVENSIS T4 D-4D
201431C273814	2014	NISSAN	ALMERA S
2014471400118	2014	HONDA	ST1300 A
2014471400118	2014	FORD	FIESTA ZETEC 90 TDCI
2014471400121	2014	VAUXHALL	INSIGNIA ES CDTI ECOFLEX S/
2014471400121	2014	RENAULT	CLIO AUTHENTIQUE
2014471400122	2014	MINI	COOPER S
2014471400122	2014	RENAULT	TRAFIC LL29 DCI 115
2014471400123	2014	HONDA	CIVIC 1.4I SE
2014471400124	2014	MITSUBISHI	
2014471400125	2014	VOLVO	XC 90 T6 SE AWD SEMI-AUTO
2014471400127	2014	FORD	FIESTA LX
2014471400130	2014	VOLKSWAGEN	POLO SE
2014471400130	2014	DAEWOO	MATIZ SE
2014471400130	2014	FORD	FIESTA ZETEC CLIMATE S-A
2014471400131	2014	FIAT	DOBLO CARGO M-JET SX 16V
2014471400131	2014	FIAT	MULTIPLA 110 SX JTD
2014471404334	2014	DAVID BROWN	
2014471404334	2014	PIAGGIO	VESPA LX 125
2014471404335	2014	KIA	CEE'D LS SW AUTO
2014471404335	2014	FORD	FOCUS TITANIUM 125
2014471404335	2014	RENAULT	SCENIC DYN VVT A
2014471404338	2014	ISUZU TRUCKS	FORWARD N75.190 AUTO
2014471404338	2014	AUDI	A1 SPORT TDI
2014471404343	2014	HONDA	HR-V
2014471404343	2014	BMW	K 1200 R SPORT
2014471404374	2014	NISSAN	MICRA S AUTO
2014471404374	2014	FORD	MONDEO EDGE TDCI 140
2014471404374	2014	FORD	MONDEO EDGE TDCI 140
2014471404378	2014	MINI	MINI COOPER AUTO

2014471404378	2014	VOLKSWAGEN	TIGUAN MATCH TDI 4MOT 140
2014471404380	2014	SAAB	9-3 SE TURBO
2014471404380	2014	HONDA	SCV 100 F-5
2014471404384	2014	FORD	TRANSIT 140 T350L RWD
2014471404384	2014	PEUGEOT	406 S HDI(90)
2014471404385	2014	FORD	FOCUS ZETEC CLIMATE TDCI
2014471404386	2014	LOTUS	EXIGE S RACE AND PREMIUM SP
2014471404386	2014	AUDI	A1 SPORT TFSI
2014471404386	2014	TOYOTA	PRIUS T3 VVT-I AUTO
2014471405583	2014	HONDA	SH125
2014471405586	2014	TOYOTA	AVENSIS T3-X D-4D
2014471405586	2014	FORD	TRANSIT 115 T350L RWD
2014471405587	2014	CHRYSLER	GRAND VOYAGER LTD XS CRDA
2014471405588	2014	BMW	X3 SPORT AUTO
2014471405590	2014	PEUGEOT	407 SE HDI
2014471405590	2014	VOLVO	
2014471405596	2014	LAND ROVER	
2014471405599	2014	FORD	TRANSIT 125 T350 RWD
2014471405600	2014	VAUXHALL	CORSA SXI+ 16V
2014471405602	2014	VAUXHALL	ASTRA CLUB 8V
2014471405602	2014	DAF TRUCKS	
201450KE5Q010	2014	VAUXHALL	INSIGNIA SE 130 CDTI
201450KH2A001	2014	VAUXHALL	VIVARO 2700 SPORTIVE CDTI
201450KH2A001	2014	AUDI	A3 SPORT TDI
201450KH2A002	2014	VAUXHALL	VECTRA SRI XPNAV CDTI A
201450KH2A003	2014	VAUXHALL	INSIGNIA EXCLUSIV 130CDTI
201450KH2A003	2014	FORD	KA COLLECTION
2014520406384	2014	SUZUKI	GSF 600 Y
2014520406384	2014	BMW	318I ES
2014520406388	2014	RENAULT	MEGANE SL OASIS 16V
2014520406388	2014	APRILIA	
2014520406390	2014	VOLKSWAGEN	TOUAREG ALTV6TDI B-TECH A
2014520406390	2014	FORD	TRANSIT 115 T350L RWD
2014520406391	2014	MG	ZR+
2014520408767	2014	PEUGEOT	206 SE SEMI-AUTO
2014520408770	2014	VAUXHALL	ASTRA LIFE A/C
2014520408774	2014	HONDA	NC 700 XA-D
2014520408774	2014	VOLKSWAGEN	GOLF GT TDI 140
2014520408776	2014	VOLVO	XC90 SE LUX D5 AWD AUTO
2014520408776	2014	CITROEN	C4 GRD PICASSO EXC-IVE HDI
2014520408776	2014	CITROEN	C3 DESIRE HDI

Highlighted accidents= the accidents involved by % NCAP stars cars.

Make & Model	Overall rating				
Mercedes Benz V-Class	2014 ★★★★★	93%	87%	67%	85%
Land Rover Discovery Sport	2014 ★★★★★	93%	83%	69%	82%
Mercedes Benz C-Class	2014 ★★★★★	92%	84%	77%	70%
Mercedes Benz GLA-Class	2014 ★★★★★	96%	88%	67%	70%
Nissan Qashqai	2014 ★★★★★	88%	83%	69%	79%
Nissan X Trail	2014 ★★★★★	86%	83%	75%	75%
Jeep Renegade	2014 ★★★★★	87%	85%	65%	74%
Kia Sorento	2014 ★★★★★	90%	83%	67%	71%
Subaru Outback	2014 ★★★★★	85%	87%	70%	73%
VW Passat	2014 ★★★★★	85%	87%	66%	76%
VW Golf Sportsvan	2014 ★★★★★	87%	85%	62%	73%
Nissan Pulsar	2014 ★★★★★	84%	81%	75%	68%
Porsche Macan	2014 ★★★★★	88%	87%	60%	66%
Ford Mondeo	2014 ★★★★★	86%	82%	66%	66%
Lexus NX	2014 ★★★★★	82%	82%	69%	71%
BMW 2 Series Active Tourer	2014 ★★★★★	84%	85%	60%	70%
Skoda Fabia	2014 ★★★★★	81%	81%	69%	69%
Tesla Model S	2014 ★★★★★	82%	77%	66%	71%
Audi A3 Sportback e-tron	2014 ★★★★★	82%	78%	66%	68%

Figure IV.1 The Vehicles make and models that awarded 5 stars by EuroNCAP assessment in 2014. (EuroNCAP 2017)

Table IV.3 The accidents involved by vehicles rated 5 EuroNCAP stars in 2010-2014 (DFT 2017)

Accident_Index	Location_ Easting_OSGR	Location_ Northing_OSGR	Accident Severity	Date	Road_ Number	make	model
2014471400130	579625	112889	2	1/9/2014	21	VOLKSWAGEN	POLO SE
2014471402838	579333	114881	1	5/23/2014	21	VAUXHALL	MERIVA DESIGN SEMI-AUTO
2014471404335	579799	114045	2	7/29/2014	21	KIA	CEE'D LS SW AUTO
2014471404384	573759	126043	2	7/31/2014	21	FORD	TRANSIT 140 T350L RWD
2014471405596	580101	111565	2	9/29/2014	21	LAND ROVER	
2014520406388	329648	113434	2	9/12/2014	303	RENAULT	MEGANE SL OASIS 16V
2013471303721	575955	119949	2	7/13/2013	21	HYUNDAI	I20 CLASSIC
2013471303784	579768	113152	2	7/22/2013	21	LEXUS	IS200 SE
2013471304592	577579	117547	2	9/1/2013	21	VOLKSWAGEN	GOLF MATCH TDI DSG
2013471306799	579562	112835	2	12/15/2013	21	HONDA	ACCORD VTEC EXECUTIVE A
2013471307006	573808	123041	2	12/24/2013	21	HONDA	CIVIC EX I-VTEC S-A
201350KH2A002	325247	110338	2	6/6/2013	303	FORD	FOCUS C-MAX GHIA
2013520305418	334320	115375	2	7/7/2013	303	MERCEDES-BENZ	E350 SE CDI BLUEEFFI-CY A
2013520307906	330297	113881	2	11/1/2013	303	ROVER	45 IMPRESSION S
201231C297412	455029	335062	2	11/10/2012	453	CHRYSLER	GRAND VOYAGER LX AUTO
2012471200656	573900	124690	2	2/5/2012	21	VOLVO	
2012471206087	578900	115630	2	11/16/2012	21	SAAB	900 S AUTO
2012471206941	579990	111700	2	12/24/2012	21	VAUXHALL	ASTRA SRI CDTI S/S
201131C050811	455395	335596	2	3/18/2011	453	VAUXHALL	INSIGNIA SE 160 CDTI
201131C307111	455044	335081	2	12/13/2011	453	RENAULT	CLIO EXPRESSION+ DCI 65
2011471104013	577580	117550	1	6/30/2011	21	VOLKSWAGEN	GOLF CL TDI
2011471104405	573330	127300	2	7/17/2011	21	TOYOTA	YARIS GS
2011471106811	573270	127920	1	10/29/2011	21	VOLKSWAGEN	GOLF MATCH TDI
2011520107056	339670	115280	2	10/30/2011	303	VAUXHALL	ASTRA SE AUTO

Accident_Index	Location_ Easting_OSGR	Location_ Northing_OSGR	Accident Severity	Date	Road_ Number	make	model
2011547583311	411790	141860	2	9/1/2011	303	AUDI	A6 ALLROAD TDI QUATTRO AUTO
2010471000757	573810	123050	2	2/3/2010	21	MERCEDES	E220 CDI CLASSIC AUTO
2010471003234	581420	109400	2	5/20/2010	21	FORD	FOCUS STYLE TD 115
2010471006002	574250	121390	2	9/10/2010	21	MAZDA	
2010471006627	580110	111470	2	10/5/2010	21	AUDI	A3 SPORT TDI AUTO
201050KH2A002	323630	109820	1	6/14/2010	303	MAZDA	6 TS2 DIESEL

IV.3 Estimating the Crash Numbers Caused by Road Users' Mistakes

The crashes which result from the road users' mistakes are estimated in this step. The road users' mistakes such as speeding, drinking alcohol, and using mobile phones are considered. The selection of these factors is based on the available data regarding contributory factors to road fatalities and serious crashes which are related to these road-user factors (DFT 2017). Table IV.4 shows these factors with the number of accidents to which they contributed in 2010-2014.

Table IV.4 The number of fatal and serious injuries (F&S) involving road user factors (2010-2014) (DFT 2017)

<table>
<tr><th colspan="2">Fatalities and serious injuries to which road user factors contributed</th><th>2010</th><th>2011</th><th>2012</th><th>2013</th><th>2014</th><th>Total</th></tr>
<tr><td colspan="2">F&S involving speeding</td><td>1400</td><td>1308</td><td>1214</td><td>1309</td><td>1453</td><td>6684</td></tr>
<tr><td colspan="2">F&S involving alcohol consumption</td><td>1252</td><td>1313</td><td>1241</td><td>1110</td><td>1100</td><td>6016</td></tr>
<tr><td colspan="2">F&S involving drug consumption</td><td>197</td><td>225</td><td>215</td><td>212</td><td>244</td><td>1093</td></tr>
<tr><td colspan="2">F&S involving use of a mobile phone</td><td>84</td><td>77</td><td>84</td><td>95</td><td>105</td><td>445</td></tr>
<tr><td colspan="2">Total</td><td>2933</td><td>2923</td><td>2754</td><td>2726</td><td>2902</td><td>14238</td></tr>
<tr><td colspan="2">Total accidents</td><td>22171</td><td>22783</td><td>22538</td><td>21232</td><td>22334</td><td>111058</td></tr>
<tr><td rowspan="2">Average value of prevention of accidents (£/Accident)</td><td>Fatal</td><td>1,838,057</td><td>1,877,583</td><td>1,917,766</td><td>1,953,783</td><td>2,066,732</td><td></td></tr>
<tr><td>Serious</td><td>210,902</td><td>216,203</td><td>219,043</td><td>223,870</td><td>235,791</td><td></td></tr>
</table>

However, these data are countrywide. The data needed for this study should be per road section. Therefore, there is a need to disaggregate this data and assign it to the road sections. For disaggregation, the following steps are taken:

1. Identify a weight for disaggregating (Chen and Yang 2007; Patterson et al. 2010); this needs to consider what factors are contributing. Since the disaggregation is for the number of road fatalities and serious injuries (FSI) to which specific factors contribute, the factor considered in this step is the number of FSI where all the factors contribute. So, the weight of disaggregating is computed by dividing the number of F&S occurring in a 100 m road section in a year by the total FSI on all roads, as shown in equation IV.2:

$$Weight\ of\ disaagregating\ (WDisagg.) = \frac{FSIi}{Total\ FSI} \qquad \dots\dots\dots (IV.2)$$

where:

FSIi = number of road fatalities and serious injuries which occurred in section I in 2010-2014

Total FS= total road fatalities and serious injuries in 2010-2014

2. Compute the number of the disaggregated road crashes per 100 m road section, by multiplying the weight of disaggregation by the total number of accidents resulting from road-user factors, as shown in equation IV.3:

$$NCRoadUserBehaviouri = WDisagg.*\ AggNCRoadUserBehaviour \qquad \dots\dots\dots (IV.3)$$

where:

NCRoadUserBehaviouri = Number of road crashes resulting from road-user factors per road section i

AggNCRoadUserBehaviour = the aggregated road crashes resulting from road-user factors

Table IV.5 shows an example of identifying the weight of disaggregation and computing the disaggregated number of accidents resulting from road-user factors for a road section of the A21 in 2010 and 2011. It can be noticed that the disaggregated number of accidents per section is a decimal number which is less than 1. Therefore, there is a need to re-assign the number of accidents to the road section as shown in step 3.

3. Assign the disaggregated number of accidents resulting from the road-user factors to the road sections; this is achieved by at first assigning one accident to the section where there was the highest disaggregated number of accidents. Then, we compute the accumulated number of disaggregated accidents of the road sections as shown in Table IV.5; when the accumulated number of disaggregated accidents equals roughly one accident, then one accident is assigned to this section.

For example, to assign the disaggregated accidents in 2010, the total disaggregated accidents in the selected section of the A21 is 1.322 accidents. In this case, one accident should be assigned to one section. Since the accidents which occurred are disaggregated equally to the sections where accidents occurred in 2010, the section is selected randomly. So one accident is assigned to section number 28.

For another example of assigning the disaggregated accidents which occurred in 2011 to the A21 road sections, the total number of disaggregated accidents is 2.18. In this case, the accumulated number of accidents is computed for these sections. The first section has the highest number of disaggregated accidents, so one accident is assigned to this section. At section 121, the accumulated number of accidents reaches to about 1.02; then one accident is assigned for section 121.

The same way of assigning is repeated for the other road sections selected in Chapter Eight for all the years 2010 to 2014.

IV.4 Estimating the Number of Crashes Caused by Road Design Features

The total number of crashes caused by the road design features is computed using equation IV.1. The results are shown in Table IV.6.

Table IV.5 Disaggregation of the total number of road accidents involved with road user behaviour factors occurred in the selected road section of A21 in 2010 and 2011

Section number	2010				2011				
	Total FSI accidents	The Weight of disaggregation *	The number disaggregated accidents involved with road users errors**	Assigning the disaggregated accidents to the 100m road sections	Total FSI accidents	The Weight of disaggregation *	The number disaggregated accidents involved with road users errors**	The accumulated number of accidents	Assigning the disaggregated accidents to the 100m road sections
1	0	0	0	0	3	0.000132	0.384892	1	1
2	0	0	0	0	0	0	0	0.384892	0
3	0	0	0	0	0	0	0	0.384892	0
4	0	0	0	0	0	0	0	0.384892	0
5	0	0	0	0	0	0	0	0.384892	0
6	0	0	0	0	1	4.39E-05	0.128297	0.51319	0
7	0	0	0	0	0	0	0	0.51319	0
8	0	0	0	0	0	0	0	0.51319	0
9	0	0	0	0	0	0	0	0.51319	0
10	0	0	0	0	0	0	0	0.51319	0
11	0	0	0	0	0	0	0	0.51319	0
12	0	0	0	0	0	0	0	0.51319	0
13	0	0	0	0	0	0	0	0.51319	0
14	0	0	0	0	0	0	0	0.51319	0
15	0	0	0	0	0	0	0	0.51319	0
16	0	0	0	0	0	0	0	0.51319	0
17	0	0	0	0	0	0	0	0.51319	0
18	0	0	0	0	0	0	0	0.51319	0
19	0	0	0	0	0	0	0	0.51319	0
20	0	0	0	0	0	0	0	0.51319	0
21	0	0	0	0	0	0	0	0.51319	0

22	0	0	0	0	0	0	0	0.51319	0
23	0	0	0	0	0	0	0	0.51319	0
24	0	0	0	0	0	0	0	0.51319	0
25	0	0	0	0	0	0	0	0.51319	0
26	0	0	0	0	0	0	0	0.51319	0
27	0	0	0	0	0	0	0	0.51319	0
28	1	4.51E-05	0.13229	1	0	0	0	0.51319	0
29	0	0	0	0	0	0	0	0.51319	0
30	1	4.51E-05	0.13229	0	0	0	0	0.51319	0
31	0	0	0	0	0	0	0	0.51319	0
32	0	0	0	0	0	0	0	0.51319	0
33	0	0	0	0	0	0	0	0.51319	0
34	0	0	0	0	0	0	0	0.51319	0
35	0	0	0	0	0	0	0	0.51319	0
36	0	0	0	0	0	0	0	0.51319	0
37	0	0	0	0	0	0	0	0.51319	0
38	0	0	0	0	0	0	0	0.51319	0
39	0	0	0	0	0	0	0	0.51319	0
40	0	0	0	0	0	0	0	0.51319	0
41	0	0	0	0	0	0	0	0.51319	0
42	0	0	0	0	0	0	0	0.51319	0
43	0	0	0	0	0	0	0	0.51319	0
44	0	0	0	0	0	0	0	0.51319	0
45	0	0	0	0	1	4.39E-05	0.128297	0.641487	0
46	0	0	0	0	0	0	0	0.641487	0
47	0	0	0	0	0	0	0	0.641487	0
48	0	0	0	0	0	0	0	0.641487	0
49	0	0	0	0	0	0	0	0.641487	0
50	0	0	0	0	0	0	0	0.641487	0
51	0	0	0	0	0	0	0	0.641487	0
52	0	0	0	0	0	0	0	0.641487	0
53	0	0	0	0	0	0	0	0.641487	0

54	0	0	0	0	0	0	0	0.641487	0
55	0	0	0	0	0	0	0	0.641487	0
56	0	0	0	0	0	0	0	0.641487	0
57	0	0	0	0	0	0	0	0.641487	0
58	0	0	0	0	0	0	0	0.641487	0
59	0	0	0	0	0	0	0	0.641487	0
60	0	0	0	0	0	0	0	0.641487	0
61	0	0	0	0	0	0	0	0.641487	0
62	0	0	0	0	0	0	0	0.641487	0
63	0	0	0	0	0	0	0	0.641487	0
64	0	0	0	0	0	0	0	0.641487	0
65	0	0	0	0	0	0	0	0.641487	0
66	0	0	0	0	0	0	0	0.641487	0
67	0	0	0	0	0	0	0	0.641487	0
68	0	0	0	0	0	0	0	0.641487	0
69	0	0	0	0	0	0	0	0.641487	0
70	1	4.51E-05	0.13229	0	0	0	0	0.641487	0
71	0	0	0	0	0	0	0	0.641487	0
72	0	0	0	0	0	0	0	0.641487	0
73	0	0	0	0	0	0	0	0.641487	0
74	1	4.51E-05	0.13229	0	0	0	0	0.641487	0
75	0	0	0	0	0	0	0	0.641487	0
76	0	0	0	0	0	0	0	0.641487	0
77	0	0	0	0	0	0	0	0.641487	0
78	0	0	0	0	0	0	0	0.641487	0
79	0	0	0	0	0	0	0	0.641487	0
80	0	0	0	0	0	0	0	0.641487	0
81	0	0	0	0	0	0	0	0.641487	0
82	0	0	0	0	0	0	0	0.641487	0
83	0	0	0	0	0	0	0	0.641487	0
84	0	0	0	0	0	0	0	0.641487	0
85	0	0	0	0	0	0	0	0.641487	0

86	0	0	0	0	0	0	0	0.641487	0
87	0	0	0	0	0	0	0	0.641487	0
88	0	0	0	0	0	0	0	0.641487	0
89	0	0	0	0	0	0	0	0.641487	0
90	0	0	0	0	0	0	0	0.641487	0
91	0	0	0	0	0	0	0	0.641487	0
92	0	0	0	0	0	0	0	0.641487	0
93	0	0	0	0	0	0	0	0.641487	0
94	0	0	0	0	0	0	0	0.641487	0
95	0	0	0	0	0	0	0	0.641487	0
96	0	0	0	0	1	4.39E-05	0.128297	0.769784	0
97	0	0	0	0	0	0	0	0.769784	0
98	0	0	0	0	0	0	0	0.769784	0
99	0	0	0	0	0	0	0	0.769784	0
100	0	0	0	0	0	0	0	0.769784	0
101	0	0	0	0	0	0	0	0.769784	0
102	0	0	0	0	0	0	0	0.769784	0
103	0	0	0	0	0	0	0	0.769784	0
104	0	0	0	0	0	0	0	0.769784	0
105	1	4.51E-05	0.13229	0	0	0	0	0.769784	0
106	0	0	0	0	0	0	0	0.769784	0
107	0	0	0	0	0	0	0	0.769784	0
108	0	0	0	0	0	0	0	0.769784	0
109	0	0	0	0	0	0	0	0.769784	0
110	0	0	0	0	0	0	0	0.769784	0
111	0	0	0	0	0	0	0	0.769784	0
112	0	0	0	0	0	0	0	0.769784	0
113	0	0	0	0	0	0	0	0.769784	0
114	0	0	0	0	0	0	0	0.769784	0
115	0	0	0	0	0	0	0	0.769784	0
116	0	0	0	0	0	0	0	0.769784	0
117	0	0	0	0	0	0	0	0.769784	0

118	0	0	0	0	0	0	0	0.769784	0
119	0	0	0	0	0	0	0	0.769784	0
120	0	0	0	0	0	0	0	0.769784	0
121	0	0	0	0	2	8.78E-05	0.256595	1.026379	1
122	0	0	0	0	0	0	0	1.026379	0
123	0	0	0	0	0	0	0	1.026379	0
124	0	0	0	0	0	0	0	1.026379	0
125	0	0	0	0	0	0	0	1.026379	0
126	0	0	0	0	0	0	0	1.026379	0
127	0	0	0	0	0	0	0	1.026379	0
128	0	0	0	0	0	0	0	1.026379	0
129	0	0	0	0	0	0	0	1.026379	0
130	0	0	0	0	0	0	0	1.026379	0
131	0	0	0	0	0	0	0	1.026379	0
132	0	0	0	0	0	0	0	1.026379	0
133	0	0	0	0	0	0	0	1.026379	0
134	0	0	0	0	0	0	0	1.026379	0
135	1	4.51E-05	0.13229	0	0	0	0	1.026379	0
136	0	0	0	0	0	0	0	1.026379	0

*The weight of disaggregation is computed using Equation 8.2

** The disaggregated number of accidents is computed using Equation 8.3

Table IV.6 The total number of fata and serious injuries road accidents caused by road design feature occurred in the selected sections of A21 in 2010-2014

Section number	The total F&S accidents involved by 5 NCAP stars					The total F&S accidents contributed by road user behaviour factors					Total accidents caused by road design features*				
	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014
1	0	3	0	0	0	0	1	0	0	0	0	2	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	2	0	0	0	0	1	0	0	0	0	1	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
46	0	0	0	2	0	0	0	0	1	0	0	0	0	1	0
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0
57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1

91	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
92	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
101	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
105	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
107	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
109	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
114	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
121	0	2	0	0	0	0	1	0	0	0	0	1	0	0	0

*Using Equation 8.1

Table IV.7 The results of the estimation of the crash cost per VKT for each 100m length of road sections of the study roads

Section number	Road name	Total cost for five years (2010-2014)	Vehicle Flow (AADT)	total cost per VKT
1	A21	3971368.8	21680	2874.471
2	A21	0	21680	0
3	A21	0	21680	0
4	A21	0	21680	0
5	A21	0	21680	0
6	A21	216203.46	21680	156.4877
7	A21	0	21680	0
8	A21	0	21680	0
9	A21	0	21680	0
10	A21	0	21680	0
11	A21	0	21680	0
12	A21	0	21680	0
13	A21	0	21680	0
14	A21	0	21680	0
15	A21	0	21680	0
16	A21	0	21680	0
17	A21	0	21680	0
18	A21	0	21680	0
19	A21	0	21680	0
20	A21	235790.52	21680	170.6648
21	A21	0	21680	0
22	A21	0	21680	0
23	A21	0	21680	0
24	A21	0	21680	0
25	A21	0	21680	0
26	A21	0	21680	0
27	A21	0	21680	0
28	A21	210902.48	21680	152.6509
29	A21	0	21680	0
30	A21	210902.48	21680	152.6509
31	A21	0	21680	0
32	A21	0	21680	0
33	A21	0	21680	0
34	A21	438086.08	21680	317.086
35	A21	0	21680	0
36	A21	0	21680	0
37	A21	0	21680	0
38	A21	0	21680	0

Section number	Road name	Total cost for five years (2010-2014)	Vehicle Flow (AADT)	total cost per VKT
39	A21	0	21680	0
40	A21	0	21680	0
41	A21	0	21680	0
42	A21	0	21680	0
43	A21	0	21680	0
44	A21	0	21680	0
45	A21	216203.46	21680	156.4877
46	A21	3907566.4	21680	2828.291
47	A21	0	21680	0
48	A21	0	21680	0
49	A21	235790.52	21680	170.6648
50	A21	0	21680	0
51	A21	0	21680	0
52	A21	223869.99	21680	162.0368
53	A21	0	21680	0
54	A21	0	21680	0
55	A21	0	21680	0
56	A21	447739.98	21680	324.0735
57	A21	0	21680	0
58	A21	0	21680	0
59	A21	0	21680	0
60	A21	0	21680	0
61	A21	0	21680	0
62	A21	0	21680	0
63	A21	0	21680	0
64	A21	0	21680	0
65	A21	0	21680	0
66	A21	223869.99	21680	162.0368
67	A21	0	21680	0
68	A21	0	21680	0
69	A21	0	21680	0
70	A21	210902.48	21680	152.6509
71	A21	0	21680	0
72	A21	0	21680	0
73	A21	0	21680	0
74	A21	210902.48	21680	152.6509
75	A21	0	21680	0
76	A21	0	21680	0
77	A21	0	21680	0
78	A21	0	21680	0
79	A21	0	21680	0

Section number	Road name	Total cost for five years (2010-2014)	Vehicle Flow (AADT)	total cost per VKT
80	A21	0	21680	0
81	A21	0	21680	0
82	A21	0	21680	0
83	A21	0	21680	0
84	A21	0	21680	0
85	A21	0	21680	0
86	A21	0	21680	0
87	A21	219043.04	21680	158.543
88	A21	0	21680	0
89	A21	0	21680	0
90	A21	2066731.9	21680	1495.897
91	A21	2066731.9	21680	1495.897
92	A21	223869.99	21680	162.0368
93	A21	0	21680	0
94	A21	0	21680	0
95	A21	0	21680	0
96	A21	216203.46	21680	156.4877
97	A21	0	21680	0
98	A21	0	21680	0
99	A21	0	21680	0
100	A21	1917766.3	21680	1388.076
101	A21	2066731.9	21680	1495.897
102	A21	0	21680	0
103	A21	0	21680	0
104	A21	0	21680	0
105	A21	210902.48	21680	152.6509
106	A21	0	21680	0
107	A21	0	21680	0
108	A21	0	21680	0
109	A21	0	21680	0
110	A21	0	21680	0
111	A21	0	21680	0
112	A21	0	21680	0
113	A21	0	21680	0
114	A21	0	21680	0
115	A21	0	21680	0
116	A21	0	21680	0
117	A21	0	21680	0
118	A21	0	21680	0
119	A21	0	21680	0
120	A21	0	21680	0

APPENDIX V

THE RATE OF ROAD FATALITIES

Table V.1 the rate of road fatalities per 100000 for all the members of the WHO (WHO 2015)

Country	The rate of road fatalities per 100000 population 2013
Afghanistan	15.5
Albania	15.1
Algeria	23.8
Andorra	7.6
Angola	26.9
Antigua and Barbuda	6.7
Argentina	13.6
Armenia	18.3
Australia	5.4
Austria	5.4
Azerbaijan	10
Bahamas	13.8
Bahrain	8
Bangladesh	13.6
Barbados	6.7
Belarus	13.7
Belgium	6.7
Belize	24.4
Benin	27.7
Bhutan	15.1
Bolivia (Plurinational State of)	23.2
Bosnia and Herzegovina	17.7
Botswana	23.6
Brazil	23.4
Bulgaria	8.3
Burkina Faso	30
Cabo Verde	26.1
Cambodia	17.4
Cameroon	27.6
Canada	6
Central African Republic	32.4
Chad	24.1
Chile	12.4

Country	The rate of road fatalities per 100000 population 2013
China	18.8
Colombia	16.8
Congo	26.4
Cook Islands	24.2
Costa Rica	13.9
CÃ´te d'Ivoire	24.2
Croatia	9.2
Cuba	7.5
Cyprus	5.2
Czechia	6.1
Democratic Republic of the Congo	33.2
Denmark	3.5
Djibouti	24.7
Dominica	15.3
Dominican Republic	29.3
Ecuador	20.1
Egypt	12.8
El Salvador	21.1
Eritrea	24.1
Estonia	7
Ethiopia	25.3
Fiji	5.8
Finland	4.8
France	5.1
Gabon	22.9
Gambia	29.4
Georgia	11.8
Germany	4.3
Ghana	26.2
Greece	9.1
Guatemala	19
Guinea	27.3
Guinea-Bissau	27.5
Guyana	17.3
Honduras	17.4
Hungary	7.7
Iceland	4.6
India	16.6
Indonesia	15.3
Iran (Islamic Republic of)	32.1
Iraq	20.2

Country	The rate of road fatalities per 100000 population 2013
Ireland	4.1
Israel	3.6
Italy	6.1
Jamaica	11.5
Japan	4.7
Jordan	26.3
Kazakhstan	24.2
Kenya	29.1
Kiribati	2.9
Kuwait	18.7
Kyrgyzstan	22
Lao People's Democratic Republic	14.3
Latvia	10
Lebanon	22.6
Lesotho	28.2
Liberia	33.7
Libya	24.2
Lithuania	10.6
Luxembourg	8.7
Madagascar	28.4
Malawi	35
Malaysia	24
Maldives	3.5
Mali	25.6
Malta	5.1
Marshall Islands	5.7
Mauritania	24.5
Mauritius	12.2
Mexico	12.3
Micronesia (Federated States of)	1.9
Monaco	0
Mongolia	21
Montenegro	11.9
Morocco	20.8
Mozambique	31.6
Myanmar	20.3
Namibia	23.9
Nepal	17
Netherlands	3.4
New Zealand	6
Nicaragua	15.3

Country	The rate of road fatalities per 100000 population 2013
Niger	26.4
Nigeria	20.5
Norway	3.8
Oman	25.4
Pakistan	14.2
Palau	4.8
Panama	10
Papua New Guinea	16.8
Paraguay	20.7
Peru	13.9
Philippines	10.5
Poland	10.3
Portugal	7.8
Qatar	15.2
Republic of Korea	12
Republic of Moldova	12.5
Romania	8.7
Russian Federation	18.9
Rwanda	32.1
Saint Lucia	18.1
Saint Vincent and the Grenadines	8.2
Samoa	15.8
San Marino	3.2
Sao Tome and Principe	31.1
Saudi Arabia	27.4
Senegal	27.2
Serbia	7.7
Seychelles	8.6
Sierra Leone	27.3
Singapore	3.6
Slovakia	6.6
Slovenia	6.4
Solomon Islands	19.2
Somalia	25.4
South Africa	25.1
Spain	3.7
Sri Lanka	17.4
Sudan	24.3
Suriname	19.1
Swaziland	24.2
Sweden	2.8

Country	The rate of road fatalities per 100000 population 2013
Switzerland	3.3
Tajikistan	18.8
Thailand	36.2
The former Yugoslav republic of Macedonia	9.4
Timor-Leste	16.6
Togo	31.1
Tonga	7.6
Trinidad and Tobago	14.1
Tunisia	24.4
Turkey	8.9
Turkmenistan	17.4
Uganda	27.4
United Arab Emirates	10.9
United Kingdom	2.9
United Republic of Tanzania	32.9
United States of America	10.6
Uruguay	16.6
Uzbekistan	11.2
Vanuatu	16.6
Viet Nam	24.5
Yemen	21.5
Zambia	24.7
Zimbabwe	28.2

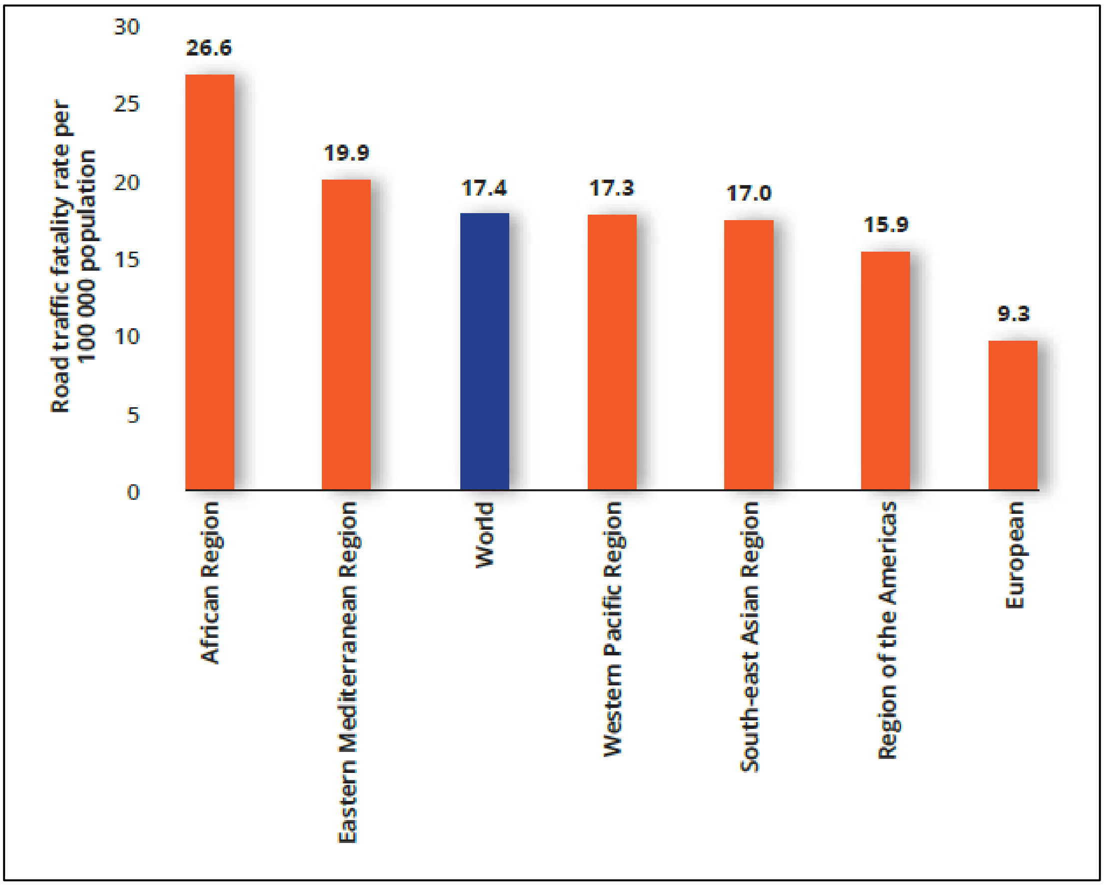

Figure V.1 The Average rate of road fatalities per 100000 population by WHO' region (WHO 2015)

APPENDIX VI

THE LIST OF PUBLICATIONS

The following papers have been written during conducting this research. some of them are based on part or more of this study. These paper are presented in conferences, published in conference proceeding or published in academic journals:

1. Jameel, A. & Evdorides, H. 2016. An investigation for an all-encompassing iRAP road Star Rating index. *Functional Pavement Design. Proceedings of the 4th Chinese-European Workshop on Functional Pavement Design (4th CEW 2016, Delft, The Netherlands, 29 June - 1 July 2016). CRC Pres*s.

2. Jameel, A. & Evdorides, H. 2017a. Review of the Road Crash Data Availability in Iraq. International Journal of Transport and Vehicle Engineering. 11(6). World Academy of Science, Engineering and Technology

3. Jameel, A. & Evdorides, H. 2017b. Review on the Statues of Road Safety in the Developing Countries: Case study of Middle East Countries. Journal of Innovative Research in Engineering & Technology1(1). P.25-30 http://sijiret.com

4. Jameel, A. K. & Evdorides, H. 2018a. Assessment of Road Safety Performance for Southeast Asia Countries. The 2nd Conference of ASEAN Road Safety 2018 (CARS 2018). 4-6 December 2018 in Selangor, Malaysia.

5. Jameel, A. K. & Evdorides, H. 2018b. Assessment of safer road user behaviour. WIT Transactions on Ecology and the Environment. 10th international conference on sustainable development and planning, Organised by the Wessex Institute, UK andf the University of Siena, Italy, 217, 755-770.

6. Jameel, A. K. & Evdorides, H. 2018c. Indicators of Safer road users' Behavior. IRF GLOBAL R2T Conference. November 7-9, 2018 – Las Vegas, NV USA.

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