UNIVERSITY OF BIRMINGHAM

A CONCEPTUAL MODEL TO EFFECTIVELY PRIORITISE RECOVERY OF ROADS DAMAGED BY NATURAL/MAN-MADE DISASTERS

by

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A thesis submitted to
The University of Birmingham
For the degree of
DOCTOR OF PHILOSOPHY

School of Civil Engineering
College of Engineering and Physical Sciences
The University of Birmingham
October 2012

“AND MY SUCCESS IS NOT BUT THROUGH ALLAH. UPON HIM I HAVE RELIED, AND TO HIM I RETURN.”

[Al-Quran 11:88]

ABSTRACT

Road recovery management is now becoming a vital issue in the road rehabilitation strategies of any road reconstruction and/or rehabilitation organisations, especially with the recent increase in the occurrence of disasters, whether they are natural such as earthquakes, tsunamis or floods, or man-made such as armed conflicts, terrorist attacks or bomb explosions.

After natural/man-made disasters, a major challenge faced by governments is to ensure a speedy recovery of roads and transportation networks so that regeneration can commence in an effective manner. In order to achieve this, a new road recovery priority (RRP) model to identify key issues and their inter-relationships giving a better understanding of factors that govern prioritisation across the affected regions has been developed and is presented in this research.

The proposed model depends on technique standards and leads to the determination of a level of priority that may be allocated to a particular event(s) in terms of the estimated factor impacts. The proposed model enables decision analysts to better understand the complete evaluation process and provide a more accurate, effective and systematic decision support tool.

An extensive review and analysis of RRP models are carried out and a proposed RRP model is developed to fill the gaps and overcome the disadvantages of previous models used for road rehabilitation projects. Interviews are conducted with experts in road reconstruction and maintenance organisations to investigate respondents' evaluation and understanding of the RRP model in terms of its ease of use, usefulness, comprehensiveness, applicability, feasibility and structure. A questionnaire survey is conducted to develop the RRP model by investigating the impact of the important proposed affecting factors that can be critical for successful implementation and application of RRP in the road rehabilitation sector.

A field survey is carried out to collect data which are essential to determine parameters in the model's application. Four case studies are carried out to investigate the RRP model's application in a variety of road conditions by using different input values in order to evaluate the usability and usefulness of the proposed model in road reconstruction projects. These provide useful examples of RRP procedures and approaches to show how to apply the proposed model. The results indicated that the proposed model can effectively facilitate the process of implementation, development and application of RRP in the road reconstruction organisations. Recommendations are given and future research works are suggested in order to improve the implementation and application of RRP in the road sector.

The application of this model may solve the problem of decision making in road recovery priority determination in a hierarchical manner so that the recovery process can be accomplished from an urgent repair need road to a lower recovery priority road.

ACKNOWLEDGEMENTS

All praises be to Almighty ALLAH (SWT) who gave me strength to strive for knowledge and created circumstances for this research to be carried out.

This research could not have been possible without the support and contributions of many people who have provided the mental energy for the development of this thesis. I start by thanking my supervisor Dr. Min An for providing enthusiastic support and thorough feedback on my work. Dr. Min An makes great efforts to support his students with feedback and ideas, and provides as much of his time as they need. Many thanks are extended to Dr. Jennaro Odoki and Dr. Gurmel Ghataora for their supervision and guidance in the first stages of the research.

This work was financially supported by the Iraqi Government/Ministry of Higher Education and Scientific Research. I am grateful to all persons in the Embassy of the Republic of Iraq/Cultural Attaché in London for their assistance and cooperation during my study.

I thank academics and colleagues in my Department at the University of Birmingham, the School of Civil Engineering, especially those who participated and provided feedback on my questionnaire survey.

I am sincerely grateful to the organisations and persons who provided their valuable time and resources at their disposal in helping me carry out field data collection in Iraq.

Special thanks go to all my teaching staff colleagues and friends who are working in the University of Technology/Building and Construction Department in Iraq for being supportive during my fieldwork and study.

Last but not least, I can never underestimate the continuous good will and motivation from my parents and family. Special thanks to my father, mother, brother and sister. Their prayers, good wishes, and endless interest are specially treasured in my heart. I owe my tremendous thanks for their unconditional love and steady encouragement, patience, understanding and moral support. Thanks to everyone who loves me.

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LIST OF ACRONYMS

AADT	Average Annual Daily Traffic
AHP	Analytic Hierarchy Process
AI	Accessibility Index
BA	Budget allocation
C	Capacity
DC	Direct Cost
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
f	factor
FA	Factor Analysis
g	group
GI_g	Group Indicator for the g^{th} factor group
GIS	Geographical Information System
GPI_g	Group Priority Index for the g^{th} factor group
$H_{g,f}$	Hierarchy of the f^{th} factor in the g^{th} factor group
IC	Indirect Cost
KPI	Key Performance Indicator
LOS	Level of Service
M&R	Maintenance and Rehabilitation
MCDM	Multiple Criteria Decision Making
n	Number of damaged road
O/D	Origin/Destination

PCA	Pavement Condition Assessment
PD	Percent Delay
PMS	Pavement Management System
PSI	Present Serviceability Index
$R_{g,f}$	Rating of the f^{th} factor in the g^{th} factor group
RRP	Road Recovery Priority
RRPI	Road Recovery Priority Index
$S_{g,f}$	Scale of the f^{th} factor in the g^{th} factor group
SL_g	Significance Level of the g^{th} factor group
SPSS	Statistical Package for the Social Sciences
TAI	Total Accessibility Index
USAID	U.S. Agency for International Development
V/C	Volume/Capacity
vpd	vehicle per day
W_g	Contribution weight of the g^{th} factor group
$W_{g,f}$	Contribution weight of the f^{th} factor in the g^{th} factor group

CHAPTER ONE

INTRODUCTION

1.1 Background

Transportation networks constitute one class of major civil infrastructure systems that is a critical backbone of modern society. The physical damage and functionality loss of the transportation infrastructure systems not only hinder societal and commercial activities, but also impair post-disaster response and recovery (Chang and Nojima, 1998; Basőz and Kiremidjian, 1996; Nojima, 1998), resulting in substantial socio-economic losses (Eguchi *et al.*, 1998; Scawthorn *et al.*, 1997; National Research Council, NRC, 1999; Chang, 2010).

The Federal Emergency Management Agency (FEMA), which is a part of the U.S. Department of Homeland Security (DHS), has identified the four phases of a disaster related planning as mitigation, preparation, response and recovery. Considerable emphasis has been placed on the preparation and response phases through evacuation plans and first response after a disaster (Cova and Church, 1997; Kovel, 2000; Sakakibara *et al.*, 2004). However, research is lacking in the recovery phase. The recovery phase is characterised by activity to return life to normal or improved levels (Cova, 1999). FEMA defines recovery as the restoration of transportation components to their condition prior to the event (Sandy, 2009).

The vulnerability of highways and bridges is exacerbated when they are subjected to natural disasters such as earthquakes and hurricanes which often cause severe disruption of the level of service provided by these transportation networks (Housner and Thiel, 1995). This service disruption in damaged transportation networks leads to significant social and economic losses to local communities. In order to control and minimise these adverse impacts on society, decision makers in departments of transportation need to carefully plan both the post-disaster reconstruction efforts of damaged networks and the rehabilitation efforts of deficient networks (Orabi, 2010).

Such a framework for decision-making provided by the model is an important first step in developing a recovery plan. A recovery plan gives transportation officials the advantage of a more efficient recovery time after a disaster. This is achieved through identifying routes of the highest priority for reconstruction in order that major roadways are incapacitated for shorter times. The identification of high-priority roadways is important because money can be directed toward maintenance and retrofitting along these roadways (Sandy, 2009).

The advantages of combining road performance measure, socio-economic and damage information can be decisive and constitute a good tool to help decision makers. Therefore, this research has focused on the development of a composite road recovery priority index. That is, the aim is to assign an index score that may capture all relevant affecting factors under various road situations after natural/man-made disasters in order to decide the first priority road (roads) for recovery. Despite the recent interest of the road recovery domain, the development of such a road recovery priority index with different types of affecting and controlling factors is a new and challenging matter.

The proposed road recovery priority model presented in this study enables decision makers in the road management, reconstruction and rehabilitation organisations to better understand the complete evaluation process and provide a more accurate, effective, and systematic decision support tool.

1.2 Thesis Layout

The following paragraphs explain the layout of the work presented in this thesis:

Chapter 2 aims at describing the research methodologies adopted in this study to commence, develop, enhance and evaluate the research and proposed model for road recovery priority after a natural/man-made disaster. This chapter presents the problem description, the aim and objectives of the research, and the research methods to achieve desirable results.

Chapter 3 aims to study the general impacts of natural/man-made disasters in the different life sectors such as infrastructure, health, environment, economy and society and to assess the effects of natural/man-made disasters on roads in order to investigate the fundamental factors of the damaged road which influence the recovery priority for these roads. Also, road recovery related literature has been discussed within this chapter.

A detailed review of various literatures that are dealing with roads maintenance management projects and identifying the subject of interest that has shortcomings and gaps to fill has been provided in Chapter 4. Insights gained from analysing the relevant researches have been highlighted and findings have been presented to provide an important background for the development of a proposed road recovery priority (RRP) model.

Chapter 5 discusses, first, the aim and objectives of the interviews conducted for this research. Then, the responses of the participants are reviewed and analysed. Third, the objectives and design of the questionnaire survey used in the research are presented. The findings from the questionnaire survey are analysed and presented. Finally, the results of the interviews and questionnaires are discussed to show how they affect the development and improvement of the RRP model.

In Chapter 6, the details of a final structure of the RRP model developed throughout the research stages are described. The proposed RRP model is developed by following methodologies to fill the gaps of existing models or the lack of such a model and to provide a useful and practical method for recovery priority of damaged roads in reconstruction and rehabilitation projects. A field survey is carried out to collect data, which are essential to determine the input parameters in the model application, is also presented in this chapter.

Chapter 7 presents the results of four case studies, which are conducted to investigate the application of the RRP model in a variety of road conditions by using different input values in order to evaluate the usability and usefulness of the proposed model in road reconstruction projects. In addition, analysis and discussion of obtained results regarding each case study is also presented.

Finally, Chapter 8 gives the conclusions and achievements of this research and outlines the recommendations for enhancing the proposed RRP model and its applications in the road reconstruction and rehabilitation organisations and presents some major aspects in which further work needs to be considered based on the presented study.

CHAPTER TWO

RESEARCH METHODOLOGY

2.1 Introduction

Natural disasters are a recurring threat to life and infrastructure worldwide today. Roads are commonly affected by flooding, closing them or reducing their serviceability at a time when they are needed the most (Keller and Ketcheson, 2011). This chapter aims at describing the research methodologies adopted in this study to commence, develop, enhance and evaluate the research and proposed model for road recovery priority after a natural/man-made disaster. This chapter starts with an overview of the motives and problems for this study and literature that encouraged conducting more subject-related research to develop a model for road recovery priority. Then, the objectives of the research are detailed and the research methods used in this study to fulfil these objectives are described. Finally, limitations that may affect the adoption and results of the research methodologies will be described. The following chapters will be dedicated to describe the adoption and application of these methodologies in addition to a description of the research final developed model.

2.2 Problem Description

Transportation network protection against natural and human-caused hazards has become a topical research theme in engineering and social sciences (Liu *et al.*, 2008). Roads are a major component of lifelines and a vital tool for the transportation of goods and services between different regions. A significant natural disaster tends to severely violate the functionality of roads in disaster area (Qi *et al.*, 2011). The phases of emergency management have been identified as preparation, response and recovery (Recovering from Disasters: The National Transportation Recovery Strategy, 2009). Considerable emphasis has been placed on the preparation and response phases through evacuation plans and first response after a disaster (Cova *et al.*, 1997; Kovel, 2000; Sakakibara *et al.*, 2004; Sandy, 2009). However, research is lacking in the recovery phase.

A major challenge faced by governments at the end of a natural/man-made disaster is to ensure a speedy recovery of its roads and transportation network, so that regeneration can commence in an effective manner. Regeneration of the road network needs to be put into context of other needs, such as health, education, security, safety, etc., that will also require addressing.

For example, many roads and highways in Iraq and other countries are damaged and suffer from distress, deformation, cracking, or other type of failure, with many of the problems having been caused by either wars or armed conflicts. Hence, one of the important issues faced by the government is the need for great attention to the maintenance and rehabilitation of these roads so that they can perform effectively.

These challenges and barriers that may affect the successful management of road rehabilitation cause the need for a more coherent and structured approach for utilising road recovery priority in road reconstruction organisations. Therefore, it is essential to develop a new model which can be used to satisfy the needs of the road organisations to successfully manage recovery of roads damaged by natural/man-made disasters. This study addresses this problem by developing a RRP model that can deal with road rehabilitation more efficiently and effectively in road reconstruction projects.

This research considers the recovery phase in the framework as described earlier in Chapter 1 which includes phases of mitigation, preparation, response and recovery. The purpose of this research is to develop a methodology needed for prioritising the recovery of road networks after natural/man-made disasters. This is accomplished through the development of a mathematical model with multiple influencing factors. This model will serve as a tool for transportation decision makers for the long-term recovery of road networks.

2.3 Aim and Objectives of the Research

2.3.1 Aim

The overall aim of this research project is to develop a comprehensive RRP model to help road reconstruction organisations to address the issue of recovering and rehabilitation road destroyed/damaged by natural/man-made disasters and to provide a better understanding of what factors govern the road recovery prioritisation of damaged area across a wide region. It is anticipated that this will improve road reconstruction management performance that may have an economic impact by eliminating wasteful time and resources and by concentrating on rehabilitation of the first priority roads.

2.3.2 Objectives

Specific objectives have been formulated and methodologies have been followed in order to achieve the stated aim. The objectives of the research are as follows:

1. To study the effects of natural/man-made disasters on people in the different life sectors such as health, environment, economy and society in the context of road infrastructure and to review current practices in order to assess the impact of these events on infrastructure, in particular roads in a selected country such as Iraq.

2. To estimate and evaluate the most important factors that influence on the priority of road recovery in the context of the different life sectors, especially roads infrastructure.

3. To study, analyse and evaluate existing models of managing road recovery priority by a critical review of the important related literature, discuss problems and fill gaps in those which negatively affect the successful implementation and application of road recovery models in the road rehabilitation context.

4. To develop a methodology for prioritising recovery of road infrastructure depending on road network performance loss through the estimated affecting factors.

5. To create an appropriate model that mimics the pressure on the traffic network system caused by damage occurring after natural/man-made disasters and examine the demands placed on project management and recovery processes. The proposed model will provide practical help to road engineers, managers, operators and decision makers for taking the first step into recovery and maintenance priority of roads. The proposed model formulates a strategic framework and a step-by-step approach to apply in

road organisations. This model will also help road reconstruction organisations to identify the most important factors that may be taken into consideration when prioritising damaged roads for recovery.

6. To apply and evaluate the model to see if it works by applying the chosen research methodology and to make the model and the methodology applicable anywhere. Questionnaire surveys and interview approaches are used to enhance the proposed model and case studies are conducted to evaluate the final developed model in terms of its ease of use, usefulness and importance to the roads maintenance organisations.

7. To provide recommendations for the future development of road recovery priority implementation and application and suggest any further factors and comments that may be included in the future to improve the proposed road recovery priority model.

2.4 Research Methodologies

A combination of quantitative and qualitative research methods has been adopted in this research to investigate road recovery priority critical success factors, tools and activities, and RRP model implementation and application in the road reconstruction sector, in order to develop, enhance and evaluate the proposed RRP model. The main methodologies adopted in this research are:

2.4.1 Literature Review

The research depends on the understanding and analysis of various recent literatures to provide a foundation for this study. Review of literature helps to support the research work with other research on the domain of factors affecting on the road rehabilitation which are damaged by natural/man-made disasters to provide more understanding and strength to the research topic and provide other examples of road recovery priority models to make the research more credible. Existing researches in the road recovery priority and some other general models will be reviewed and analysed. The advantages and disadvantages of the current researches will be studied in order to search for appropriate solutions of problems. This provides a theoretical basis for developing a road recovery priority model that fills gaps of other previous researches and presents an integrated RRP model for the road reconstruction organisations.

2.4.2 Interviews

The interview is probably the most common research method in qualitative research, because it provides an easy and flexible method that can be used to capture important ideas and detailed opinions to enrich the research (Bryman and Bell, 2003; Ahmed, 2010).

Interviews with academics and practitioners in road maintenance engineering and an in-depth study of the general proposed models will help to estimate the most controlling factors on road recovery priority after disasters to enable the development of a road recovery priority model to be used more effectively and efficiently in road maintenance and rehabilitation organisations. Interviewees will be carefully selected and will be asked to provide important opinions and aspects that need to be considered when developing the proposed RRP model, and also to evaluate and discuss the components of this model and provide suggestions for further development of the model.

The interviews follow a semi-structured approach. A procedure as shown in Appendix A will be used in the interviews, but the interviewees will be given flexibility to refer to and discuss their opinions and interests in the road recovery priority field. This also means that questions that are not included in the "questions" list can be asked regarding details and description on things mentioned by the interviewees (Bryman and Bell, 2003). This method may help to encourage the interviewees to provide more important, valuable and detailed responses to the interview questions (Kendall and Kendall, 2002).

2.4.3 Questionnaire Survey

The questionnaire survey is one of the tools used by researchers to confirm, deny or enhance what was already believed or known. Questionnaire survey is important and popular methodology because of its ability to define and detail various characteristics of key issues that can be important and interesting for certain readers and organisations (Chauvel and Despres, 2002). A questionnaire survey also has the ability to provide results that can be quantified and so can be easily treated and analysed statistically. It provides the ability to extend the results obtained from a sample of respondents to a larger population when it is not practical and efficient to work with the entire population. It also provides fast and straightforward results compared with other research methods to allow researchers and practitioners to act in a relatively quick and intellectually respectable manner (Chauvel and Despres, 2002; Ahmed, 2010).

A questionnaire survey has been conducted in this research to investigate the critical influencing factors on the rehabilitation of roads damaged by natural/man-made disasters and estimate the percentage impact of these factors on the road recovery priority. The main objective of the questionnaire is to estimate some values of the model parameters which will then be used in the application of the proposed RRP model. The questionnaire survey helps the research to reach to a final coherent structure of the RRP model that can help to successfully manage prioritisation of the road recovery process in the road reconstruction organisations.

2.4.4 Case Studies

Case study approach is one of several strategies of doing research that has particular advantages compared with other ways, such as experiments, surveys, histories and the analysis of archival information. A common feature of a case study is that it aims to clarify the reasons why a decision or a set of decisions has been adopted, the procedures of implementing the decision and the results for applying such decision (Schramm, 1971; Ahmed, 2010).

According to Yin (2003), a case study is an empirical inquiry that investigates a phenomenon and studies its contextual conditions, especially which might be highly relevant to the phenomenon of study. In general, case studies are the preferred strategy when the researchers are dealing with "how" and "why" questions, having little control over events, and investigating a contemporary phenomenon within some real-life context (Yin, 2003; Ahmed, 2010).

The case study is also a comprehensive research strategy that benefits from the prior development of theoretical propositions to guide the design, data collection and data analysis approaches and techniques (Stoecker, 1991). Since this research aims to investigate why and how road maintenance organisations adopt and apply the priority model of a road recovery, this method has been chosen to fulfil the purpose.

Case studies of four roads in Baghdad city, the capital of Iraq, have been conducted. The case studies have been carried out to investigate some values of the model parameters which will then be used in the general application of the proposed model, evaluate the presented RRP model in terms of its usability and usefulness and demonstrate how the developed model can be used to solve the prioritisation problems of road recovery.

The case studies also aimed to ascertain the advantages of the proposed RRP model in use and sought to find appropriate solutions for problems. The research studied areas for road recovery priority processes in the road reconstruction companies such as implementing or building a structure for the RRP model, applying or using the proposed model to solve problems and impediments related to prioritisation of road recovery.

Among the tools used in the case studies were conducting interviews, observation, and investigating hard data. This research has utilised the knowledge of people whose jobs are related to road maintenance and rehabilitation, such as civil engineers, roads engineers, academics, knowledge managers, decision makers and frequent users.

2.5 Research Stages

The methodologies and stages followed during the research life-cycle are represented in Figures 2.1 and 2.2.

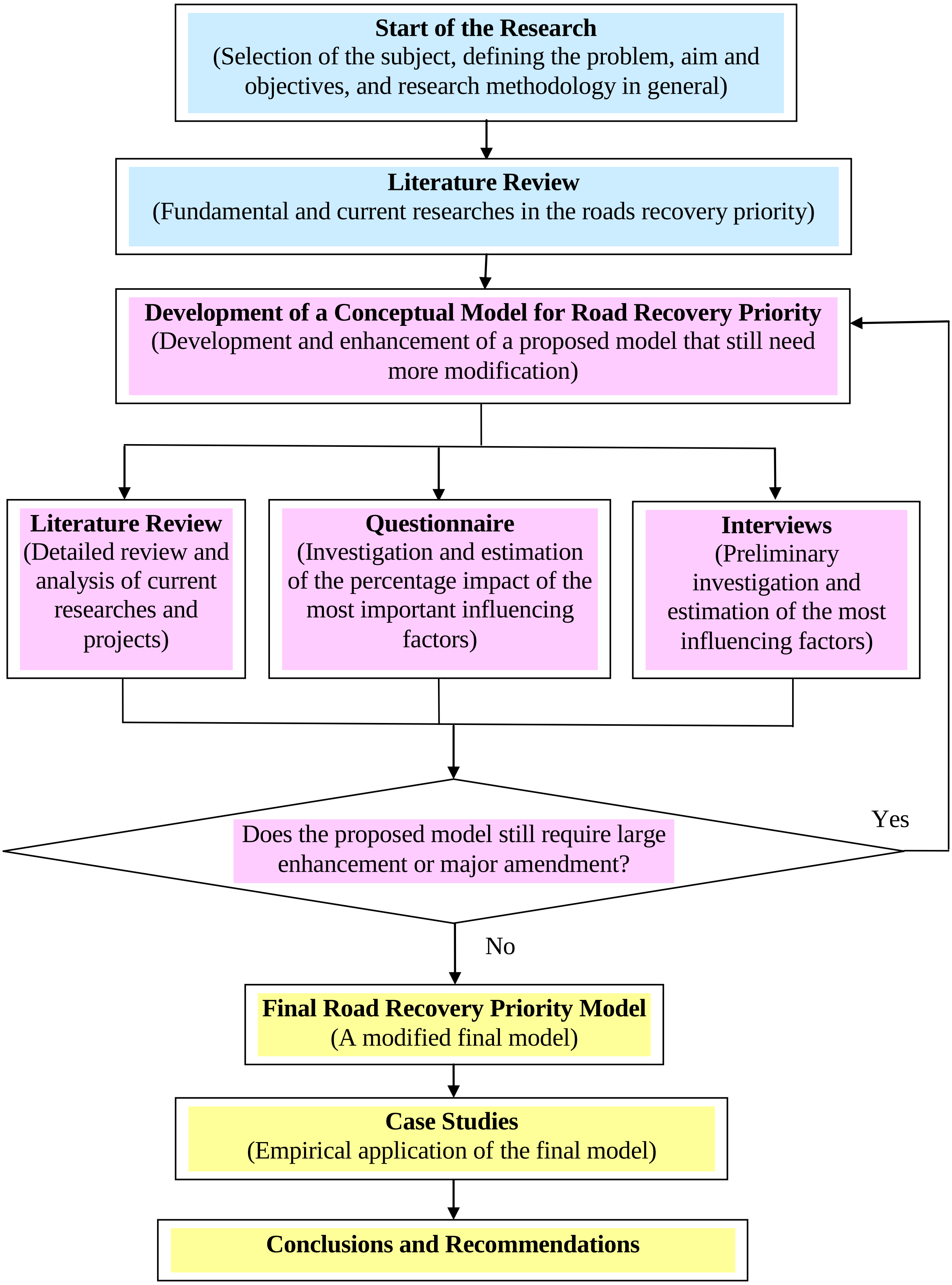

Figure 2.1: Research model

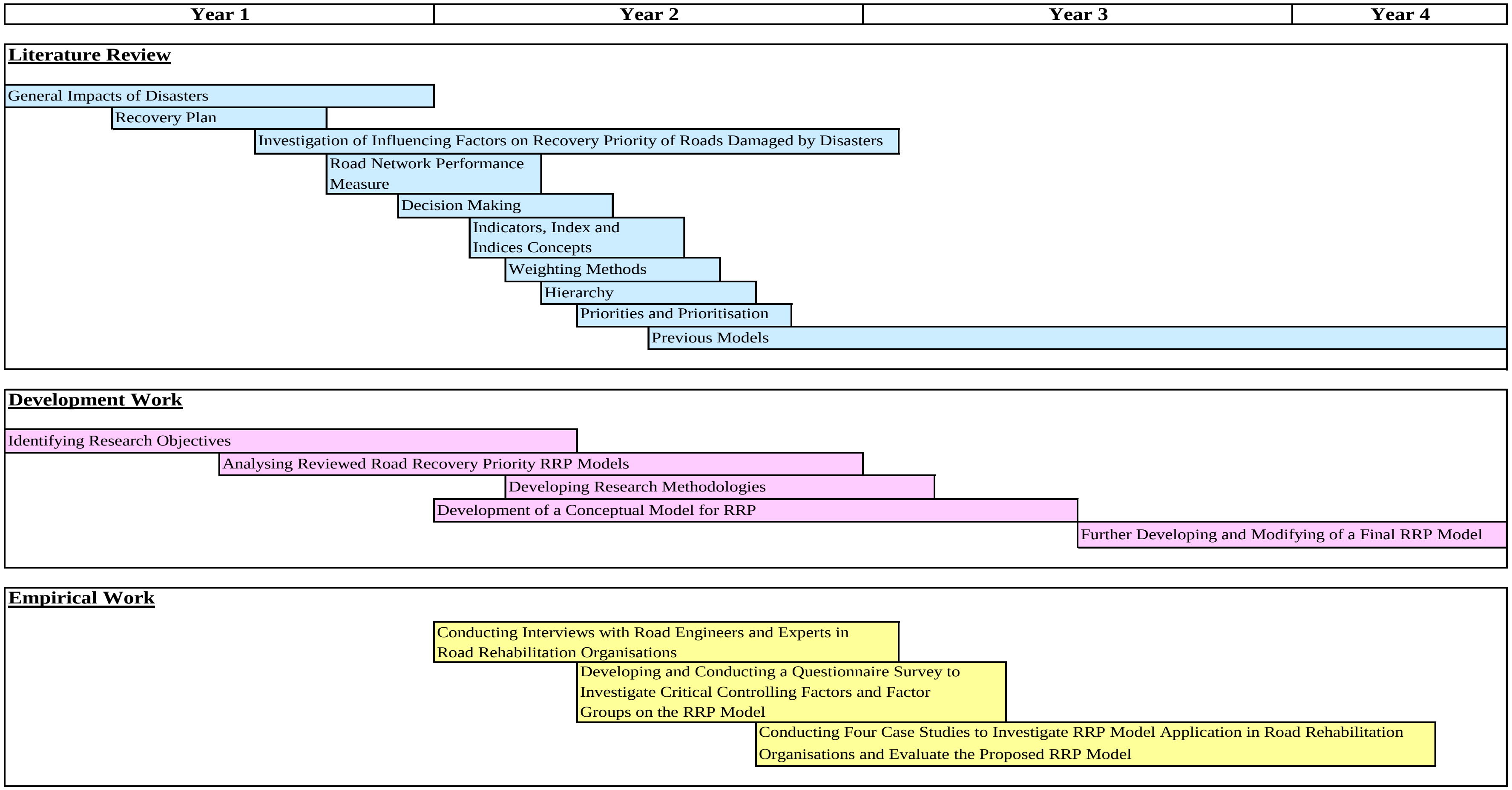

Figure 2.2: Research stages and methodologies

As shown in Figure 2.1, the road recovery priority model has been developed and enhanced from its first step presenting in a conceptual model into a final developed model through continuous reviewing of literature and projects, conducting questionnaire surveys with academics and practitioners, and organising interviews with people from the domain of road maintenance institutions.

These methods have been used to investigate tools, processes, methods and influencing factors, and to collect experts' and practitioners' feedback and ideas for development of the proposed model. This helped the researcher to identify key parts of the proposed model, evaluate the appropriateness of the proposed model, identify important factors that should be included in the development of the model, and finally, to decide required amendments and improvements that might be useful to enhance the developed model.

The research went through an evaluation process through an extensive study of prioritising damaged roads for recovery after natural/man-made disasters, an in-depth review of recent RRP literature and capturing feedback from the research participants. Therefore, limitations of the current researches and the developed model and recommendations to enhance them were concluded and applied.

Chapters 3, 4 and 5 provide more details of how the adopted methodology of the research helped to develop the proposed model for road recovery priority to be more practical and useful for implementation and application in road maintenance and rehabilitation projects.

2.6 Limitations

Applying and implementing a model for road recovery priority in a road reconstruction organisation is a complicated task because the concept is somehow new and also it involves the participation of a large number of factors to be included in it. Also, a huge amount of data is required regarding socio-economic, road network, traffic and damage considerations. This requires a considerable amount of time (perhaps years) to be accomplished, and substantial courage and awareness from organisational management in order to be familiar with such model.

Financial factors and costs (such as reconstruction cost, time cost, unemployment cost, business interruption cost, fuel consumption cost) are a complicated task because it needs a lot of work and time in order to collect data regarding these factors and there is a need to present methods and procedures in order to estimate the value of the related costs so they can then be used in the proposed model. This requires further researches and thus needs a long time to be accomplished. So, because that the time extent is limited in this study, financial (economic) factors are not included in the application of the proposed model. However, these factors have been included in the interview and questionnaire surveys in order to identify their contributing impact weight. Also, they are included in the mathematical equations of the proposed RRP model.

In addition, the lack of practical examples in the road reconstruction companies which cover all of the influencing factors that have been included in the presented RRP model, makes it difficult to draw a comparison between the practical and presented results obtained from the model. This can be considered with another check, in addition to the presented case studies, to effectively investigate the design, implementation and application of the presented model.

Another limitation to the research is that most of the employees in the road reconstruction institutions feel they lack the authority to provide such details due to the restrictions of privacy and confidentiality regulations.

2.7 Summary

This chapter highlighted the importance and need to conduct more research to pinpoint and estimate the most important influencing factors that should be taken into account when recovering roads damaged by natural/man-made disasters and to develop a model that aids in prioritisation of those roads for recovery. This model is important because it can help to manage the prioritisation process of road rehabilitation for road projects. The research aims at developing a model that fills the gaps of previous researches.

Research methods were adopted in this thesis in order to satisfy the research aim and objectives, beginning with an extensive review of road recovery priority literature and existing researches and models. The advantages and disadvantages of the previous researches were analysed to provide a theoretical basis for the development of the proposed model.

Interviews with academics and practitioners in the road maintenance institutions were conducted to estimate and evaluate the most important factors affecting road recovery priority and to improve the proposed model of the research. Furthermore, a questionnaire survey was used to investigate the impact percentages of the influencing factors. This helps to determine some parameters which will be then used in the proposed model.

Finally, four case studies were carried out to investigate the applicability of the proposed model and to evaluate it in terms of usability and usefulness to the roads maintenance organisations. The methodologies, stages and limitations of the research were reviewed and discussed in this chapter, while the application and results of these methodologies will be discussed in the following chapters.

CHAPTER THREE

INTRODUCTION TO THE DISASTERS AND RECOVERY

3.1 Introduction

This chapter aims to study the impacts of natural/man-made disasters on the different life sectors such as infrastructure, health, environment, economy and society and to assess the effect of natural/man-made disasters on roads in order to investigate fundamental factors of the damaged road which influence on the recovery priority for these roads. Also, road recovery related literature has been discussed within this chapter.

Natural disasters not only cause fatalities and injuries but also result in infrastructure damage, substantial social and economic impacts (Sinha, 2008). The roadway transportation system is the key channel for transportation and civil activities. Its destruction after a disaster can have a great impact on road connections, inhibiting the progress of rescue missions (Yan and Shih, 2009). Similarly to natural disasters, man-made disasters can also damage road networks.

Post-war reconstruction begins in the hearts and minds of those who suffer the horrors of war and want to change societies so that there is no return to mass violence. For them planning reconstruction often begins during conflict and is an essential part of negotiating their way towards peace. For the outsiders, post-war reconstruction is always seen as a novel undertaking that only begins when violent conflict has come to an end. Post-war reconstruction is attracting attention from the media, academics, aid-practitioners and policymakers as never before (Barakat, 2005).

Therefore, transportation network protection against natural and human-caused hazards has become a topical research theme in engineering and social sciences (Liu *et al.*, 2008).

Odds are that even when a disaster event is localised to a particular area, a much wider transportation facility location will be impacted. It is necessary, therefore, to carefully examine the recovery process that ensues after a natural disaster. This examination is likely to reveal bottlenecks and problem areas that require further analysis, and will hopefully reveal insights into the recovery process that have been previously absent (Final Report, University of Virginia, 2001).

3.2 Disaster Classification

A disaster is a calamitous event that occurs without any prior warning and causes substantial interruption requiring prompt management attention. Disasters come in many types and forms. They can be classified as natural or man-made. Natural disasters include floods, hurricanes, tornadoes, earthquake and others. There are many man-made threats and they vary by the type of operation. For simplicity, they can be classified as armed conflict, fire and toxic releases, bomb explosions and civil unrest (Zurich Risk Engineering, 2001). Disaster categories can be illustrated in Table 3.1 (Zurich Risk Engineering, 2001; Wolshon *et al.*, 2005; Pradhan *et al.*, 2007).

Table 3.1: Disaster categories

Disaster Cause	
Natural	**Man-made**
Earthquake	Armed conflict
Volcanic eruption	Bomb explosions
Tornado	Civil unrest
Tsunami	Terrorist attack
Wildfire	Toxic releases
Fire	Nuclear contamination
Flood	Dam failure
Hurricane	Fire
Building collapse	Building collapse
Biological outbreak	Explosion
	Hazardous liquid spill
	Biological outbreak
	Oil spill

3.3 Impacts of Disasters

3.3.1 Infrastructure

Infrastructure is defined as the basic facilities, systems (e.g., transportation and communications systems, water and power lines), installations (e.g., military installations), public institutions (e.g., hospitals, schools, factories, post offices, prisons), and associated capital equipment considered essential for enabling productivity in a country's or community's economy. This definition also includes means to sustain the infrastructure (Anke, 1999).

The impact of natural/man-made disasters on the infrastructure sector includes many types such as damage to transportation system, water system, energy networks, public institutions, etc. (Anke, 1999). The impacts can be summarised in Table 3.2.

Table 3.2: Summary of impacts of disasters on infrastructure sector

Sector	Results	Causes
Infrastructure	Damage to infrastructure	Destruction of transportation system
		Damage to energy distribution networks for electricity, gas and petroleum
		Damage to water system
		Destruction of sanitation system
		Poor communication facilities
		Damage to public institutions (e.g., schools, factories, post offices, prisons)
		Impact on irrigation schemes
		Looting and vandalism the institutions during the disaster
		Lack of spare parts, supply of chlorine and erratic electricity supply
	Temporary housing	Damage to a lot of houses

3.3.2 Environment

Different types of damage result from the impact of natural/man-made disasters on the environment such as damage to effect on ecosystems and pollution (Srinivas and Nakagawa, 2008; Medact, 2003) as illustrated in a summary in Table 3.3.

Table 3.3: Summary of impacts of disasters on environment sector

<table>
<tr><th>Sector</th><th>Results</th><th>Causes</th></tr>
<tr><td rowspan="6">Environment</td><td rowspan="4">Effect on ecosystems</td><td>Damage to mangroves, coral reefs, forests, coastal wetlands, vegetation, sand dunes and rock formations, animal and plant biodiversity and groundwater</td></tr>
<tr><td>A large numbers of displaced people are temporarily resettled</td></tr>
<tr><td>Spread of solid and liquid waste and industrial chemical</td></tr>
<tr><td>Destruction of sewage collectors</td></tr>
<tr><td rowspan="2">Pollution</td><td>Water, air and sea</td></tr>
<tr><td>Human and economic crises created by disasters and armed conflict</td></tr>
</table>

3.3.3 Society

Increased poverty and hunger, decreased education, psychological trauma and increased humanitarian aid are types of effects resulting from the disasters (Barakat, 2005; Mohammad, 1999; Anke, 1999). These effects can be summarised in Table 3.4 for the society sector.

Table 3.4: Summary of impacts of disasters on society sector

Sector	Results	Causes
Society	Increased poverty and hunger	Increased unemployment
		Breakdown in local government
		Increased numbers of widows and orphans
		Increased burdens on women
	Decreased education	Poor school attendance, especially for girls
		Population displacement
	Psychological trauma	A lot of people are killed, missing and resettled
		Lack of safe and supportive environment for emotional healing
		People worry that they might not live longer
		Long term negative impact on reconciliation and community reconstruction
		Low morale
		Refugees in camps have little hope of being able to earn living
		Insecurity and lawlessness
	Increased humanitarian aid	Widespread damage of the infrastructure, shortages of food and water and economic damage
		A great effort is needed for burying bodies

3.3.4 Health

The effect of disasters on health can result in many types such as increased mortality, increased morbidity and increased disability (Medact, 2004; Medact, 2003; Anke, 1999). The description and causes of these impacts can be shown in the given summary in Table 3.5.

Table 3.5: Summary of impacts of disasters on health sector

Sector	Results	Causes
Health	Increased mortality	Physical trauma
		Deaths avoidable through health care (e.g., emergency intervention, preventive measures, medication)
		Lack and looting of drugs
		Destruction of clinics
		Damage to medical vehicle and equipment
		Inability to maintain cold chain for vaccines
		Infectious diseases (e.g., diarrhoea diseases, respiratory infection)
		Medical staff may be killed
	Increased morbidity	Injuries due to physical trauma (e.g., burns, poisoning)
		Infectious diseases: water-related (e.g. cholera, typhoid),vector-borne (e.g., malaria), and other communicable diseases(e.g., Tuberculosis, AIDS)
		Nutrition: acute and chronic malnutrition and deficiency disorders
		Injuries due to increased societal violence, including sexual violence
		Reproductive health: more stillbirths and premature births, more babies with low birth weight and more delivery complications
		Impact of psychosocial trauma on mental health (e.g., anxiety, depression, suicide)
	Increased disability	Physical
		Psychological
		Social

3.3.5 Food Security and Nutrition

Table 3.6 shows a summary of the impact of natural/man-made disasters on the food security and nutrition sector. Damage to market roads, lack of agricultural inputs, destruction of food processing and killing of livestock are examples of this impact (Anke, 1999).

Table 3.6: Summary of impacts of disasters on food security and nutrition sector

Sector	Results	Causes
Food Security and Nutrition	Decline of agricultural production	Physical insecurity
		Lack of agricultural inputs and extension services
		Destruction of food processing, storage and distribution systems
		Damage to roads and markets
		Loss of income and employment
		Prices rising
	Limited stock of food	Livestock may be killed during the disaster or as a result of disease
		Fuel shortages
		Inaccessible transportation system
		Insecure environment
		Fisheries are impacted by disaster

3.3.6 Economics

Natural/man-made disasters cause adverse economic effects such as increasing food prices in the markets due to destruction of the transportation system, disruption of trade, reducing the investment and increasing unemployment (Lyons, 2009; Anke, 1999; Le, 2005). A summary of the impacts of these events on the economic sector is shown in Table 3.7.

Table 3.7: Summary of impacts of disasters on economic sector

Sector	Results	Causes
Economic	Adverse economic effects	Unemployment increases and families become dependent on government and foreign aid
		Damage to agriculture
		Damage to export-oriented sector which generating foreign exchange earnings
		Losses in the tourism
		Reducing the investment
		A lot of money is needed for the reconstruction
		Disruption of trade
		Increasing food prices in the markets due to destruction of transportation system

3.4 Investigation of Influential Factors on Recovery Priority of Roads Damaged by Natural/Man-Made Disasters

The removal or blockage of one or more network links, particularly those that are heavily travelled or those containing bridges, could have direct and serious economic consequences in terms of overall system travel-time increases, but also with respect to freight logistics/supply chain management (Bell, 2000; Chen *et al.*, 2002; Smith *et al.*, 2003). Not only could supply routes and delivery schedules be disrupted, but also the costs associated with rescheduling and rerouting could be prohibitive for both suppliers and resellers. Rerouting traffic could also result in additional safety risks and congestion on alternate interstate segments, particularly if a large volume of commercial vehicle traffic was routed to links that were already operating at or close to capacity. Depending on the spatial layout of the network (i.e., network topology) and on specific origins and destinations, different types of traffic could have very difficult time rerouting in the event of a link failure (Bell, 2000).

Current infrastructure management practices typically address the complex decision-making required just to manage demand on individual congested portions of the highway network by identifying critical highway segments using localised level-of-service (LOS) measures such as the volume/capacity (V/C) ratio (Bremmer *et al.*, 2004; Dheenadayalu *et al.*, 2004). A V/C ratio greater than one is indicative of congestion. When a high ratio is identified, improvements are implemented at the segment or corridor level to alleviate or reduce congestion on that particular segment. Often the solution to congestion planning problems is to simply add more capacity along existing highway segments. In effect, this is a localised solution. Performance improvements are measured via a decrease in travel time on specific segments in the local area of the improvement.

The localised V/C approach, however, may not enable traffic engineers and planners to identify the most critical highway segments or corridors in terms of maximising system-wide, travel-time benefits associated with a highway improvement project. Bremmer *et al.* (2004) point out that traditional congestion measurements are based on volume and capacity information, but are often inadequate in many cases. Potential problems associated with the V/C ratio are illustrated in the hypothetical and greatly simplified network as shown in Figure 3.1.

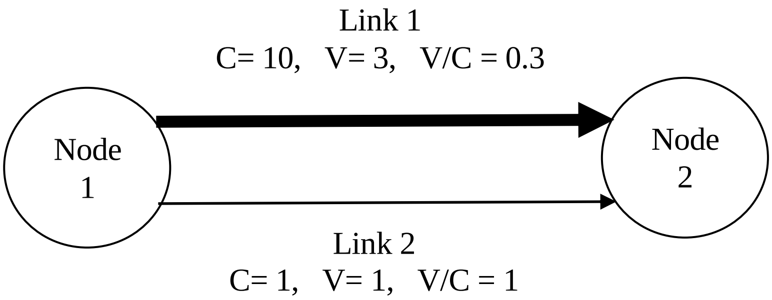

Figure 3.1: Example illustrating critical links using V/C ratios

For example, a comparison of V/C ratios suggests Link 2 is the more critical link — that is, the ratio on Link 2 is equal to 1, while the ratio on Link 1 is equal to 0.3. However, Link 1 carries three times the traffic volume of Link 2. If Link 1 were eliminated, or even partially blocked, rerouted traffic from Link 1 cannot be accommodated on Link 2 as it does not have the capacity to handle the additional traffic. On the other hand, if Link 2 were blocked, rerouted traffic can be accommodated easily on Link 1. Link 1 is actually the more critical link, although the V/C ratio does not adequately reflect its importance to the highway network.

Sugiyanto *et al.* (2011) stated that congestion will generate many problems due to inefficiency. With congested roads, vehicle speed will be simultaneously up and down, and the average speed will be lower and hence the cost will increase. Therefore, road users will suffer from increasing vehicle operating costs and losing more time and the environment will be in a worse condition due to pollution.

Essential for any successful strategy to maximise the social benefits of transport and to minimise the costs of traffic congestion is a combination of efficient transport economy measures, sustainable road design, and intelligent traffic control (Hansen, 2001).

The time loss of road vehicles because of traffic congestion, in general, is determined on the basis of roughly estimated queue lengths, time periods of congestion and mean queue speed. The time loss of road users due to traffic congestion is determined, in general, by comparing the average trip time on congested links with the trip time under free-flow conditions corresponding to the design speed of the road. The easiest manner of registration of congested traffic is used frequently by observing the queue length (Hansen, 2001).

In the first some days after the event the travel pattern in the city is quite different from a normal situation, as indicated by Shariat *et al.* (2004). Travels for job, entertainment, school, and shopping are not the same as before and are usually omitted. So, the paths which provide access to and from hospitals to population centres can be considered as the basic network. The reliable provision of access between population centres and hospitals is considered as the first criterion for the functionality assessment of the city transportation network. Another criterion is the importance of the relief centre or the hospital (Shariat, 2002).

Shariat *et al.* (2004) stated a concept, which they called the Accessibility Index, for the decision making on prioritisation of the transportation system components retrofit. They used the total number of population centres in the city, the number of available hospitals and the capacity of the hospitals as factors in their method. Also, they used five types of damage classification of the bridges: no damage, slight, moderate, extensive and collapse (Shariat *et al.*, 2004).

Sullivan *et al.* (2010) advanced a methodological approach that employs different link-based capacity-disruption values for identifying and ranking the most critical links and quantifying network robustness in a transportation network. They showed that system-wide travel-times and the rank-ordering of the most critical links in a network can vary dramatically based on both the capacity-disruption level and on the overall connectivity of the network.

When modelling transportation network-disruptions the traffic flow regimen and the assumptions related to the disruptive event are important. Traffic flows can vary dramatically on a particular link depending on whether a disruption is modelled as a complete or partial reduction in the capacity on that link and on the actual duration of the disruption. It is also the case that traffic that re-routes as a result of the disruption may be chosen from many different alternative paths or even cancel certain trips altogether (Sullivan *et al.,* 2010).

The relationship of the capacity-disruption level is defined as the reduction in the capacity on a given link due to some type of disruption expressed as a percentage. Using a 100% capacity-disruption level effectively removes the link from the network (either physically or functionally) and reduces the capacity on a given link to zero (Sullivan *et al.,* 2010).

Sullivan *et al.* (2010) also stated that the most obvious problem resulting from completely removing a network links to model disruptions is the creation of isolated sub-networks, which are no longer accessible when the single link connecting them to the network has been removed. A graphical example of an isolating link and an isolated sub-network is provided in Figure 3.2.

When an isolating link is removed from the network, it becomes impossible to estimate the system-wide impact of that link on travel time for the trips originating from, or destined for, locations within an isolated sub-network using traditional network analysis techniques. Travel time on these links become infinite because no traffic can traverse the link, which compromises the model results. For systems with one or more isolated sub-networks, the presence of traffic on the isolating links may have a substantial impact on how network performance is measured as the traffic on the isolating links has no alternative travel path (Sullivan *et al.,* 2010).

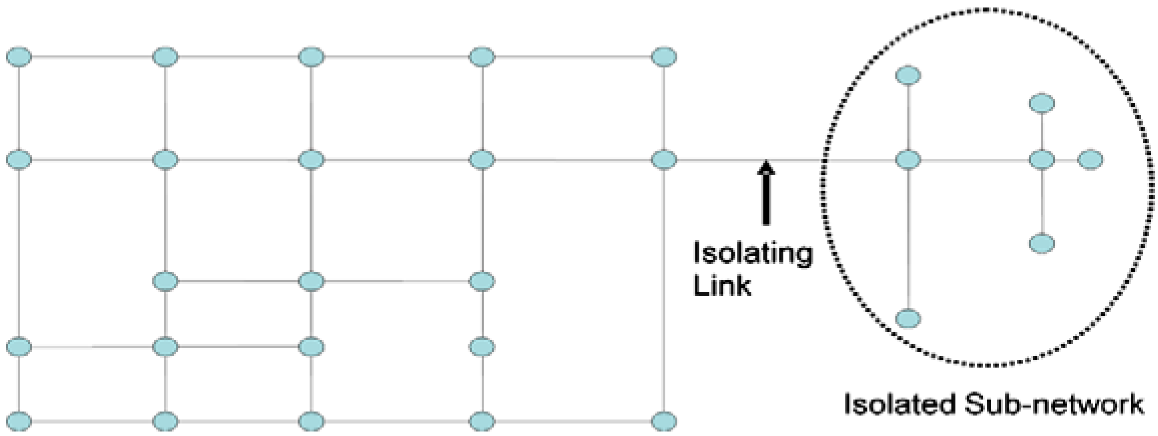

Figure 3.2: Illustration of an isolating link and an isolated sub-network

Historically, transportation planners have focused on the links or nodes in a network that have the largest volume of traffic passing through them. Commonly used performance measures include the link-specific average annual daily traffic (AADT) collected from traffic counters, and the Volume-to-Capacity ratio (V/C) which is the output of common travel demand models (FHWA, 2008). As transportation networks become more heavily used, planning and maintenance approaches focusing on AADT and V/C may not be adequate because they are inherently localised and static in nature (Sullivan *et al.,* 2010).

User service time measure was defined as the quality of service. In the case of roadways, for example, a project may improve the quality of service if it decreases the traffic delays experienced by motorists (Merkhofer, 1997).

Sinha (2008) stated that multi-objective decision analysis should be done in order to prioritise recovery activities based on available data pertaining to average daily traffic (ADT), population density and total estimated cost. Accordingly, the activities located in highly populated areas with heavy traffic flows have received high priority.

The physical damage to road infrastructure and the related hazards provide the beginning of an economic damage assessment. The direct losses such as the repair or replacement costs for the damaged roads are easy to notice and observe, since they are directly caused by the incident. However, they are only part of the total losses that are caused by the disasters. From an economic perspective there are indirect costs too, associated with the damage caused by natural disasters like temporary unemployment, business interruption, etc. (Sinha, 2008).

Goodwin (2005) treats time as a sort of money; spends, save, lose or waste it, with a value that depends on a whole range of factors. The traditional way of calculating the total economic cost of congestion compares the actual travel conditions with the conditions that would apply if everyone is travelling at 'free flow' speed; i.e.

unencumbered by any other vehicles, and driving as fast as they choose (subject, of course, to the legal speed limit).

Orabi *et al*. (2009b) stated that the performance loss is measured in terms of the additional travel time spent by travellers on the damaged transportation network compared to the pre-disaster conditions. This total daily travel time is compared to the pre-disaster total daily travel time to estimate the additional daily travel time.

The travel time is often considered to be the most important factor that affects travellers on damaged transportation networks, especially when they need to travel longer detours or their original routes but with significantly reduced speeds. Travellers are often reported to choose routes that they perceive to have the least travel time. Accordingly, travel routes that are perceived to be faster attract larger traffic volumes. These routes can then experience traffic volumes that exceed their capacities, creating traffic congestions and increased travel times that in turn cause travellers to consider other faster alternatives (Orabi *et al*., 2009a).

Also, the researchers stated that as the recovery efforts progress, the functional status of different road segments can dynamically alternate between open, partially closed and closed (Orabi *et al*., 2009b).

Orabi *et al*. (2009a) stated that data is needed in the network performance loss model to represent the traffic data and the topology of the transportation network. The traffic data include: (1) the traffic demand on the network which can be described by the origin-destination (O/D) pair flows; (2) the capacity of the road segments; (3) the free flow speed for each road on the network; and (4) the functions used to estimate the travel time on the different routes of the network. The network topology include data on: (1) the nodes which represent the traffic loading/unloading points to/from the network such as cities, intersections and exits; (2) the links which represent the road segments connecting different nodes; and (3) the incidence information which identifies the relationship between nodes and links and the direction of traffic flow on each link.

The model designed by the researchers to focus on the construction related costs of the recovery efforts, including direct cost (DC) and indirect cost (IC) while non-construction related costs (e.g., road user and business disruption) are not included. The DC includes the cost of reconstruction resources. The IC includes time-dependent costs such as site overhead (Orabi *et al*., 2009a).

Available metrics for measuring the functional performance of transportation networks include: travel time, distance, direct cost, reliability and comfort as indicated by Bell and Iida (1997).

Longer road lengths are likely to score higher with more facilities, services and population along its length. Another important basic indicator is the population served by the road as mentioned by Leyland (2010).

Chang (2003) proposed a mathematical model for comparing restoration strategies in the urban area of Seattle, Washington. The author also developed an approach for post-disaster restoration of highway networks with performance measured in terms of transportation accessibility to the regional population. Two different strategies were compared for repairing highway networks to allow the greatest concentrations of the population in and out of the urban area. The first strategy evaluated was the repair of the least physically damaged areas to the most severely damaged areas. The second strategy was to repair an entire route irrespectively of the damage state of the route.

Similar research carried out by Sakakibara *et al*. (2004) where a topological index was used to quantify road network depressiveness/concentration in a disaster situation and prevent isolating city districts for evacuation. The most robust network was defined as the network that minimised the isolation of districts in a catastrophic disaster. The topological index was calculated based on the various links and nodes representing a given road network structure. A larger topological index means a more dispersed road network. A dispersed road network is less likely to cause isolation of districts in a disaster because it provides more possibilities of connection with neighbouring districts than a concentrated network. This method was applied to a highway network in the Hanshin region of Japan.

Yan and Shih (2009) studied rural roadway networks and developed a model with the objective of minimising the length of time for emergency repair and relief distribution with the shortest possible period of time. This research admittedly was not concerned with long-term repairs. The model was tested on a highway network in Taiwan.

Sato and Ichii (1995) studied the feasibility of using Genetic Algorithms to optimise the restoration process of lifeline networks after an earthquake. The research established an index to measure the efficiency of the restoration process that would be minimised to provide the restoration time of each damaged component in the network. The optimisation was the restoration process to reduce the inconvenience of delayed travel times of the damaged road network.

A model found by Sandy (2009) allows specific routes to be chosen for reconstruction based on a set of criteria determined by the user. The criteria for his research include giving priority to local industry in order to speed the economic recovery of a disaster stricken area. Typically, entities such as hospitals, schools, residential areas or business parks are those where the restoration of transportation accessibility is critical.

Impacts from a natural disaster have a widespread effect on the economy of that area. Experience has shown that the effects of disasters on highway components not only disrupt traffic flows, but the economic recovery is also impacted (Werner *et al*., 2000).

Physical damage to housing and lifeline services can lead to indirect economic losses due to business disruption (Guha, 2001; Cho *et al.*, 2001).

Kovel (2000) suggested that an effective recovery model should consider, at a minimum, which roadways should be evaluated, the resources available for repairs and the extent of likely damage to these roadways and the transportation components contained within them. A list of factors considered in the development of this model is given below:

- Functional classification of roadways considered for reconstruction, such as interstates, arterials and collectors.
- Administrative classification of roadways was also considered, such as US highways and state routes.
- Types of transportation components in the study area. Examples include bridges, overpasses and tunnels. Other transportation components, such as

intersections and uninterrupted segments of roadway, were not considered for that research.

- Sizes of the transportation components. Examples include the number of spans or length on a bridge or length of a tunnel.
- Costs of repair or replacement of the transportation components.
- Locations of the transportation components.
- Possible damage levels to the facilities with varying types of disasters. Damage levels are classified as slight damage, moderate damage, extensive damage or complete damage.
- Locations of major roadways used by priority entities as decided by state and local officials. Examples of priority entities could include hospitals, schools, residential areas or businesses.
- Locations of major businesses.
- Shortest paths from businesses to the perimeter of damage of a disaster (Kovel, 2000).

Traffic congestion, queues on roads, does cost money as stated by Koopmans (2003). The fact that motorists cannot reach their destination within the time that corresponds with freely flowing traffic conditions leads to a loss of time, and therefore a loss of productivity.

Natural disasters often cause significant damage to existing transportation networks leading to substantial socio-economic disruption for the public, as stated by Housner and Thiel (1995). As a result of the 1991 Northbridge earthquake, the level of service of critical highways was severely disrupted at four locations in the north-western Los Angeles metropolitan area (Chang and Nojima, 2001).

Zamichow and Ellis (1994) stated that the 1991 Northbridge earthquake resulted in major disruptions in the movement of people and goods. In addition, the closure of parts of Interstate 10 (Santa Monica Freeway) alone caused financial losses to Los Angeles and its neighbouring communities which were estimated at $1 million per day in lost wages and depressed economy.

Extreme weather conditions or other natural phenomena can make large parts of the road network impassable as indicated by Berdica (2002). The resulting congestion effects and delays cause serious losses in terms of travel time as well as other costs (e.g., in the cases of 'just in time' deliveries).

Travel time is identified as a common thread, in that it exists not only as a direct measure but also as an element of other indicators. In the Highway Capacity Manual, speed is chosen as a simple indicator for the level of service. Speed is directly influenced by traffic flow in that low volumes permit high or steady speed while high volumes cause low or varying speed. In other words, traffic volume should be kept at a lower level than the capacity of the street in order to retain high transport quality. These indicators can measure transport system performance (Berdica, 2002).

Noland *et al.* (1998) found that the extra travel costs resulting from increased travel times were in fact not as great as those connected to an increasing probability of arriving at the 'wrong' time, so called scheduling capacity.

An inspection was carried out by Tanaka *et al.* (2000) to grasp the overview of the expressway network damage and to construct the repair strategies and estimate the restoration time for all structures. The inspection was focused on structural damages and road surface conditions. The structural damages are classified into five categories; they are collapse, major damage, moderate damage, minor damage and no damage. The road surface conditions are classified into three categories; they are impossible to driving, possible to driving with some problems and possible to driving without any problems.

In the road network system, according to necessity of network reliability analysis and studies of earthquake damage materials, the researchers divided damage degree into three grades as stated by Chunguang and Huiying (2000):

- Basic good: Road is basically good or slight crack, bridge is basically good, but some non-structures have slight damage. It can meet normal transportation capacity, and can be used.
- Slight destruction: Road has many cracks, but can be still gone through. Some parts of bridge have damage. It can be used by appropriately repairing and strengthening.
- Heavy destruction: The surfaces of road have many cracks. It is inevitable to repair in a period of time; the important parts of bridge have damages. The load capacity will decrease (Chunguang and Huiying, 2000).

The functional performance measures of the highway system after earthquakes reflect (a) physical performance of links, (b) network properties such as capacity and redundancy, (c) decrease in O/D trips due to overload, (d) increase in trip length due to detouring actions, and (e) increase in travel time due to detouring and congestion (Nojima and Sugito, 2000).

The required inventory data, which were needed for the earthquake risk assessment model for Taiwan, can take two forms. The first is the inventory data such as the square footage of buildings of a specified type, the length of roadways or the population in the study region. They are used to estimate the amount of exposure or potential damage in the region. The second data type include characteristics of the local economy, which are important in estimating losses, e.g., rental rates, construction costs, regional economic output, or regional unemployment rates (Loh *et al.*, 2000).

Hosseini and Vayeghan (2008) proposed a somehow new concept for roads, the “road service area”, which is defined based on a major origin-destination pair and their surrounding industrial, cultural centres, or the centres of any type of economic activity. By using this concept, each country can be divided into some “road service areas” and then these areas can be prioritised based on various parameters, including hazard, vulnerability, and the transportation service presented in each area.

The parameters which are used in the risk calculation are of two kinds. One is related to seismic hazard and vulnerability, and the other one is related to transportation service. The relative length of the road is one of the parameters included in the seismic hazard and vulnerability in each “service area”. The relative population is one of the parameters with regard to transportation service in each “service area” (Hosseini and Vayeghan, 2008).

When applied to a specific damage condition of road network, maximum flow is an essential ingredient in determining serviceability of the system as stated by Fenves and Law (1979).

Nojima (1998) stated that maximum flow is introduced as a performance measure of road networks subject to failure. When detailed and precise information is available, one can estimate network performance in terms of flow-dependent measures such as traffic volume at arbitrary routes or cross-sections, and travel time required for arbitrary O/D pairs. Functional degradation can be evaluated on the basis of pre-quake capacity of individual links and post-earthquake structural damage pattern (Nojima, 1998).

Basoz and Kiremidjian (1996) consider the time delay and use the information primarily for retrofit prioritisation strategies. Kiremidjian *et al.* (2007) illustrated that the risk from earthquakes to a transportation system is evaluated in terms of direct loss from damage to bridges and travel delays in the transportation network. The time delays can result from closure of particular routes because of excessive damage to key components such as bridges, or due to reduced flow capacity (either from imposed lower speed limit or closure of number of available traffic lanes) due to minor or moderate damage.

The fragility functions are used to estimate the damage to the bridges for the scenario event resulting from ground shaking. The fragility functions define the probability of being or exceeding one of five damage states for a given ground motion level. The five damage states are: (1) no damage; (2) minor; (3) moderate; (4) major; and (5) complete (Basoz and Mander, 1999).

Because of the abrupt change in traffic demand just after the occurrence of a severe event such as an earthquake in a large vulnerable city, the transportation network should not only be safe enough to offer its normal service to the city, but also it should be able to cope with this increased demand. This is why the transportation network in many large and populated cities in earthquake prone areas are highly vulnerable on the one hand, and there are financial limitations, time restrictions and only a small number of retrofit experts, particularly in developing countries, on the other hand. Therefore, it is necessary to consider a prioritisation scheme for the retrofit of city transportation system components (Nicholson and Du, 1997).

Leng *et al.* (2010) stated that at present, the network reliability researches are focused on network connection reliability, travel time reliability and capacity reliability (Leng *et al.*, 2009; Chen *et al.*, 2000; Asakura, 2007). The travel time reliability is the probability of which a trip between a given O/D pair can be made successfully within a specified interval of time for a given level of traffic demand (Lo *et al.*, 2006; Uno *et al.*, 2009). It was originally proposed by Asakura and Kashiwadani in 1991 to investigate the impact of O/D demand level fluctuation on travel time. Capacity reliability is the probability of which the network can accommodate a certain traffic demand at a required level of service (LOS). It was proposed by Chen *et al.* (2000).

Based on the features of two-lane highways and intersection control, several candidate service measures were considered, such as volume/capacity ratio, average travel speed, percent time spent following, travel time, percent free-flow speed, density, and delay (Yu, 2006). Based on an evaluation of the advantages and disadvantages of the candidate service measures, percent delay (PD) was chosen as an appropriate single service measure for the interrupted-flow facility of a two-lane highway with signalised intersections. The PD is defined as the ratio of delay to free-flow travel time, expressed as a percentage. The intent of this definition is to reflect that it is the amount of delay relative to the free-flow travel time that is more important to travellers rather than just the total amount of delay (Yu and Washburn, 2009).

Corley and Sha (1982) proposed an algorithm for identifying the most vital links or nodes in a network whose removal results in the greatest increase in the shortest distance between two specific nodes.

Author of this thesis agrees with the factors aforementioned by the previous researchers, which the author believes that they are important when dealing with the issue of recovery priority for roads damaged by natural/man-made disasters. The author also believes that other factors are also essential for a successful strategy for road recovery such as the restoration time for all roads. It is also necessary to estimate how much traffic congestion, queues, travel delay, loss of time, and loss of productivity costs in terms of money. So, in this work, efforts has been made to join the above-mentioned factors which can more comprehensively estimate the performance of the stochastic road network and provide a more reasonable calculation method in order to develop a model which can provide help in determining the first priority roads for recovery after natural/man-made disasters.

3.5 Recovery Plan

3.5.1 Introduction

A recovery is one of the phases of emergency management, as shown in Figure 3.3. The planning, training, exercising, implementation of appropriate technologies, and creation and strengthening of vital partnerships involved in recovery are ongoing for communities. Each of these process steps is necessary for the development of viable recovery programmes and initiatives in the preparedness phase of emergency management. However, direct recovery activities, such as actual rebuilding and construction, only begin when the immediate lifesaving activities of the response phase are completed (Recovering from Disasters: The National Transportation Recovery Strategy, 2009).

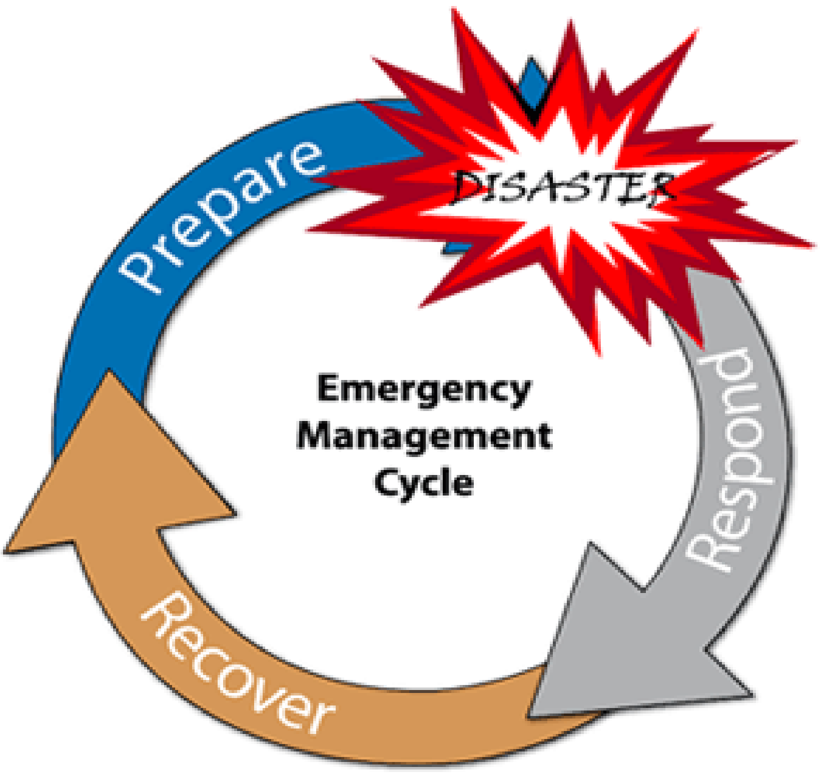

Figure 3.3: Emergency management cycle

Rebuilding damaged physical infrastructure (e.g., water and electricity supply systems, sewage disposal, transport infrastructure) and social infrastructure (e.g., schools, community centres and clinics), constitutes a major challenge in post-conflict reconstruction. The challenge is usually compounded by pre-existing shortcomings, under funding, poor management and maintenance, as well as by the sudden surges in demand at the end of conflict, for example, from the returning population.

Physical infrastructure is usually tackled first because it provides the platform for many other elements. Reconstruction, population return, economic revitalisation and peace building depends on that platform. Issues of prioritisation, linked to the often formidable scale of rehabilitation works, are salient and unique aspects in infrastructure reconstruction.

The first task of a government emerging from conflict is to ascertain the degree of physical, political, economic and social reconstruction required in order to steer the country back to the road of development. This will clearly differ depending on the nature and geography of the conflict, the degree of destruction and the state of development prior to conflict. The second task of the government must therefore be to identify the potential obstacles to reconstruction and development that may impede or even undermine the recovery process (Barakat, 2005).

Disaster recovery operations highlight the importance of the recovery period and the need to anticipate the demands that recovery will probably create. Public officials must be prepared to lead the community to recovery (victims and their families, emergency workers and volunteers), restore utilities, repair roads, and programme future development without losing sight of the less visible damage caused by emergencies and disasters (Comprehensive Emergency Management Plan, 2007).

Transportation network reconstruction in many natural disaster issues is a main research topic. No matter what emergency evacuation and rescue strategies are implemented, the role of transportation network reconstruction is the kernel of these issues. The emergency evacuation and rescue network reconstruction problem is to find the optimal transportation network recovery strategies after natural disaster and armed conflict. The so-called "network reconstruction" is recovery road capacities that is destroyed by natural disaster (Wang and Hu, 2005).

Recovery consists of providing immediate support during the early recovery period necessary to return vital life support systems to minimum operation levels, and continuing to provide support until the community returns to normal (Petak, 1985). It covers a wider range of work including compensations and programmes devised for social and economic healing operations. The main purpose of the recovery planning is to ensure the continuity of the organisations' operations in the crisis field to stabilise the essential functions and systems of the community in the shortest time. Nevertheless, many recovery plans face failure because it is a post-crisis event and consists of contingency, where no pre-determined principles work and most of the work requires ad hoc operations (Sandhu, 2002; Unlu *et al.*, 2010).

The purpose of recovery planning is to anticipate what will be needed to restore the community to full functioning as rapidly as possible through pre-event planning and cooperation between citizens, businesses and government. Successful community recovery from disaster will only occur if everyone in the community understands the process, and how they fit in. Individuals, agencies, organisations and businesses must understand their responsibilities and must coordinate their work efforts with the country's recovery leadership. This recovery plan and its associated recovery support functions are intended to guide the country's post-disaster and short and long-term recovery efforts (Comprehensive Emergency Management Plan, 2007).

3.5.2 Recovery Phase

The recovery phase begins during the response phase as shown in Figure 3.3. Initial focus of recovery planning is on impact assessment. The country's response to disaster impacts will follow a "phased approach" that includes short-term and long-term.

- **Short-term recovery** operations begin during the response phase of the emergency and can last up to six months. Short-term tasks can be grouped into as follows:
    - Emergency Response: Public Safety Phase – Impact to two weeks (e.g., medical care, grants, public information, temporary housing).
    - Emergency Assistance: Human Services Phase – Impact 24 hours to five months (e.g., damage assessment, reconstruction planning, restore utilities such as water, power and sewer).
    - Short-term Recovery: Emergency Restoration and Repairs Phase – Impact to six months (e.g., repairing urgent roads, returning vital life support systems to minimum operation levels).
- The goal of **long-term recovery** is to restore the community to the pre-disaster and pre-conflict (or better) condition. Some of the long-term recovery

activities are extensions of short-term activities; other long-term tasks begin after short-term tasks are completed. The long-term recovery phase can last up to 10 years (Comprehensive Emergency Management Plan, 2007).

3.5.3 Concept of Recovery

Bruneau *et al.* (2003) has defined seismic resilience as the ability of a system to reduce the chances of a shock, to absorb such a shock if it occurs (abrupt reduction of performance) and to recover quickly after a shock (re-establish normal performance).

A broad measure of resilience can be expressed, in general terms, by the concepts illustrated in Figure 3.4. This approach is based on the notion that a measure, Q(t), which varies with time, has been defined for the quality of the infrastructure of a community. Specifically, performance can range from 0% to 100%, where 100% means no degradation in service and 0% means no service is available. For example, if an earthquake occurs at time t_0, it could cause sufficient damage to the infrastructure such that the quality is immediately reduced (from 100% to 50%, as an example, in Figure 3.4). Restoration of the infrastructure is expected to occur over time, as indicated in that figure, until time t_1 when it is completely repaired (indicated by a quality of 100%) (Bruneau *et al.*, 2003).

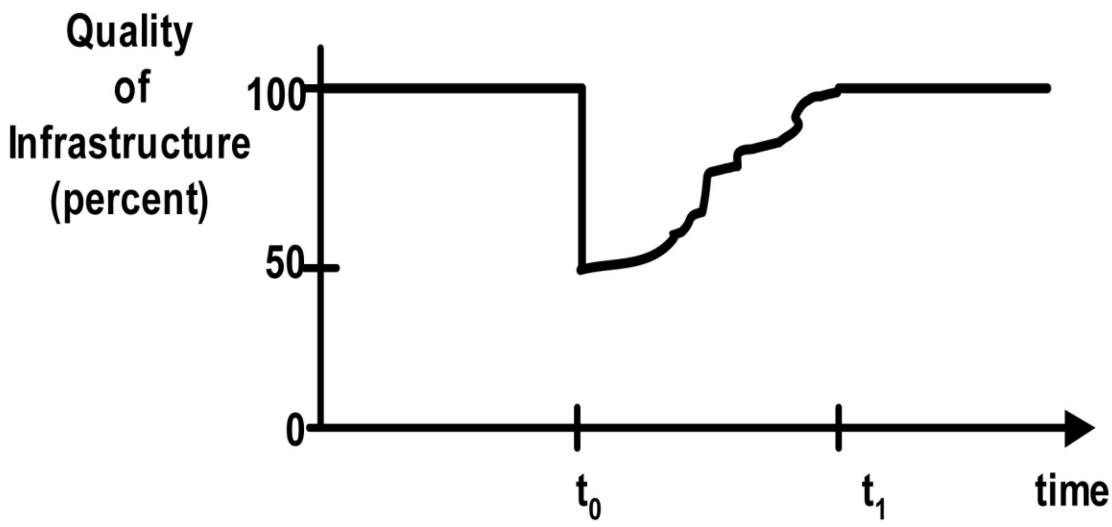

Figure 3.4: Measure of seismic resilience; conceptual definition

In principle, the strategy for measuring community resilience is to quantify the difference between the ability of a community's infrastructure to provide community services prior to the occurrence of an earthquake and the expected ability of that infrastructure to perform after an earthquake. Some of the factors that must be addressed in developing an appropriate scale include:

- The quality of the community infrastructure prior to any earthquakes.
- The expected reduction in quality of the infrastructure over time due to the occurrence of any earthquake.
- The expected length of time that the infrastructure quality is below the pre-earthquake level.
- The set of all possible earthquakes that threaten a community and their probabilities of occurrence (Bruneau *et al.*, 2003).

3.5.4 Recovery Function

Cimellaro *et al.* (2006) stated that different kinds of recovery functions can be chosen depending on system and society response. Three recovery functions are shown in Figure 3.5: linear, exponential and trigonometric.

The simplest form is a linear recovery function that is generally used when there is no information regarding the society response. The exponential recovery function is used where the society response to an extreme event is very fast driven by an initial inflow of resources, but then the rapidity of recovery decreases. Trigonometric recovery function is used when the society response to a drastic event is very slow initially. This could be due to lack of organisation and/or resources. As soon as the community organises himself, thanks for example to the help of other communities, then the recovery system starts operating and the rapidity of recovery increases.

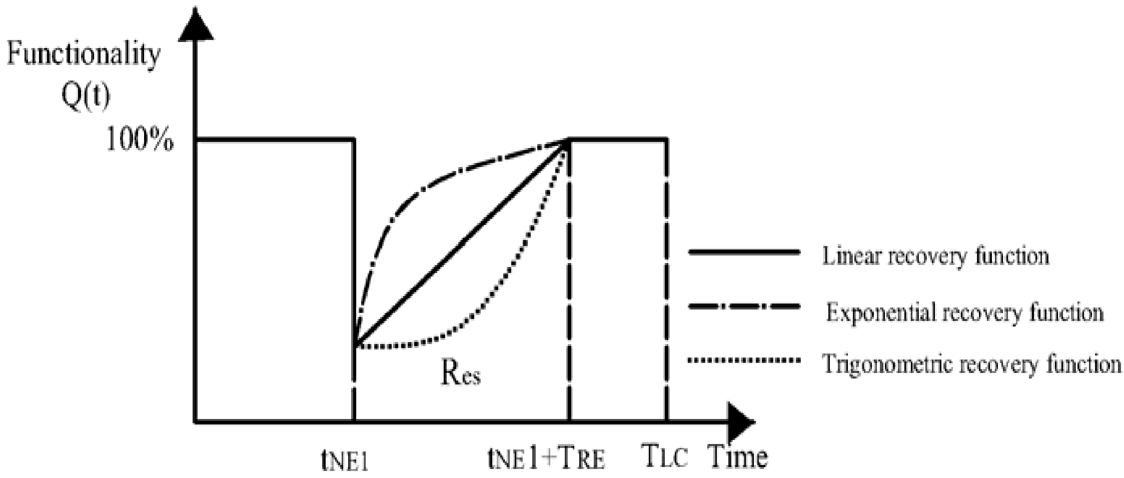

Figure 3.5: Recovery functions

Where T_{RE} is the recovery time, t_{NE} is time of occurrence of an extreme event and T_{LC} is time over a control period of time (life cycle) (Cimellaro *et al.*, 2006).

3.5.5 Recovery of Iraqi Roads

Iraq's transportation networks are vital supports, a series of crucial bridges, reconnecting Iraqi cities and commerce, culture, and infrastructure. By 2004, U.S. Agency for International Development (USAID) had rebuilt provinces while re-establishing key commercial links to neighbouring countries. A new railway connects Iraq's only deep water port to a faster and more reliable distribution system, improving the movement of goods and equipment throughout the country while benefitting local exporters.

USAID completed 36 detailed assessments and demolished irreparable bridge sections in the rebuilding of three key bridges: the Al Mat Bridge, the Khazir Bridge, and the Tikrit Bridge (USAID, 2006).

The Al Khazir Bridge, (Figures 3.6 and 3.7), consists of a pair of dual-lane bridges crossing the Al Khazir River (two lanes in each direction). One end span in each direction was destroyed. Bechtel demolished the damaged spans and rebuilt the abutments. The reconstruction plan included running traffic on a military bridge on one westbound lane while repairs were made to the eastbound lanes. Two-way traffic was diverted to the eastbound lanes once their construction was complete, enabling repair of the westbound lanes. The bridge reopened to full traffic flow at the end of April 2004 (USAID/Bechtel, 2006).

Figure 3.6: The Al-Khazir Bridge

Figure 3.7: The Al-Khazir Bridge

The Tikrit Bridge, (Figure 3.8), is a two-lane bridge with a single lane in each direction. Due to heavy damage, traffic was using military bridges for eastbound traffic and the remaining bridge deck and sidewalk for westbound traffic. The bridge was completed and reopened to traffic in September 2004, restoring a vital link between Northern and Southern Iraq (USAID/Bechtel, 2006).

The Al Mat Bridge comprises a pair of dual-lane bridges that suffered extensive damage. Bechtel constructed a bypass in summer 2003 to keep traffic moving between Baghdad and Jordan through the Al Wadi valley. In March 2004, all demolition and reconstruction was completed and the bridge opened to traffic, enabling several thousand vehicles a day to deliver humanitarian aid and supplies to Baghdad from Amman, Jordan (USAID/Bechtel, 2006).

Figure 3.8: The Tikrit Bridge

The U.S. Army Corps of Engineers Gulf Region Division reworked more than 80 kilometres of road and an additional 120 kilometres of hard surface roads were added. The Tameen road segment, one of 17 road projects, has improved mobility for 30,000 people in three villages and the surrounding area.

These improvements generally include roadbed preparation and the paving of existing dirt roads. The finished work leaves behind graded shoulders, culvert installation, and general drainage improvements. These improvements will not only provide paved roads for the residents, but also substantially decrease emergency vehicle response times. These efforts provide benefit to the residents in the area and help to reduce vehicle maintenance (Defend America, 2005).

3.6 Summary

This chapter aimed at providing the required background of information related to the aim of the research to develop a model for road recovery priority implementation and application in road reconstruction and rehabilitation projects. The chapter started with a general classification of disasters. Then, the chapter reviewed important impacts of disasters on different sectors of life such as infrastructure, society and economic.

In the following section of this chapter, investigation is done to give a better understanding of the important factors that govern and affect the recovery priority of roads damaged by natural/man-made disasters.

Finally, an introduction to the recovery plan is provided in term of phases, concept and function to assist as a starting point in this research in order to investigate the different areas of the road recovery priority, identify the subjects of interest that require more research work, and to provide required background that simplify understanding and developing the road recovery priority model.

The following chapter will discuss the fundamental literature review and the research methods followed to achieve the desirable results.

CHAPTER FOUR

FUNDAMENTAL LITERATURE REVIEW

4.1 Introduction

Assaf (2011) stated that one of the pressing concerns that people have is the sudden advent of a mass disaster that could bring death and wreak havoc and destruction on the communities. This concern is shared by societies of different time and places. Whether these hazards are floods, earthquakes, tsunamis, volcanic eruptions, wildfires, hurricanes, terrorist attacks, or landslides, societies have placed high priorities on efforts to mitigate, prepare for, respond to, and recover from disasters. Over the past decade there has been a noticeable increase in research related to the disruption of transportation networks which has been largely motivated by major catastrophic events (Sullivan *et al.*, 2010).

Project management becomes critical following situations where lives and extensive amounts of capital are placed in jeopardy. Recovery efforts following a hurricane strike represent important projects that must be managed carefully and efficiently, in order to ensure that all systems return to an on-line status in the minimum amount of time possible (Final Report, University of Virginia, 2001).

This chapter aims at providing a detailed review of various literatures that are dealing with road maintenance management projects and identifying subjects of interest that have shortcomings and gaps to fill. Insights gained from analysing the related researches will be highlighted and findings will be presented to provide an important background for the development of a proposed road recovery priority RRP model. This chapter concentrates on the following issues: pavement management system; decision making; road network performance measure; indicators, index and indices concepts; weighting methods; hierarchy; analytic hierarchy process; priorities and prioritisation and finally previous models.

4.2 Pavement Management System

Disasters including natural and man-made make heavy losses in life and property each year. This subject can affect society, economy, and environment and can be a serious threat for development. In the last 10 years over 200 million people have been affected in terms of both life and property. This figure is seven times more than losses in wars. For example, after the earthquake in Bam (a city in south Iran), tsunami in south-eastern of Asia, fire in Australia, and other disasters, the management of disaster has been considered more than before (Shamshiry *et al.*, 2011).

The demand for a more systems level approach to infrastructure management, engineering the interrelationships between planning, design, construction, maintenance and rehabilitation, has motivated significant advances in the development of infrastructure management systems, e.g., for pavements, bridges, and public works. Pavement management systems (PMS) share a common functionality, namely, a network inventory, pavement condition evaluation, pavement performance prediction, and management planning methods, network and project-level, as stated by Haas *et al.* (1994); however, PMS's take on many different forms depending on the particular organisation and its priorities (Gendreau and Soriano, 1998). Rational pavement evaluation and performance prediction should consider both functional aspects, safe and comfortable ride, and structural aspects, strength, deflections and fatigue (Mooney *et al.*, 2005).

Crisis management is an applied science which is a tool to systematically observe past events for analysis in order to find an instrument which can be used to prevent disaster incidence or be ready for collation and in cases of incidence, expedite relieving and circumstance improvements.

Crisis management is schematisation, organisation, and taking consideration in a way that leads to a reduction of disaster impression on casualties and environment. Crisis management procedure includes three basic phases which are: preparation for crisis incidence, relieving and responding in the case of crisis incidence, and improving recuperation and reconstruction after happening (Shamshiry *et al.*, 2011).

Crisis management has been gaining priority in policy agendas of many countries. An increase in the number of man-made disasters and natural disasters has led governments to invest more in crisis management systems (Tamer, 2004). The failure of crisis management results in tragic consequences, significant property damage and human loss.

Crisis management has been defined by Unla *et al.* (2010) from different aspects such as administration, recovery and response activities, mitigation efforts or organisational collaboration.

New types of crises around the world show that the traditional top-down crisis management style does not work effectively. New crises such as terrorist attacks and large-scale natural disasters urge governments to plan a crisis management that is more effective. Particularly, the September 11 terrorist attacks had a significant impact on other countries' crisis management approaches (Unla *et al.*, 2010).

As stated in Hudson *et al.* (1992), the function of a PMS is to improve the efficiency of decision-making, expand its scope, provide feedback on the consequences of decisions, and insure the consistency of decisions made at different management levels within the same organisation.

Gendreau and Soriano (1998) stated that one of the components of a PMS is the planning module that enables the managing agency to determine what maintenance and rehabilitation (M&R) actions should be taken, given the current and predicted condition of the pavement sections within its jurisdiction and the financial resources placed at its disposal. It is with this element that pavement engineers can establish a programme of actions to be performed in the next planning period and plan future M&R investments, in order to maintain or improve the condition of their pavement structures. However, determining the best M&R strategy for a large pavement network over a medium to long-term planning horizon, while respecting stringent budgetary constraints, is evidently a highly complex problem.

It is impossible to expand all the sections and to meet all the travel demand with a high level of service given the current fiscal environment. In a world of limited resources, where funds do not necessarily keep pace with the growing demand for infrastructure improvements, not to mention the increasingly costly maintenance of aging infrastructure, it is essential to make well informed public policy choices when selecting specific segments for improvement (FHWA, 1995).

4.3 Decision Making

Saaty (1994) stated that policy makers at all levels of decision making in organisations use multiple criteria to analyse their complex problems. Multi-criterion thinking is formally used to facilitate their decision making. Through tradeoffs it clarifies the advantages and disadvantages of policy options under circumstances of risk and uncertainty. It is also a tool vital to forming corporate strategies needed for effective competition.

A decision-making approach should have the following characteristics;

- Be simple in construct,
- Be adaptable to both groups and individuals,
- Be natural to our intuition and general thinking,
- Encourage compromise and consensus building, and
- Not require inordinate specialisation to master and communicate (Saaty, 1982).

In addition, the details of the processes leading up to the decision-making process should be easy to review.

The core of the problem should be addressed to satisfy the need to assess the benefits, the costs, and the risks of the proposed solutions. The questions must be answered as follows: Which consequences weigh more heavily than others? Which aims are more important than others? What is likely to take place? What should plan for and how does this bring it about? These and other questions demand multi-criteria logic (Saaty, 1994).

To make a decision one needs various kinds of knowledge, information, and technical data. These concerns are:

- Details about the problem for which a decision is needed,
- The people or actors involved,
- Their objectives and policies,
- The influences affecting the outcomes, and
- The time horizons, scenarios, and constraints (Saaty, 1994).

Briefly, decision making can be seen according to Saaty (1977) as a process that involves the following steps:

1. Structure a problem with a model that shows the problem's key elements and their relationships.
2. Elicit judgments that reflect knowledge, feelings, or emotions.
3. Represent those judgments with meaningful numbers.
4. Use these numbers to calculate the priorities of the elements of the hierarchy.
5. Synthesise these results to determine an overall outcome.
6. Analyse sensitivity to changes in judgment (Saaty, 1977).

A useful way to proceed in structuring a decision is to come down from the goal as far as one can by decomposing it into the most general and most easily controlled factors. One can then go up from the alternatives beginning with the simplest sub criteria that they must satisfy and aggregating the sub criteria into generic higher level criteria until the levels of the two processes are linked in such a way as to make comparison possible (Saaty, 1994).

4.4 Road Network Performance Measure

Transportation agencies are increasingly moving away from evaluation and decision making based on a parochial set of system goals, such as only initial agency cost or life-cycle agency cost, to those based on a relatively wide array of criteria such as user cost, traffic safety, facility/traveller security or vulnerability to natural and man-made disaster, facility condition and longevity, and community values. This can help agencies achieve more balanced, rational, defensible, and cost-effective decisions and can enable enhanced investigation of trade-offs among performance criteria (Sinha *et al.*, 2009).

As stated by Sun and Gu (2011); a pavement condition assessment (PCA) is a key component of the decision-making process of transportation asset management. It provides a quantitative means for evaluating pavement deterioration for an entire highway network.

Despite some differences, the performance objectives for road systems can be broadly categorised as: safety; system condition and preservation; accessibility; mobility; cost effectiveness; reliability; socio-economic impacts and environmental impacts (TAC, 2006; Cambridge Systematics, Inc. *et al.*, 2006; Austroads National Performance Indicators, 2008; Litzka *et al.*, 2008). The performance objectives set by the transportation agencies are met through quantifiable key performance indicators (KPIs) (Lounis *et al.*, 2008). The KPIs for roads should incorporate the stakeholder requirements, efficiency of the road network service providers and effective actions by the policy sectors. Haas *et al.* (2009), for example, categorised the basic framework for roads as follows:

(i) General key performance indicators (provide a macro-level view), and
(ii) Detailed key performance indicators (describe service quality provided to road users, and institutional productivity and effectiveness).

Lounis *et al.* (2008), however, categorised KPIs for roads into two:

(i) Physical or structural KPIs (measure the structural demands of the road pavement), and
(ii) Functional performance indicators (measure the demands related to road pavements by the road users).

Decision making process for road network management becomes exceedingly complex as different KPIs are non-commensurable and assigning weights is challenging (Park *et al.*, 2007; Jiang and Li, 2005; Shah *et al.*, 2004; Chiang *et al.*, 2009). Overall a global infrastructure and road performance assessment is a complex process, which depends on KPIs that are subjected to different types of uncertainties.

Ismail *et al.* (2011) stated that the assessment of performance for road systems requires methods that combine human knowledge and experience as well as expert judgment.

Network-disruption analysis is a methodological approach that has been successfully applied to transportation maintenance and planning problems to identify and rank the most critical links in a network and to evaluate the robustness of the network as a whole

(Sullivan *et al.*, 2009; Scott *et al.*, 2006; Jenelius *et al.*, 2006; Poorzahedy and Bushehri, 2005; Myung and Kim, 2004; Chen, 2000). Network robustness is defined as the degree to which the transportation network can function in the presence of various capacity disruptions on component links. A ‘‘robust” network can compensate for disruptions on network links with relative ease and with only slight increases in overall system-wide travel times. A ‘‘non-robust” network does not adjust well to disruptions on network links and is subject to substantial increases in system-wide travel times (Sullivan *et al.*, 2010).

Existing research has shown that the performance metrics, terminology, methodologies, and even the underlying modelling assumptions used in network-disruption studies can vary dramatically depending on the application, problem domain, and the specific goals of the research (Sullivan *et al.*, 2009).

Network-disruption analysis has received increased attention in recent years largely due to events such as the 1995 earthquake in Kobe, Japan, the attacks on the World Trade Centre in New York City in 2001, and the I-35 bridge collapse in Minneapolis, MN in 2007, which have emphasised the reality of the possibility of large-scale catastrophic transportation infrastructure failures (Sullivan *et al.*, 2009).

Modelling disruptions in transportation networks initially began as an effort to quantify the adverse impacts associated with a reduction of capacity on specific links (Chen, 2000; Du and Nicholson, 1997; Asakura, 1996). Over time, studies have evolved to consider many different types of network disruptions and a number of different objectives or outcomes are associated with network-disruption studies. Some studies seek to identify the link(s) or region(s) most in need of improvement or protection, presumably as a resource–allocation measure (Jenelius, 2007a,b; Sohn, 2006; Jenelius *et al.*, 2006; Berdica and Mattsson, 2007; Ham *et al.*, 2005; Poorzahedy and Bushehri, 2005; Murray-Tuite and Mahmassani, 2004); while others seek to develop ‘‘reliability envelopes” which demonstrate the likelihood of a network’s continued functioning under various states of degradation or disruption (O’Kelly and Kim, 2007; Matisziw *et al.*, 2007a,b; Church and Scaparra, 2007).

Within the domain of network-disruption literature, different network performance measures are frequently used. Furthermore, different authors may define seemingly identical performance measures in distinct ways. For example, there are studies that utilise robustness (Grubesic *et al.*, 2007; Snyder and Daskin, 2007; Wilson, 2007; Dong, 2006; Scott *et al.*, 2006), importance or criticality (Berdica and Mattsson, 2007; Chen *et al.*, 2007; Murray *et al.*, 2007; Taylor and D’Este, 2007; Jenelius, 2007a,b; Matisziw, 2007a,b; Husdal, 2006; Sohn, 2006; Poorzahedy and Bushehri, 2005; Jenelius *et al.*, 2006; Grubesic, 2005; Myung and Kim, 2004; Latora and Marchiori, 2004), adaptability or resilience (Holmgren, 2007; Nagureney and Qiang, 2007), capacity reliability (Church and Scaparra, 2007), connectivity reliability (Grubesic *et al.*, 2007; Chen *et al.*, 2007; Matisziw *et al.*, 2007a,b; O’Kelly and Kim, 2007), and travel-time reliability (Lam *et al.*, 2007). A thorough review of studies in network-disruption analysis is provided by Sullivan *et al.* (2009).

Network ‘‘flexibility’’ addresses spatial organisation in various infrastructure (e.g., communications and transportation) planning and engineering practices. Feitelson and Salomon (2000) identified network flexibility as a network attribute that relates to a network's physical characteristics and to the level-of-service it provides users. The authors suggest that differences in network flexibility have important ramifications for spatial organisation, particularly at the macro level. Morlok and Chang (2004) defined ‘‘system capacity flexibility’’ as the ability of a transport system to accommodate variations or changes in traffic demand while maintaining a satisfactory level of performance. A flexible highway network must therefore be able to adapt to changes in the quantity of traffic, freight commodity mix and spatial flows from one geographic area to another (Scott *et al.*, 2006).

Bell (2000) offers the following definition of ‘‘network reliability’’. A network is reliable if the expected trip costs are acceptable even when users are extremely pessimistic about the state of the network. According to Bell, reliability pertains directly to instances of natural disasters when parts of the transportation network may fail and also to road space reallocation among competing transportation modes such as transit, pedestrians and cars. He points out that reliability has two dimensions: network connectivity and performance reliability. In the case of network connectivity, the more sparsely connected the network, the more difficult it may be for travellers to arrive at their destinations on schedule if there are segment blockages or failures. Measuring reliability is difficult as it includes both the physical infrastructure and the behavioural responses of travellers. Chen *et al.* (1999) considered capacity reliability as a network performance index that builds upon the network reliability concepts introduced by Bell and Iida (1997). Chen *et al.* (2002) defined capacity reliability as the probability that the network can accommodate certain traffic demand at a required service level, while accounting for drivers, route choice behaviour (Chen *et al.*, 2002).

Scott *et al.* (2006) believed that a transportation network should not only meet O/D demand, but should provide ample connectivity so as not to be overly vulnerable to disruptions on individual segments within the system. This directly supports the importance of the concepts of transportation flexibility and reliability. The underlying goal of the planning and management process should encourage the development of well connected highway networks that focus on spatial relationships between different segments, as well as using the traditional V/C measure. They introduce a new measure for identifying critical network links and evaluating network performance that considers not only traffic flows and capacity, but also network connectivity. They test how well the proposed measure performs compared to the traditional V/C ratio by using three hypothetical networks, each of which is characterised by a different level of connectivity. They demonstrate that our approach, known as the Network Robustness Index, yields different highway planning solutions than the traditional V/C ratio. Moreover, these solutions yield far greater system-wide benefits, as measured by travel-time savings, than solutions identified by the V/C ratio (Scott *et al.*, 2006).

Two measures are commonly used to evaluate different aspects of highway performance, as mentioned by Ducruet and Rodrigue (2003). The first, the V/C ratio, is used to evaluate congestion on specific highway segments. The ratio is a localised performance metric and thus does not consider the performance of the network as a whole. The second, the gamma index, is a connectivity index that considers for a network the relationship between the actual number of links and the maximum number of possible links. The value of gamma ranges between 0 and 1. A value of 1 indicates a completely connected network, and is extremely unlikely in reality (Scott *et al.*, 2006).

Scott *et al.* (2006) defined a new measure, the Network Robustness Index (NRI), for evaluating the critical importance of a given highway segment (i.e., network link) to the overall system as the change in travel-time cost associated with rerouting all traffic in the system should that segment become unusable. An immediate question concerning the use of the NRI is how well a particular transportation network performs when specific links are disrupted due to natural (e.g., mudslides, earthquakes) or human-induced (e.g., vehicle collisions, terrorism) occurrences.

4.5 Indicators, Index and Indices Concepts

The concept of indicators has gained popularity in recent years. In general, an indicator can be defined as a quantitative or qualitative measure that is deduced from a series of observed facts to reveal the relative positions of objects in a certain area (Nardo *et al.*, 2005). One of the useful characteristics is that an indicator can represent large amounts of information in a simple manner. Indicators can be used for several objectives, like monitoring performance, identifying trends, predicting problems, assessing policy impact, prioritising measures, benchmarking, etc. (Litman, 2007; Sharpe, 2004; Hermans *et al.*, 2008).

Moreover, there is a rapid development of composite indicators, or indices which are a combination of individual indicators, in several domains. In order to combine information from several underlying dimensions into one index, an essential step is to assign a correct weight to each indicator. This will help the policymakers to have a useful tool for prioritising their actions (Hermans *et al.*, 2008; Nardo *et al.*, 2005; Sharpe, 2004).

There is a high demand to develop and use decision support tools, by the transportation sector and other concerned agencies, to improve short-term management and long-term planning of the aging/damaged roads effectively under shrinking budgets and increasing demands for higher level of service. The cost of restoring and/or replacing deteriorated roads is three to five times greater than the cost of regular maintenance (Harral and Asif, 1998). As a result, the decision makers, at different levels of government(s), use various performance indices to rank roads and prioritise their decision actions (TAC, 2006). Ranking or performance assessment (or measurement) is a process to achieve the pre-determined objectives of transportation agencies (Lounis *et al.*, 2008). A thorough literature review of the state-of-knowledge and state-of-the practice in Canada, USA, Australia and Europe (TAC, 2006; Cambridge Systematises, 2006; PIARC, 2008; Austroads National Performance Indicators, 2011; Litzka *et al.*, 2008; Park *et al.*, 2007) highlights that different transportation agencies have used different indicators and criteria to meet their predefined performance objectives (Chang *et al.*, 2003; Bandara and Gunaratne, 2001; Jiang and Li, 2005; Ismail *et al.*, 2011).

Vanier *et al.* (2006) stated that the performance indicators used to evaluate the individual systems can be very subjective or virtually non-existent. On top of all this, decision-makers at higher levels (both technical and political) must optimise their investments based on a number of uncertain, and at times subjective and conflicting, criteria, including: type of maintenance intervention, overall network performance, risk and reliability, life cycle costs, desired levels of service, budgetary constraints, construction costs and social costs.

Road safety is one of the policy areas where the use of indicators is rapidly gaining ground (Safety Net, 2005). The multidisciplinary character of road safety implies that policymakers should take various influential factors into account. Also, being an international issue, the level of road safety is often compared over countries. To reduce the dimensions of the problem, the creation of a composite indicator can be helpful. One of the main issues in creating a road safety performance index is the weighting of the indicators. This exercise implies that a value judgement is needed for each of the possible measures taken to influence road safety. A higher weight for a certain indicator stresses its relatively higher importance in the global measurement of road safety. Given the limited resources that can be used to improve road safety, a well considered construction of indicator weights is crucial to steer future investments (Hermans *et al.*, 2008).

In general, road safety performance indicators are related to the road user (e.g., speeding), the vehicle (e.g., defects) and the road (e.g., bad maintenance) (World Health Organisation, WHO, 2004).

A number of steps are involved in the creation of a composite indicator (Nardo *et al.*, 2005). The theoretical framework has to be developed, appropriate indicators selected and data found. Next, these values are weighted, aggregated and clearly presented (Al Haji, 2005; WHO, 2004).

The evaluation of the road network characteristics can be made through direct measuring, visual condition surveys, or a combination of both. In most cases, these measurements or surveys are then expressed in the form of a quality index. These indices are either objective (i.e., based on a direct quantified measurement) or subjective (i.e., based on judgment). They can correspond to a single or to a combination of some or all of the pavement characteristics that are evaluated by the agency; they are then respectively referred to as individual, composite or overall indices (Tessier, 1990; Baladi *et al.*, 1992). These indices define the state of deterioration of the pavement at a specific time (Gendreau and Soriano, 1998).

According to Leng *et al.* (2010), there is no comprehensive performance index, since most of the focuses are limited to one single performance estimation index.

4.6 Weighting Methods

Weighting is a solution to identify the key information. In the absence of a weighting instrument, measuring the relative weights of the sources is acceptable (Saaty, 1994). This usually relies on the subjective judgments made by decision makers and/or experts. A simple method is to guess each element according to an absolute rating scale, and compare it with other elements in the whole set by dividing its weight by the total to get its relative weight, where those with heavier weights are key elements. Weighting of elements has two major functions. First, it helps to prioritise (rank) elements so that the key elements can be determined. Second, as it helps to identify the key elements, it can be used to make more accurate business decisions, such as formulation of information management strategies and investment of appropriate technology for key business practices (Cheng and Li, 2001).

As mentioned by Vanier *et al.* (2006), the weighting of the maintenance objectives depends on the attitude of the decision-maker towards the risk of failure, economy, and network reliability.

In incorporating different performance criteria in transportation decision making, a key aspect is to assign weights to the criteria to reflect their relative importance (Keeney and Raiffa, 1993; Sinha *et al.*, 2009).

Sinha *et al.* (2009) stated that after performance criteria have been weighted and scaled, it is possible to express the overall impact of each transportation alternative in terms of an overall or combined performance level represented by weighted and scaled values of the criteria. Each alternative can be ranked on the basis of the overall resulting change of combined performance it offers to the facility.

A theory behind five common weighting techniques has been discussed by Hermans *et al.* (2008). They described the working method and focused on the advantages and disadvantages of, respectively, factor analysis, analytic hierarchy process, budget allocation, data envelopment analysis and equal weighting.

4.6.1 Factor Analysis

The first weighting procedure is based on factor analysis (FA). A factor analysis is often used to reduce the dimensions of a problem. However, it would be interesting to reduce the problem to a smaller number of dimensions, called factors, which explain a large part of the total variance. Each factor, consisting of a number of indicators, can be given an interpretation. Several guidelines are available for assessing the optimal number of factors to which the problem can be reduced (Sharma, 1996).

The use of factor analysis in the composite indicators field is not rare. However, this technique is often used to examine the interrelationships between the indicators instead of determining weights. The most important drawback is that weights are based on correlations which do not necessarily correspond to the real-world links between the phenomena being measured (Saisana and Tarantola, 2002). In addition, deducing weights from factor analysis requires a certain level of correlation (to reduce the problem in a number of factors), a justified selection of the optimal number of factors (as the weights depend on the chosen number of factors) and clear rotation results (because only the highest rotated factor loadings are used in the computation of weights). This method is most valuable in cases where several indicators are considered to measure each risk domain (Hermans *et al.*, 2008).

4.6.2 Analytic Hierarchy Process

Analytic hierarchy process, or AHP, is a method developed by Saaty in the early 1970s in the field of decision theory (Haas and Meixner, 2006). As stated by its name, a complex problem is translated into a hierarchy consisting of an overall goal (enhancing road safety), several (or sub) criteria contributing to this goal and a number of alternatives of which the best has to be selected. Both quantitative and qualitative criteria can be handled (Haas and Meixner, 2006). In their context, experts judge the relative contribution of each indicator to road safety compared to another indicator. They answer the questions ‘which one of the two is contributing more to the overall goal?’ and ‘how large is the intensity of the difference?’

AHP is a comprehensible and popular technique that can be used for very complex decisions involving numerous levels of criteria and sub-criteria. Despite the subjective characteristic and a possibly large inconsistency, the information from well-selected experts is valuable for deducing indicator weights. In cases of several experts, numerous possibilities exist to come to one final set of weights. In the end, one weight will be obtained for each indicator. This set of weights can be similar to the weights of one randomly selected expert or incorporate the opinion of all (consistent) experts. In the latter case, the average or the median can be calculated or the group of experts could vote or reach consensus after a debate (Hermans *et al.,* 2008).

This method will be discussed in more details in Section 4.8 as it has been used in the proposed model presented in this study.

4.6.3 Budget Allocation

Budget allocation (BA) is another well-known method for obtaining indicator weights. A selected panel of experts is asked to distribute a given budget over the indicators in such a way that spending more on an indicator implies that (s)he wants to stress its importance. The weights can be obtained from a simple ratio.

In general, the BA method has four phases (Nardo *et al.*, 2005). First, the experts have to be selected. It is important to gather experts with a wide spectrum of knowledge and experience. Second, each expert allocates the pre-determined budget of *N* points to the indicators. In the third step, weights are calculated from these figures. More specifically, the share of budget allocated to an indicator equals its weight. The fourth step is an optional one in which the procedure is iterated until convergence is reached.

Budget allocation is a simple and often used technique with some limitations. First, the selection of experts is crucial and should be well-considered. It is possible that the results are biased if an expert assigns a high weight to a dimension on which his/her country performs well. Second, the method may not measure the importance of a specific indicator but the need for political intervention in that dimensions (Nardo *et al.*, 2005). Finally, the maximum number of indicators to distribute the budget over is limited to 10 enabling the expert to keep an overview (Hermans *et al.*, 2008).

4.6.4 Data Envelopment Analysis

Data envelopment analysis (DEA) developed by Charnes *et al.* (1978), is a performance measurement technique that can be used for evaluating the relative efficiency of decision-making units (DMU's). For each DMU the efficiency is defined as the ratio of the weighted sum of outputs to the weighted sum of inputs (Cooper *et al.*, 2000). Thereby, a set of weights is determined resulting in the best possible score for that country. This implies that dimensions on which the country performs relatively well get a higher weight.

Compared to the previously discussed weighting methods, DEA is different. DEA is a method that can handle raw values making the normalisation of indicators redundant. However, this implies that the weights do not sum up to one, which makes the comparison of indicator weights with other weighting methods impractical. Furthermore, a separate model is constructed for each country resulting in country-specific weights instead of one set of indicator weights for all countries.

DEA compares the performance of a country to the performance of the other countries in the data set. Since the model chooses the optimal weights under the imposed restrictions, no other weighting set yields a higher composite indicator value. The results are influenced by the countries in the data set; hence this approach is only about relative efficiency (Anderson, 2006). Although the DEA domain is very extensive and numerous models exist, making the selection of an appropriate model a rather difficult task, this technique can be translated to be useful for composite indicators. This weighting method has already been used for a number of indices (Cherchye *et al.*, 2004, 2006; Cherchye and Kuosmanen, 2002). Its strongest point is that the weights are endogenously determined and derived directly from the data (Cooper *et al.*, 2000). However, a number of disadvantages are linked to the standard model leading to adapt some aspects. Furthermore, bounds defined by more than one expert can easily be incorporated leading to more acceptable weights. The presented DEA model is most valuable when individual expert opinions are available and there is no agreement on the correct set of weights (Hermans *et al.*, 2008).

4.6.5 Equal Weighting

As it is clear by the name of this method, the same weight is assigned to each indicator. Since the sum of all weights equals one, each indicator gets the weight $1/l$ (with l the number of indicators in the analysis). It is also possible to use equal weighting for the main categories and for all indicators in those categories. In that case the weights depend on the number of indicators in each category.

Although from a scientific point of view equal weighting is a too simple technique, a large majority of composite indicators is constructed by means of this default weighting method. The most important drawback is that no insights are gained in the difference in importance of the indicators. As a result, equal weighting is not of great value for policymakers (nor researchers). In addition, it is unlikely that the resulting weights are similar to the real, unknown weights. When two or more indicators are measuring the same, there is a risk of double weighting (DSTI, 2003). Finally, in cases of fixed weighting, country rankings may change by using another normalisation method (Cherchye *et al.*, 2006). The researchers conclude that equal weighting is a solution in cases where no other weighting method yields valid results. This approach works best if all indicators are uncorrelated or if they are all highly correlated (Hermans *et al.*, 2008).

Table 4.1 summarises the main advantages, disadvantages and requirements of each method.

Table 4.1: Summary information on the five weighting methods

Weighting Method	Main Advantages	Main Disadvantages	Main Requirements
Factor Analysis	Indicators are grouped, an interpretation can be given to each factor	Weights based on correlations may differ from reality	Some correlation between indicators, justification of the optimal number of factors, clear rotation results
Analytic Hierarchy Process	Detailed expert information, incorporate quantitative and qualitative criteria, numerous levels of criteria	Inconsistency, subjectivity	Carefully selected group of experts (with time), small number of criteria, sufficiently different criteria
Budget Allocation	Comprehensible, easy computation	Weight may indicate need for intervention, weight may represent dimensions a country performs on well	Carefully selected group of experts, maximum number of indicators is 10
Data Envelopment Analysis	Optimal weights derived from data and restrictions, value judgements can be included, no normalisation needed	Results are relative i.e. influenced by the countries in the data set, sum of weights is not one (like for other weighting methods)	Value judgements to obtain realistic weights, several countries in data set
Equal Weighting	Simple	No insights in indicator importance, no added value for policymakers, risk of double weighting	No valid results from other weighting methods, all indicators uncorrelated or highly correlated

4.7 Hierarchy

Although most people have an idea of what a hierarchy is, few use the concept in their thinking. Fewer still realise how important and powerful a hierarchy is as a model of reality when viewing a complex system of interacting components. Hierarchies are order-preserving structures. They involve the study of order among partitions of a set.

The partitions are called the levels of the hierarchy. Conceptually the simplest hierarchy is linear, rising from one level to an adjacent level. The complexity of the arrangement of the elements in each level may be the same or it may increase from level to level (Saaty, 1977).

Advantages of hierarchies:

1. They provide a meaningful integration of systems. The integrated behaviour or function of a hierarchical organisation accounts for the fact that complicated changes in a large system can result in a single component. It is the opposite of what we generally expect.
2. They use aggregations of element in the form of levels to accomplish tasks.
3. Greater detail occurs down the hierarchy levels; greater depth in understanding its purpose occurs up the hierarchy levels. From the upper level the constraints of the hierarchy are taken for granted and the question is, "How could the constraints arise?"
4. Hierarchies are efficient and will evolve in natural systems much more rapidly than non-hierarchical systems having the same number of elements.
5. Hierarchies are reliable and flexible. Local perturbation does not perturb the entire hierarchy. The overall purpose of the hierarchy is divided among the levels whereby each solves a partial problem and the totality meets the overall purpose. The units on the higher level are not concerned with the overall purpose but with specific goals of that system that should be attempted not in terms of the overall goal but in terms of specific goals of each level (Saaty, 1977).

Saaty (1977) has found modelling complex problems with hierarchies useful in stimulating participation and interaction among the people concerned. It seems to provide an opportunity for richer involvement of decision makers both in the formulation and in the quantitatively oriented solution of their problems level.

4.8 Analytic Hierarchy Process

Multiple criteria decision-making (MCDM) research has developed rapidly and has become a main area of research for dealing with complex decision problems (Sun and Gu, 2011).

Saaty (1994) stated that AHP is a powerful method to solve complex decision problems. Any complex problem can be decomposed into several sub-problems using AHP in terms of hierarchical levels where each level represents a set of criteria or attributes relative to each sub-problem. The AHP method is a multi-criteria method of analysis based on an additive weighting process, in which several relevant attributes are represented through their relative importance. AHP has been extensively applied by academics and professionals, mainly in engineering applications involving financial decisions associated to non-financial attributes.

AHP is a structured technique for dealing with complex decisions. It helps decision makers find the decision that best suits their needs and their understanding of the problem (Forman and Gass, 2001). It is a multi-criteria decision-making (MCDM) technique that is used to generate weights (Carlsson and Fullér, 1996). The AHP uses objective mathematics to process the subjective and personal preferences of an individual or a group in decision making (ASTM, 1995; Saaty, 2001), and works on a premise that complex problems can be handled by structuring them into a simple and comprehensible hierarchical structure. Once the basic weights and input criteria are identified, the final step of the AHP process is to synthesise through the hierarchy. Simple weighted mean can be applied to the selection criteria to demonstrate how AHP weights can be used in alternative prioritisation techniques (Vanier *et al.*, 2006).

As discussed by Moazami *et al.* (2011), due to the fact that prioritisation is a decision making process, statistical models are not very responsive. Therefore, designers must use decision making processes. The AHP is one of the simplest and most useful processes and appropriate for approximate usages. At present AHP is used in many cases when decisions in bridge and road construction are made (Zavadskas *et al.*, 2008). Su *et al.* (2006) applied AHP method to rank 25 major rail projects to determine implementation priorities and budget allocations. Farhan and Fwa (2009) concluded that the absolute AHP method can be successfully utilised for pavement maintenance prioritisation.

Therefore, AHP is suited to transportation investment decision-making problems because there is a preponderance of situations in this area of engineering where there exists a hierarchy of importance across the various performance criteria. AHP effectively captures survey respondents' preferences for relative weights. Also, by virtue of its inherent structure, AHP is an appropriate method when the analysis involves the use of relative weights in a multivariate value or utility function framework (Sinha *et al.*, 2009).

AHP has become quite popular in research due to the fact that its utility outweighs that of other research methods. AHP considers both qualitative and quantitative approaches to research and combines them into a single empirical inquiry. The development of AHP can be traced back to the early 1970s, in response to the resources allocation and planning needs for the military (Saaty, 1980). As the methodological procedure of AHP can be easily incorporated into multiple, objective programming formulations with interactive solution process (Yang and Lee, 1997), it has received wider attention in various fields. Using the area of construction as an example, a recent literature review paper in construction partnering had raised the use of it in construction research (Li *et al.*, 2000). Moreover, Chua *et al.* (1999) used AHP to identify the critical factors conductive to the success of construction projects. McIntyre *et al.* (1999) applied the AHP method to determine a weighted scale for selecting a divisional director for a construction party. Saaty (1990) refers to the former as the relative measurement function of AHP and the latter as the absolute measurement function.

AHP is a hierarchal representation of a system. A hierarchy is an abstraction of the structure of the system, consisting of several levels representing the decomposition of the overall objective to a set of clusters, sub-clusters, and so on, down to the final level which would usually be the alternatives or scenarios to be selected. The clusters or sub-clusters can be forces, attributes, criteria, activities, objectives, etc. (Cheng and Li, 2001).

4.9 Priorities and Prioritisation

4.9.1 What are Priorities?

Basically, a priority is something that is considered more important than other things. It involves making a choice or choices. It can get confusing because there are all kind of situations and contexts when these choices might be made (Draft Briefing, Priorities and Prioritisation, 2006, Available online, last accessed on 05.11.2011).

Keller and Ketcheson (2011) stated that for post disaster assessment work, repair priorities have dominantly been based on road use and standard of the road, with the most heavily used and important roads receiving top priority. Other factors influencing project priorities include land manager priorities; opportunities for road closure or rerouting; right-of-way conflicts; watershed, legal, and sensitive species issues; and funding limitations. Evaluation and prioritisation of these many factors can be difficult. Evaluation processes have been developed that use a series of qualitative or quantitative criteria that, when they are combined, result in relative risk values.

As stated by Wu and Flintsch (2009), in a public decision making context, e.g.; highway network management, there is often more than one objective that needs to be achieved. These multiple, often conflicting, objectives are often not only incommensurate but also may have significantly different impacts on the resulting solutions.

When something has been chosen as a priority, what does happen to everything else? This depends on the situation and context. For example, the things that have not been chosen to do first today, may be done second or tomorrow or perhaps it has been decided that they are not important to spend time on at all. Those things that are not on the priority list for the service may still need maintaining, or maybe they can be reduced or stopped altogether.

It can be as important to decide on those things that are not priorities and what happens to them, as it is to decide on priorities. Sometimes these are called 'non-priorities' but they can also be described as being of lower preference or lower resource allocation. If all the lower preference activities continue regardless, it could put the real priorities at risk (Draft Briefing, Priorities and Prioritisation, 2006, Available online, last accessed on 05.11.2011).

4.9.2 What is Prioritisation?

As a principle, prioritisation means doing 'first things first'; as a process, it means evaluating a group of items and ranking them in their order of importance or urgency (Prioritisation, APEXPH, Available online, last accessed on 05.11.2009).

Prioritisation is a process whereby an individual or group places a number of items in rank order based on their perceived or measured importance or significance. Prioritising issues is an important process, in that it assists an organisation in identifying the issues on which it should focus its limited resources (Prioritisation, 2003, Available online, last accessed on 05.11.2009).

Saaty (1994) stated that prioritisation involves eliciting judgments in response to questions about the dominance of one element over another when compared with respect to a property.

Vanier *et al.* (2006) defined prioritisation as the preference ranking of projects. The prioritisation for the age-, condition-, risk-, initial cost-, and life cycle cost-based criteria means that the projects having the worst scores for that criterion have the highest priority; that is, oldest first, worst condition first, riskiest first, lowest initial cost first, lowest life cycle cost-based first.

Prioritisation is the process of choosing. Choosing priorities involves excluding things or accepting they have a lower preference, and for anyone with vested interests this can be hard to take. This can also make it hard for those managing the prioritisation process.

There are different ways of tackling the process of prioritising but it will need to involve the following:

1. Analysing of information that will help to decide on all the potential priorities. This might include information about community needs, about political priorities, and about current performance.
2. Clarifying about all the possible options that could be priorities and the implications of choosing or not choosing these.
3. Identifying an opportunity to get all the issues, and everyone’s thoughts, on the table. This might involve analysing the information in a number of ways, either informally or in a more structured way, for example by looking at what is important versus what is urgent, value versus cost, or impact versus do-ability or deliverability. It might be also needed to think about short-term versus long-term goals and national versus local issues.

4. Choosing the priorities on the basis of the discussions and analysis that has taken place. This might be done in a number of ways; for example deciding on what it will be 'start, stop and continue', or what is a 'priority/not a priority', or what the 'musts, shoulds, coulds and won'ts' are or by allocating points between competing options.

This process should reveal what the priorities are and also the things that are not priorities or are a lower preference (Draft Briefing, Priorities and Prioritisation, 2006, Available online, last accessed on 05.11.2011).

Prioritisation is an increasingly important concept for transportation system planning and programming. Planners need to prioritise. They need to make hard choices about which projects to select for funding, and which to scale back, postpone or not fund at all. Formal priority systems can help planners identify and justify the choices that achieve the greatest benefit in this complex environment (Merkhofer, 1997).

4.9.3 Why is Choosing Priorities Important?

Priorities are important because it is impossible to do everything that people want. It can also help to avoid over-optimism in planning. People usually think they will be able to achieve more than they really will – prioritisation, by limiting the plan, can overcome this.

There is also something about reducing the overall number of items to concentrate on. Setting priorities can also be important for achieving economies of scale or 'critical mass'. 'Bunching up', rather than spreading everything too thinly, can make for a better job (Draft Briefing, Priorities and Prioritisation, 2006, Available online, last accessed on 05.11.2011).

4.9.4 Principles of Prioritisation

According to prioritisation theory, projects should be prioritised based on the ratio of benefits generated to project costs. If proposed projects are independent of one another and can be either funded or not, then the set of projects offering the greatest possible benefit for the available budget will be that which is produced by ranking the projects by their benefit-to-cost ratios and then funding them from the top down until the budget is exhausted. Another basic prioritisation principle is that the prioritising criteria should be derived from objectives. By definition, any incremental improvement in the achievement of an objective is a benefit (Merkhofer, 1997).

Vanier *et al.* (2006) stated that as sufficient funds do not exist to maintain or renew all deficient assets in any one jurisdiction, it is necessary to prioritise and select those interventions that come closest to meeting the organisation’s prime objectives. Although it is possible to select the optimal maintenance and rehabilitation, M & R, investment in a current year, it is very difficult to optimise the selection of M & R investments each year in a short or a long planning horizon (e.g. five or 10 years).

Performance measures were defined to quantify the degree to which transportation system objectives are achieved. Facility usage, or throughput of people, vehicles, and freight, was defined as the performance measure for quantifying the satisfaction of demand. Thus, projects were assumed to improve the satisfaction of customer demand if they resulted in increased facility usage, or throughput (Merkhofer, 1997). Vanier *et* *al.* (2006) stated that the performance indicators used to evaluate the individual systems can be very subjective or virtually non-existent.

4.9.5 Prioritisation Methods

Prioritising methods establish the relative value of choices or alternatives. They answer the question, "What is the most important?" The results can be prioritised in a ranking of the choices to show what should be done first, what requires the greatest attention, and what needs the most resources. Methods differ depending on whether the priorities are based on objectives or criteria.

- ***Objective Priorities:*** Actions or choices can be prioritised in terms of how they affect the achievement of an objective or fit into a structured process. These can be called objective priorities.
- ***Criteria Priorities:*** Project priorities can also be based on a set of criteria. Cost-benefit or cost-performance analyses are examples of this sort of priority setting. Whatever choices yield the greatest value on the criterion measure get highest priority.

Prioritising methods can also be used in situations where a variety of perspectives or preferences have to be taken into account. In these cases, setting priorities is necessary as a basis for cohesive planning and to establish group-based guides for decisions (Cresswell *et al*., 2000).

It was indicated in a study which has been carried out to single out the most critical links and bridges within the network, that the prioritisation method may be classified based on the following properties:

(i) Evaluation of the risk of the bridges, which can be mainly based on engineering judgment (e.g., criteria multiplied by subjective weights) or mainly based on the outcome of a physically-based model.

(ii) Consequences of structural failure of the bridges. These can be based on the single bridge, for example the cost of failure, or as part of a network, for example the time to go from a point to a different one (Prioritisation Techniques, Available online, last accessed on 05.11.2009).

Some prioritisation methods heavily rely on group participation, whereas other methods are less participatory and are more focused on baseline data issues. It is important to remember that no one method is best all of the time. Moreover, each method can be adapted to suit the particular needs of a given community or group. Here, some of the prioritisation methods are displayed in no particular order (Prioritisation, 2003, Available online, last accessed on 05.11.2009). Lounis and Cohn (1993 & 1995) stated that there is no single optimal (or superior) solution that simultaneously yields a minimum (or maximum) for all objective functions.

Simplex Method

With the Simplex method, group perceptions are obtained by the use of questionnaires. The method assists a decision-making group to analyse problems more efficiently. The answers to the questionnaires are scored and ranked and the issues with the highest scores are given the highest priority.

An added feature of the Simplex method is that particular problems can be given more weight, thus raising its priority level. However, this method relies heavily on the way in which the questionnaire presents the problems and questions (Prioritisation, APEXPH, Available online, last accessed on 05.11.2009).

Nominal Group Planning Method

Nominal Group Planning was developed for situations where individual judgments must be tapped and combined to arrive at decisions which cannot be determined by one person. This strategy is best used for problem exploration, knowledge exploration, priority development, programme development and programme evaluation.

The model is used in basically the same way for each application. This method involves little math and is based more on group discussion and information exchange.

Group members generate a list of ideas or concerns surrounding the topic being discussed. This list becomes decision-making criteria and the prioritisation is the ultimate result of consensus and a vote to rank order the criteria (Prioritisation, APEXPH, Available online, last accessed on 05.11.2009).

Criteria Weighting Method

The Criteria Weighting method is a mathematical process whereby participants establish a relevant set of criteria and assign a priority ranking to issues based on how they measure against the criteria. The calculated values do not necessarily dictate the final policy decision, but offer a means by which choices can be ordered (Prioritisation, APEXPH, Available online, last accessed on 05.11.2009).

4.9.6 Comparison of Prioritisation Techniques

Different techniques are suited to different types of decisions, groups and data. Table 4.2 provides a summary of the techniques described here and the strengths and weaknesses of each (Prioritisation, APEXPH, Available online, last accessed on 05.11.2009).

Table 4.2: Strengths and weaknesses of the prioritisation methods

Method	Strengths	Weaknesses
Simplex	Efficient and quick to use, once questionnaire is constructed. Can be used with any size group. Allows for weighting of problems.	Requires the development of a questionnaire. Relies heavily on how questions are asked.
Nominal Group Planning	Motivates and gets all participants involved. Can be used to identify areas for further discussion and can be used as part of other techniques (e.g., to help develop a Simplex questionnaire). Allows for many ideas in a short period of time. Stimulates creative thinking and dialogue. Uses a democratic process.	Vocal and persuasive group members can affects others. A biased or strong minded facilitator can affect the process. May be overlap of ideas due to unclear wording or inadequate discussion.
Criteria Weighting	Offers numerical criteria with which to prioritise. Mathematical process (this is a weakness for some). Objective; may be best in situations where this is competition among the issues. Allows group to weight criteria differently.	Can become complicated. Requires predetermining criteria.

4.9.7 Some Limitations and Considerations in Priorities

According to the discussion above the limitations and considerations in prioritisation can be summarised as follows:

Tough choices: Priorities always involve tough but necessary choices. The process of identifying and setting priorities will almost certainly involve conflict and controversy. Some planning and preparation is necessary to keep the work on track (Cresswell *et al.*, 2000).

More tough choices: Setting priorities does not end the tough decision process. Even though most important choices have been known, it still needs to figure out exactly how to allocate resources and work assignments (Cresswell *et al.*, 2000).

4.10 Previous Models

As an example, modelling bridges in a transport network will be used to illustrate previous models.

According to the Applied Technology Council, ATC, (1983), seismic rating for the i^{th} bridge is computed as the sum of hazard, bridge resistance and bridge importance. Each item may vary between 0 and 10. Its value is assigned via engineering judgement.

Kawashima and Unjoh (1990) stated that vulnerability of the i^{th} bridge, D_i, depends on properties derived from hazard and resistance. Each property is weighted and then summed up. Weights are derived from observation of damages from past events, for example, earthquakes. The most influential properties are highlighted.

Babei and Hawkins (1991) stated that priority for the i^{th} bridge, I_i, depends on hazard, bridge resistance, and cost of failure. The latter is computed considering network behaviour. Bridge resistance may be computed with the provisions in ATC, 1983.

Ranking for the i^{th} bridge, R_i, as mentioned by Federal Highway Administration, FHWA, (1995) is computed as the product of hazard and bridge resistance. Resistance may vary between 0 and 10 and is computed based on engineering judgement. The authors suggest further taking into account "socio-economic" issues by subjectively increasing R_i.

According to Basoz and Kiremidjian (1996), ranking for the i^{th} bridge, R_i, is computed as the sum of vulnerability and importance. The network behaviour is taken into account within the importance factor.

Nielson and DesRoches (2003) stated that priority for the i^{th} bridge, I_i, is the median value of the bridge fragility curve with respect to a selected limit state (slight, moderate, extensive damage and collapse).

Priority for the i^{th} bridge, R_i, depends on properties derived from hazard, resistance and cost. The weights are given via engineering judgement, according to Unjoh *et al.* (2000).

Prioritisation techniques can be of important help to the decision makers, giving a rational ranking for among bridges to detect the critical ones and best upgrading level.

Prioritisation methods lead to the priority value: P_b, for every bridge in a stock. P_b is expressed in the format:

$$P_b = f(F_b, R_b, C_b) \dots \quad (4.1)$$

where f is the dependent function, F_b is the force on the bridge (hazard), R_b is the resistance of the bridge (e.g. fragility), and C_b is the cost of bridge failure (Prioritisation Techniques, Available online, last accessed on 05.11.2009).

The ATC (1983) method is based on direct and indirect evaluation of risk based on engineering judgement and cost of failure. The ATC formulation reads:

$$P_b = f(F_b, R_b, C_b) = F_b \times \mathrm{w_f} + R_b \times \mathrm{w_r} + C_b(\mathrm{U_b}, \mathrm{U_B}) \times \mathrm{w_c} \dots \quad (4.2)$$

The priority of the bridge is expressed as the sum of bridge seismic hazard, F_b, resistance, R_b, cost of failure, C_b, with each input variable multiplied by a different weight. Both the quantification of the input variables, each one within the 0-10 range, and of the weights, equal to 10/3, is very subjective. The function which measures the consequences of failure is called the utility; U. U_b is the utility of the bridge by itself and U_B is the bth bridge utility as part of the network.

A very similar approach is followed by the FHWA (1995). The formula for ranking bridges reads:

$$P_b = f(F_b, R_b, C_b) = F_b \times R_b + C_b(\mathrm{U_b}, \mathrm{U_B}) \dots \quad (4.3)$$

Apart from the slight difference in the formulation of *f*, with hazard and resistance multiplied by each other, the terms within Equation (4.3) are computed nearly in the same way as the ATC. C_b should finally be added, based on subjective considerations "to include such factors as bridge importance, network redundancy, no seismic deficiencies, remaining useful life, and the like".

An approach to prioritisation presented by Babei and Hawkins (1991) can be expressed as:

$$P_b = f(F_b, R_b, C_b) = F_b \times R_b \times C_b(\mathrm{U_b}, \mathrm{U_B}) \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (4.4)$$

For R_b , the ATC formulation should be used. C_b is accounted for via a "criticality factor" C_f, which lies in the 0-6 range and is computed in a rather subjective way considering traffic volume on or under the bridge, detour length, emergency route designation, bridge length, utilities carried on the bridge, route type on and under the bridge, and a "remaining life factor" K, which accounts for the remaining useful life.

Basoz and Kiremidjian (1996) used an approach mathematically similar to what was first proposed by ATC, but very much detailed as for hazard, structural resistance and costs are concerned. The model proposed may be recast in the form:

$$P_b = f(F_b, R_b, C_b) = F_b \times \mathrm{w_f} \times R_b \times \mathrm{w_r} + C_b(\mathrm{U_b}, \mathrm{U_B}) \times \mathrm{w_c} \dots \dots \dots \dots \dots \dots \dots (4.5)$$

Structural behaviour is taken into account via computation of the vulnerability, which is done in a traditional way comparing hazard and structural fragility. To this term, they add the term which quantifies failure consequences and that depends on bridge utility within the network it belongs to. They recognise that the terms that define bridge utility (traffic flow, location within the network, highway type, etc.) cannot be quantified in monetary value since this step depends on the decision maker (Basoz and Kiremidjian, 1996).

Several definitions have been proposed by scholars for the concept of risk in relation with hazard and vulnerability between the early 1980s (Shah, 1984) and recent years (Hosseini and Yaghoobi, 2006). Davidson and Shah (1997) have proposed an urban earthquake disaster risk index (EDRI) used for risk assessment, based on the concepts of hazard (H), exposure (E), vulnerability (V), external context factors (C) and response situation (R), as the main variables, and giving a weight to each of these, as:

$$EDRI = w_H \times H + w_E \times E + w_V \times V + w_C \times C + w_R \times R \quad (4.6)$$

In Equation (4.6) each of the main variables is calculated by combining its components and their weight factors. For example, H, which is the hazard, can be calculated by:

$$H = w_{H1} \times X_{H1} + w_{H2} \times X_{H2} + w_{H3} \times X_{H3} + w_{H4} \times X_{H4} + w_{H5} \times X_{H5} + w_{H6} \times X_{H6} + w_{H7} \times X_{H7} \quad (4.7)$$

Hosseini and Yaghoobi (2008) proposed a somehow new concept for roads, the 'road service area', which is defined based on a major origin-destination pair and their surrounding industrial, cultural centres, or the centres of any type of economic activity as shown in Figure 4.1.

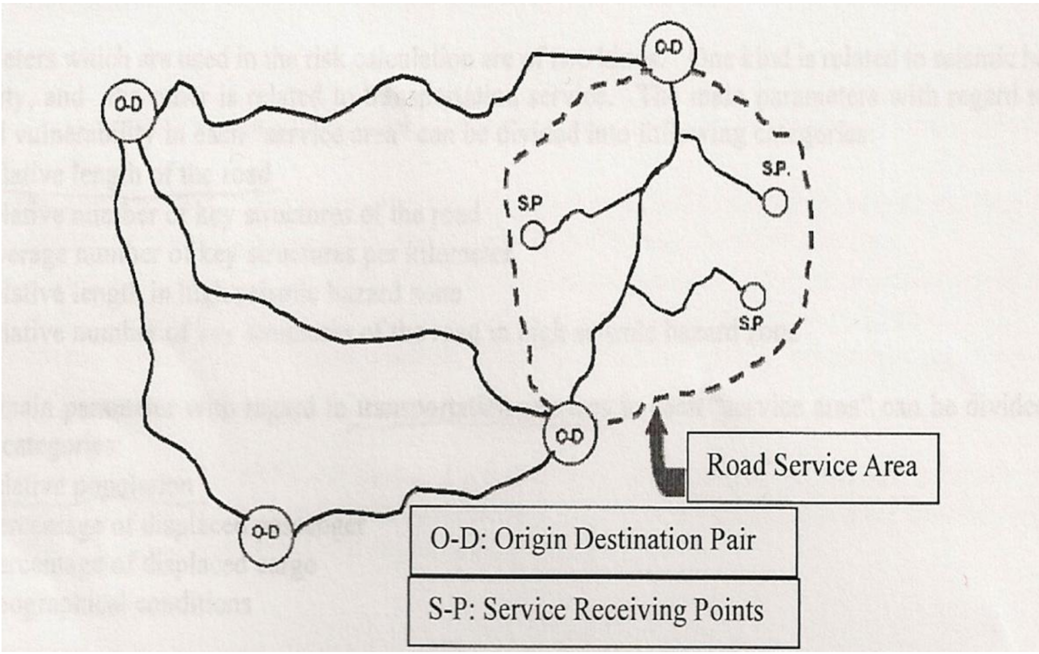

Figure 4.1: Road service area and its components

By using this concept, each country can be divided into some "road service areas" and then these areas can be prioritised based on various parameters, including hazard, vulnerability, and the transportation service presented in each area. For this purpose the risk of service area Q, R_Q can be calculated by giving a weight factor to each parameter as:

$$R_Q = \sum_{1}^{n} Factor \times Weight_{Factor} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.8)$$

in which Factor, $Weight_{Factor}$ and n are respectively the incorporating factors or parameters, their weights and the number of parameters. Then by combining all contributing parameters with their associated weights an importance ratio can be calculated for each "service area" based on which prioritisation can be performed. This model has been used for risk management in which features, on which the importance of a road in the transportation system of a county depends, as well as parameters affecting the road function in the aftermath of a major event, e.g., an earthquake, are taken into consideration (Hosseini and Yaghoobi, 2008).

Shariat *et al.* (2004) presented a method in which the vulnerable components of a transportation system are prioritised for retrofitting based on their service level to the rescue and relief traffic. The reliable provision of accesses between population centres and hospitals is considered as the first criterion for the functionality assessment of the city transportation network. The second criterion is the number of casualties in each population centre. The higher this number the greater is the importance of that centre and its accessibility. The third criterion is the importance of the relief centre or the hospital. Although the number of beds is not the only factor in the importance of a hospital, and other factors such as the capacity of the emergency, and orthopaedics sections as well as the fame of the hospital and its potential capacity increase are also important, as stated by Shariat (2002), this number has been considered as the main factor in the study for the capacity evaluation of hospitals. To apply these criteria to evaluation of the transportation system and decision making on prioritisation of the system components retrofit, the author used a new concept called the Accessibility Index (*AI*) which can be defined as follows.

If I_i is the number of injured people in a population centre, the relative importance or weighting factor W_i of that centre can be defined as:

$$W_i = \frac{\mathrm{I_i}}{\sum_{\mathrm{i=1}}^{\mathrm{p}} \mathrm{I_i}} \qquad (4.9)$$

in which p is the total number of population centre with casualties. A capacity factor C_j can be also defined for each hospital j, by which the relative importance factor γ_j can be defined as:

$$\gamma_j = \frac{C_j}{\sum_{j=1}^{q} C_j} \quad \text{(4.10)}$$

where q is the number of available hospitals. To have an estimation of the accessibility A_i between origin-destination pairs Equation (4.11) can be used.

$$A_i = \sum_j \left[\sum_l P_{ij}^l \right] \times \gamma_j \qquad l \in \{R_{ij}\} \quad \text{(4.11)}$$

in which $\{R_{ij}\}$ is the set of all possible paths (routes) between origin-destination pair of i and j. In Equation (4.11), l is the indicator of any existing path between i and j, and P_{ij}^l is the stability probability of path l, varying between 0.0 for the totally failed path and 1.0 for the fully functional path. This probability itself can be calculated as the product of stability probabilities of all components in path l, namely:

$$P_{ij}^l = \prod_{k=1}^{n} P_{ij}^{lk} \quad \text{(4.12)}$$

In this evaluation each path like l is considered to have n components, and P_{ij}^{lk} is the stability probability of the k^{th} component. It should be noted that without a powerful crisis management, even without heavy damage to the transportation network components, the functionality of the network will decrease to a great extent because of the unpredicted public reaction (Hosseini and Mirza, 1999). By using the concepts presented by Equation (4.9) to (4.12), the Accessibility Index AI_i can now be defined as:

$$AI_i = \mathrm{A_i} \times W_i \dots \quad (4.13)$$

and the Total Accessibility Index for the whole network, TAI, can then be given by:

$$TAI = \sum_{i=1}^{p} AI_i \dots \quad (4.14)$$

in which p is again the total number of population centres in the city. Obviously, the higher value of *TAI* means the better condition of the whole network. By simulation of any transportation network and by using some appropriate earthquake scenarios and calculating the values of the Total Accessibility Index for various combinations or sets of paths, the set which gives the highest value of *TAI* can be considered as the optimum network for rescue and relief activities, and accordingly, the vulnerable components in this optimum network have the highest priority for retrofitting (Shariat *et al.,* 2004).

However, the aforementioned formulas can be used for introducing the optimum transportation network for rescue and relief activities and prioritisation of components retrofit in the very first hours after the occurrence of a serious event, e.g., an earthquake.

Pavement condition can be characterised by a variety of performance indicators for evaluating different aspects of pavement performance. For roadway pavements, these indicators may include surface deterioration, pavement deflection, rut depth, roughness and skid resistance (Haas *et al.*, 1994; Jung *et al.*, 2008).

To rank the priority of each road segment, the most common approach is to aggregate individual indices to form a linearly combined index (Shahin and Kohn, 1979; ERES Consultants, 1986; Haas *et al.*, 1994):

$$\text{Combined Index} = \sum W_i \times X_i \quad \ldots \quad (4.15)$$

where W_i and X_i are respectively weights and values of the i^{th} index. The benefit of having a combined index for describing pavement condition is twofold. First, it constitutes a unified basis for comparison of pavement conditions of different road segments. Second, it provides a simple communication tool to convey summary information to senior administrators, elected officials, and the public (Sun and Gu, 2011).

4.11 Summary

Previous studies have investigated practices in roads recovery prioritisation, but the factors affecting it and developed models for implementation and/or application are still far from sufficient and many of them lack important characteristics and factors which are necessary to be applied efficiently and effectively in the road maintenance organisations. Identifying, summarising and discussing gaps of previous studies is important to provide critical background that helps in the process of proposing and developing a model that provides a structured method to fill the gaps of the existing researches in the road construction and maintenance projects. Disadvantages and gaps in current studies can be summarised as follows:

- A large amount of researches by many authors has concerned the impacts of either natural disasters or man-made disasters on life sectors but there is a lack of information regarding the impacts of these two events on a road's infrastructure. There are no references that take both the events of natural disasters and man-made disasters into consideration.

- Despite the significant contributions of the above research studies, there is a lack of reported research that focuses on the prioritisation models that have been proposed for determining which roads in a transport network should be given priority to recover first.
- Many of the general models lack details and comprehensiveness to satisfy the need of road organisations in the sector of reconstruction and rehabilitation.
- Most researches only focus on one of two main processes in the domain of road recovery priority, i.e., either identifying some important factors or providing a model of road rehabilitation. There is a need to include both these issues in one research in order to give a better solution for the problem.
- Many researches do not provide different categories of factors that govern the issue of road recovery priority. Identifying different groups of influencing factors will help road reconstruction organisations to identify different activities, procedures and tools to process and manage road rehabilitation. This can also help in identifying factors available, factors missed and additional factors needed to be included in the road recovery priority model.
- There is a shortage of case studies that investigate the effect of man-made disasters on the road network system and also related models for road recovery priority.

- Most of the researches deal with the short-term recovery during the rescue and relief operations; while there is a need for great attention and more extensive studies in the long-term recovery.
- Non construction related recovery costs (e.g., road users and business disruption) and their impacts on road prioritisation are not included in most of the previous studies.
- There is no reported research that focused on the impact weight of the affecting factors which is the level of importance for each affecting factor (i.e., how much the percentage of effect for each factor on the road recovery priority).
- As the concept of indicators and index is relatively new in the recovery priority, not much attention has been paid to these topics so far.

Reviewing previous studies and analysing their gaps and shortages also helps to identify the major characteristics, relationships and components that can compose an appropriate, comprehensive, practical and useful model for road recovery priority implementation and application in road reconstruction and maintenance projects.

The design of the proposed road recovery priority RRP model in this research has been adopted to ensure overcoming shortages of the existing models and to provide practical methods for implementing and applying the RRP model in road reconstruction and rehabilitation organisations. This model overcomes the disadvantages as summarised previously. In the model, new and many components and influencing factors are introduced and improvements are implemented to ensure it is more practical and comprehensive. Other methods of interviews and questionnaires are conducted to help to enhance the proposed RRP model as will be described and discussed in the following chapter.

CHAPTER FIVE

INTERVIEW AND QUESTIONNAIRE SURVEYS

5.1 Introduction

Although previous studies have tried to study recovery processes, tools and some critical factors of roads damaged by natural/man-made disasters, most of these studies do not consider the special characteristics and features of the damaged area and their influencing factors that can affect efforts and projects. Furthermore, many of these studies lack the adoption of a systematic way and suffer from a lack of empirical studies for the pavement management system (PMS) of the road reconstruction sector. This chapter studies activities, methods, tools and influencing factors in a systematic way to enhance the proposed RRP model so that it can be easily and effectively used by road reconstruction and rehabilitation organisations for successful RRP implementation and application.

First, in this chapter, the aims and objectives of the interviews conducted for this research are discussed. Then, the responses of the participants are reviewed and analysed. Second, the objectives and design of the questionnaire survey used in the research are presented. The findings from the questionnaire survey are analysed and presented. Finally, the results of the interviews and questionnaires are discussed to show how they affect the structuring, development and improvement of the RRP model. By incorporating the results of the interviews and questionnaires into the proposed RRP model a more structured and comprehensive RRP model has been developed for implementation and application in road reconstruction projects.

5.2 Interview Survey

The interview is probably the most common research method in qualitative research, because it provides an easy flexible method that can be used to capture important ideas and detailed opinions to enrich the research. Interviewees will be asked to provide general opinions and important aspects that need to be considered (Bryman and Bell, 2003; Ahmed, 2010).

5.2.1 Aim and Objectives of Interview Survey

As part of the research effort to assign and assess factors that influence the RRP to develop a comprehensive and appropriate RRP model, interviews were conducted with experts in the PMS road reconstruction and maintenance organisations. The aim of the interviews was to investigate respondents' evaluation and understanding of the RRP model in terms of its ease of use, usefulness, comprehensiveness, applicability, feasibility and structure; in addition; to identify the influencing and controlling factors from the respondents' point of view.

Many people, including practitioners and academics from the highway sector known for having experience and/or published work, were chosen and asked to participate in interviews for the purpose of this study. Also, some face-to-face discussions were arranged to encourage discussion and solve problems. General questions about RRP model (see Appendix A), were sent to the people who showed interest in participating in the research.

Adopting semi-structured interviews with questions of an open-ended nature was the method adopted by the research interviews to encourage respondents to provide useful detailed opinions and ideas, and to identify and discuss important and critical factors, which enabled the research to identify issues that can be important for the development of the RRP model for road reconstruction and rehabilitation projects after natural/man-made disasters.

5.2.2 Respondents

Interviews were conducted with thirty-two people who agreed to participate in the research. The interviewees include fifteen academics with wide experiences in PMS research and publishing, seven PMS managers with more than eight years experience in PMS applications and ten senior managers with more than thirteen years experience in the road reconstruction and maintenance projects and with a wide experience in the PMS domain. The interviewees were chosen regarding their experiences and background in the PMS and road rehabilitation domain and their willingness and interest in participating.

However, the responses and results were filtered to ensure the exclusion of unnecessary irrelevant outcomes. Also, the respondents were given the opportunity to review their responses in order to edit contents and provide comments. In some occasions, opinions from respondents were discussed with other respondents to collect feedback, refine results and improve outcomes. Also, some face-to-face discussions were arranged to encourage discussion and solve problems.

In 2003, road networks were seriously damaged in the Iraq War. The interview has been conducted in Iraq with governmental departments, academic institutes and industry. They are:

1. Ministry of Transportation
    - Department of Planning and Following Office.
    - Department of Researches and Studies
2. Ministry of Construction and Housing
    - The State Corporation for Roads and Bridges
    - National Centre for Engineering Consultations
    - General Office for Works and Maintenance
    - Construction Engineering Office
3. Mayoralty of Baghdad – Projects Division
4. Ministry of Planning and Development Cooperation – The Central Bureau of Statistics and Information Technology
5. Ministry of Higher Education and Scientific Research – Consultive Offices in University of Technology, Baghdad University and Al-Mustanseria University.
6. Industrial firms (road companies).

5.2.3 Analysis of the Responses

The comments and discussions provided by the interviewees reflect their opinions, perspectives, ideas and evaluations about the proposed RRM model in terms of its characteristics, such as ease of understanding and use, comprehensiveness, applicability, feasibility, structure, usefulness, etc. In general, the respondents gave positive comments and agreed that the developed RRP model is useful, relatively comprehensive and appropriate. The comments given by the respondents are discussed in the following paragraphs.

The comments received in the early stages of the development of the RRP model described the RRP model as interesting, new and informative, and stated that it addressed the important issues of road reconstruction management and PMS research.

Respondents suggested important and critical factors to be included within each of the five components for the proposed RRP model, where every component can be represented and explained more clearly. By providing details for each component, an enhanced RRP model can be developed to provide better details for RRP adoption in road reconstruction and rehabilitation projects.

All of the respondents agreed that the proposed RRP model should be properly developed, relatively simple, easy to understand and follow, and should include the essential factors needed for the successful implementation and application. Respondents believed that the proposed RRP model will make the implementation and application of road prioritisation for recovery in rehabilitation projects easier, more structured and more effective.

The development of the final RRP model will take into consideration the useful comments and suggestions provided by the interviewees, combined with other results of the questionnaire survey that will be detailed and discussed in the following section.

Suggestions, recommendations, opinions and experiences provided by the respondents to the study interviews in addition to the previous literature reviews of the researchers had a great effect in identifying and estimating the important factors that may be included in the road recovery priority model after natural/man-made disasters.

According to the opinions of the reviewers and the factors which had been handled by previous researchers, estimated factors have been included within each group in this study to be influential on the road priority for recovery. Hence, each group consists of a number of estimated sub-group factors. As a result, twenty-nine factors have been chosen in this study. The classification of these groups and the factors which are included in each group are shown in Table 5.1.

Table 5.1: Classification of the estimated groups and the factors within each group which have been included in the road recovery priority model

Group (g)		Factor (f)	
No.	**Name**	**No.**	**Name**
1	Socio-Economic Factors	1,1	Number of critical socio-economic facilities
		1,2	Area of socio-economic buildings (m^2)
		1,3	Capacity of socio-economic buildings (person/m^2)
		1,4	Population served by a road (habitant)
		1,5	Area served by a road (km^2)
		1,6	Type of area (urban or rural)
2	Road Network Factors	2,1	Type of road
		2,2	Number of nodes
		2,3	Number of links
		2,4	Length of road (km)
		2,5	Number of lanes in each direction
		2,6	Pavement structure
3	Traffic Factors	3,1	Traffic classification
		3,2	Traffic flow (vpd)
		3,3	Delay time (min.)
		3,4	Additional trip length (km)
		3,5	Queue length (m)
		3,6	Level of service (LOS)
		3,7	Reduction in average speed (km/hr)
		3,8	Traffic control pattern
4	Damage Factors	4,1	Percentage of damaged road (%)
		4,2	Severity of damage
		4,3	Number of open lanes in each direction
		4,4	Number of damaged layers
		4,5	Present serviceability index (PSI)
5	Financial Factors	5,1	Direct cost (reconstruction or repair)
		5,2	Time cost

Group (g)		Factor (f)	
No.	**Name**	**No.**	**Name**
		5,3	Extra fuel consumption
		5,4	Effect on economic (temporary unemployment cost and business interruption cost)

5.3 Questionnaire Survey

The questionnaire survey is one of the tools used by researchers to confirm, deny or enhance what was already believed or known. Survey methodology is important and popular because of its ability to define and detail various characteristics of key issues that can be important and interesting for certain readers and organisations. A questionnaire survey also has the ability to provide results that can be quantified and so can be easily treated and analysed statistically. It provides the ability to extend the results obtained from a sample of respondents to a larger population when it is not practical and efficient to work with the entire population. It also provides fast and straightforward results compared with other research methods to allow researchers and practitioners to act in a relatively quick and intellectually respectable manner (Chauvel and Despres, 2002; Ahmed, 2010).

Common methods for establishing relative weights, as stated by Sinha *et al.* (2009), often involve the administration of a questionnaire survey to gauge the relative preference of survey respondents for each system goal and/or performance measure. Survey respondents, who represent the decision makers, include agency engineers, facility users and other stakeholders.

Vanier *et al.* (2006) stated that priorities can quickly change depending on any number of factors. The prioritisation shows the importance of selecting suitable weights, the significance of the deciding criteria and the contributions of the individual values for each criterion.

5.3.1 Aim of Questionnaire Survey

Saaty (1977) stated that a fundamental problem of the decision theory is how to derive weights for a set of activities according to importance. Importance is usually judged according to several criteria. Each criterion may be shared by some or by all of the activities. The criteria may, for example, be objectives which the activities have been devised to fulfil.

Therefore, in this research, the questionnaire survey has been conducted and aims to estimate the weight value (level of importance) $W_{g,f}$ of each factor in each factor group (which can be defined as the contribution weight of the f^{th} factor in the g^{th} factor group) and the weight value (level of importance) W_g of each group (which can be defined as the contribution weight of the g^{th} factor group) which are influential on the road recovery priority. This will help in investigating the impact of the critical factors for implementing the RRP model in the road rehabilitation sector.

In the Direct Weighting Method, the survey respondent assigns numerical values directly to individual goals on a predefined scale such as 1–10, 1–100, etc. (Stillwell *et al.*, 1987; Barron and Barret, 1996; Dodgson *et al.*, 2001). Direct weighting methods include point allocation (a number of points are allocated by the survey respondent to each performance criteria in proportion to its perceived importance), categorisation (the survey respondent assigns the performance criteria to different categories and each category is assigned a weight on the basis of its perceived importance) and ranking (the survey respondent arranges all performance criteria in order of decreasing importance).

Of the direct weighting methods, point allocation can be considered the most appropriate for most transportation problems because unlike ranking, it yields a cardinal, rather than ordinal, scale of importance. Since these weights are often intended for use in a multivariate value function, the cardinality property is important. Compared to other weighting methods, the direct weighting methods are simple to use (Sinha *et al.*, 2009).

5.3.2 Questionnaire Design

The questionnaire was designed to seek opinions from highway and PMS's managers, academicians, workers and team members, senior and junior engineers, or any employee who may have good experience in implementing or applying PMS in road reconstruction and rehabilitation organisations. The questionnaire asks participants to provide their evaluation for the importance of different factors and groups according to their experiences and perceptions. During the research stages, the questionnaire has been developed and enhanced in shape, design and content. The questionnaire was checked and evaluated through a pilot study and was corrected and enhanced in terms of structure, content and format. The questionnaire was designed to include four main sections as shown in Appendix B. Section 1 seeks general information about the participants and their companies, such as the profession and years of experience of the respondent. These will be used to describe characteristics of the questionnaire respondents.

Section 2 asks respondents, according to their experiences and opinions, to give the level of importance of the listed estimated influencing factors within each of the suggested groups on the road recovery priority. Section 2 is divided into five parts according to the five groups of factors which are socio-economic factors, road network factors, traffic factors, damage factors and financial factors.

In Section 3, the respondents were asked to provide their level of importance of the estimated groups when prioritising damaged roads after natural/man-made disasters for recovery.

Sections 2 and 3 were dedicated to evaluating a rate of impact of the estimated factors and groups that will be then used in the proposed RRP model. This evaluation uses a five-point scale where 1 is very low impact, 2 for low impact, 3 for medium impact, 4 for high level of impact and 5 for very high impact level. The description of each criterion is given in Table 5.2 below. The respondents were asked to leave boxes blank if they did not know or were unsure of their response.

Table 5.2: Criteria's description of the five-point scale for the impact rate

Impact Rate (IR)	Criteria	Description
1	very low impact	0 % ≤ The effect percentage ≤ 20 %
2	low impact	20 % < The effect percentage ≤ 40 %
3	medium impact	40 % < The effect percentage ≤ 60 %
4	high impact	60 % < The effect percentage ≤ 80 %
5	very high impact	80 % < The effect percentage ≤ 100 %

Two blank boxes were left at the end of each group of factors for respondents to give the name and level of impact of any other factors corresponding to each group or any other factor groups they have known and not mentioned in the questionnaire.

Two questions were included in section 4 of the questionnaire. Question 1 asks the participants to give their evaluation of the success of the RRP model according to the factors and groups listed in sections 2 and 3 of the questionnaire when prioritising roads damaged by natural/man-made disasters for recovery and rehabilitation. Question 2 seeks the extent of using (or planning to use) such a RRP model or a similar model in the respondent's institution (company).

The evaluation in section 4 uses a six-point Likert scale. In question 1, level 1 refers to unsuccessful at all, 2 means slightly successful, 3 is moderately successful, 4 is successful, 5 is very successful and, finally, 6 means extremely successful. In question 2, level 1 refers to not used at all, 2 means planned to use, 3 is slightly used, 4 is moderately used, 5 is very used and, finally, 6 means extremely used.

Using a scale with an even number of six points and asking participants not to answer when they were not sure helped to avoid problems of "Leniency" and "Central tendency" by encouraging respondents to show whether they lean more towards the "successful" or "unsuccessful" directions of the scale rather than choosing the midpoint (Kendall and Kendall, 2002; Albaum, 1997; Trochim, 2006; Ahmed, 2010).

A feedback section was included at the end of the questionnaire to allow respondents to provide comments about the questionnaire survey and invite more opinions and suggestions on the handled issue.

The results of the questionnaire help to build and structure the RRP model to enable organisations to plan and manage their road rehabilitation efforts successfully. The results evaluate importance and influence of the different factors which are important to shape a more useful and comprehensive RRP model for successful and effective implementation and application in the road rehabilitation project in order to help organisations manage resources and efforts successfully to obtain required results and potentials. Hence, addressing the results of the questionnaire into the RRP model is necessary in helping road reconstruction and maintenance organisations to identify the key factors, that if effectively adopted can make the implementation and application of RRP more successful.

5.3.3 Respondents

Respondents have been carefully chosen including:

1. Academicians in Highways and Transportation Departments in the universities of Baghdad city in Iraq.
2. PhD students in Highways and Transportation Departments in the UK and Iraqi Universities.
3. Practitioners in road companies and governmental institutions regarding highway works in Baghdad city.

5.3.4 Experience Years

In order to obtain reasonable and accurate results, the experience years of the respondents are included in the questionnaire according to Table 5.3. People with (0 – 5) years of experience have been given a weight of (0.2), others with (5 – 10) years of experience have been given a weight of (0.3) and a weight of (0.5) has been given to people with (over 10) years of experience. For example, for a participant with seven years of experience, its estimated impact rate value for each factor and each group, which is obtained from the questionnaire, will be multiplied by an experience weight value (W_2) of 0.3.

Table 5.3: Experience weight values

Experience (E) (Years)	Weight Value (W) (%)
$0 \leq E_1 \leq 5$	$W_1 = 0.2$
$5 < E_2 \leq 10$	$W_2 = 0.3$
$E_3 > 10$	$W_3 = 0.5$

A questionnaire feedback sample is given in Appendix C. Appendix D presents a questionnaire data base for all respondents.

5.3.5 Reliability and Validity of the Questionnaire Results

Testing the reliability and validity of the questionnaire results is very important before conducting any further analysis. Reliability tests are used to provide an indication of the degree to which the measures used to evaluate the same thing are homogeneous and consistent (Saraph *et al.*, 1989; Black, 1999; Antony *et al.*, 2002; Ahmed, 2010).

In order to assess the reliability of empirical measurements, four methods can be used: (1) the retest method, (2) the alternative form method, (3) the split-halves method, and (4) the internal consistency method (Nunnally, 1967; Sellitz *et al.*, 1976; Ahmed, 2010). The first three methods have major limitations (particularly for field studies) such as requiring two independent administrations on the same sample or the need for two alternate forms of the measuring instrument (Nunnally, 1967). That made the fourth method the most used form of reliability estimation for the field type of studies (Saraph *et al.*, 1989). Hence, the internal consistency method was adopted for this research.

The internal consistency method estimates the degree to which items in a set are homogeneous by calculating a reliability coefficient called Cronbach's alpha (Cronbach, 1951). In this study, Cronbach's alpha was computed by using the SPSS (originally, Statistical Package for the Social Sciences) reliability programme to perform an internal consistency analysis for the responses of sections 2 and 3 of the questionnaire. Examples of reliability results provided by using the SPSS programme are shown in Appendix E.1. Generally, Cronbach's alpha refers to a sufficiently homogenous elements if its value is greater than 0.7 (Cronbach, 1951). However, when Cronbach's alpha is less than the value 0.7 the reliability can be maximised by eliminating an item or more from a sub-section. The analysis was performed for each group separately and then for all groups together and the values for Cronbach's alpha were greater than 0.7 as shown in Appendix E.1.

Table 5.4 summarises the original alpha values associated with all the items included in each sub-section, the items that should be removed from the original sets if alpha is less than 0.7 to maximise its value, and the final computed alphas for the reduced sets. This is important to ensure that all the activities and factors that will be analysed in the following sections of this study have high internal consistency, and are thus reliable.

The results in Table 5.4 show that all the calculated Cronbach's alpha values for the sections and sub-sections of the questionnaire results are greater than the value 0.7. This indicates that the responses for the items in these sections and sub-sections are homogenous and having high internal consistency. So, the results of these sections and sub-sections can all be included in the analysis of the questionnaire responses in the following sections.

Table 5.4: Reliability analysis results

Questionnaire sections		**No. of original items**	**Original alpha value**	**Item for deletion**	**Alpha if item deleted**
Section 2	**Evaluation for each group**				
2.1	Socio-economic factor group	6	0.846	-	0.846
2.2	Road network factor group	6	0.884	-	0.884
2.3	Traffic factor group	8	0.945	-	0.945
2.4	Damage factor group	5	0.848	-	0.848
2.5	Financial factor group	4	0.802	-	0.802
Section 3	**Evaluation for all groups**	5	0.904	-	0.904

Validity tests aim at evaluating the extent to which a measure is testing what is intended to be measured (Saraph *et al.*, 1989). The two tests, i.e. content validity and criterion-related validity, are usually used in literature for an approximately similar number of responses to test validity of the questionnaires' results. Content validity cannot be evaluated numerically but it depends on evaluations and judgements by the researchers on whether the instrument or the questionnaire contains items that cover all aspects of each variable being measured (Nunnally, 1967; Saraph *et al.*, 1989; Badri *et al.*, 1995; Yusof and Aspinwall, 2000; Ahmed, 2010).

In this study, because the selection of all the measurement items in the questionnaire was based on in-depth reviews of the PMS and RRP literatures after natural/man-made disasters, and these items were reviewed, edited and detailed according to feedback and evaluations from academicians and practitioners, the questionnaire measures developed in this study can be judged as having content validity. Furthermore, an evaluation by practitioners and academicians indicated that the items included in each sub-section are relatively comprehensive and well represented to evaluate and measure presented activities, tools or factors.

Criterion-related validity refers to the extent to which a measuring instrument is related to an independent measure of a relevant criterion (Yusof and Aspinwall, 2000). Since the questionnaire is measuring the importance of a set of activities, tools and factors for a successful implementation and application of the RRP model, the results for sections 2 and 3 can be related to a question that asks respondents to evaluate the success of the questionnaire items to deliver a successful implementation and application of the RRP model in road reconstruction and rehabilitation projects after natural/man-made disasters. For this purpose, a question was included in the questionnaire (See question 4.1 in Appendix B) that requires respondents to evaluate the success of the RRP model, estimated factors and estimated factor groups by using six levels where 1 refers to unsuccessful at all and 6 refers to extremely successful.

To determine the extent of the relationship between the “average importance score” for each factor given by each respondent (independent variables), and his/her evaluation to the level of success of the RRP model, estimated factors and estimated factor groups, a multiple regression analysis was carried out by using the SPSS programme and the results were presented as shown in Appendix E.2. The R-square and the adjusted R-square value (adjusted coefficient of determination) resulting from this analysis was

0.724 and 0.581 respectively when all of the factors which have been included in the RRP model were taken into account. This indicates that the RRP model's estimated factors have a high degree of criterion-related validity and a high degree of predictive capability.

The correlation is one of the most common and most useful statistics. A correlation is a single number that describes the degree of relationship between two variables. In this study, a correlation was computed by using the SPSS to perform the strength of relationships between factors within each group and between groups. The results of the correlation analysis were presented in Appendix E.3. The results indicated that there is a strong relationship between factors in groups 3, 4 and 5 with a confidence level of 99 per cent. For factors in group 2, there was a strong relationship with a confidence level of 99 per cent between four factors and with a confidence level of 95 per cent between two factors. The results for group 1 indicated that there was a strong relationship with a confidence level of 99 per cent between three factors and with a confidence level of 95 per cent between two factors. There was no relationship between two factors but the relationship between these two factors and the others within the same group is still a strong one. The correlation results between groups showed that there was a strong relationship with 99 per cent confidence level. In general, the relationships exist between factors and groups and it is a strong relationship with a confidence level of 99 per cent.

5.3.6 Response Characteristics

In order to define the response characteristics and to evaluate the importance level of factors and groups included in the proposed RRP model, the responses to sections 1, 2, 3 and 4 of the survey need to be analysed. The response characteristics are investigated by calculating the numbers and percentages of occurrence of responses from Section 1 in the questionnaire. The level of importance of the RRP model's factors and groups are investigated in Sections 2 and 3 of the questionnaire through calculating the mean scores and the number and percentage of occurrence for the respondents' ratings. Calculating numbers and percentages of occurrence of the responses in Section 4 investigates the evaluation of success of adopting the RRP model when prioritising roads that have been damaged by natural/man-made disasters for recovery and rehabilitation according to the handled factors and groups. Also, section 4 investigates the percentage of using (or planning to use) such a RRP model or a similar model.

5.3.6.1 Section 1: Response Characteristics

A total of 86 out of 120 questionnaires have been received, which represents a 71.7 per cent response rate. This is adequate to satisfy the survey objectives and to be acceptable.

As discussed previously, the experience years of the respondents are included in the questionnaire according to Table 5.3. The respondents are classified as 7 people with experience of 0 – 5 years, 22 people that have 5 – 10 years of experience and 57 respondents with years of experience of greater than 10 years as shown in Table 5.5 and are presented in Figure 5.1.

Table 5.5: Classification and percentages of respondents according to their experience years

Experience (E) (Years)	**Number of Respondents**	**Percentage of Respondents (%)**
$0 \leq E_1 \leq 5$	7	8.14
$5 < E_2 \leq 10$	22	25.58
$E_3 > 10$	57	66.28
	Total = 86	

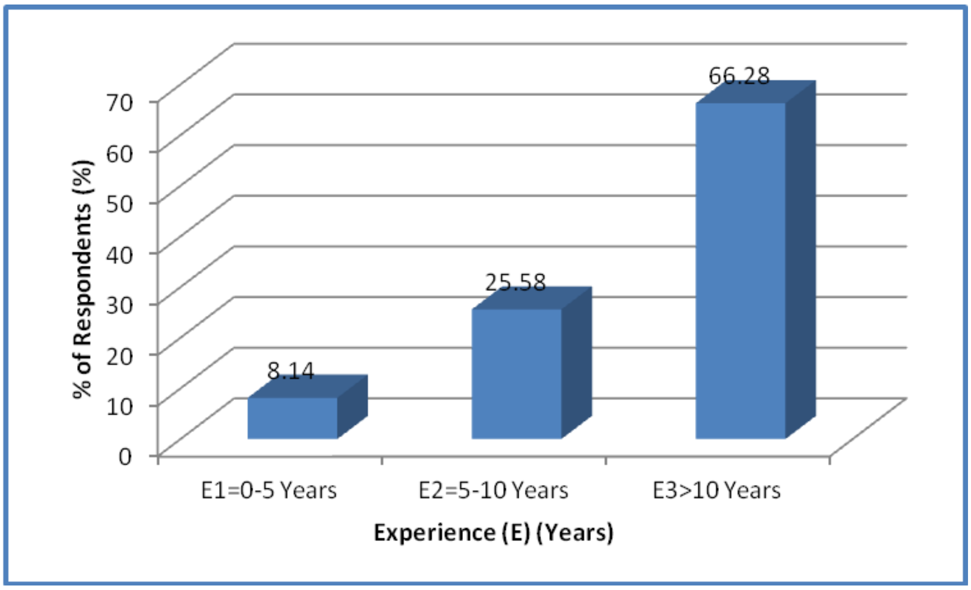

Figure 5.1: Percentages of respondents according to their experience years

<u>5.3.6.2 Section 2 (2.1 to 2.5): Importance Level of RRP Model's Factors</u>

The results of sub-sections 2.1 to 2.5 are analysed to evaluate the importance level of factors within each of the proposed factor groups for the RRP model in the respondents' organisations. Factors in sub-sections 2.1 to 2.5 are proposed in the developed RRP model of the research to define the critical factors that influence on prioritising roads damaged by natural/man-made disasters for recovery in the rehabilitation projects.

Appendix D.1 presents a questionnaire data base for all respondents' evaluation regarding the importance level of the proposed factors. The resulted percentage level of importance for each factor within each group listed in sub-sections 2.1 to 2.5 are summarised and presented in Table 5.6 to 5.10 and illustrated in Figures 5.2 to 5.6.

It can be noticed from Table 5.6 and Figure 5.2 for the socio-economic group that factor Nos. 1 and 4 (number of socio-economic buildings and population served by a road) are the most important factors within this group. While factor Nos. 2, 3 and 5 (which are related to area of socio-economic buildings, capacity of these buildings and area served by a road) are lower level of importance compared to other factors according the questionnaire respondents.

Table 5.6: Detailed percentage level of importance for each factor in group 1

	Level of Importance	**Factor No.**						
		1*	**2***	**3***	**4***	**5***	**6***	
Percentage of Responses (%)	Very high	44.2	2.3	4.7	38.4	8.1	24.4	Average
	High	37.2	7.0	16.3	45.3	24.4	43.0	
	Medium	16.3	22.1	27.9	12.8	31.4	15.1	
	Low	0.0	30.2	34.9	3.5	27.9	10.5	
	Very low	2.3	38.4	16.3	0.0	8.1	7.0	
	Very high + High	81.4	9.3	21.0	83.7	32.5	67.4	49.2
	Very low + low	2.3	68.6	51.2	3.5	36.0	17.5	29.8

* Factor No. 1 is Number of critical socio-economic facilities, Factor No. 2 is Area of socio-economic buildings (m^2), Factor No. 3 is Capacity of socio-economic buildings ($person/m^2$), Factor No. 4 is Population served by a road (habitant), Factor No. 5 is Area served by a road (km^2) and Factor No. 6 is Type of area (urban or rural).

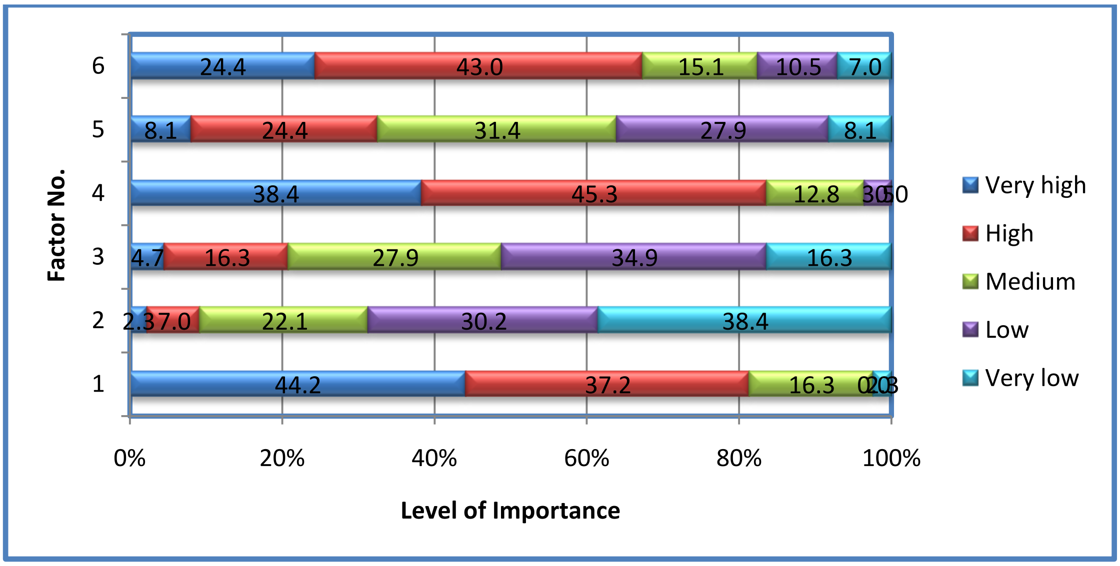

Figure 5.2: Detailed percentage level of importance for each factor in group 1

For the road network group, the respondent results indicated that factor Nos. 1 and 4 (type and length of road) are the most important as most of the respondents level of importance are very high and high for these factors as illustrated in Table 5.7 and Figure 5.3. On the other hand, pavement structure factor received 53.5 per cent of respondents with low and very low level of importance.

Table 5.7: Detailed percentage level of importance for each factor in group 2

	Level of Importance	**Factor No.** 1*	2*	3*	4*	5*	6*	
Percentage of Responses (%)	Very high	45.3	14.0	10.5	25.6	14.0	0.0	Average
	High	39.5	38.4	39.5	34.9	41.9	23.3	
	Medium	14.0	34.9	36.0	22.1	33.7	23.3	
	Low	0.0	9.3	11.6	15.1	9.3	32.6	
	Very low	1.2	3.5	2.3	2.3	1.2	20.9	
	Very high + High	84.9	52.3	50.0	60.5	55.8	23.3	54.5
	Very low + low	1.2	12.8	14.0	17.4	10.5	53.5	18.2

* Factor No. 1 is Type of road, Factor No. 2 is Number of nodes, Factor No. 3 is Number of links, Factor No. 4 is Length of road (km), Factor No. 5 is Number of lanes in each direction and Factor No. 6 is Pavement structure.

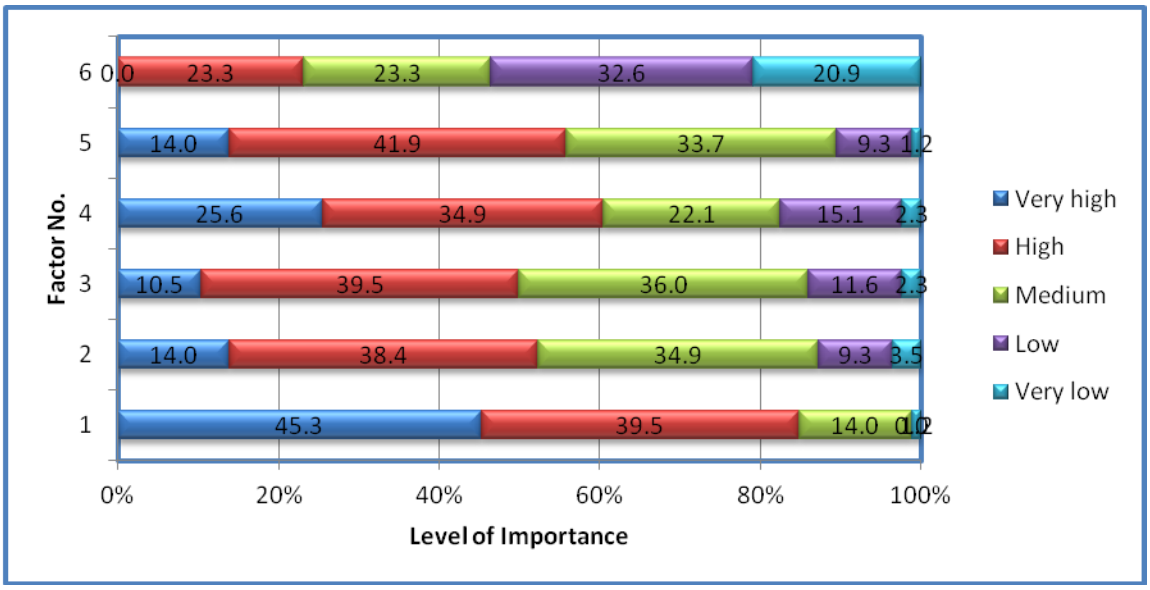

Figure 5.3: Detailed percentage level of importance for each factor in group 2

Table 5.8 and Figure 5.4 shows the detailed questionnaire results regarding the traffic group. These results indicated that there is a small difference in the level of importance of its factors. The respondents' results showed that factor Nos. 2 and 3 (traffic flow and delay time) were the factors with most very high and high level of importance. Conversely, traffic control pattern is the one with the highest low and very low level of importance.

Table 5.8: Detailed percentage level of importance for each factor in group 3

	Level of Importance	Factor No. 1*	2*	3*	4*	5*	6*	7*	8*	Average
Percentage of Responses (%)	Very high	25.6	45.3	53.5	33.7	33.7	36.0	34.9	12.8	
	High	38.4	46.5	33.7	36.0	39.5	40.7	43.0	34.9	
	Medium	24.4	5.8	12.8	25.6	22.1	20.9	18.6	32.6	
	Low	8.1	2.3	0.0	4.7	4.7	2.3	2.3	12.8	
	Very low	3.5	0.0	0.0	0.0	0.0	0.0	1.2	7.0	
	Very high + High	64.0	91.9	87.2	69.8	73.3	76.7	77.9	47.7	73.5
	Very low + low	11.6	2.3	0.0	4.7	4.7	2.3	3.5	19.8	6.1

* Factor No. 1 is Traffic classification, Factor No. 2 is Traffic flow (vpd), Factor No. 3 is Delay time (min.), Factor No. 4 is Additional trip length (km), Factor No. 5 is Queue length (m), Factor No. 6 is Level of service (LOS), Factor No. 7 is Reduction in average speed (km/hr) and Factor No. 8 is Traffic control pattern.

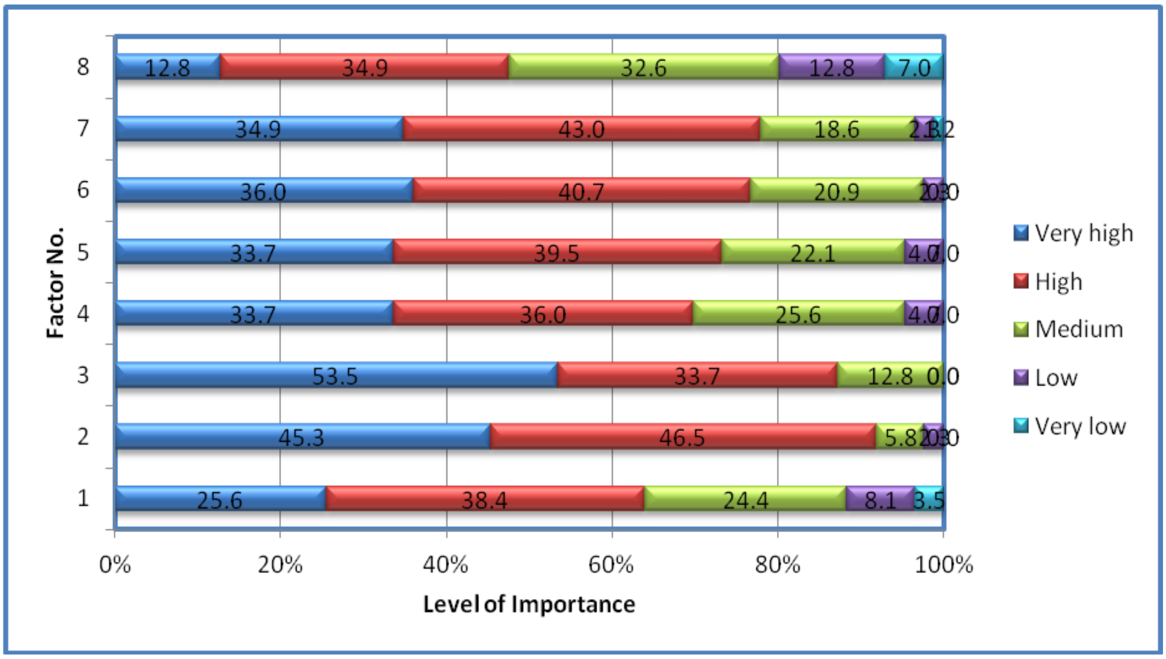

Figure 5.4: Detailed percentage level of importance for each factor in group 3

For damage group of factors, factor Nos. 2 and 1 (severity of damage and percentage of damaged road) received the most very high and high level of importance from respondents. While the factor of high percentage of responses with low and very low is the number of damaged layers. The results are illustrated in Table 5.9 and Figure 5.5.

Table 5.9: Detailed percentage level of importance for each factor in group 4

	Level of Importance	Factor No.					
		1*	2*	3*	4*	5*	
Percentage of Responses (%)	Very high	34.9	36.0	9.3	1.2	7.0	Average
	High	43.0	52.3	44.2	16.3	38.4	
	Medium	17.4	7.0	31.4	47.7	37.2	
	Low	4.7	4.7	15.1	18.6	11.6	
	Very low	0.0	0.0	0.0	16.3	5.8	
	Very high + High	77.9	88.4	53.5	17.4	45.3	56.5
	Very low + low	4.7	4.7	15.1	34.9	17.4	15.3

* Factor No. 1 is Percentage of damaged road (%), Factor No. 2 is Severity of damage, Factor No. 3 is Number of open lanes in each direction, Factor No. 4 is Number of damaged layers and Factor No. 5 is Present serviceability index (PSI).

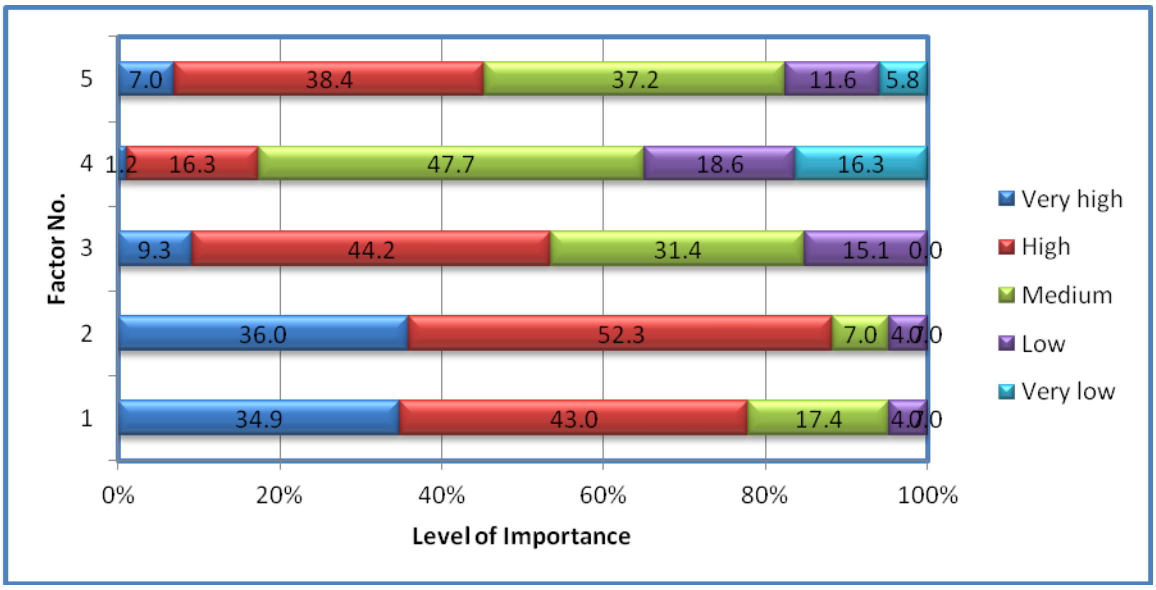

Figure 5.5: Detailed percentage level of importance for each factor in group 4

Finally, Table 5.10 and Figure 5.6 give detailed results regarding the financial group. There is a significant difference between factor Nos. 4 and 1 on one hand and factor

Nos. 2 and 4 on the other hand regarding the level of importance. Effect on economic and direct cost factors received high percentage of responses with very high and high level of importance and vice versa for time cost and fuel consumption factor.

Table 5.10: Detailed percentage level of importance for each factor in group 5

	Level of Importance	**Factor No.**				Average
		1*	**2***	**3***	**4***	
Percentage of Responses (%)	Very high	39.5	1.2	0.0	50.0	
	High	43.0	32.6	8.1	39.5	
	Medium	15.1	31.4	34.9	10.5	
	Low	2.3	30.2	32.6	0.0	
	Very low	0.0	4.7	24.4	0.0	
	Very high + High	82.6	33.7	8.1	89.5	53.5
	Very low + low	2.3	34.9	57.0	0.0	23.5

* Factor No. 1 is Direct cost (reconstruction or repair), Factor No. 2 is Time cost, Factor No. 3 is Extra fuel consumption and Factor No. 4 is Effect on economic (temporary unemployment cost and business interruption cost).

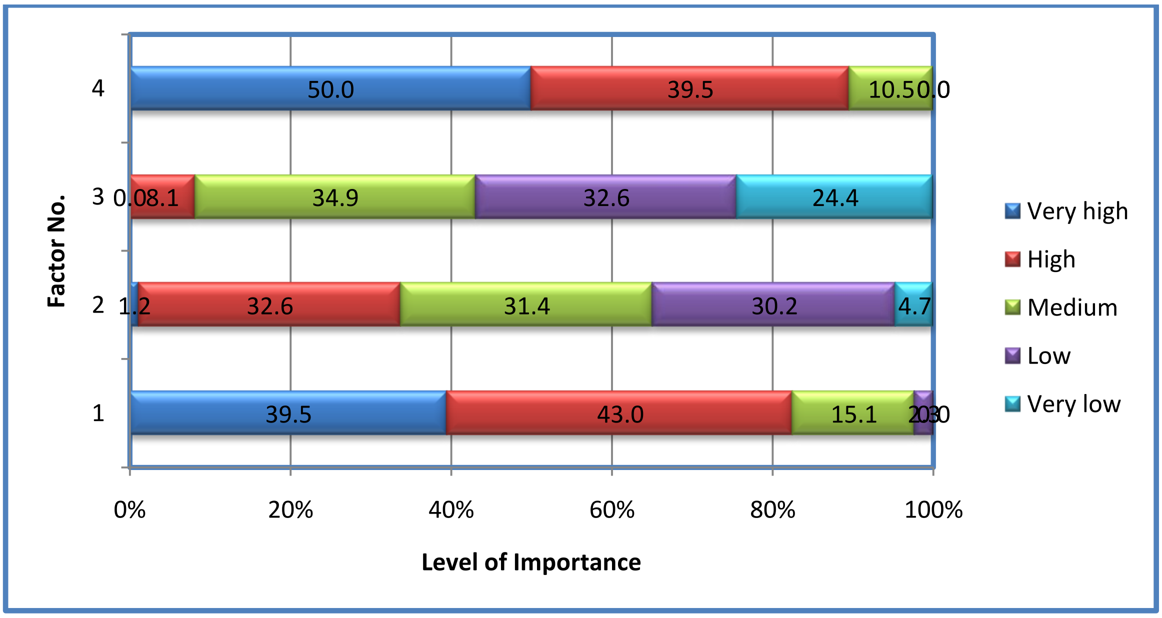

Figure 5.6: Detailed percentage level of importance for each factor in group 5

The average level of importance of all factors included in each group can be calculated in order to give an overall indication for each group regarding the level of importance. The results are presented in Table 5.11 and can be illustrated in Figures 5.7 to 5.11 for group 1 to 5 respectively. As can be seen, the percentages of questionnaire's respondents which indicate that the presented factors for the proposed RRP model with level of importance (impact rate) of high and very high are: 49.2%, 54.4%, 73.5%, 56.5% and 53.5% for group 1, 2, 3, 4 and 5 respectively. While 29.8%, 18.2%, 60.2%, 15.3% and 23.6% for group 1, 2, 3, 4 and 5 respectively of the responses indicate that the presented model's factors are with low and very low level of importance. As an average result for all groups, 57.4% of questionnaire's respondents indicate that the proposed factors are of high and very high level of importance, while 18.6% of responses indicate that these factors are of low and very low level of importance. This indicates that, in general, the factors included in sub-sections 2.1 to 2.5 are important for the successful implementation or building of the RRP model in the road rehabilitation projects. So, it can be concluded that all of the RRP model's factors included in the questionnaire sub-sections 2.1 to 2.5 play a key role in the building and implementation of the proposed RRP model for recovery of roads damaged by natural/man-made disasters.

Table 5.11: Percentage level of importance for each group

	Level of Importance	Group No. 1*	2*	3*	4*	5*	Average
Percentage of Responses (%)	Very high	20.3	18.2	34.4	17.7	22.7	
	High	28.9	36.2	39.1	38.8	30.8	
	Medium	20.9	27.3	20.3	28.1	23.0	
	Low	17.8	13.0	4.7	10.9	16.3	
	Very low	12.0	5.2	1.5	4.4	7.3	
	Very high + High	49.2	54.4	73.5	56.5	53.5	57.4
	Very low + low	29.8	18.2	6.2	15.3	23.6	18.6

*Group No. 1 is Socio-economic factors, Group No. 2 is Road network factors, Group No. 3 is Traffic factors, Group No. 4 is Damage factors and Group No. 5 is Financial factors.

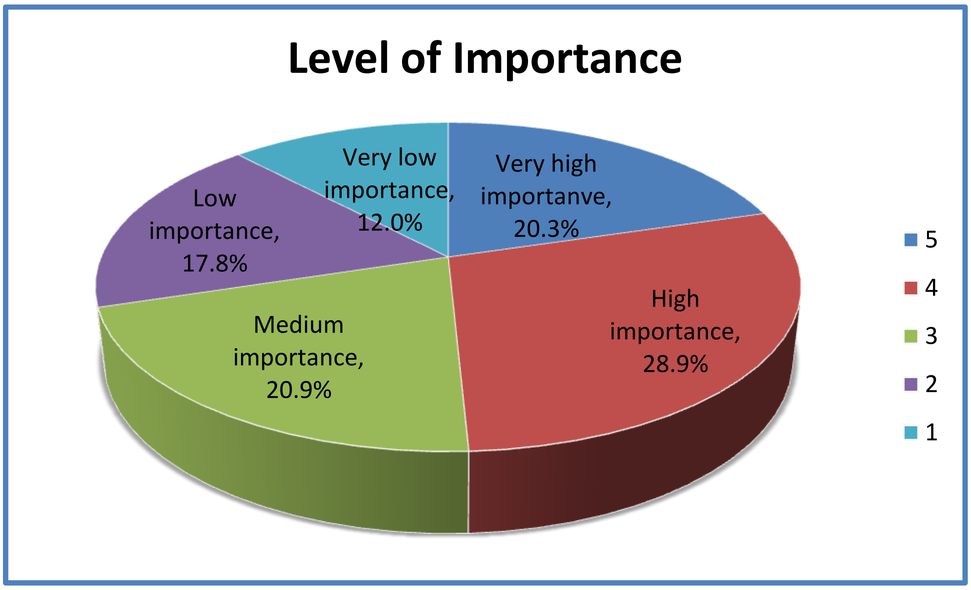

Figure 5.7: Percentage level of importance for Group 1

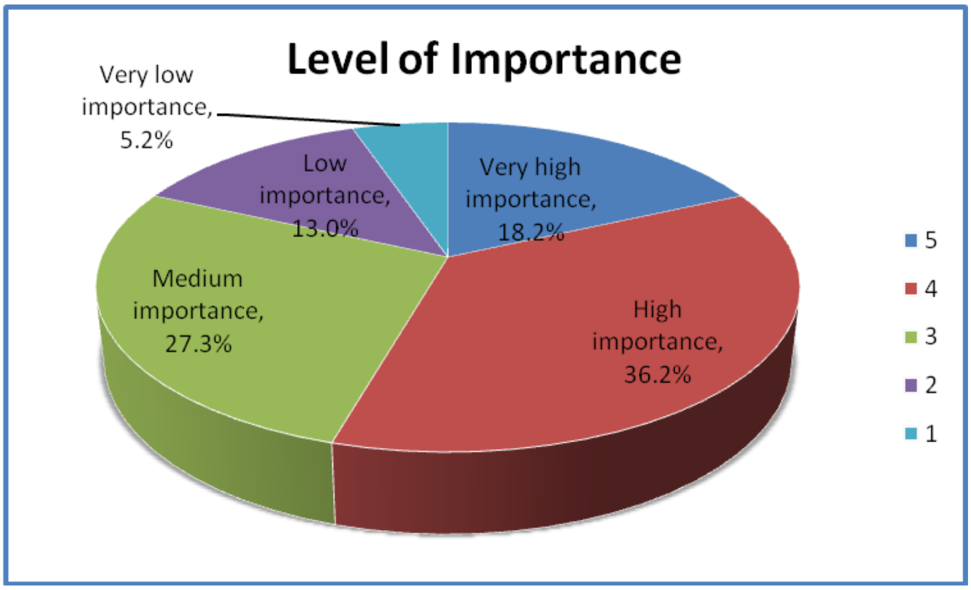

Figure 5.8: Percentage level of importance for Group 2

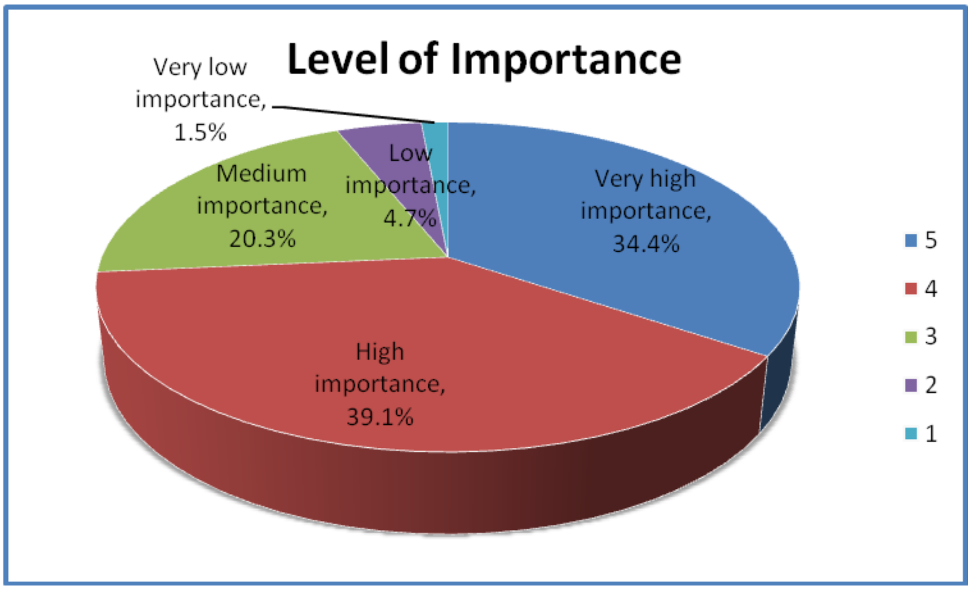

Figure 5.9: Percentage level of importance for Group 3

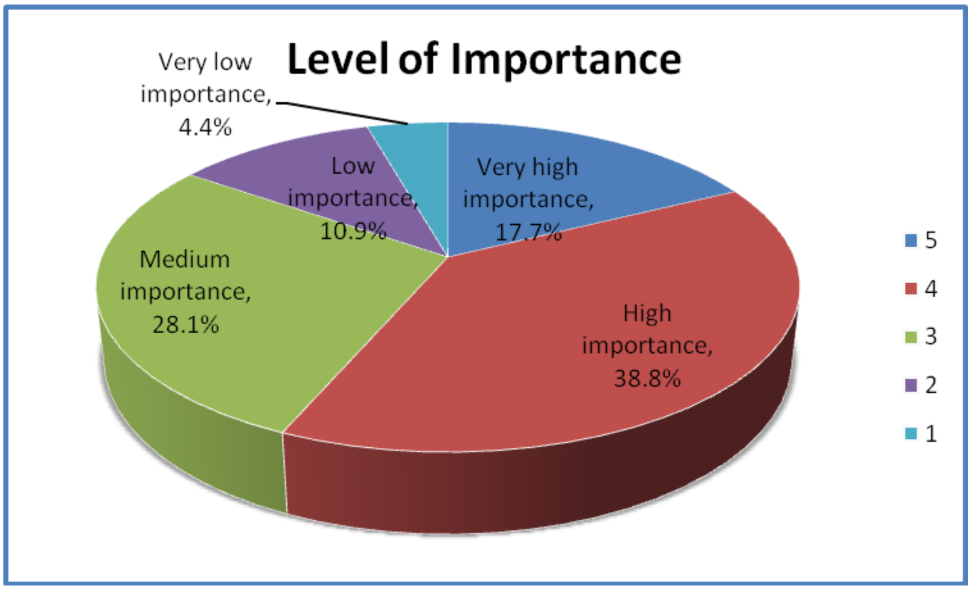

Figure 5.10: Percentage level of importance for Group 4

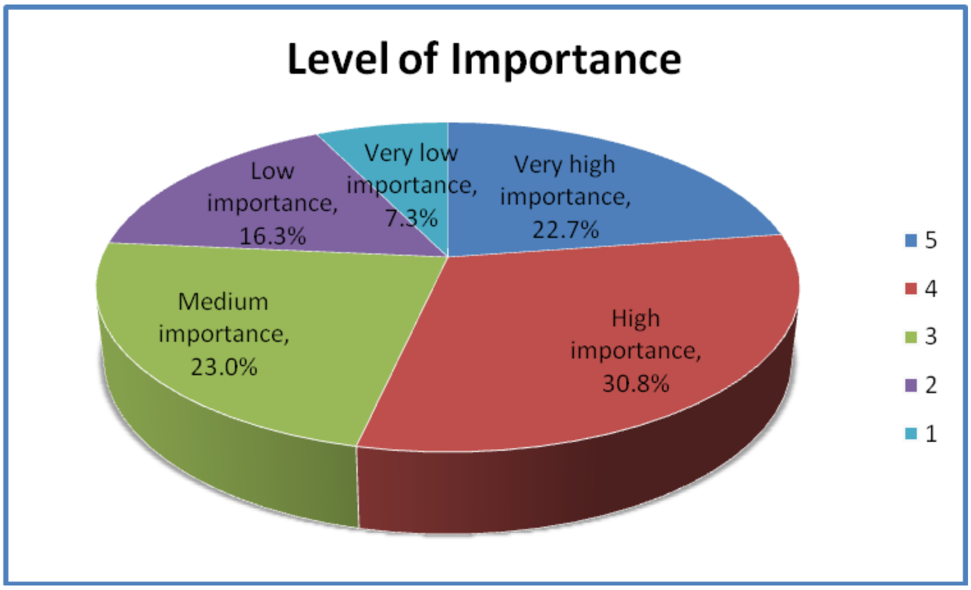

Figure 5.11: Percentage level of importance for Group 5

In order to determine the weight value for each factor within each group $W_{g,f}$, the weighted average method has been applied and is given in Eq. (5.1):

$$AIR_{g,f} = \frac{\sum_{E=1}^{3}\sum_{IR=1}^{5} IR \times N_{IR,E} \times W_E}{\sum_{E=1}^{3}\sum_{IR=1}^{5} N_{IR,E}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.1)$$

where $AIR_{g,f}$ is the average impact rate for the fth factor in the gth factor group, E is the experience years range for the participant which is a three-point scale according to Table 5.3, W_E is the experience weight value which can be obtained using Table 5.3, IR is the impact rate for each participant in the questionnaire which is a five-point scale according to Table 5.2, and $N_{IR,E}$ is the number of participant for each of the five-point scale impact rate for each of the three-point scale experience years.

Eq. (5.1) should be used for each factor within each group. For example, for the socio-economic group which includes six factors; Eq. (5.1) should be repeated six times in order to obtain the average impact rate $AIR_{1,f}$ for each factor within this group.

Then by dividing each single $AIR_{g,f}$ for each factor by the sum of the $AIR_{g,f}$ values for all factors within a group; the weight value $W_{g,f}$ of the fth factor in gth group can be calculated as shown in Eq. (5.2):

$$W_{g,f} = \frac{AIR_{g,f}}{\sum_{f=1}^{F} AIR_{g,f}} \quad \text{(5.2)}$$

<u>Sample of Calculation:</u>

For Number of critical socio-economic facilities factor ($F_{1,1}$):

As discussed in Table 5.5, the respondents are classified as 7 people with experience of (0 – 5) years, which in turn classified to 1, 1, 4, 0 and 1 respondent with impact rate of 5, 4, 3, 2 and 1 respectively. And 22 people that have (5 – 10) years of experience classified as 8, 8, 6, 0 and 0 people with 5, 4, 3, 2 and 1 impact rate respectively. Finally, 57 respondents with years of experience of greater than 10 years classified into 5, 4, 3, 2 and 1 impact rate as 29, 22, 5, 0 and 1 respondents respectively as explained in Table 5.12.

Table 5.12: Classification of respondents for number of critical socio-economic facilities factor according to the impact rate and experience years

Impact rate	**Number of occurrence**		
	W_1 = 0.2	**W_2 = 0.3**	**W_3 = 0.5**
5	1	8	29
4	1	8	22
3	4	6	5
2	0	0	0
1	1	0	1
Sub-Total	**7**	**22**	**57**
Total	**86**		

By using Eq. (5.1):

$$AIR_{1,1} = [1(1)(0.2) + 2(0)(0.2) + 3(4)(0.2) + 4(1)(0.2) + 5(1)(0.2) + 1(0)(0.3) + 2(0)(0.3) + 3(6)(0.3) + 4(8)(0.3) + 5(8)(0.3) + 1(1)(0.5) + 2(0)(0.5) + 3(5)(0.5) + 4(22)(0.5) + 5(29)(0.5)] \div [1 + 0 + 4 + 1 + 1 + 0 + 0 + 6 + 8 + 8 + 1 + 0 + 5 + 22 + 29]$$

$$AIR_{1,1} = 1.816$$

Similarly:

$$AIR_{1,2} = 0.853$$

$$AIR_{1,3} = 1.091$$

$$AIR_{1,4} = 1.793$$

$AIR_{1,5} = 1.260$

and $AIR_{1,6} = 1.577$

Then $W_{1,1}$ can be calculated using Eq. (5.2):

$$W_{1,1} = \frac{1.816}{[1.816 + 0.853 + 1.091 + 1.793 + 1.260 + 1.577]} = 0.216$$

Similarly:

$W_{1,2} = 0.102$

$W_{1,3} = 0.130$

$W_{1,4} = 0.214$

$W_{1,5} = 0.150$

and $W_{1,6} = 0.188$

Similarly, Eqs. (5.3) and (5.4) can be used to determine the average impact rate for the g^{th} factor group AIR_g and the weight value for each group W_g respectively as:

$$AIR_g = \frac{\sum_{E=1}^{3}\sum_{IR=1}^{5} IR \times N_{IR,E} \times W_E}{\sum_{E=1}^{3}\sum_{IR=1}^{5} N_{IR,E}} \quad \dots\dots (5.3)$$

$$W_g = \frac{AIR_g}{\sum_{f=1}^{F} AIR_g} \quad \dots\dots (5.4)$$

where AIR_g stands for the average impact rate for the g^{th} factor group and W_g stands for weighted value of the g^{th} group

Excel was used for a number of purposes in this research. Excel spreadsheets are here used to list the input data regarding respondents impact weight and to use equations (5.1) to (5.4) in order to obtain the required output results of the final impact contribution weight for each factor, $W_{g,f}$, and for each group of factors, W_g.

The questionnaire result values of rating of importance for the factors listed in sub-sections 2.1 to 2.5, which are obtained by applying Eqs. (5.1) and (5.2), are summarised and represented in Table 5.13 and the questionnaire results for this section can be shown in Figures 5.12 to 5.16 for groups 1 to 5 respectively.

Table 5.13: Questionnaire result values of factor's weight $W_{g,f}$

Group (g)	Factor (f)	$W_{g,f}$	
		No.	Value
1	1	$W_{1,1}$	0.216
	2	$W_{1,2}$	0.102
	3	$W_{1,3}$	0.130
	4	$W_{1,4}$	0.214
	5	$W_{1,5}$	0.150
	6	$W_{1,6}$	0.188
2	1	$W_{2,1}$	0.204
	2	$W_{2,2}$	0.168
	3	$W_{2,3}$	0.165
	4	$W_{2,4}$	0.175
	5	$W_{2,5}$	0.171
	6	$W_{2,6}$	0.117
3	1	$W_{3,1}$	0.119
	2	$W_{3,2}$	0.135
	3	$W_{3,3}$	0.138
	4	$W_{3,4}$	0.124
	5	$W_{3,5}$	0.126
	6	$W_{3,6}$	0.128
	7	$W_{3,7}$	0.126
	8	$W_{3,8}$	0.104
4	1	$W_{4,1}$	0.230
	2	$W_{4,2}$	0.236
	3	$W_{4,3}$	0.197
	4	$W_{4,4}$	0.151
	5	$W_{4,5}$	0.186
5	1	$W_{5,1}$	0.303
	2	$W_{5,2}$	0.215
	3	$W_{5,3}$	0.165
	4	$W_{5,4}$	0.317

The weight values $W_{1,f}$ for factor group 1 (socio-economic group) are represented in Figure 5.12. It can be noticed from this figure that the number of critical socio-economic facilities and the population served by a road have the greatest level of importance on the road recovery priority within this group and have a close weight value ($W_{1,1}$ = 0.216 and $W_{1,4}$ = 0.214). Conversely, the area of socio-economic buildings has the smallest effect ($W_{1,2}$ = 0.102).

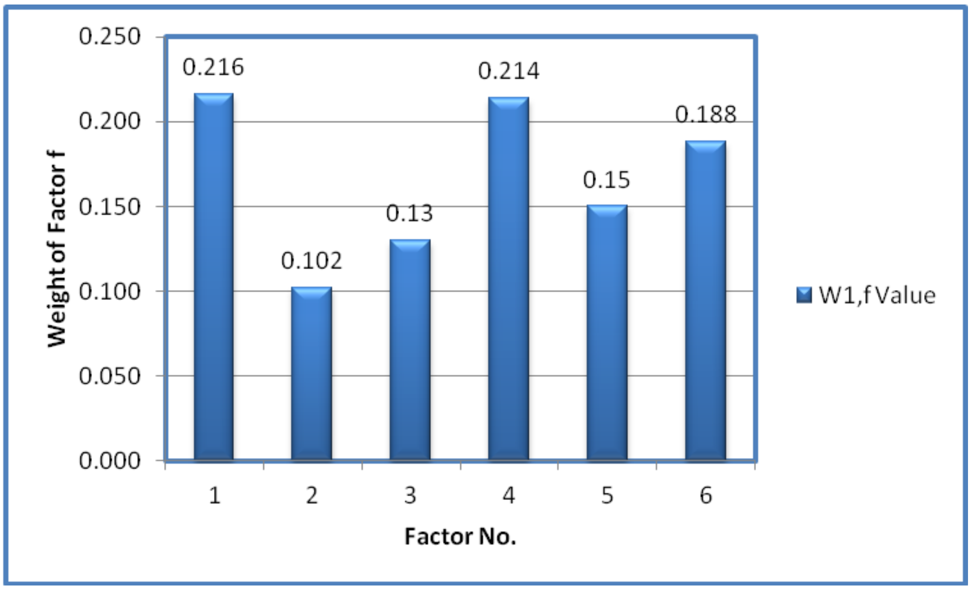

Figure 5.12: Weight values $W_{1,f}$ of factor *f* within socio-economic group

The questionnaire results shown in Figure 5.13 for road network group demonstrate that the type of road (whether it is interstate, bridge, highway, primary or secondary) has a significant impact ($W_{2,1}$ = 0.204) compared with other factors in this group. The second level of impact goes to the length of road and number of lanes in each direction in which their weight values are nearly identical ($W_{2,4}$ = 0.175 and $W_{2,5}$ = 0.171). The smallest level of importance is for the pavement structure factor ($W_{2,6}$ = 0.117).

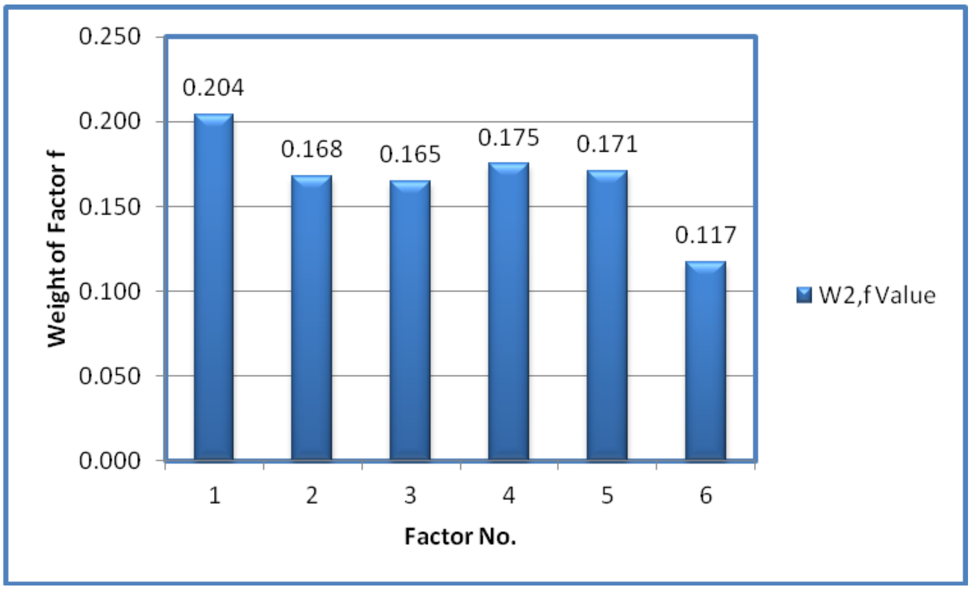

Figure 5.13: Weight values $W_{2,f}$ of factor *f* within road network group

Regarding the traffic factor group, the results founded from the questionnaire indicates that there is a slight difference in the weight values for the factors as illustrated in Figure 5.14. The delay time factor ($W_{3,3}$ = 0.138) and the traffic flow factor ($W_{3,2}$ = 0.135) have the greatest level of importance on the road recovery priority. On the other hand, the traffic control pattern factor has the smallest weight value ($W_{3,8}$ = 0.104) compared with the other factors.

It can be noticed from Figure 5.15 for factor group 4 (damage factors group) that there are considerable differences between the weight values of the factors. There is a marked impact of the severity of damage factor (whether it is severe, major or minor) ($W_{4,2}$ = 0.236) and the percentage of damage road factor ($W_{4,1}$ = 0.230). The number of open lanes in each direction factor takes the third place ($W_{4,3}$ = 0.197), while there is a slight impact of the number of damaged layers factor ($W_{4,4}$ = 0.151).

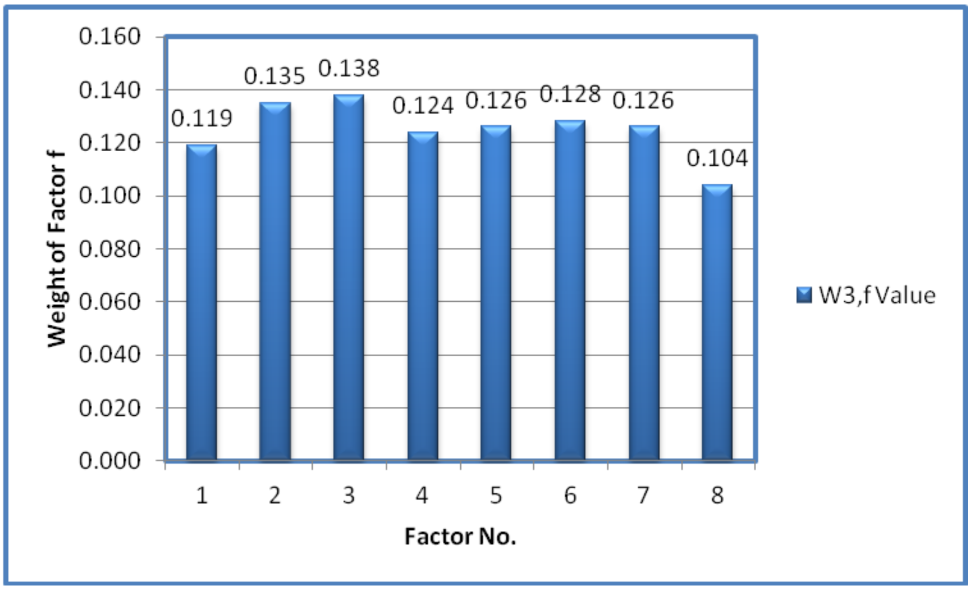

Figure 5.14: Weight values $W_{3,f}$ of factor *f* within traffic group

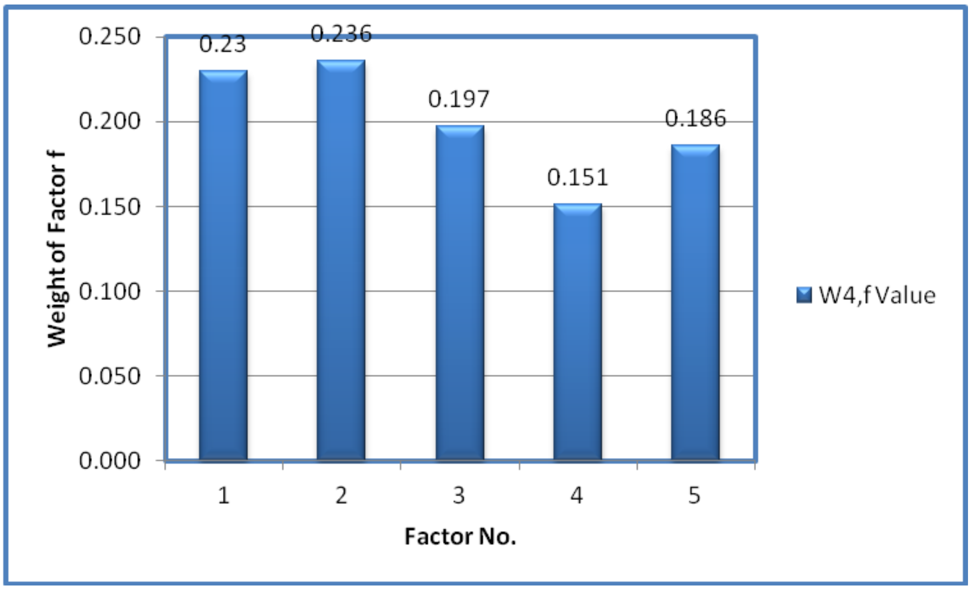

Figure 5.15: Weight values $W_{4,f}$ of factor *f* within damage group

Figure 5.16 shows the questionnaire results for the financial group. It can be noticed that the effect on the economic factor has a significance level of importance on the road recovery priority ($W_{5,4}$ = 0.317). The second percent of impact is for the direct cost factor ($W_{5,1}$ = 0.303), while the extra fuel consumption factor has the smallest weight value ($W_{5,3}$ = 0.165).

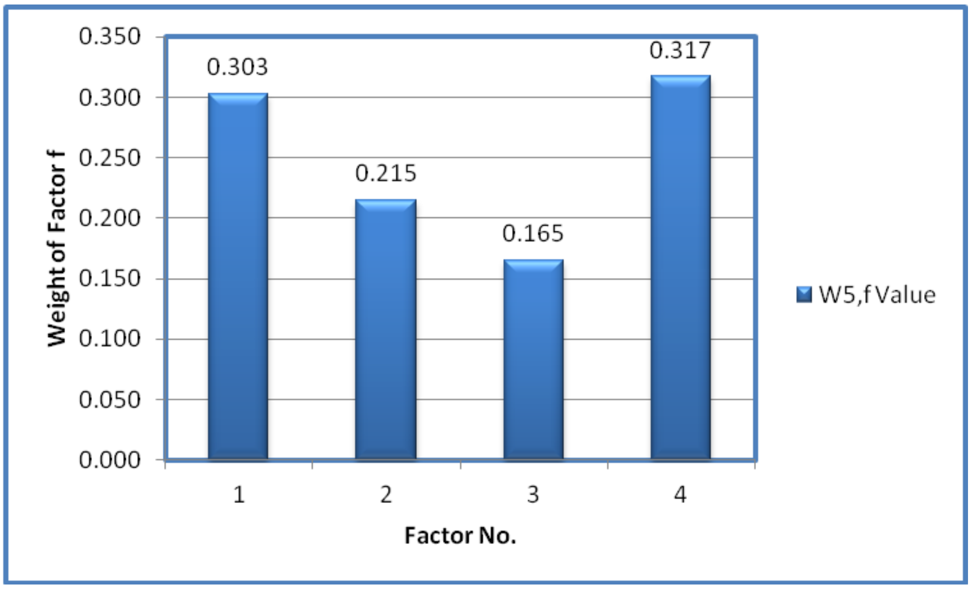

Figure 5.16 Weigh values $W_{5,f}$ of factor *f* within financial group

5.3.6.3 Section 3: Importance Level of RRP Model's Groups

Five groups in section 3 of the questionnaire are proposed in the developed RRP model of the research to define factor groups that influence on prioritising roads damaged by natural/man-made disasters for recovery in the rehabilitation projects. Appendix D.2 presents a questionnaire data base for all respondents' evaluations regarding the importance level of the proposed groups. The results of section 3 are analysed to evaluate the importance and level of each proposed group for the RRP model in the respondents' organisations. Table 5.14 and Figure 5.17 give detailed results of percentages level of importance for responses regarding each group. It can be noticed that group 4 (damage group) is the one with the highest percentage of very high and high level of importance. On the other hand, group 2 (road network) has the lowest percentage of such level of importance. However, there is a slight difference in percentage level of importance between groups 1, 3, 4 and 5.

Table 5.14: Detailed percentage level of importance for all groups

	Level of Importance	**Group No.**					
		1*	**2***	**3***	**4***	**5***	
Percentage of Responses (%)	Very high	37.2	11.6	37.2	38.4	47.7	Average
	High	44.2	54.7	43.0	46.5	33.7	
	Medium	14.0	26.7	17.4	10.5	16.3	
	Low	4.7	4.7	2.3	4.7	2.3	
	Very low	0.0	2.3	0.0	0.0	0.0	
	Very high + High	81.4	66.3	80.2	84.9	81.4	78.8
	Very low + low	4.7	7.0	2.3	4.7	2.3	4.2

*Group No. 1 is Socio-economic factors, Group No. 2 is Road network factors, Group No. 3 is Traffic factors, Group No. 4 is Damage factors and Group No. 5 is Financial factors.

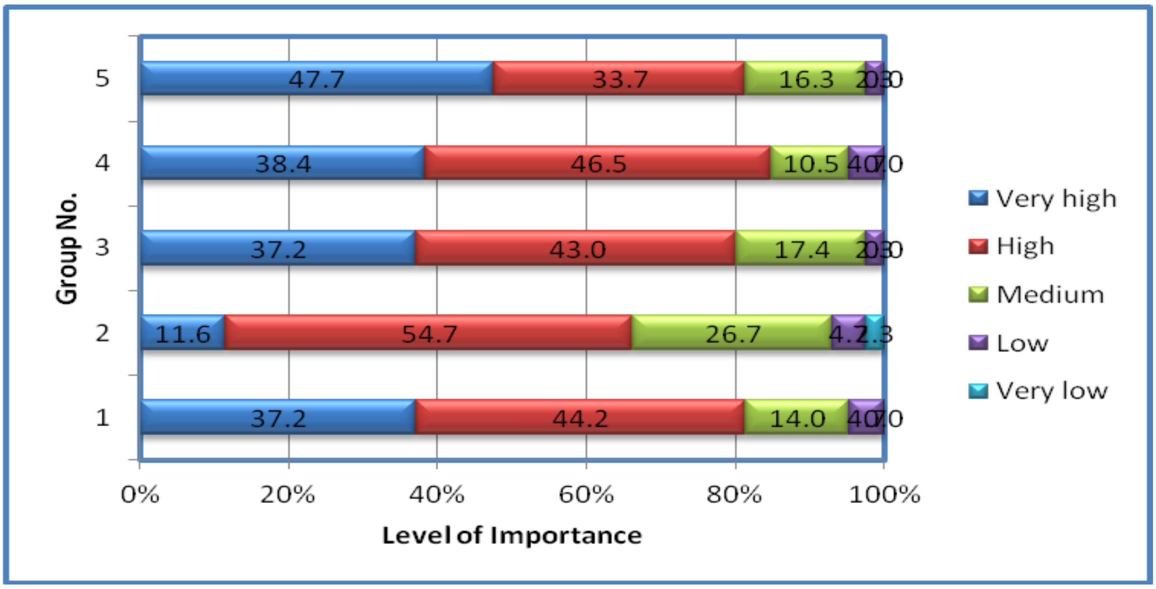

Figure 5.17: Detailed percentage level of importance for all groups

The percentage rating of importance for all groups listed in section 3 is summarised and given in Table 5.15 and Figure 5.18. The percentages of questionnaire's respondents which indicate that the presented groups of the proposed RRP model with level of importance (rate of impact) of high and very high is 78.8%, while 4.2% of the responses indicate that the presented model's groups is with low and very low level of importance. This indicates that the groups included in section 3 are important for the successful implementation or building of the RRP model in the road rehabilitation projects and it is necessary to include these groups in the proposed RRP model.

Table 5.15: A summary of percentage level of importance for all groups

Level of Importance	Percentage of Responses (%)						
	Very high	High	Medium	Low	Very low	Very high + High	Very low + low
	34.4	44.4	17.0	3.7	0.5	78.8	4.2

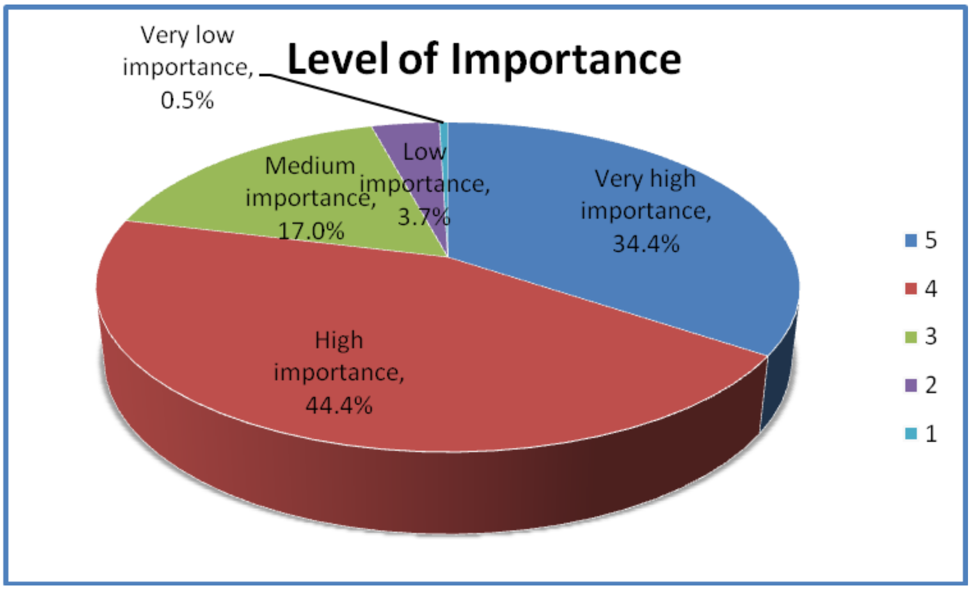

Figure 5.18: A summary percentage level of importance for all groups

The results of section 3 are analysed to evaluate the importance level of the proposed factor groups for the RRP model in the respondents' organisations. The questionnaire result values of rating of importance for each group listed in this section, which are obtained by applying Eqs. (5.3) and (5.4) are summarised and presented in Table 5.16 and Figure 5.19.

Table 5.16: Questionnaire result values of group's weight W_g

Group (g) No.	1	2	3	4	5
W_g Value	0.204	0.180	0.202	0.206	0.208

It is obvious from Figure 5.19 that the resulted level of importance for four groups are quite close, which are the financial group (W_5 = 0.208), damage group (W_4 = 0.206), socio-economic group (W_1 = 0.204) and traffic group (W_3 = 0.202). The financial group is considered to be the highest impact group on road recovery priority, while the road network group has a slight impact (W_2 = 0.180) compared with other groups.

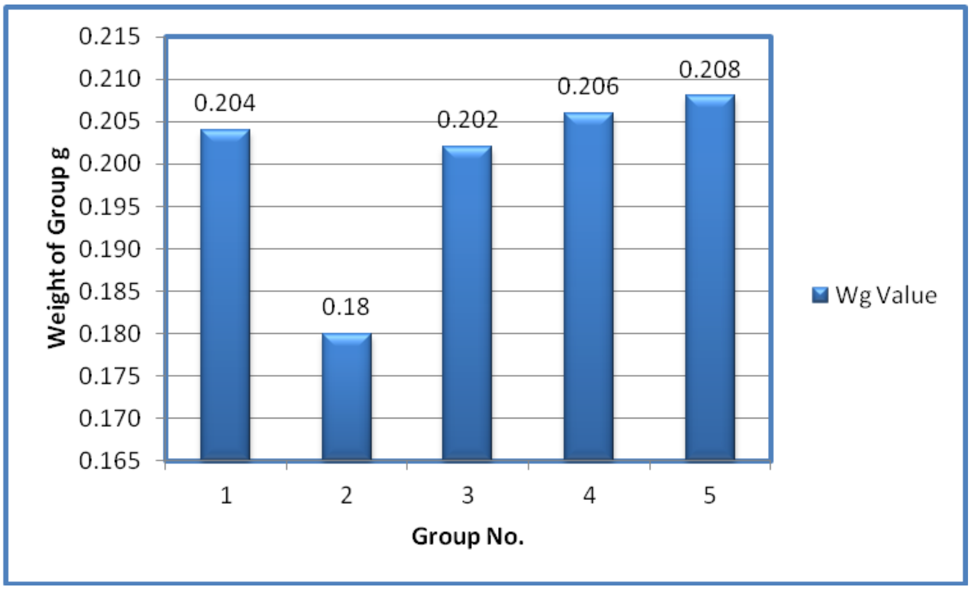

Figure 5.19: Weight values W_g of each factor group *g*

5.3.6.4 Section 4: Evaluation of Success and Usage Level of the RRP Model

Appendix D.3 presents a questionnaire data base for all respondents' evaluations regarding success and usage of the proposed RRP model which is given in section 4 of the questionnaire. Sub-section 4.1 of the questionnaire presents the success evaluation when adopting the RRP model according to the factors and groups listed in sections 2 and 3 of the questionnaire in order to prioritise roads damaged by natural/man-made disasters for recovery and rehabilitation.

The percentage rating of the success evaluation obtained from the questionnaire (sub-section 4.1) is summarised and presented in Table 5.17 and Figure 5.20. The percentages of questionnaire's respondents which indicate that the presented groups and factors of the proposed RRP model with success level extremely successful, very successful and successful is 91.8%, while 8.2% of the responses indicate that the presented model is with moderately successful, slightly successful and unsuccessful at all level of success. The average evaluation of success for all respondents resulted from the questionnaire is 5.012 out of the six-point scale. This indicates that the proposed RRP model can play a very important and successful role for recovery of roads damaged by natural/man-made disasters.

Table 5.17: Percentage level of success for the RRP model

Percentage of Responses (%)					
Extremely successful	Very successful	Successful	Moderately successful	Slightly successful	Unsuccessful at all
33.7	43.0	15.1	7.0	1.2	0
91.8			8.2		

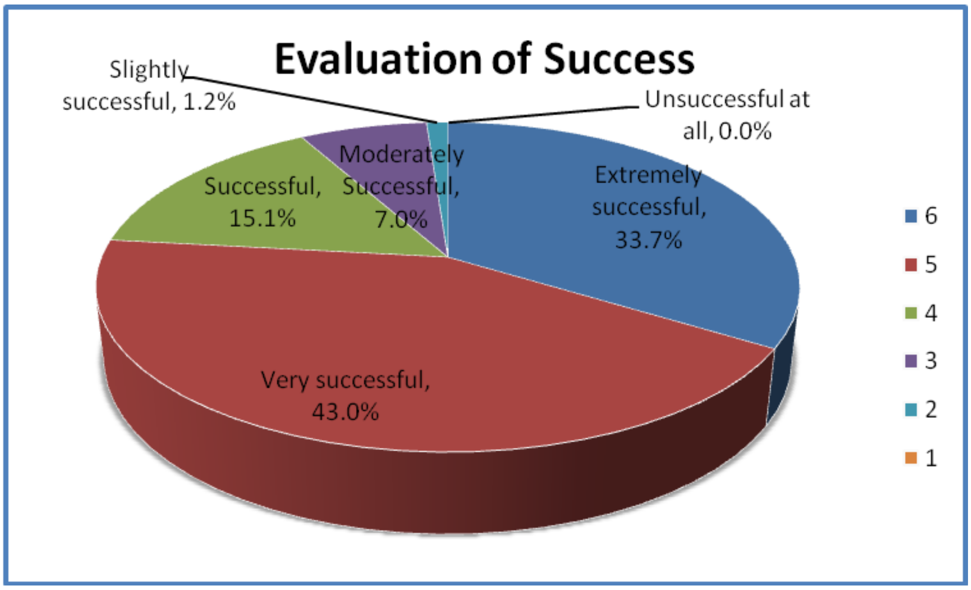

Figure 5.20: Percentage level of success for the RRP model

The extent of using the RRP model or a similar model for road recovery projects in the respondent's organisations (especially in Iraq) is demonstrated in sub-section 4.2. The percentage rating of using the RRP model or a similar model obtained from the questionnaire (sub-section 4.2) is summarised and presented in Table 5.18 and Figure 5.21. The questionnaire's respondents indicated that 30.2% (nearly one-third) are not using such a RRP model at all. 62.8% (nearly two-thirds) of the respondents are planned to use such a RRP model in their organisations. The average extent of using such a model in the respondent's organisations is 1.779 out of the six-point scale. This indicates that the road rehabilitation organisations in Iraq lack of the RRP model, they are planned to use such a model and there is an urgent need to have a strategy in the short term to have such a model which can play a very important and successful role in the recovery projects of roads damaged by natural/man-made disasters.

Table 5.18: Percentage level of use for the RRP model or a similar model

Percentage of Responses (%)					
Extremely used	Very used	Moderately used	Slightly used	Planned to use	Not used at all
0	0	1.2	5.8	62.8	30.2

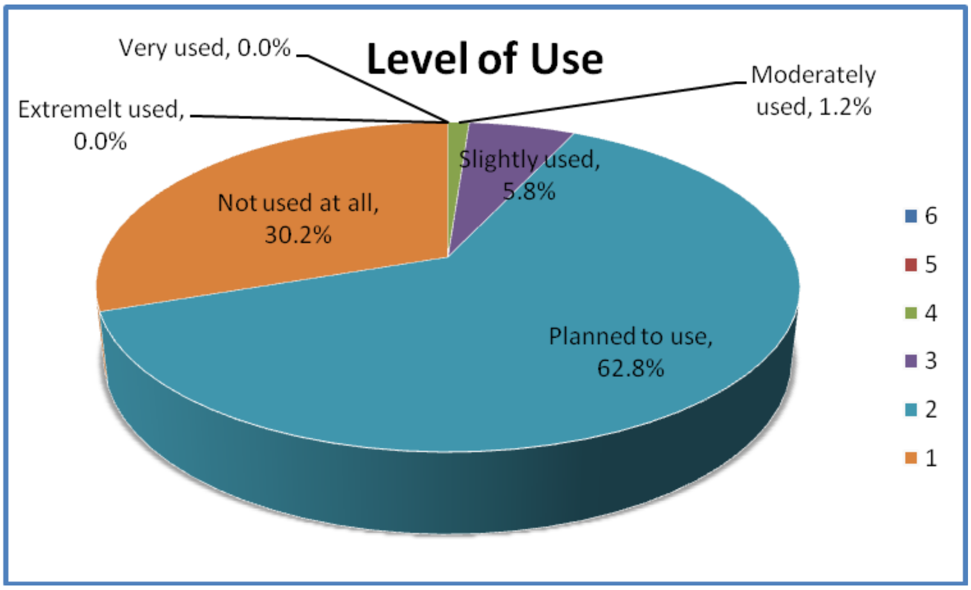

Figure 5.21: Percentage level of use for the RRP model or a similar model

5.4 Summary of Findings

The suggestions, recommendations, opinions and experiences provided by the respondents to the research interviews and questionnaires had a great effect on the development and enhancement of the proposed RRP model of this study in order to achieve a final structure of a RRP model for implementation and application in the road rehabilitation projects. The results of the interviews and the questionnaire survey have been supported by a continuous review of recent literature and projects' reports to develop a practical RRP model that is useful in the context of road projects. The final results of the interviews and questionnaires have important effects on the research developed RRP model and encourages for more development and refinement of the model to achieve the desired consequences. The final results concluded from the conducted interviews and questionnaires which have positive impact on the development of the RRP model can be summarised as follows:

- The results of the interviews and questionnaires have shown a high importance of the contents proposed in the RRP model and their usefulness for a successful adoption of RRP in the road reconstruction and rehabilitation organisations. However, the results highlighted the importance of developing the RRP model in a way that is easy to understand and follow.
- It has been found from the results of the interviews and questionnaires that it is highly important to include sufficient details and descriptions in the RRP model about the estimated groups and factors that may affect RRP efforts in the road reconstruction and rehabilitation organisations. This chapter proposes different groups of influencing factors on road recovery priority after natural/man-made disasters. Five factor groups has been estimated in this study to affect in the prioritisation of roads recovery, which are socio-economic factors, road network factors, traffic factors, damage factors and financial factors. Each of these groups consists of number of estimated factors. For example, there are six estimated factors in the socio-economic group. As a result, twenty-nine identified factors have been used in this study. The results of the questionnaires and interviews showed the importance of proposed groups and factors that it is

important to deal with these groups and factors for successful applications of the RRP model.

- The results of the interviews and questionnaires have shown the importance of applying more efforts during the early RRP implementation and development stages, such as in the analysis and design stages, in order to achieve a model design that better aligns with road objectives and procedures and to reduce time and effort wastage caused by design errors and reworks.
- The results of the SPSS show that all the calculated Cronbach's alpha values for sections and sub-sections of the questionnaire results are greater than the value 0.7. This indicates that the responses for the items in these sections and sub-sections are homogenous, having high internal consistency and can all be included in the analysis of the questionnaire responses.
- The R-square resulting from the SPSS analysis, when all of the factors included in the RRP model are taken into account, indicates that the RRP model's estimated factors have a high degree of criterion-related validity and a high degree of predictive capability.
- As an average result for all groups, 57.4 per cent of questionnaire's respondents indicate that the proposed factors are with level of importance of high and very high. While 18.6 per cent of responses indicate that these factors are of low and very low level of importance. The percentages of the questionnaire's respondents that indicate that the presented groups of the proposed RRP model with level of importance (rate of impact) of high and very high is 78.8 per cent, while 4.2 per cent of the responses indicate that the presented model's groups is of low and very low level of importance. This indicates that, in general, the

groups and factors included in the questionnaire are important for the successful building and implementation of the RRP model in the road rehabilitation projects.

- Each estimated factor within each proposed group used in this study contributes a different weight value to the overall road recovery priority. According to the questionnaire's results, the most important factor within the proposed socio-economic factor group is the number of critical socio-economic facilities with impact weight of 21.6 per cent. The type of road (whether it is interstate, bridge, highway, primary or secondary) has the most impact rate of 20.4 per cent compared with other factors in the road network group. For the traffic group, the questionnaire results indicated that the delay time factor has the greatest level of importance on the road recovery priority with an impact weight of 13.8 per cent. Regarding the damage factor group, the results found from the questionnaire indicate that the severity of damage factor (whether it is severe, major or minor) with an importance rate of 23.6 per cent is the highest impact factor. Finally, the greatest level of importance on the road recovery priority factor within the financial factor group obtained from the questionnaire is for the effect on the economic factor with an impact weight of 31.7 per cent.
- A different weight has been contributed by each estimated group used in this study value to the overall road recovery priority. Based on the questionnaire results, it was found that the major contribution is from the financial factor group which contributes 20.8 per cent. The damage factor group has the second place of impact which is 20.6 per cent. While road network factor group has the lowest impact on road recovery priority which is 18.0 per cent.

- The average evaluation of success for the proposed RRP model of all respondents resulting from the questionnaire is 5.012 out of the six-point scale. This indicates that the proposed RRP model can play a very important and successful role in the recovery of roads damaged by natural/man-made disasters.
- The results of the questionnaire responses showed the importance of applying evaluation and monitoring mechanisms by using techniques such as capturing feedback about the model use, or developing evaluation measures to ensure a continuous process of model improvement. However, the results showed a low use level of such a RRP model or a similar model in the road reconstruction and rehabilitation projects in Iraq. This indicates that the road rehabilitation organisations in Iraq lack the RRP model and there is an urgent need to have a strategy in the short-term to have such a model which can play a very important and successful role in the recovery projects of roads damaged by natural/man-made disasters. The results of the questionnaire showed a need to enhance the awareness of the people and organisations in the road reconstruction and rehabilitation about the importance of using such a RRP model to show efficiency and practicality of prioritising the recovery of damaged roads after natural/man-made disasters.
- The result of this study has demonstrated that the estimated factors and groups and the obtained weight values can provide engineers, managers and decision makers with useful information that can be used in performing recovery process for roads damaged by natural/man-made disasters.

This chapter has discussed the application and results of methodologies used in this research to develop and enhance a RRP model for implementation and application in road reconstruction and rehabilitation projects. The next chapter will present the final enhanced structure of the developed RRP model proposed in this research to help to achieve successful adoption in the organisations of road rehabilitation.

CHAPTER SIX

DEVELOPMENT OF A RRP MODEL FOR IMPLEMENTATION AND APPLICATION IN ROAD REHABILITATION PROJECTS

6.1 Introduction

On the basis of the conducted questionnaires, interviews, and literature review, it is essential to develop a RRP model to manage the recovery of roads damaged by natural/man-made disasters effectively and efficiently in road reconstruction and rehabilitation projects. The proposed RRP model includes influential factors and factor groups which are proposed and concluded from the interviews and questionnaire stage, importance level of these factors and groups and collected data of the damaged roads according to the proposed groups and factors. This model should also take into consideration the ease and simplicity in use and implementation in the road rehabilitation organisations.

Saaty (1977) stated that the object is to use the weights which are called priorities, for example, to allocate a resource among the activities or simply implement the most important activities by rank if precise weights cannot be obtained. The problem then is to find the relative strength or priorities of each activity with respect to each objective and then compose the result obtained for each objective to obtain a single overall priority for all the activities. Frequently the objectives themselves must be prioritised or ranked in terms of yet another set of (higher-level) objectives. The priorities thus obtained are then used as weighting factors for the priorities just derived for the activities.

Hermans *et al.* (2010) stated that one of the main advantages of an index over a set of individual indicators is that the overall road safety picture is presented as the different risk factors are joined in this index. In general, an index results from the aggregation of a set of indicator values and a set of weights. As the concept of indicators and indices is relatively new in the road safety field, not much attention has been paid to these topics so far.

In general, indicator weights can be determined based on correlations (factor analysis), experts' opinions (budget allocation or analytic hierarchy process), optimisation models (data envelopment analysis) or equally distributed (equal weighting) (Hermans *et al.*, 2010). Here in the presented research, it has been focused on weights which represent the idea of experts concerning the importance of the indicators.

The RRP model proposed in this research, the items proposed in the model and the questionnaire survey provide a definition of the RRP procedures and tools that should be adopted by road reconstruction and rehabilitation organisations to achieve successful implementation and application of the RRP model. The proposed RRP model of this research can be best used to evaluate damaged roads according their priority need for recovery.

Although some literature may help to provide information and methods for managing road recovery priority, there is still a need to develop a more comprehensive and structured model for implementation and application in road projects for recovery, which will be discussed in more detail in the following sections. This chapter presents the final structure of the proposed RRP model. The advantages of the proposed RRP model and how this model fills the gaps of other previous literatures and the need for such models to prioritise roads after natural/man-made disasters for recovery will be discussed to illustrate its importance and usefulness.

6.2 Components and Descriptions of the RRP Model

The first stage of the proposed RRP model for road reconstruction and rehabilitation projects is proposed to represent the main components of the RRP model that facilitate its understanding and show the relationships among the different parts. The proposed RRP model consists of four phases as shown in Figure 6.1.

Phase 1 starts the RRP model with identifying factors and factor groups that may affect activities and components of the RRP.

Phase 2 refers to deciding the required procedures and mathematical equations to successfully deal with the controlling factors and factor groups.

Phase 3 covers estimation and calculation of the model's parameters presented in the proposed equations of the model.

Phase 4 refers to application of the presented model for road recovery priority.

Each phase of the proposed RRP model will be described in detail in the following sections.

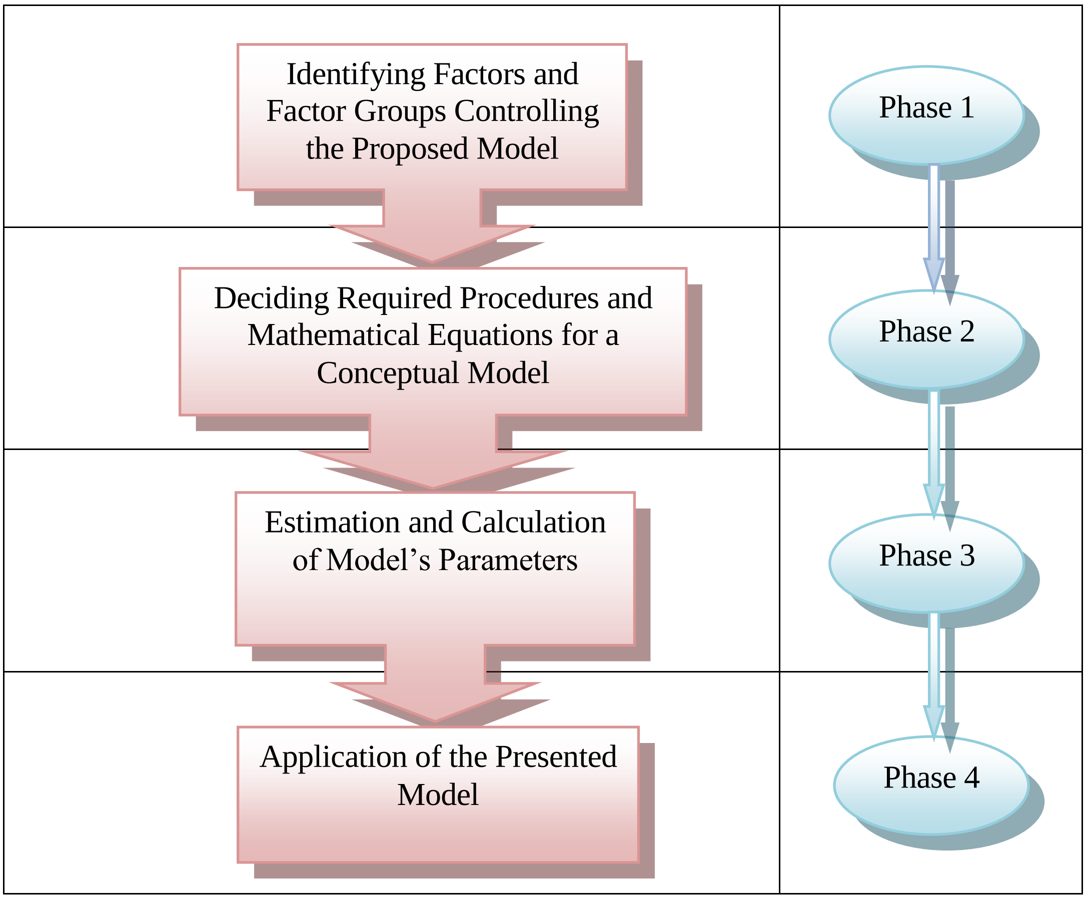

Figure 6.1: Components of the proposed RRP model for road reconstruction and rehabilitation projects

6.2.1 Phase 1: Identifying Factors and Factor Groups Controlling the Proposed RRP Model

Before discussing other components of the proposed RRP model, it is important to identify the factors and factor groups that may affect road recovery priority. These factors and groups can affect the effectiveness, efficiency and the overall performance of the RRP model.

Although many literatures have been done regarding recovery of roads damaged by disasters, however, it would be useful to propose a method in this research which can used to distinguish among five important different groups of factors that should be taken into consideration as they are useful and vital for recovery of damaged roads in the road reconstruction and rehabilitation organisations. The reason for such a classification is that it differentiates among five types of groups with different nature and conditions. A literature search carried out in this research with addition to the suggestions obtained from the interviews indicates that the important influential factors can be classified into five groups which are: socio-economic factor group; roads network factor group; traffic factor group; damage factor group; and finally, financial factor group.

The proposed RRP model can be described as a function of socio-economic group, road network group, traffic group, damage group and financial group of factors. Therefore, the RRP model can illustrated as:

$$RRP = f(Socio\text{-}economic\ group\ + Road\ network\ group\ + Traffic\ group\ + Damage\ group\ + Financial\ group\ ) \ldots \ldots \ldots \ldots \ldots \ldots . \ldots \ldots \ldots (6.1)$$

Based upon the opinions of the interviewees and people who provided feedback in the questionnaire survey and the information provided by previous researchers, a number of estimated factors have been included within each group in this study to influence the road priority for recovery. Hence, each group consists of a number of estimated sub-group factors. As a result, twenty-nine factors have been identified and chosen in this study.

It is important in this context to provide an adequate level of detail of factors and groups to help road reconstruction organisations to identify required processes and procedures to solve the issue of damaged roads after natural/man-made disasters without negatively affecting their way of carrying out works or the special characteristics that differentiate each company from others. This will also provide an appropriate platform to deal with the organisation's requirements.

The classification of these groups and the factors included within each group are shown in Table 5.1 in Chapter five. That table can help road reconstruction organisations to put in mind factors and factor groups that may affect the process of road recovery priority and to help them identify further possible procedures and solutions required to enhance the RRP model performance.

Cost Consideration

The controlling factors used in this study can be used to put in mind the cost consideration as shown in Table 6.1. Also, cost consideration can be estimated according to the road network performance loss. It should be noted that the non construction related recovery costs, such as road users, business disruption and individual income decline, are also included in the proposed model. The non construction related costs of factors that should be taken into consideration are illustrated in Table 6.1.

Table 6.1**:** Cost considerations of the proposed model's factors

Group	Factors	Cost Considerations
Socio-Economic Factors	Number of critical socio-economic facilities	More critical facilities → traffic congestion → long trip length → more delay time + more traffic accidents → less working hours → less income
	Area of socio-economic buildings	More area of socio-economic buildings → more people working in it + more traffic congestion → long trip length → more delay time + more traffic accidents → less working hours → less income
	Capacity of socio-economic buildings	More capacity of socio-economic buildings → more people working in it → less working hours → less income
	Population served by a road	Populated area → more number of roads across it + more critical facilities + more working people + traffic congestion → long trip length → more delay time
	Area served by a road	More area served by a road → more number of roads across it + more critical facilities + traffic congestion → long trip length → more delay time
	Type of area	Urban area → populated area → more number of roads across it + more critical facilities
Road Network Factors	Type of road	Interstate, bridge, highway and primary routes → serve more population and more critical facilities and/or urban area
	Number of nodes	More nodes → more junctions and on/off ramps → more traffic congestion
	Number of links	More links → more junctions and on/off ramps → more traffic congestion
	Length of road	More length → more nodes and links + more area served by a road + more population and more critical facilities
	Number of lanes in each direction	More traffic lanes → more traffic capacity → populated or urban area → more critical facilities → more congestion
	Pavement structure	Rigid pavement → more recovery cost than flexible pavement
Traffic Factors	Traffic classification	More percentage of class (1) vehicles → more reduction in average speed → more delay time → long trip length → less working hours → less income
	Traffic flow	More traffic flow → populated or urban area → more critical facilities → more congestion

Group	Factors	Cost Considerations
	Delay time	Increasing delay time → long trip length → less working hours → less income
	Additional trip length	Increasing trip length → more delay time → less working hours → less income
	Queue length	Increasing queue length → more delay time + more traffic accidents → less working hours → less income
	Level of service	Decreasing level of service → low traffic flow → more traffic congestion → more delay time
	Reduction in average speed	Reducing average speed → more traffic congestion → more delay time → less working hours → less income
	Traffic control pattern	Increasing roads working with electric traffic signals → more traffic disruption → more traffic congestion
Damage Factors	Percentage of damaged road	Increasing percentage of damaged road → low traffic flow → more delay time → more traffic disruption + more traffic congestion+ more recovery cost
	Severity of damage	Increasing degree of damage → low traffic flow + more traffic congestion → more delay time + more recovery cost
	Number of open lanes in each direction	Decreasing number of open lanes → low traffic flow + more traffic congestion and /or using other routes → more trip length → more delay time + more recovery cost
	Number of damaged layers	Increasing number of damaged layers → low traffic flow + more traffic congestion and /or using other routes → more trip length → more delay time + more recovery cost
	PSI	Less Present Serviceability Index (PSI) → low traffic flow + more traffic congestion → more delay time + more recovery cost
Financial Factors	Direct cost	Increasing road repair and reconstruction → more recovery cost
	Time cost	Increasing road repair time + increasing traffic delay time → less working hours → less income
	Extra fuel consumption	Increasing traffic congestion → more fuel consumption → more cost
	Effect on economic	Increasing temporary unemployment + increasing business interruption → more economic decline

6.2.2 Phase 2: Deciding the Required Procedures and Mathematical Equations for the Proposed Model

Prioritisation is an increasingly important concept for transportation system planning and programming. Planners need to prioritise. They need to make hard choices about which projects to select for funding, and which to scale back, postpone or not fund at all. Formal priority systems can help planners identify and justify the choices that achieve the greatest benefit in the complex environment (Merkhofer, 1997).

Tasks are assigned for recovery efforts based upon priorities of restoring transportation services. For example, if a road is in a critical condition and needs an effort to return to a normal traffic flow, the repair crew will have to make that trip immediately, thus ignoring several sites along the way where replacements are needed (Final Report, University of Virginia, 2002). Therefore, it should be determined whether it is considered better to recover several roads or to concentrate on the more important ones. Also, it should be determined which roads are the most important to recover first, and which roads are not vital and can wait while other more pressing needs are met. Factors and factor groups involved in the proposed model are used in determining priority indices which in turn are used in deciding which roads will receive the highest priority as discussed later in this chapter.

In general, all the controlling factor groups with their including factors for a number of damaged roads which are needed to determine their priority to recover can be expressed as a significance level matrix (SL) reflecting the effect of this group (and the factors included in it) on the road network performance loss and the recovery cost shown below.

$$SL = \begin{bmatrix} SL_{1,1} & SL_{1,2} \dots & SL_{1,g} \\ SL_{2,1} & SL_{2,2} \dots & SL_{2,g} \\ \vdots & \vdots & \vdots \\ SL_{n,1} & SL_{n,2} \dots & SL_{n,g} \end{bmatrix} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad (6.2)$$

Where, $SL =$ significance level, n = damaged road no. and g = controlling factor groups.

Then, each controlling factor group can be converted to a set of group indicators for each damaged road. In general, any number of factor groups can be used. In the presented model, this will result in five types of indicators regarding to five factor groups.

$$GI = \begin{bmatrix} GI_{1,1} & GI_{1,2} \dots & GI_{1,g} \\ GI_{2,1} & GI_{2,2} \dots & GI_{2,g} \\ \vdots & \vdots & \vdots \\ GI_{n,1} & GI_{n,2} \dots & GI_{n,g} \end{bmatrix} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . \dots \dots \quad (6.3)$$

Where, $GI =$ group indicator.

By given weight for each group and multiplying it by the group indicator, then a group priority index can be obtained for each group of factors.

$$GPI = \begin{bmatrix} GPI_{1,1} & GPI_{1,2} \dots & GPI_{1,g} \\ GPI_{2,1} & GPI_{2,2} \dots & GPI_{2,g} \\ \vdots & \vdots & \vdots \\ GPI_{n,1} & GPI_{n,2} \dots & GPI_{n,g} \end{bmatrix} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots .. \quad (6.4)$$

Where, $GPI =$ group priority index.

Finally, the road recovery priority index value for each damaged road can be calculated as the summation of the indices for all factor groups. Matrix $RRPI$ can be written to illustrate the recovery priority index value for each damaged road.

$$RRPI = \begin{bmatrix} GPI_1 \\ GPI_2 \\ \vdots \\ \vdots \\ GPI_n \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (6.5)$$

Where, $RRPI$ = road recovery priority index.

The damaged roads are then sorted and ranked according to their recovery priority index values. The decision is made to determine which roads are vital to recover and which roads are not important and can wait while recovering the urgent roads. The road with the highest priority index means that it has a high priority and, therefore; it needs to be recovered first. These matrices will help to build and develop the mathematical equations of a successful RRP model.

<u>Model Mathematical Equations</u>

By using the concepts presented by Davidson and Shah (1997); Hosseini and Yaghoobi (2008); Shariat (2002); Shariat *et al.* (2004) and ATC (1983), a new conceptual model has been developed in the area of recovery priority for roads damaged by natural/man-made disasters.

An index for road recover priority will be composed consisting of five indicators. Each group of factors is represented by one appropriate quantifiable indicator for which reliable and comparable data are available. However, combining essential road recovery indicators in a composite index offers an overall view on road recovery measure.

The road recovery priorities can be obtained by the following equations:

$$SL_g = W_{g,1} * R_{g,1} + W_{g,2} \times R_{g,2} + W_{g,3} \times R_{g,3} + \cdots\cdots\cdots\cdots\cdots\cdots\cdots + W_{g,f} \times R_{g,f} \quad \ldots\ldots (6.6)$$

or:

$$\mathrm{SL_g} = \sum_{f=1}^{F} W_{g,f} \times R_{g,f} \quad \ldots\ldots (6.7)$$

in which $R_{g,f}$, $W_{g,f}$ and F are respectively the rating of the f^{th} factor in the g^{th} factor group, the contribution weight of the f^{th} factor in the g^{th} factor group, and the total number of factors in each group. By combining all contributing parameters with their associated weights, a significance level SL_g can be calculated for each of the g^{th} factor group within the 0.0 – 1.0 range in which a value of 0.0 represents a very poor road condition according to the corresponding group of factors and a value of 1.0 represents an excellent road condition.

In Eq. (6.7), $W_{g,f}$ can be obtained from a questionnaire survey and $R_{g,f}$ can be given by:

$$R_{g,f} = \frac{H_{g,f}}{S_{g,f}} \quad \ldots\ldots (6.8)$$

in which $H_{g,f}$ is the hierarchy of the f^{th} factor in the g^{th} factor group and $S_{g,f}$ is the scale of the f^{th} factor in the g^{th} factor group. The rating value reflects the situation of the collected input data of each factor regarding its degree of effect on the road network. It shows the grade of the collected real value of data for each factor. The scale value reflects the extent of the input data for each factor (e.g. 2, 5, 7, etc.) depending on the estimated ranges for each factor.

Depending on the ranges of the collected data for the case studies, the hierarchy value $H_{g,f}$ corresponding to each single data for each factor (*f*) within each group (*g*) can be estimated. This, in turn, can lead to estimate the scale value for each factor $S_{g,f}$ as the largest value of its hierarchy. The hierarchy $H_{g,f}$ and scale $S_{g,f}$ values can be generalised to be applicable anywhere for any road. These values will be illustrated in Section 6.2.3.2.

The group indicator for the g^{th} factor group, GI_g, can be calculated from Eq. (6.9) within the 0.0 – 1.0 range in which a high value indicates that a road should have a high priority for recovery according to the corresponding group of factors.

$$GI_g = 1 - SL_g \quad \ldots (6.9)$$

For example, if a factor group with a significance level of 0.3 which represents a poor case, then the group indicator for this group is 0.7 which is obtained by subtracting 0.3 from 1. Therefore this needs a high priority for recovery for the specified group of factors.

The group priority index for the g^{th} factor group GPI_g, can be calculated by giving a weight, W_g, for each factor group multiplied by the group indicator for each group as:

$$GPI_g = GI_g \times W_g \quad \ldots (6.10)$$

W_g can also be obtained from a questionnaire survey. GPI_g is within the 0.0 – 1.0 range in which a high value indicates that a road should have a high priority for recovery according to the corresponding group of factors.

Finally, the road recovery priority index for the n^{th} road, $RRPI_n$, can be then given by the sum of the group priority indices for all factor groups within a road as:

$$RRPI_n = \sum_{g=1}^{G} GPI_g \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . . (6.11)$$

in which *n* and *G* are the number of roads and the total number of groups within the road network respectively.

6.2.3 Phase 3: Estimation and Calculation of Model's Parameters

This phase shows estimation and calculation of parameters which are presented in the proposed mathematical equations of the conceptual model for the RRP. The required parameters are classified into two types. Type one presents the estimation of the impact weight (level of importance) values for factors and factor groups included in the proposed model ($W_{g,f}$ and W_g). An estimation and calculation of hierarchy ($H_{g,f}$) and scale ($S_{g,f}$) values for model's factors is the second type of parameters. These two types of parameters are explained in the following sections.

6.2.3.1 Type One: Impact Weight Values of Factors and Factor Groups

The results of the questionnaire help to build and structure the RRP model to enable organisations to plan and manage their road rehabilitation efforts successfully. These results evaluate the importance and the influence of the different factors which are important to shape a more useful and comprehensive RRP model for successful and effective implementation and application in the road rehabilitation projects in order to help organisations manage resources and efforts successfully to obtain required results and potentials. Hence, addressing the results of the questionnaire into the RRP model is necessary in helping road reconstruction and maintenance organisations to identify the key factors, that if effectively adopted can make the implementation and application of RRP more successful.

The results of sub-sections 2.1 to 2.5 in the questionnaire are analysed to evaluate the importance level of factors within each proposed group for the RRP model in the respondents' organisations.

The weighted average method has been applied in order to determine the impact weight value for each factor within each group $(W_{g,f})$ and the impact weight value for each group (W_g) which are estimated to be influence on the RRP model as discussed in section 5.3.6.2 and 5.3.6.3 in Chapter 5.

The questionnaire result values of the impact weight for factors included in the proposed RRP model are estimated, summarised and represented in Table 5.13 and can be also shown in Figures 5.12 to 5.16. Similarly, the results of section 3 of the questionnaire are analysed to evaluate the importance level of the proposed factor groups for the RRP model in the respondents' organisations. The questionnaire result values of the impact weight for each proposed group are summarised and represented in Table 5.16 and Figure 5.19. Please refer to Chapter five for the details regarding the impact weight of factors and factor groups presented in the conceptual RRP model.

The proposed influential factors within each group can be ranked according to their importance level which was investigated through section 2 of the questionnaire survey conducted during this research and discussed in Chapter five and can be presented in Table 6.2. Similarly, Table 6.3 presents a ranking of the proposed groups according to their importance level that was investigated through section 3 of the questionnaire survey.

Table 6.2: Impact hierarchy for the proposed controlling factors

Impact Hierarchy	**Factor No.**	**Name**	**Importance Level Value (%)**
Group 1: Socio-economic factors			
1	1,1	Number of critical socio-economic facilities	0.216
2	1,4	Population served by a road	0.214
3	1,6	Type of area	0.188
4	1,5	Area served by a road	0.150
5	1,3	Capacity of socio-economic buildings	0.130
6	1,2	Area of socio-economic buildings	0.102
Group 2: Roads network factors			
1	2,1	Type of road	0.204
2	2,4	Length of road	0.175
3	2,5	Number of lanes in each direction	0.171
4	2,2	Number of nodes	0.168
5	2,3	Number of links	0.165
6	2,6	Pavement structure	0.117
Group 3: Traffic factors			
1	3,3	Delay time	0.138
2	3,2	Traffic flow	0.135
3	3,6	Level of service (LOS)	0.128
4	3,5	Queue length	0.126
5	3,7	Reduction in average speed	0.126
6	3,4	Additional trip length	0.124
7	3,1	Traffic classification	0.119
8	3,8	Traffic control pattern	0.104
Group 4: Damage factors			
1	4,2	Severity of damage	0.236
2	4,1	Percentage of damaged road	0.230
3	4,3	Number of damaged lanes in each direction	0.197
4	4,5	PSI	0.186
5	4,4	Number of damaged layers	0.151
Group 5: Financial factors			

Impact Hierarchy	Factor No.	Name	Importance Level Value (%)
1	5,4	Effect on economic	0.317
2	5,1	Direct cost (reconstruction or repair)	0.303
3	5,2	Time cost	0.215
4	5,3	Extra fuel consumption	0.165

Table 6.3: Impact hierarchy for the proposed controlling factor groups

Impact Hierarchy	Group No.	Name	Importance Level Value (%)
1	5	Financial factors	20.8
2	4	Damage factors	20.6
3	1	Socio-economic factor	20.4
4	3	Traffic factors	20.2
5	2	Roads network factors	18.0

6.2.3.2 Type Two: Hierarchy and Scale Values of Factors

At the beginning, a dummy data has been generated regarding the proposed influencing factors and groups of factors. The dummy data has helped to check the key characteristics of the proposed RRP model and the important affecting factors presented in it. Also, these data aid in giving a preliminary conception for the real data which is required to determine the hierarchy and scale values, in addition to the real data required for the model application. This, in turn, helps to refine and enhance the proposed RRP model in order to transfer the preliminary conceptual RRP model into a final, refined, and improved RRP model.

Then, depending on the comments and suggestions presented by the interviewers and the ranges of the real collected data for the four conducted case studies, the hierarchy value $H_{g,f}$ corresponding to each single data for each factor (*f*) within each group (*g*) can be estimated. This, in turn, can lead to estimate the scale value for each factor $S_{g,f}$ as the largest value of its hierarchy and it is constant for any other value of hierarchy within this factor.

In order to identify hierarchy $H_{g,f}$ and scale $S_{g,f}$ values for each factor presented in this research, real data has been collected regarding each factor. This can help to estimate the maximum and minimum number for the input data for that factor. Also, suggestions and opinions obtained from the questionnaire and the interview survey of respondents in road organisations help to aid in this stage. For each factor, the extent between the maximum and minimum number of data has been divided into a different number of ranges regarding each single factor. A hierarchy value has been given for each range between 1 as a first hierarchy and the last hierarchy value is different from one factor to another. So, for each estimated range of data, there is a specific value of hierarchy (from 1 to 7 as maximum). The maximum number of hierarchy for each factor is considered to be the scale for that factor which is constant for any single data of each factor. If the input value of data for a single factor corresponding to a specific road is high, this means that it is a critical case and then it is given a first hierarchy. Conversely, a less hierarchy is to be considered when the input value of data is low.

The hierarchy and scale values will be discussed in the following sections regarding each factor within each factor group included in the RRP model and the data corresponding to each factor are listed in Tables 6.4 – 6.15, 6.17 – 6.21, 6.23 – 6.26 and

6.28 – 6.31 regarding each group. The hierarchy $H_{g,f}$ and scale $S_{g,f}$ values can be also presented as figures to show the difference trend of the hierarchy of each factor within each group. Tables 6.4 – 6.15, 6.17 – 6.21, 6.23 – 6.26 and 6.28 – 6.31 can be converted to Figures 6.2 to 6.26 to give a better representation for the hierarchy values. Each single factor data can be used in its corresponding hierarchy figure in order to obtain the required hierarchy value for this factor.

Financial factors and costs (such as reconstruction cost, time cost, unemployment cost, business interruption cost, fuel consumption cost) are a complicated task because it needs a lot of work and time. This requires a considerable amount of time (perhaps years) to be accomplished. A financial group of factors has been included in the interview and questionnaire surveys in order to estimate its impact weight in the proposed RRP model and also included in the structure of the proposed model. However, it is not included in the model application as detailed collected data is required regarding this group. Thus, this cannot be achieved within the limited time extent of this research.

6.2.3.2.A $H_{1,f}$ and $S_{1,f}$ Values for Socio-Economic Factor Group

Critical Socio-Economic Facilities

A critical facility is a facility served by the transportation system that is necessary for a community's wellbeing. Following a major disaster or armed conflict, it is vital to restore access, via the road network, to these critical facilities that provide vital services to as many people as possible (Final Report, University of Virginia, 2002).

There are a variety of types of critical facilities that need to be accounted for in the prioritisation model. Particular facilities have an obvious need during the time period following a disaster or a conflict, such as hospitals and fire stations. However it is very short sighted to only consider these facilities. It is aimed to account for facilities that people need access to following a disaster or a conflict in the short, medium, and long timeframe. Critical facilities are the facilities that provide those services that people need to go about their lives. Some of these services are:

a) Health (rescue squad, hospitals, medical supplies, trash removal, water and sewage plants),

b) Safety (police, structural safety, electrical wires, return routes, fire fighters),

c) Education (schools, universities),

d) Food (grocery stores, food distribution to stores, restaurants),

e) Transportation (airports, train stations, bus stations, public transportation), and

f) Government operations (ministries, public institutions, jails, courts, post offices, military installations, public works centres).

Critical facilities remain the most important criteria for the prioritisation, but other data must also be considered (Final Report, University of Virginia, 2002).

The collected number of socio-economic buildings in each road (segment of road) has been estimated to be in the ranges between 10 to 200 buildings. This number has been divided into seven ranges as shown in Table 6.4. The first hierarchy ($H_{1,1}$=1) is given for number of buildings equal or greater than 200 and the last hierarchy ($H_{1,1}$=7) for zero number of buildings. So, the scale ($S_{1,1}$) for this factor will be 7 which is last hierarchy. For example, if the number of critical socio-economic facilities is 90 for a specific road, then by using Figure 6.2, the corresponding hierarchy value $H_{1,1}$ will be 2.25 for this factor. The largest value of hierarchy for the number of critical socio-economic facilities factor is 7, so that, the scale value $S_{1,1}$ for this factor is 7 which is constant for any other value of hierarchy within this factor.

Table 6.4: $H_{1,1}$ and $S_{1,1}$ values for number of critical socio-economic facilities factor

Number of critical socio-economic facilities	Hierarchy values $H_{1,1}$	Scale value $S_{1,1}$
≥ 200	1	7
100	2	
60	3	
35	4	
20	5	
10	6	
0	7	

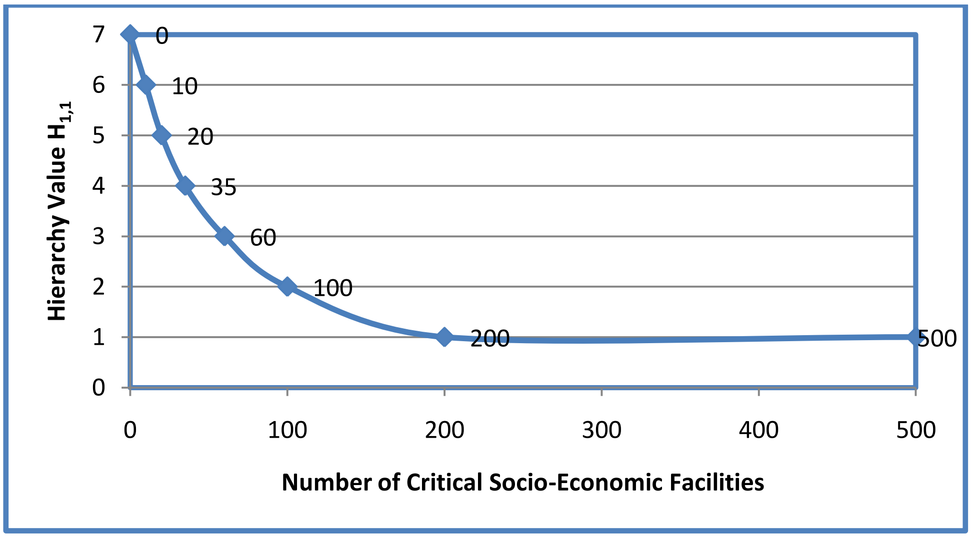

Figure 6.2: Hierarchy values $H_{1,1}$ for number of critical socio-economic facilities factor

Area of Socio-Economic Buildings

The square footage of buildings of a specified type is considered to be one of the required inventory data, as stated by Loh *et al.* (2000), which is needed for the earthquake risk assessment model.

Sometimes there are a large number of socio-economic buildings but the area of these buildings is small, while perhaps a road has few such buildings but with a large total area of those buildings. So, to give a better representation of the critical facility, the area of these facilities may need to be included in the RRP model.

Seven values of hierarchy have been estimated for the area of socio-economic buildings within a specific road. The first hierarchy is given for area equal or greater than 1,000,000 m^2 and last hierarchy for zero m^2. Also, the scale for this factor will be 7 as shown in Table 6.5 and Figure 6.3.

Table 6.5: $H_{1,2}$ and $S_{1,2}$ values for area of critical socio-economic buildings factor

Area of socio-economic buildings (m^2)	**Hierarchy values $H_{1,2}$**	**Scale value $S_{1,2}$**
≥ 1,000,000	1	7
400,000	2	
200,000	3	
100,000	4	
50,000	5	
10,000	6	
0	7	

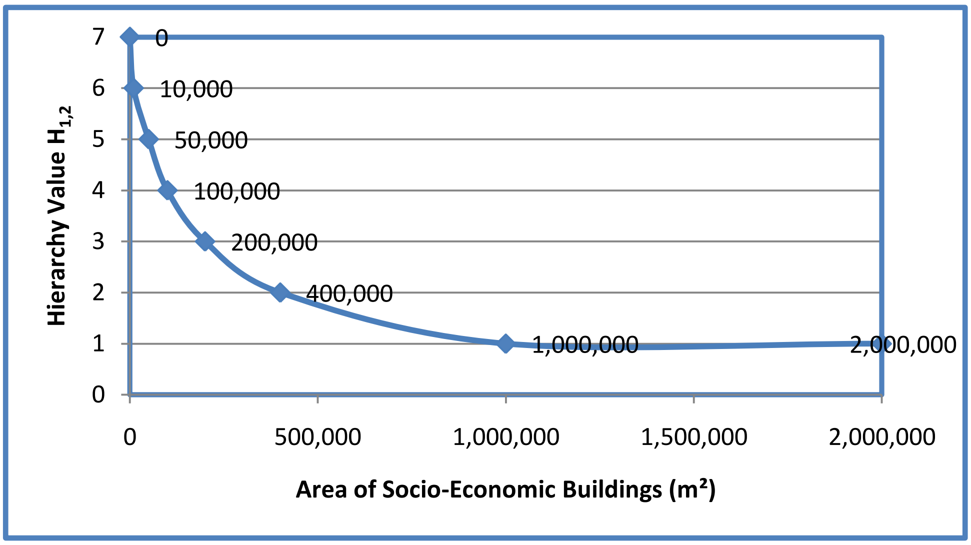

Figure 6.3: Hierarchy values $H_{1,2}$ for area of critical socio-economic buildings factor

<u>Capacity of Socio-Economic Buildings</u>

Another representation for the critical socio-economic facilities is to include the capacity of the buildings served by a specific road in person per m^2. It should be noted that two roads (segments) with the same number of buildings but different capacities cannot be in the same hierarchy. So, including capacity of these critical in the proposed model will overcome the issue of many buildings with a small total capacity.

Table 6.6 shows that 6 hierarchy values have been given to the capacity of socio-economic building factor with a first hierarchy of 1, a last hierarchy of 6 and a scale of 6.

Table 6.6: $H_{1,3}$ and $S_{1,3}$ values for capacity of socio-economic buildings factor

Capacity of socio-economic buildings (person/m²)	**Hierarchy values $H_{1,3}$**	**Scale value $S_{1,3}$**
1.0	1	6
0.8	2	
0.6	3	
0.4	4	
0.2	5	
0.0	6	

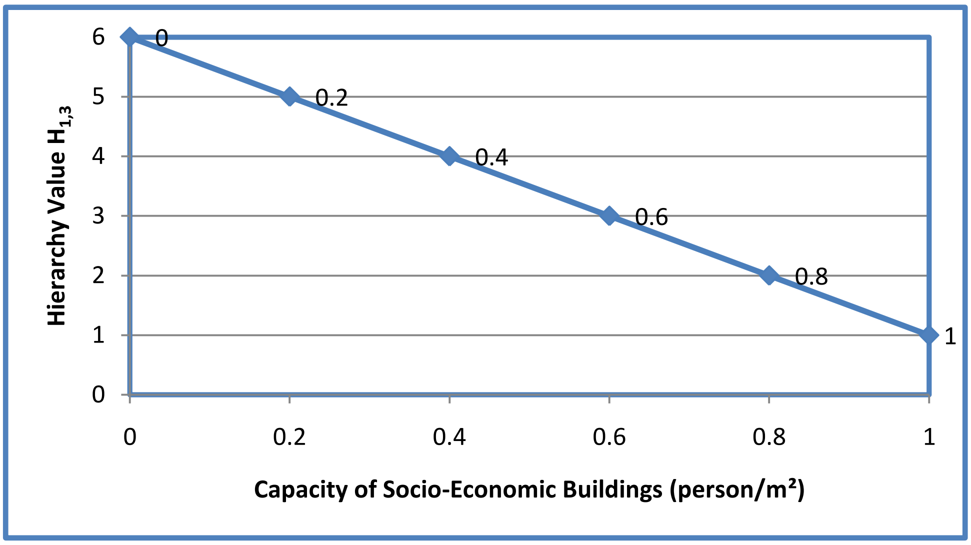

Figure 6.4: Hierarchy values $H_{1,3}$ for capacity of socio-economic buildings factor

Population

The next important piece of data to consider is population. Population is important to the model because the goal is to get as many people to as many facilities as quickly as possible. While the facilities are most important, the location of the people is very important to the model as well (Final Report, University of Virginia, 2002).

For a population equal or greater than 1,500,000 habitants served by a road, it is given a hierarchy value of 1, and a 6 hierarchy value is given zero habitant population. The scale is 6 for this factor.

Table 6.7: $H_{1,4}$ and $S_{1,4}$ values for population served by a road factor

Population served by a road (habitant)	Hierarchy values $H_{1,4}$	Scale value $S_{1,4}$
≥ 1,500,000	1	6
700,000	2	
400,000	3	
200,000	4	
100,000	5	
0	6	

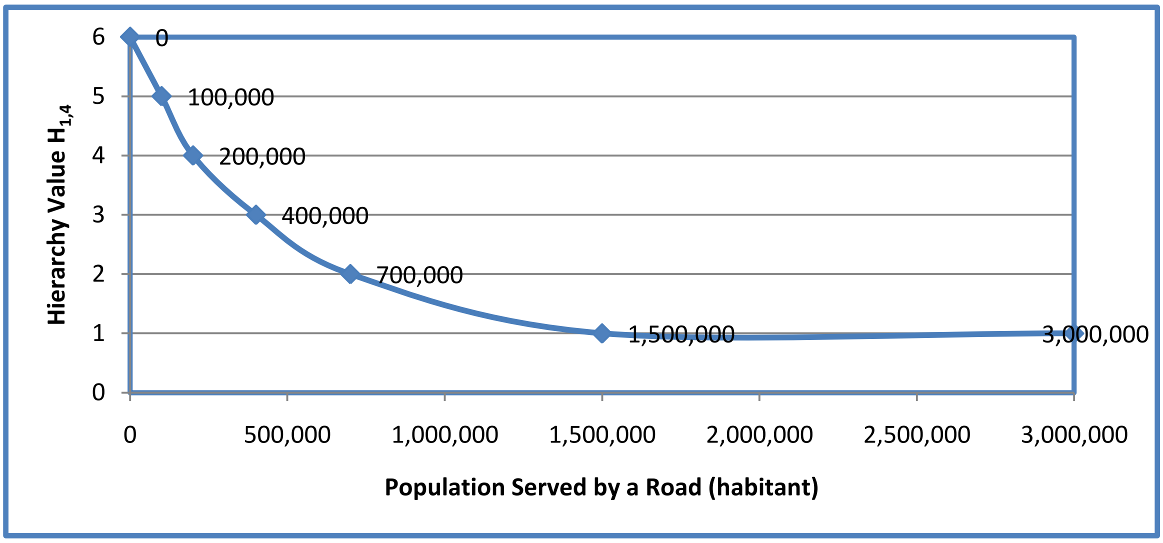

Figure 6.5: Hierarchy values $H_{1,4}$ for population served by a road factor

Area Served by a Road

The area served by a road is an important factor to include in the proposed model as it reflects in some way the socio-economic situation of the road. For example, it can give an indication whether there are a high or small number of socio-economic buildings within it. Also, it can sometimes reflect the intensity of the population (i.e. for a large area, in general, it has a large population and a high number of critical buildings).

A first hierarchy is given for equal or greater than 100 km^2 of area served by a road while for zero km^2, the hierarchy is considered to be 7 as shown in Table 6.8. The scale is 7.

Table 6.8: $H_{1,5}$ and $S_{1,5}$ values for area served by a road factor

Area served by a road (km^2)	**Hierarchy values $H_{1,5}$**	**Scale value $S_{1,5}$**
≥ 100	1	7
60	2	
35	3	
20	4	
10	5	
5	6	
0	7	

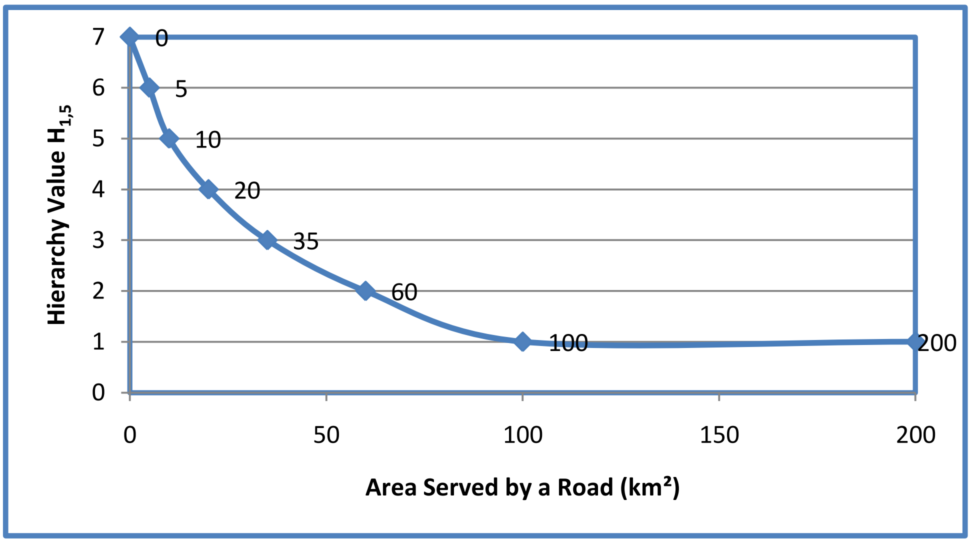

Figure 6.6: Hierarchy values $H_{1,5}$ for area served by a road factor

Type of Area

The type of area (whether it is urban or rural) is important because it explains whether it is a populated or non-populated area which leads to the number of roads across the area. In rural (non-populated) areas there might be only two or three roads across the whole area. Also it can give an indication whether it has many or few critical buildings (a rural area normally has few such buildings and vice versa for an urban area).

The type of area is classified as urban and rural. Hence, the urban area is the most important and considered to be as a first hierarchy, while the rural area comes in second place in terms of hierarchy. Since there are two types of area and two hierarchy values, then the scale for this factor will be 2.

Table 6.9: $H_{1,6}$ and $S_{1,6}$ values for type of area factor

Type of area	Hierarchy values $H_{1,6}$	Scale value $S_{1,6}$
Urban	1	2
Rural	2	

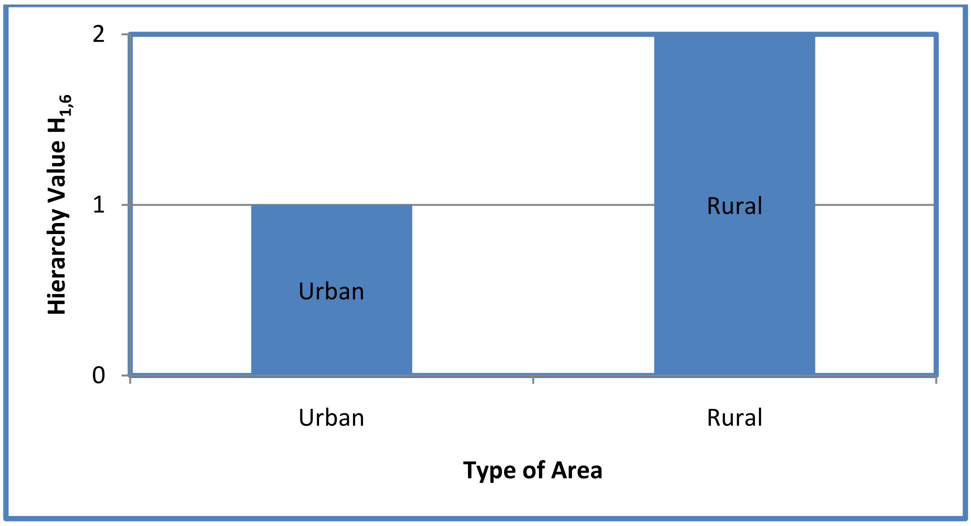

Figure 6.7: Hierarchy values $H_{1,6}$ for type of area factor

6.2.3.2.B $H_{2,f}$ and $S_{2,f}$ Values for Road Network Factor Group

Type of Road

A road has been classified into five types in this study which are interstate, bridge, highway, primary and secondary. Each type has been given a different hierarchy value starting with 1 for an interstate road to 5 for a secondary road as shown in Table 6.10 and Figure 6.8. Since there are five types of roads, then the scale will be 5.

Table 6.10: $H_{2,1}$ and $S_{2,1}$ values for type of road factor

Type of road	Hierarchy values $H_{2,1}$	Scale value $S_{2,1}$
Interstate	1	5
Bridge	2	
Highway	3	
Primary	4	
Secondary	5	

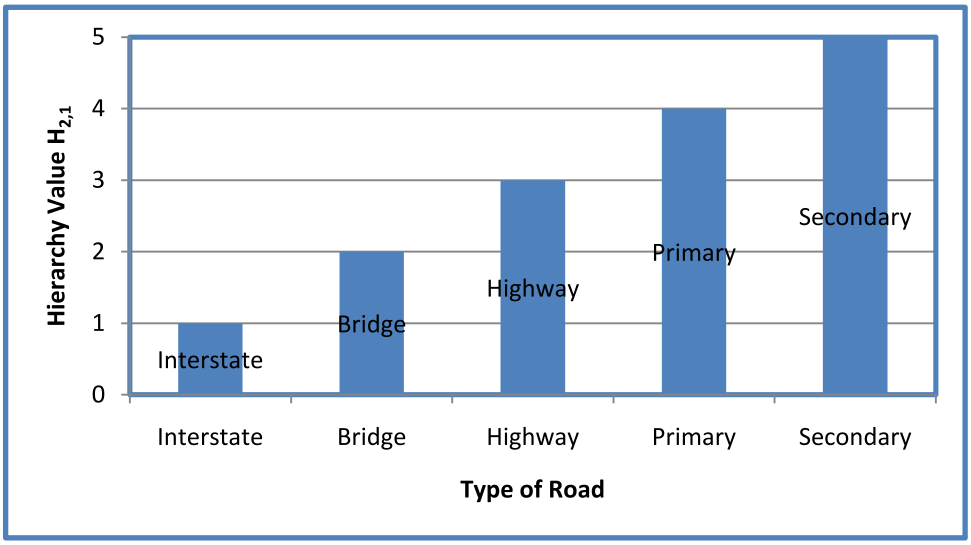

Figure 6.8: Hierarchy values $H_{2,1}$ for type of road factor

Number of Nodes

The nodes represent the traffic loading/unloading points to/from the network such as cities, intersections, and exits (Orabi *et al.*, 2009a).

Increasing nodes leads to put more pressure on the road network after damage caused by a natural/man-made disaster.

The number of nodes have been classifies into seven ranges; in which a hierarchy of 1 is given for road with 18 nodes or greater and a last hierarchy value of 7 is given for 2 nodes. The scale value for this factor is 7.

Table 6.11: $H_{2,2}$ and $S_{2,2}$ values for number of nodes factor

Number of nodes	Hierarchy values $H_{2,2}$	Scale value $S_{2,2}$
≥ 18	1	7
11	2	
8	3	
6	4	
4	5	
3	6	
2	7	

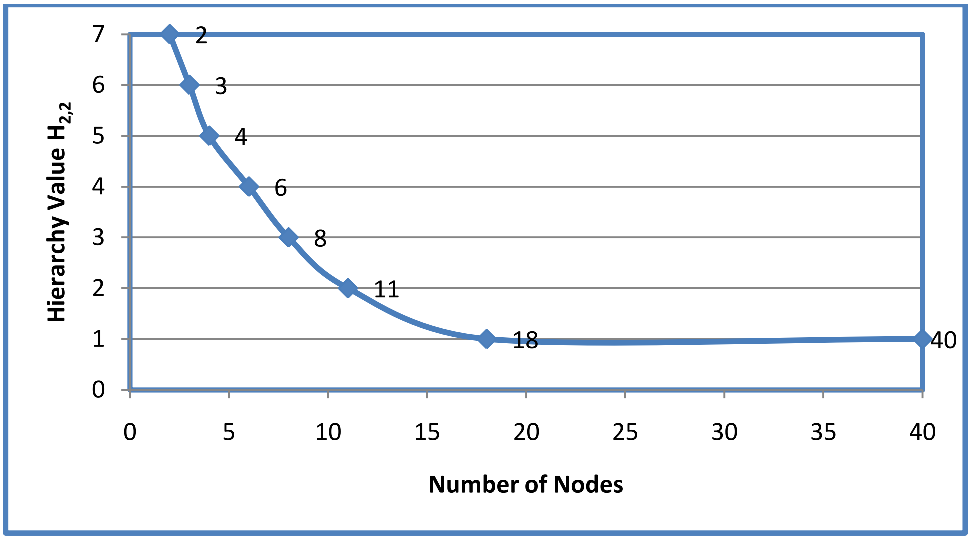

Figure 6.9: Hierarchy values $H_{2,2}$ for number of nodes factor

Number of Links

The links represent the road segments connecting different nodes (Orabi *et al.*, 2009a). After a disaster, the damage of a link may cause a disruption for the whole road network. Too many links put more pressure on the damaged road rather than a few links. This in turn leads to the first recovery priority for the road with many links.

It is estimated that with number of links equal or greater than 18, a first hierarchy is considered and the last hierarchy for the number of links equals to 1 as listed in Table 6.12 and illustrated in Figure 6.10.

Table 6.12: $H_{2,3}$ and $S_{2,3}$ values for number of links factor

Number of links	Hierarchy values $H_{2,3}$	Scale value $S_{2,3}$
≥ 18	1	7
12	2	
8	3	
5	4	
3	5	
2	6	
1	7	

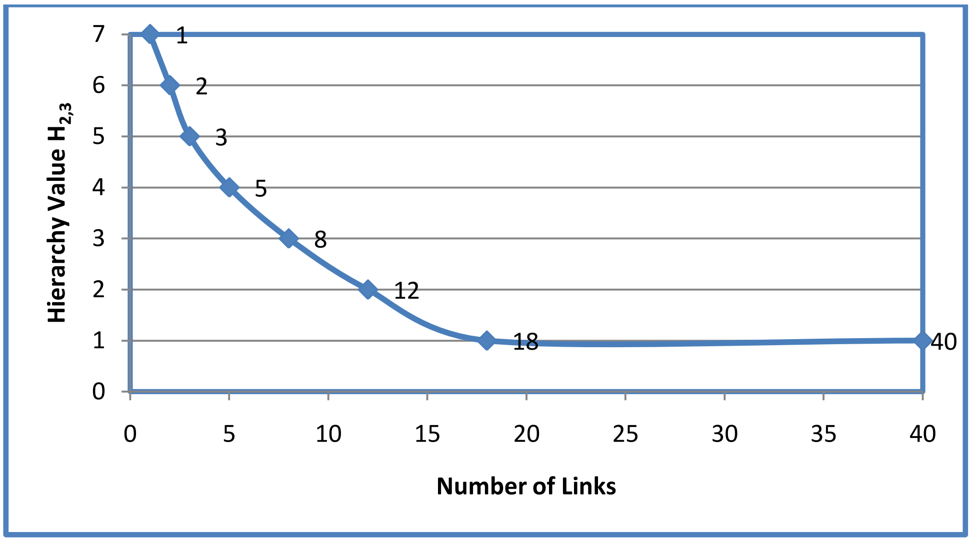

Figure 6.10: Hierarchy values $H_{2,3}$ for number of links factor

Length of Road

Road length is a very important piece of information for the model because it is the basis to determine the nodes and links in a road segment (Final Report, University of Virginia, 2002).

This factor has been classified into six ranges between equal or greater than 20 km and zero km. The higher length will take the first hierarchy while the lower length will be in the last hierarchy as shown in Table 6.13. The scale value is 6 for length of road factor.

Table 6.13: $H_{2,4}$ and $S_{2,4}$ values for length of road factor

Length of road (km)	Hierarchy values $H_{2,4}$	Scale value $S_{2,4}$
≥ 20	1	6
11	2	
7	3	
4	4	
2	5	
0	6	

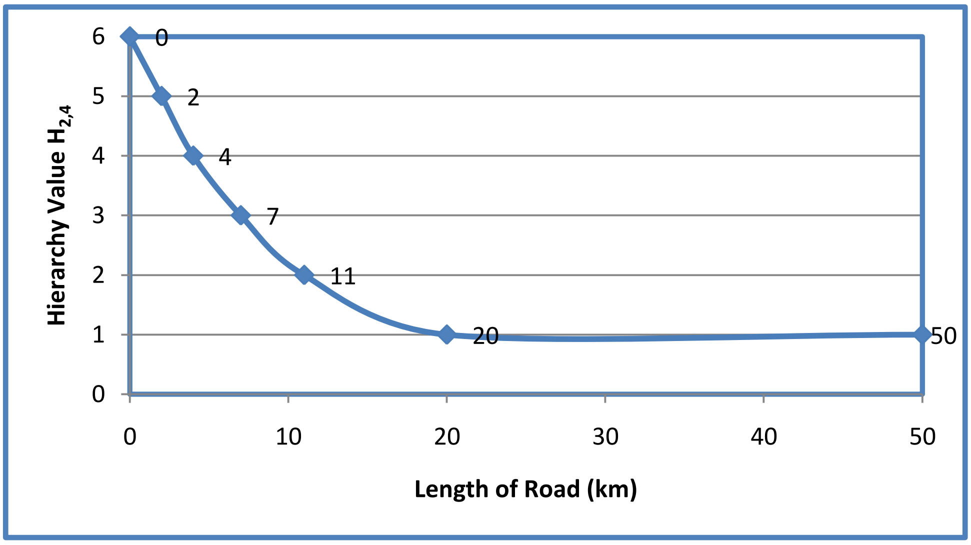

Figure 6.11: Hierarchy values $H_{2,4}$ for length of road factor

Number of Lanes in each Direction

Dheenadayalu *et al.* (2004) conclude that one of the most important localised capacity factors is the number of lanes.

Number of lanes is important because it illustrates the traffic capacity of the road. More lanes indicate that the road has a high traffic flow and therefore need first priority for recovery. In some cases the multi-lane road is less affected by a natural disaster or a man-made disaster than a single lane road because not all of the lanes are damaged and the intact lanes can be used in the traffic movement. In such cases, this issue has been overcome by including the number of open lanes factor as will be discussed later in the damage group of factors.

Five ranges have been estimated regarding the number of lanes in each direction of a road. A hierarchy value of 1 is given for a road with 5 lanes or greater while 5 hierarchy value is given for only one lane road and a scale value of 5.

Table 6.14: $H_{2,5}$ and $S_{2,5}$ values for number of lanes factor

Number of lanes in each direction	**Hierarchy values $H_{2,5}$**	**Scale value $S_{2,5}$**
≥ 5	1	5
4	2	
3	3	
2	4	
1	5	

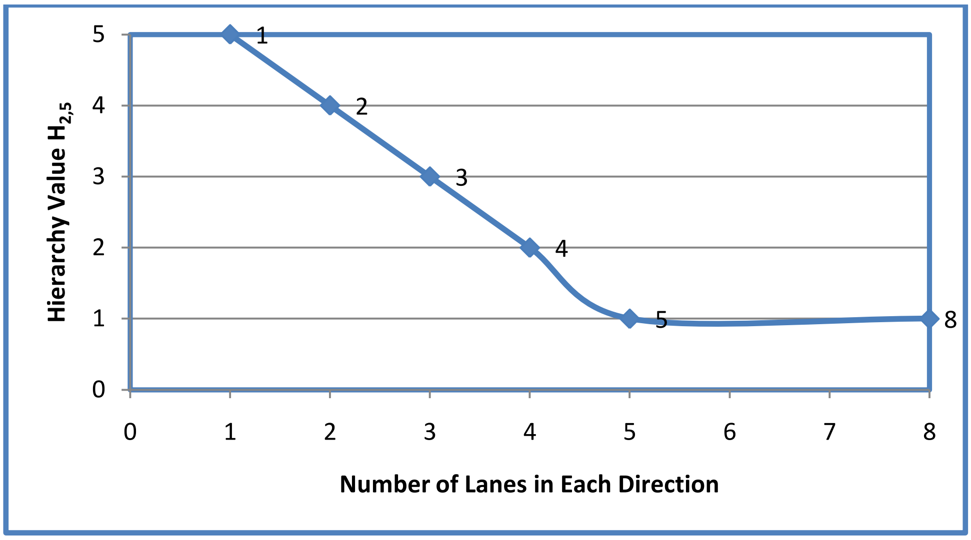

Figure 6.12: Hierarchy values $H_{2,5}$ for number of lanes factor

Pavement Structure

The structure of the pavement and the materials used in it (whether it is rigid or flexible pavement) is also important because it has an effect on the cost of the road recovery.

There are two main types of a pavement structure: rigid and flexible pavement. Sometimes a rigid pavement is resurfaced by a flexible layer. So, the road has been classified according to the pavement structure in this research into three types; with a first hierarchy being given to the rigid pavement, second hierarchy for a rigid pavement resurfaced with a flexible layer, while the last hierarchy is given for the flexible pavement. This in turn leads to a scale value of 3.

Table 6.15: $H_{2,6}$ and $S_{2,6}$ values for pavement structure factor

Pavement structure	Hierarchy values $H_{2,6}$	Scale value $S_{2,6}$
Rigid	1	3
Rigid and Flexible	2	
Flexible	3	

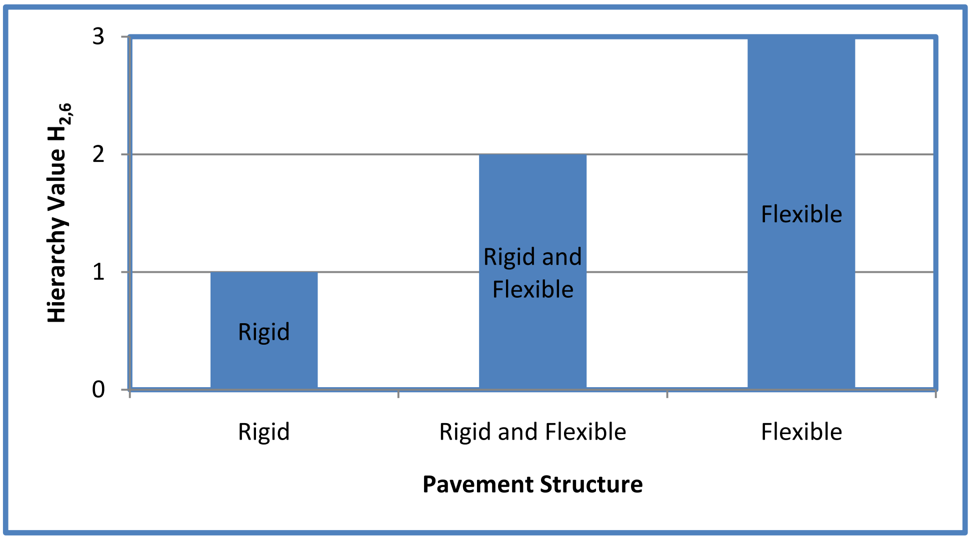

Figure 6.13: Hierarchy values $H_{2,6}$ for pavement structure factor

6.2.3.2.C $H_{3,f}$ and $S_{3,f}$ Values for Traffic Factor Group

Vehicles of Class (1)

For the purpose of clear and elaborated data, the volume of traffic needs to be classified in terms of vehicle types. The classification of vehicles into different types can vary according to the local conditions and the exact reason for the survey (Overseas Road Note 40, 2004). The important point is that classifications can be flexible and those responsible for carrying out a survey should be aware of national practices (The Highway Agency, 1996).

In this study, the traffic has been classified into three classes and their types and description is shown in Table 6.16. Passenger cars are considered as (Class (1)). Light commercial vehicles, mini buses and buses are considered as commercial vehicles (Class (2)), while light trucks, medium trucks, heavy trucks and articulated vehicles can be considered as truck vehicle type (Class (3)).

Table 6.16: Traffic classification

Class	Type	Description
1	Passenger cars	Passenger vehicles seating not more than five persons, station wagons and taxis
2	Light commercial vehicles	All two-axles vehicles with single rear tyres not included as cars or mini-bus
	Mini-buses	Mini-buses with 9-15 seats
	Buses	Purpose-built bus with more than 15 seats
3	Light trucks	Two axle truck, petrol driven, and with twin rear tyres
	Medium trucks	Two axle diesel truck with twin rear tyres
	Heavy trucks	Three axle diesel truck with twin rear tyres
	Articulated vehicles	Multi-axle articulated tractor and trailer

Because the fact that Class (1) of cars represents the most percentage of road vehicles, so it is considered as a controlling factor within traffic factor group despite the small percentages of Classes (2) and (3) vehicles.

According to the carried field data survey, the per cent of Class (1) vehicles has been classified into seven ranges with first hierarchy for cars of 100 per cent of Class (1) vehicles while cars of zero per cent has been considered as last hierarchy. The scale for this factor is 7.

Table 6.17: $H_{3,1}$ and $S_{3,1}$ values for traffic classification factor

Vehicles of class (1) (%)	Hierarchy values $H_{3,1}$	Scale value $S_{3,1}$
100	1	7
90	2	
80	3	
70	4	
60	5	
50	6	
0	7	

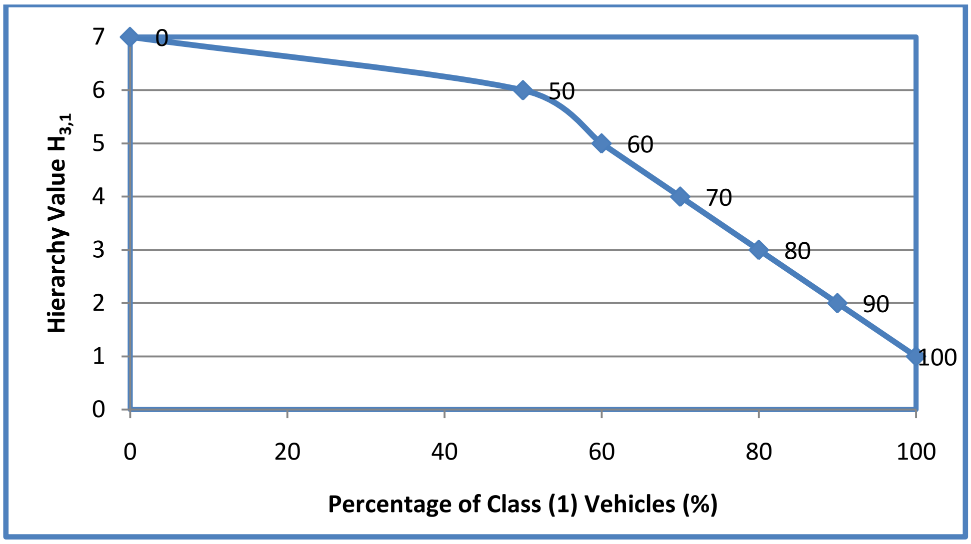

Figure 6.14: Hierarchy values $H_{3,1}$ for traffic classification factor

Traffic Flow

After disasters or armed conflicts, especially in urban regions, traffic capability is significantly reduced due to physical damage to transportation facilities and a high demand of emergency traffic, resulting in degradation of urban activities and failure in post-event traffic movement (Nojima and Sugito, 2000).

Estimates of traffic flow along road sections are needed for most aspects of planning and management. The level of traffic will influence the road standards of maintenance in terms of recovery prioritisation. The first step in assessing demand is to estimate baseline traffic flows to determine the traffic volume actually travelling on the road. The estimate normally used is the annual average daily traffic (AADT), classified by the vehicle category. This is defined as the total annual traffic in both directions divided by 365. Estimates of AADT are normally obtained by recording actual traffic flows over specific shorter period than a year, and results are scaled to give an estimate of AADT (Robinson *et al.*, 1998). A manual method of counting will be used for the case study.

Traffic flow is considered as the second important factor within the traffic factor group according to the questionnaire survey and has been classified into seven ranges of input data in the presented research. First hierarchy is given to traffic flow equal or greater than 300,000 vpd (vehicle/day) or to a strategic road. Robinson *et al.* (1998) stated that there may be roads with relatively low levels of traffic which, nevertheless, have key strategic importance because of the places that they link. This may assign top priority for maintenance work to these, since it is considered vital to keep strategic roads in good condition. Roads with traffic flow of zero vpd are considered to be in the last hierarchy and the scale is considered to be 7 for this factor.

Table 6.18: $H_{3,2}$ and $S_{3,2}$ values for traffic flow factor

Traffic flow (vpd)	**Hierarchy values $H_{3,2}$**	**Scale value $S_{3,2}$**
≥ 300,000 or Strategic road	1	
150,000	2	
80,000	3	
30,000	4	7
10,000	5	
1,000	6	
0	7	

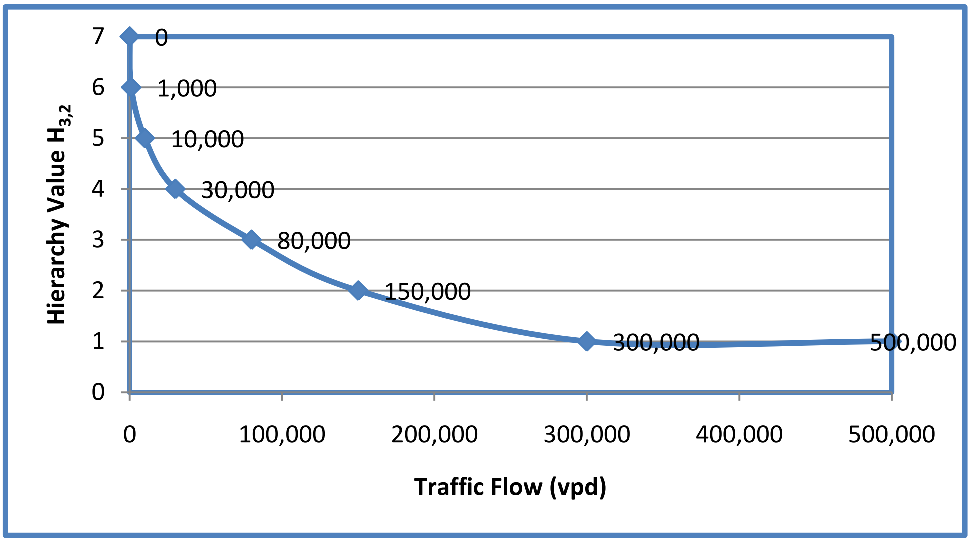

Figure 6.15: Hierarchy values $H_{3,2}$ for traffic flow factor

Delay Time

The travel time is often considered to be the most important factor affecting travellers on damaged transportation networks, especially when they need to travel longer detours or their original routes but with significantly reduced speeds. Travel routes that are perceived to be faster attract larger traffic volumes. These routes can then experience traffic volumes that exceed their capacities, creating traffic congestions and increased travel times that in turn cause travellers to consider other faster alternatives (Bell and Iida, 1997).

Delay is defined by Yu and Washburn (2009) as the average travel time incurred by motorists travelling on the facility in excess of the free-flow travel time.

Delay time is considered as the most important factor within the traffic factor group according to the questionnaire results obtained from this research. Five ranges of delay time have been estimated for this factor starting with hierarchy no. 1 for roads with delay time of 60 minutes or greater and hierarchy no. 5 for those with zero minutes delay time and the general scale value is 5.

Table 6.19: $H_{3,3}$ and $S_{3,3}$ values for delay time factor

Delay time (minutes)	Hierarchy values $H_{3,3}$	Scale value $S_{3,3}$
≥ 60	1	5
30	2	
15	3	
5	4	
0	5	

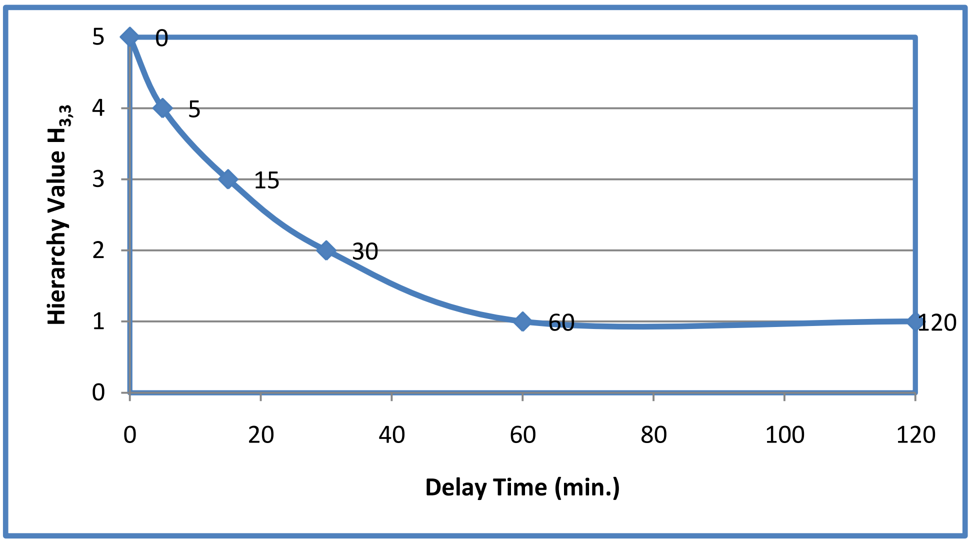

Figure 6.16: Hierarchy values $H_{3,3}$ for delay time factor

Additional Trip Length

The affected functional performance decreases in O/D (origin/destination) trips due to overload and leads to an increase in trip length due to detouring actions (Nojima and Sugito, 2000). When certain highway links are damaged, some motorists may take alternate highway routes rather than use arterial street detours. Thus if O/D flows remained constant, these longer trips would increase total traffic volume on the network (Chang and Nojima, 1998).

For an additional trip length equal or greater than 20 km, first hierarchy has been given while roads with zero km additional trip length have been considered as last hierarchy and the scale is 7 for this factor as shown in Table 6.20.

Table 6.20: $H_{3,4}$ and $S_{3,4}$ values for additional trip length factor

Additional trip length (km)	**Hierarchy values $H_{3,4}$**	**Scale value $S_{3,4}$**
≥ 20	1	7
11	2	
7	3	
4	4	
2	5	
1	6	
0	7	

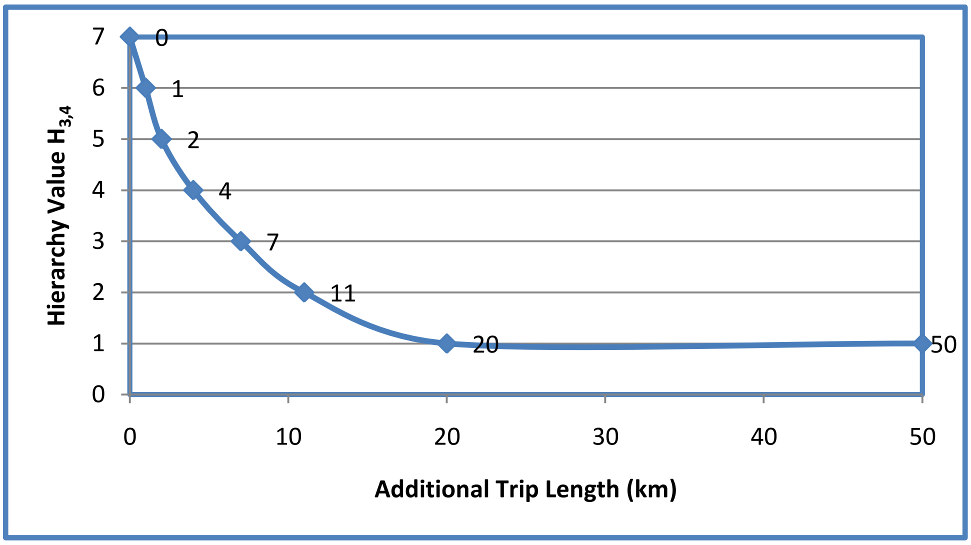

Figure 6.17: Hierarchy values $H_{3,4}$ for additional trip length factor

Queue Length

Queue length is a function of demand flow through the damaged area and area capacity. When demand exceeds capacity queues will grow, when demand equals capacity, queues will remain constant and when capacity exceeds demand, either there will be no queuing, or queues will start to disperse (Maclean, 1978).

When a queue is present, determined by the vehicle arrival rate and the lane capacity, vehicles will be stationary for a time, and subsequently move up through the queue. At this stage, vehicles experience a stop-and-go situation. The number of vehicles stored (queued) and the individual delay at any given time could be obtained from Equation (6.12) (Dudek and Richards, 1982). This is a function of the number of vehicles in the queue at any given time (t), the number of open lanes, and the average space occupied by vehicles in the queue.

$$L_t = \frac{Q_t \times l}{N} \quad (6.12)$$

Where: L_t = estimated length of queue length in feet at time *t*, Q_t = estimated number of vehicles in queue at time *t*, N = number of open lanes upstream from lane closure, L = average space occupied by a vehicle in the queue (l = 40 ft).

Seven ranges of queue length have been estimated as shown in Table 6.21. A first hierarchy is given for 2,000 m queue length or greater and a last hierarchy is given for those with queue length of zero m. The scale is considered to be 7 corresponding to the seven ranges of the queue length.

Table 6.21: $H_{3,5}$ and $S_{3,5}$ values for queue length factor

Queue length (m)	Hierarchy values $H_{3,5}$	Scale value $S_{3,5}$
≥ 2,000	1	7
1,000	2	
500	3	
250	4	
100	5	
20	6	
0	7	

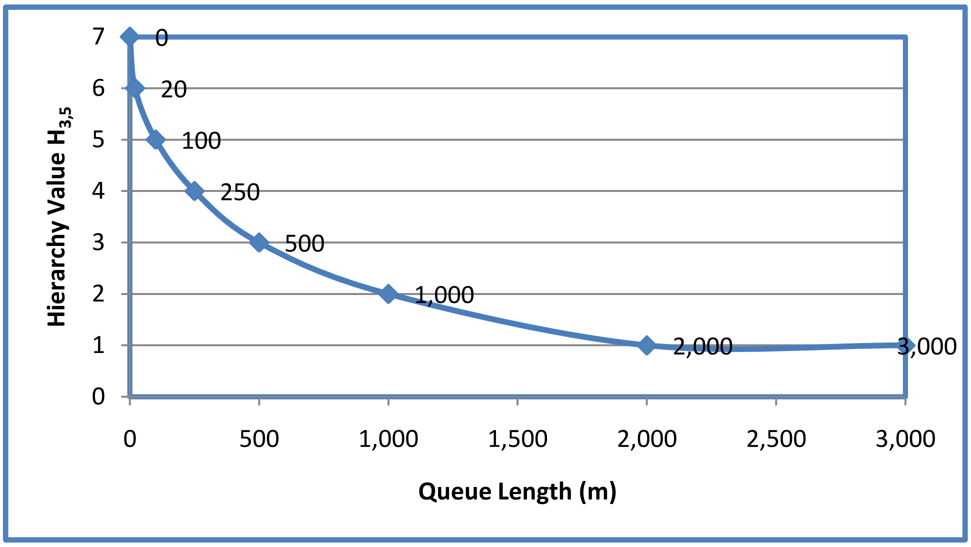

Figure 6.18: Hierarchy values $H_{3,5}$ for queue length factor

Level of Service LOS

The Highway Capacity Manual (2000) described the capacity (C) by the Level of Service (LOS). The LOS is a measure used by traffic engineers to determine the effectiveness of elements of transportation infrastructure. The LOS is most commonly used to analyse highways, but the concept has also been applied to intersections, transit and water supply systems as well. The LOS for road or highway system can be described using qualitative scale A through F, with A being the best and F being the worst. A detailed description of the LOS as provided in the Highway Capacity Manual (2000) and AASHTO Geometric Design of Highways and Streets (Green Book) is summarised in Table 6.22 (Ismail *et al.*, 2011).

The selected values of LOS, or thresholds, should be chosen such that they correspond to drivers' level of satisfaction with the operating conditions for the given level of the service measure (Yu and Washburn, 2009).

Since road level of service is affected adversely after natural/man-made disasters, it is important to know the level of service in order to determine the priority of roads for recovery after these events. There are six types level of service which are A, B, C, D, E and F. Each of these LOS has been given a specific hierarchy; F LOS is on the first hierarchy and A LOS is on the last hierarchy while the scale for this factor is 6.

Table 6.22: Description of level of service (LOS) for roads

Level of Service	Performance Measure	Description
A	Very good	Traffic flows at or above the posted speed limit and all motorists have complete mobility between lanes
B	Good	It is slightly more congested, with some impingement of manoeuvrability; two motorists might be forced to drive side by side, limiting lane changes. It does not reduce speed from LOS A
C	Fair	It has more congestion than B, where ability to pass or change lanes is not always assured. At LOS C most experienced drivers are comfortable, roads remain safely below but efficiently close to capacity, and posted speed is maintained
D	Poor	It is perhaps the level of service of a busy shopping corridor in the middle of a weekday, or a functional urban highway during commuting hours: speeds are somewhat reduced, motorists are hemmed in by other cars and trucks
E	Very poor	It is a marginal service state. Flow becomes irregular and speed varies rapidly, but rarely reaches the posted limit. It is a common standard in larger urban areas, where some roadway congestion is inevitable
F	Unacceptable	It is the lowest measurement of efficiency for a road's performance. Flow is forced; every vehicle moves in lock step with the vehicle in front of it, with frequent slowing required. It describes a road for which the travel time cannot be predicted. Facilities operating at LOS F generally have more demand than capacity

Table 6.23: $H_{3,6}$ and $S_{3,6}$ values for level of service factor

LOS	**Hierarchy values $H_{3,6}$**	**Scale value $S_{3,6}$**
F	1	6
E	2	
D	3	
C	4	
B	5	
A	6	

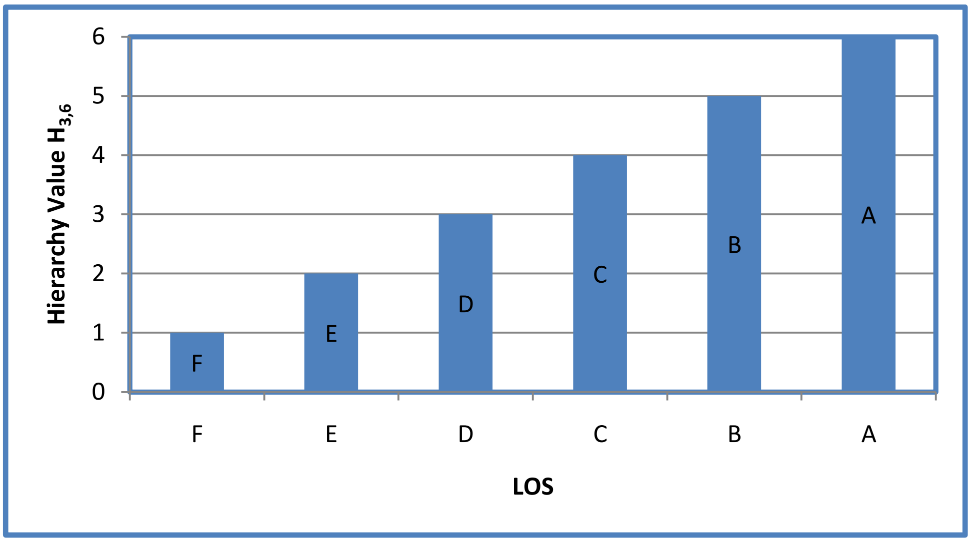

Figure 6.19: Hierarchy values $H_{3,6}$ for level of service factor

Average Speed Reduction

The effect of lane closures on traffic flow is the significant reduction of vehicle speeds. The speed of vehicles travelling through a damaged zone depends upon the number of open lanes where vehicles travelling in the lane adjacent to a damaged area would be most affected as compared to vehicles in a traffic lane furthest from the damaged area. Vehicles would also be subject to the speed limit imposed (Ahmed, 2002).

The increase of a traffic load on the road network caused by the damage of a link of a section of road due to the occurrence of a disaster will cause more traffic congestion and queue length and finally a reduction in the average speed of vehicles travelling on that network. This in turn adversely affect on the road network movement. Therefore there is a need to put the reduction in average speed factor into consideration when prioritising roads for recovery.

The average speed reduction factor has been classified into seven ranges. A hierarchy no. 1 is given to average speed reduction of 100 km/hr while a hierarchy no. 7 is given for the reduction in average speed of 0 km/hr and the scale for this factor is 7.

Table 6.24: $H_{3,7}$ and $S_{3,7}$ values for average speed reduction factor

Average speed reduction (km/hr)	Hierarchy values $H_{3,7}$	Scale value $S_{3,7}$
100	1	7
50	2	
40	3	
30	4	
20	5	
10	6	
0	7	

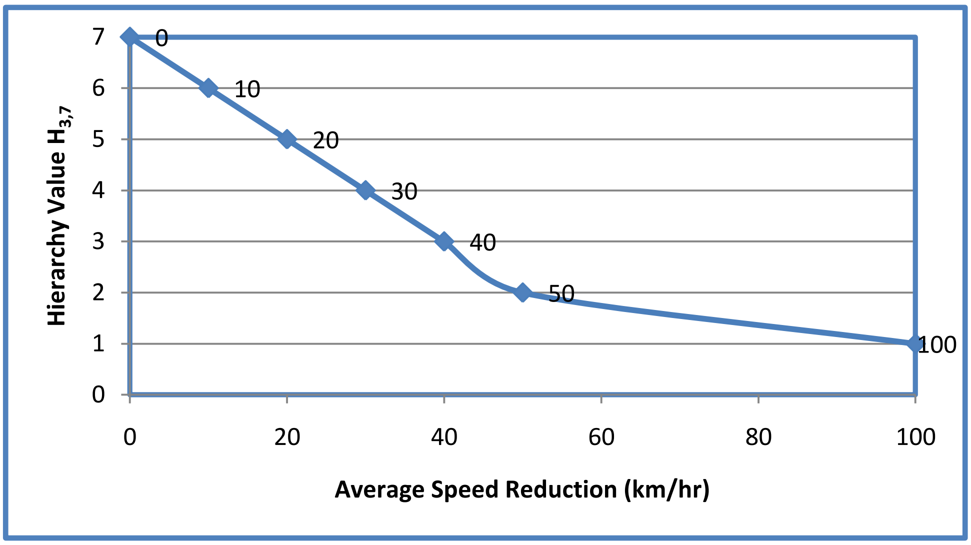

Figure 6.20: Hierarchy values $H_{3,7}$ for average speed reduction factor

Type of Traffic Control Pattern

It is important to know the traffic pattern of a road, particularly whether or not it is worked with electric traffic signals. If so, the adverse effect of disasters will be more since there will be no electricity after these events for a while, which leads to a turbulence in the traffic movement. So, the congestion, delay time and trip length will be more and this will adversely affect on the traffic flow and level of service.

If the road network is working with electric traffic signals; first hierarchy is given to it as the adverse effect on transport movement will be more than the one without electric traffic signals which it is given a second hierarchy. The scale is 2 as two types of traffic control patterns have been taken into account.

Table 6.25: $H_{3,8}$ and $S_{3,8}$ values for traffic control pattern factor

Type of traffic control pattern	Hierarchy values $H_{3,8}$	Scale value $S_{3,8}$
Electric traffic signals	1	2
No electric traffic signals	2	

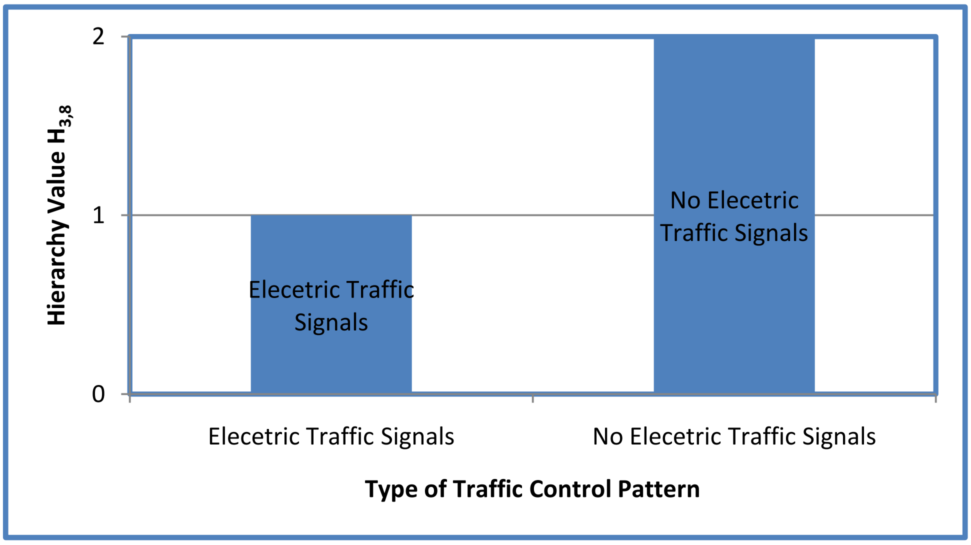

Figure 6.21: Hierarchy values $H_{3,8}$ for traffic control pattern factor

6.2.3.2.D $H_{4,f}$ and $S_{4,f}$ Values for Damage Factor Group

Percentage of Damaged Road

Knowing the damaged distance helps in determining the percentage damage of a road. This will aid in deciding which road needs to be given priority to recover or needs to be recovered first. In order to decide the percentage of damaged road, the distance of road which has been damaged and the length of road needs to be known.

Six ranges of percentage of damaged road have been estimated. A first hierarchy value is given for road with 100 per cent of damage while a last hierarchy is given for that with 0 per cent of damage. Since six ranges of per cent of road damage have been considered for this factor, so the scale for it is considered to be 6.

Table 6.26: $H_{4,1}$ and $S_{4,1}$ values for percentage of damaged road factor

Percentage of damaged road (%)	**Hierarchy values $H_{4,1}$**	**Scale value $S_{4,1}$**
100	1	6
80	2	
60	3	
40	4	
20	5	
0	6	

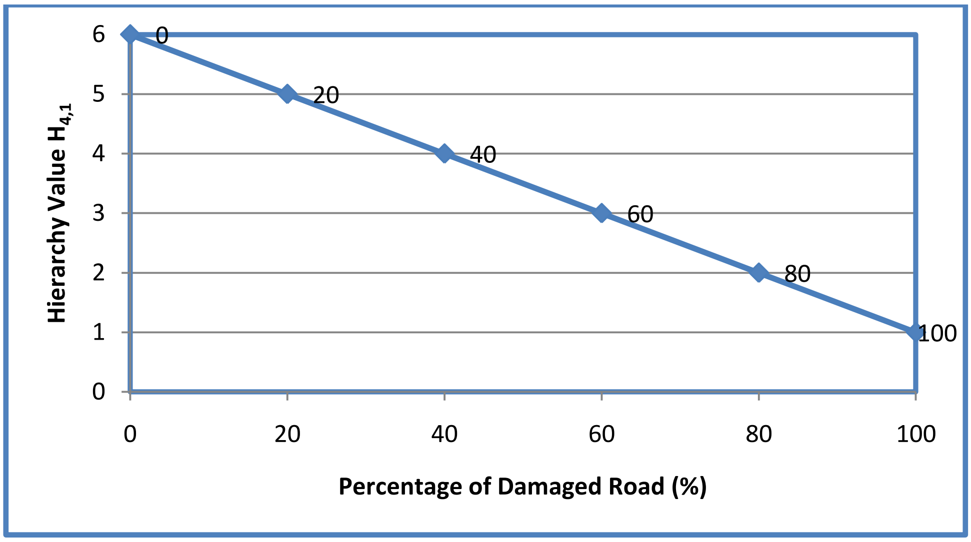

Figure 6.22: Hierarchy values $H_{4,1}$ for percentage of damaged road factor

<u>Type (Severity) of Damage</u>

Determining the type of damage, whether it is complete collapse, bomb explosion, or failure due to excessive vehicles weight, is also important in the modelling. Sometimes, in cases of bomb explosion or failure due to excessive weight, some of the road lanes are not damaged and still working. Hence the road can be used although this will put traffic pressure on these lanes, whereas in cases of a complete collapse, the road and its lanes is completely damaged and there is an urgent need to recover it first.

Severity of damage has been classified in this study as minor, major or severe according to type and description of damage as shown in Table 6.27 below. The method used to determine each level of damage is also given in this table.

Table 6.27: Classification of severity of road damage

Severity of Damage	Type	Description	Method of Measuring
Minor	Roughness	Uncomfortable riding, longitudinal unevenness	Field observation by visual assessment
Major	Surface distress	Surface rutting, cracking, spalling, bomb explosion	Field observation by visual assessment
Severe	Structural defect	Structural damage of the pavement layers, bomb explosion, complete collapse, failure due to excessive vehicles weight	Manually using Benkelman beam

Each type of damage is given a different hierarchy value; 1, 2 and 3 for severe, major and minor respectively. The scale value is considered to be 3 according to three types of damage.

Table 6.28: $H_{4,2}$ and $S_{4,2}$ values for severity of damage factor

Type (Severity) of damage	Hierarchy values $H_{4,2}$	Scale value $S_{4,2}$
Severe	1	3
Major	2	
Minor	3	

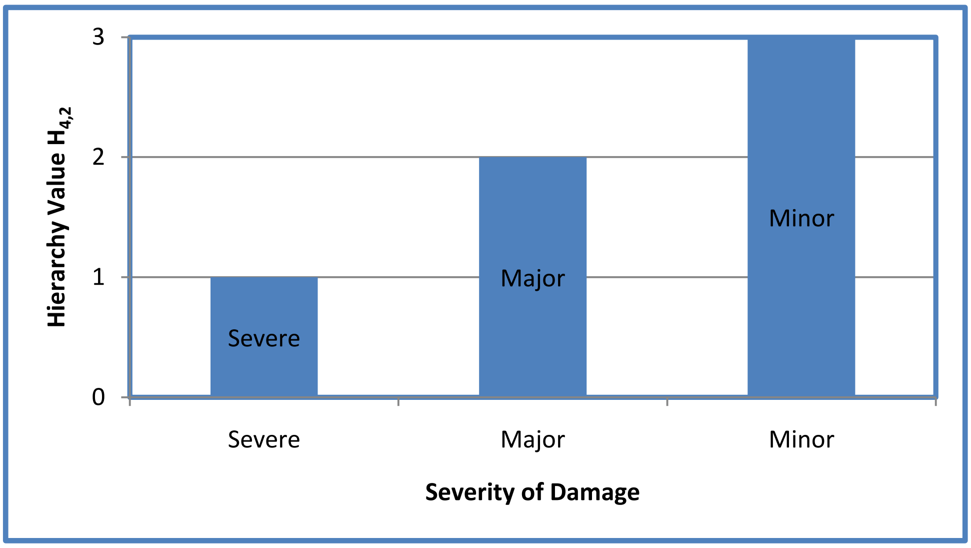

Figure 6.23: Hierarchy values $H_{4,2}$ for severity of damage factor

Number of Open Lanes in each Direction

It is important to include the number of open lanes in each direction within the damage group of factors. For example, in the case of two roads, the first with two lanes and both of them are damaged and the other with three lanes in which two of them are damaged. Although there are two damaged lanes for both roads, there is no open lane for the first road while there is still one open lane for second road. So the first road needs to be recovered before the second one. From the standpoint of the number of lanes in each direction factor which is included within the road network group, the first recovery priority is given for the second road as it has a higher number of lanes. Therefore it is important to include the number of open lanes to provide a better and more accurate way in decision making.

Five values of hierarchy have been estimated for this factor. If there is no open lane, a hierarchy of 1 is given for a road while when open lanes are equal or greater than four, a hierarchy of five is given and the scale will be 5 as shown in Table 6.29.

Table 6.29: $H_{4,3}$ and $S_{4,3}$ values for number of damaged lanes factor

Number of open lanes in each direction	**Hierarchy values $H_{4,3}$**	**Scale value $S_{4,3}$**
0	1	5
1	2	
2	3	
3	4	
≥ 4	5	

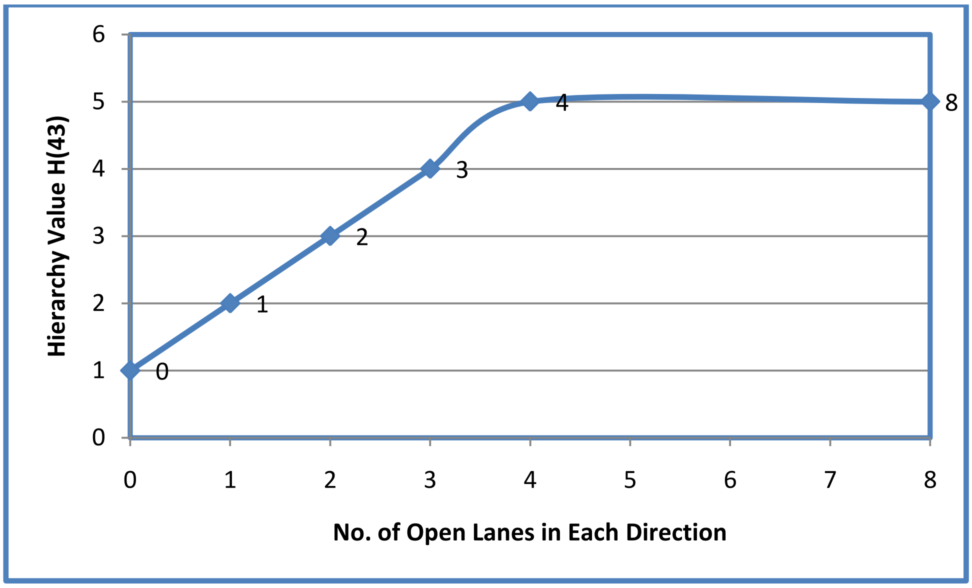

Figure 6.24: Hierarchy values $H_{4,3}$ for number of open lanes factor

Number of Damaged Layers

The number of damaged layers is also an important factor and needs to be put into account when prioritising roads for recovery. For example, if there is a comparison between two roads to decide which of them needs to be recovered first; one with three damaged layers and the other with only one damaged layer. In such a situation the traffic movement will be impossible for the first road which in turn leads to its closure, while sometimes (e.g., during rescue and relief operations) the second road can be used by vehicles because only the surface layer is damaged. In this case the first road should have the first hierarchy for recovery and the second road can be recovered later. However, if the whole layers of pavement are damaged, this will cost more in the recovery rather than only one or two damaged layers.

The hierarchy for this factor has been classified into four values; first, second, third and fourth hierarchy for the number of damaged layers of 3 (or all), 2, 1 and 0 respectively. According to four values of hierarchy, the scale value is 4.

Table 6.30: $H_{4,4}$ and $S_{4,4}$ values for number of damaged layers factor

Number of damaged layers	**Hierarchy values $H_{4,4}$**	**Scale value $S_{4,4}$**
3 or all	1	4
2	2	
1	3	
0	4	

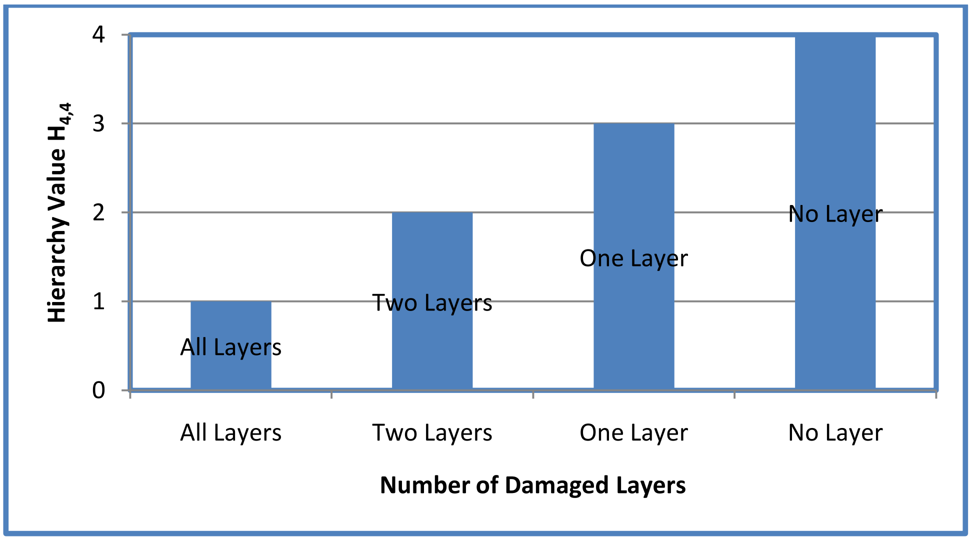

Figure 6.25: Hierarchy values $H_{4,4}$ for number of damaged layers factor

Present Serviceability Index PSI

The present serviceability index (PSI), one of the most common indicators used to evaluate pavement performance, is incapable of transforming one's imprecise judgment into an exact number between 0 (the worst) and 5 (the best). In the traditional approach, the inspector rates an exact number on a scale from 0 to 5 with five adjective designations in order to identify the corresponding pavement performance (Pan *et al.*, 2011).

Difference in a present serviceability index can be obtained from Equation (6.13).

$$\Delta PSI = P_{\circ} - P_t \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (6.13)$$

Where: ΔPSI = difference in a present serviceability index, $P_{\circ}$ = initial design serviceability index and can be obtained from the recorded and published data, P_t = design terminal serviceability index and can be obtained from the recorded and published data or, if it is not available, can be obtained from Equations (6.14) or (6.15) (AASHTO, 1993; Pavement Serviceability, Available online, last accessed on 05.11.2009).

- For flexible pavements:

$$PSI\ (or\ P_t) = 5.03 - 1.91\log(1 + SV) - 1.38 \times RD^2 - 0.01 \times \sqrt{C + P} \ldots 6.14)$$

- For rigid pavements:

$$PSI\ (or\ P_t) = 5.41 - 1.80\log(1 + SV) - 0.09 \times \sqrt{C + P} \ldots \ldots \ldots \ldots \ldots \ldots \ldots (6.15)$$

Where: PSI = statistical estimate of the meanPSI, SV = slope variance (roughness), RD = rut depth, C = cracking (ft^2 / 1000 ft^2) and P = patching (ft^2 / 1000 ft^2) (AASHTO, 1993; Pavement Serviceability, Available online, last accessed on 05.11.2009).

Six values of hierarchy have been estimated for ΔPSI values starting with first hierarchy for road with ΔPSI of 5 and for road with ΔPSI value of 0; a last hierarchy has been given. A scale value of six has been estimated for this factor as shown in Table 6.31.

Table 6.31: $H_{4,5}$ and $S_{4,5}$ values for ΔPSI factor

ΔPSI	**Hierarchy values $H_{4,5}$**	**Scale value $S_{4,5}$**
5	1	6
4	2	
3	3	
2	4	
1	5	
0	6	

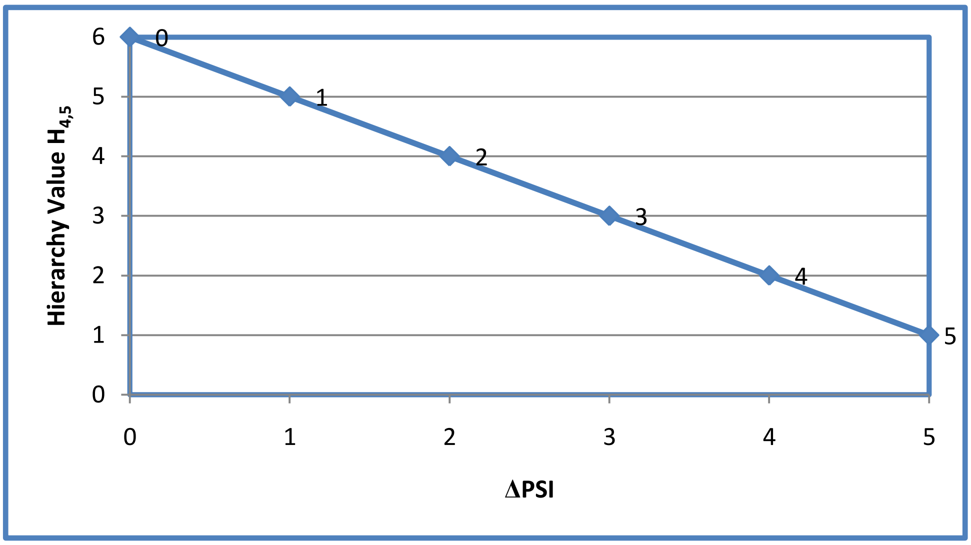

Figure 6.26: Hierarchy values $H_{4,5}$ for ΔPSI factor

6.2.4 Phase 4: Application and Testing of the Presented Model

Application of the proposed model will be done by using a case study of Baghdad's roads to see if the proposed model works. Then, other case studies will be used to test the efficiency and the effectiveness of the proposed model. This will help to check that it can be used and applied anywhere for any type of input data according to the case study (road) situation. This will be discussed later in detail in Chapter seven.

After describing the model's components, a general flow chart of the proposed RRP model can be shown in Figure 6.27.

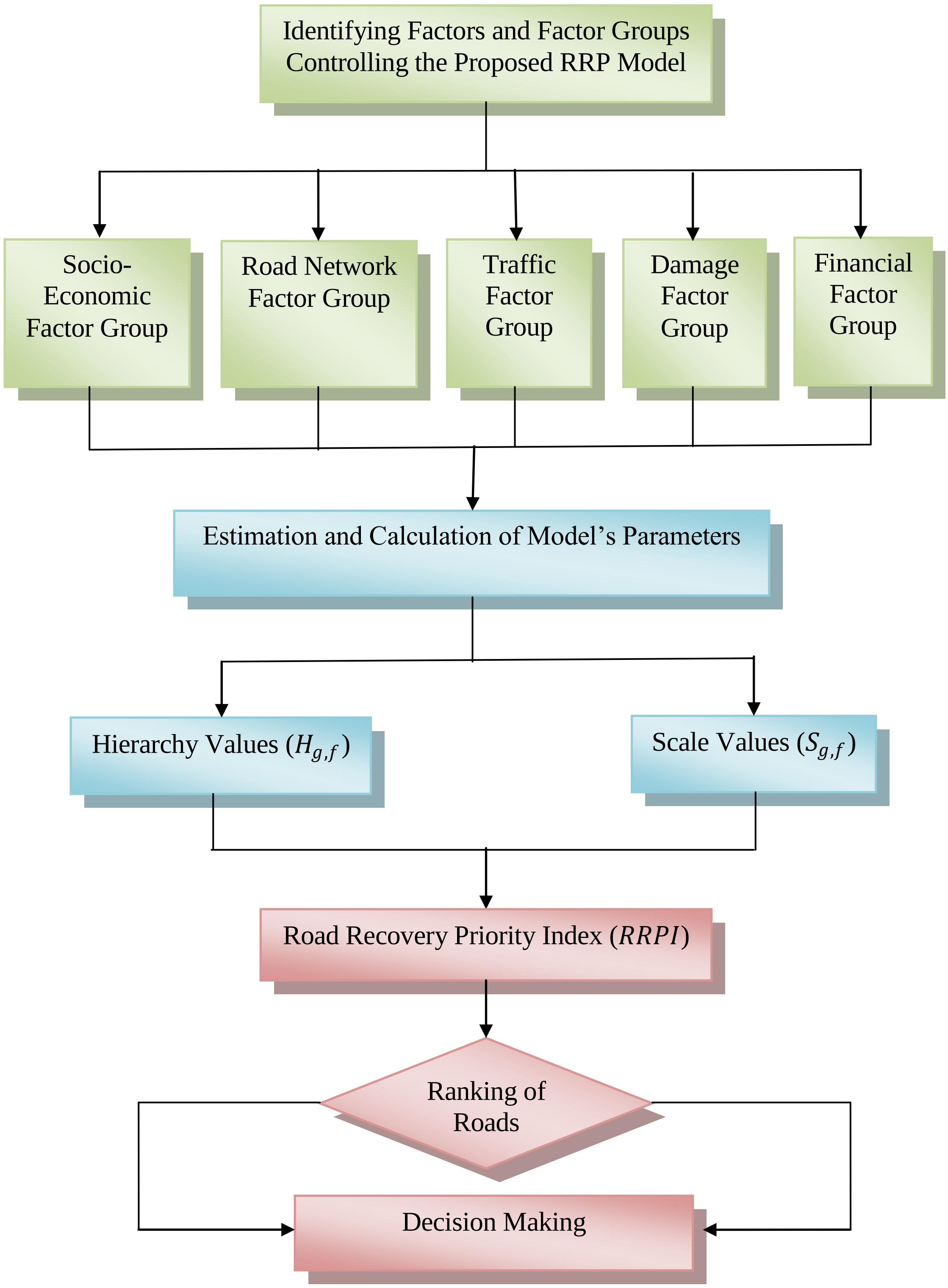

Figure 6.27: A flow chart of the proposed RRP model

6.3 Model Application Procedures

There are three main tasks involved in the application and implementation of the presented model which are: preparation of model inputs, estimation and calculation of model parameters and decision making.

6.3.1 Task (1): Preparation of Model Inputs

The first task is to prepare the input data. The input data include the weight (level of importance) value for each factor within each factor group $W_{g,f}$, weight value for each group of factors W_g, the scale value for each factor in each group $S_{g,f}$ and in addition to each single data value for each factor within each group such as traffic flow, population, percentage of damage road, etc.

6.3.2 Task (2): Estimation and Calculation of Model Parameters

The second task is to estimate and calculate the parameters that will be used in the proposed RRP model. Values of the hierarchy $H_{g,f}$ for each factor within each group are estimated depending on the input data as discussed in Section 6.2.3.2 previously. Then, rating values $R_{g,f}$ are calculated by using Equation (6.8) for each factor. Calculations are then done to obtain values of significance level for each group of factors SL_g, group indicator for each group GI_g and group priority index for each factor group GPI_g by using Equations (6.7), (6.9) and (6.10) respectively. Road recovery priority index for each road damaged by a natural/man-made disaster $RRPI_n$ can be determined by Equation (6.11). A sample of detailed calculations will be given later in section 7.4.3 in Chapter seven.

6.3.3 Task (3): Decision Making

The final task is with regard to the decision making. Ranking method is the traditional way in which a specific problem is addressed. Several different decision criteria may be used for ranking, depending on the managing agency preferences, such as rank by distress, distress and traffic, net present value, benefit-cost ratio, or other composite criteria relating to the particular characteristics and function of each section (Gendreau and Soriano, 1998). As stated by Juang and Amirkhanian (1992), the priority-ranking method is perhaps the most frequently used pavement management system and the major advantage is its simplicity and ease of use (Bham *et al.*, 2002).

Therefore, in this stage, all damaged roads are ranked according to their recovery priority index values $RRPI_n$. Then a comparison is made between the $RRPI_n$ values for all damaged roads to decide which road needs to be first recovered. Obviously, the road with the highest $RRPI$ value needs urgent repair. On the other hand, recovery can be postponed for the road with the lowest $RRPI$ value.

A summary of the model application procedure is presented as a framework and shown in Figure 6.28.

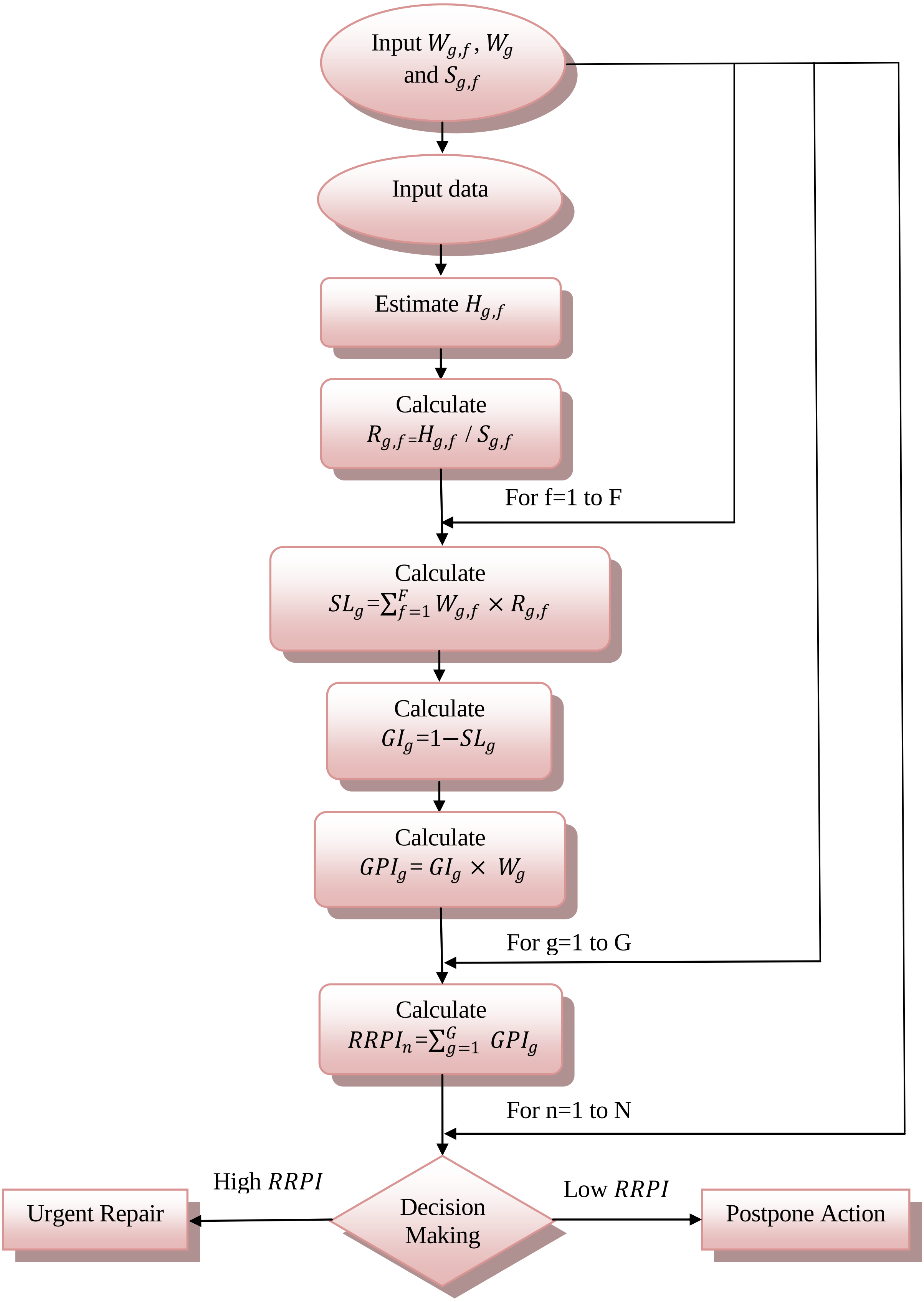

Figure 6.28: A summary of the model application procedures

6.4 Required Data

The required data related to each factor can be categorised into four types which are: interviews, questionnaire, field measurement, and some document records in the organisations. From these data, the scale $S_{g,f}$ and the hierarchy $H_{g,f}$ for each factor within each group can be obtained. The variables and sources of information provided data for various parameters of the recovery priority model are presented in Table 6.32.

Table 6.32: Data items and sources of information

No.	Data Required Details	Data Source
1	The weight value $W_{g,f}$ of each factor in each group	Questionnaire
2	The weight value W_g of each factor group	Questionnaire
3	Data concerning each factor from which a hierarchy $H_{g,f}$ for each factor within each group can be determined	Field data (measurement, interviews and document records)
4	The scale $S_{g,f}$ for each factor within each group in order to determine the rating $R_{g,f}$ for each factor	Field data (measurement, interviews and document records)

6.5 A Comparison between the Proposed RRP Model and the Previous Models

One of the most important issues that have been fulfilled in the proposed RRP model is that it has integrated many important controlling factors which affect road recovery priority. Such a development can solve the problems which the previous models have. For example, many of the existing models may either lack necessary affecting components and factors or may not consider the problems from different aspects such as socio-economic, road network, traffic, damage and financial. However, the proposed

RRP model has taken these factors into consideration to fulfil the requirements of road organisations in the rehabilitation sector. Moreover, most of the existing models are designed for rescue and relief operations in a short-term recovery period, while the proposed RRP model has been designed for repair and rehabilitation of damaged roads and transportation networks for a long-term recovery period. Moreover, many of the existing models have been used for the purposes of risk assessment, risk management and network performance loss but not for the purpose of the road recovery priority. However, the principles of the existing models and their important factors are used as the basis of the development of the proposed RRP model. Table 6.33 shows a qualitative assessment of the new proposed model comparing with the previous models.

Table 6.33: A qualitative assessment of the new proposed model with the previous models

References	Limitations of the previous models	Advantages of the proposed RRP model
ATC (1983)	Available for seismic rating only, which considers natural disaster hazard, bridge resistance and bridge importance as controlling factors. This model is designed for bridges only. Equal weights (10/3) of factors are used in this model.	Available for natural/man-made disasters and for any type within each category, which considers many important factors and groups of factors as discussed previously in this thesis. The proposed model is designed for bridges, interstate, highway, primary and secondary roads. The weights of factors and groups can be determined according to the questionnaire survey.
Babei and Hawkins (1991); Unjoh *et al.* (2000)	These models consider natural disaster hazard, bridge resistance and cost of failure only as controlling factors. They are designed for bridges only.	The proposed model considers many important factors and groups of factors as discussed previously. It is designed for bridges, interstate, highway, primary and secondary roads.
Basoz and Kiremidjian (1996)	Ranking for the bridges is computed as the sum of vulnerability and importance factor only. This model is designed for bridges only.	
Nielson and DesRoches (2003)	Priority for the bridges depends on the bridge fragility only as a severity of damage. This model is designed for bridges only.	
FHWA (1995)	This model considers natural disaster hazard and bridge resistance only as controlling factors. It is designed only for bridges. The model suggests for further improvement taking into account	The proposed model considers many important factors and groups of factors as discussed previously. It is designed for bridges, interstate, highway, primary and secondary roads. Socio-economic issues have been covered within the

References	Limitations of the previous models	Advantages of the proposed RRP model
	socio-economic issues.	proposed model.
Kawashima and Unjoh (1990)	Available for determining the vulnerability of the bridges which considers natural disaster hazard and bridge resistance only as controlling factors. This model is designed for bridges only.	Available for determining the road recovery priority, which considers many important factors and groups of factors as discussed previously in this thesis. The proposed model is designed for bridges, interstate, highway, primary and secondary roads.
Davidson and Shah (1997)	Available for risk assessment only. This model is based on the concepts of natural disaster hazard, exposure, vulnerability, external context factors and response situation as the main variables. It is designed for short-term recovery.	Available for recovery priority, which considers many important factors and groups of factors as discussed previously in this thesis. The proposed model is designed for long-term recovery.
Hosseini and Yaghoobi (2008)	Available for risk management only. The priority is based on disaster hazard, vulnerability, and the transportation service presented in each road service area. This model is designed for short-term recovery.	
Shariat (2002); Shariat *et al.* (2004)	These models are used for rescue and relief activities (i.e., for short-term recovery). They consider the hospital only as critical socio-economic facilities. These models consider the accesses between population centres and hospitals, the number of casualties and the importance of the hospital as controlling factors.	The proposed model is designed for long-term recovery. It considers all types of socio-economic facilities such as schools, universities, commerce centres, government institutes and hospitals. The proposed model considers many important factors and groups of factors as discussed previously.

References	Limitations of the previous models	Advantages of the proposed RRP model
Orabi *et al.* (2009a; b)	Available for determining the network performance loss only. The model considers the traffic data, topology of the transportation network and the construction-related costs only as controlling factors, while socio-economic factors, damage factors and non-construction related costs are not included. The delay time, queue length, trip length and reduction in average speed are not included within the traffic data for this model.	Available for road recovery priority. Socio-economic factors, damage factors and non-construction related costs are also included in the proposed model. The delay time, queue length, trip length and reduction in average speed are also included within the traffic group of factors.

6.6 Characteristics and Advantages of the Presented RRP Model

The new presented road recovery priority model RRP has been developed to simplify the processes of building, implementation, use and improvement of RRP model by providing a structured, comprehensive and easy to use method for managing the recovery process of roads damaged by natural/man-made disasters in road reconstruction and rehabilitation organisations. This model overcomes and solves problems as described earlier in Chapters two, three and four that exist in the area of prioritising damaged roads for recovery, and emphasises the important roles of it. The advantages of the new RRP model can be summarised as follows:

- The new RRP model represents and classifies all content data that are required in the processes of structuring, implementation and application of the model. The proposed RRP model differentiates among four types of required data:

interviews, questionnaire, field measurement, and document records. This can help to provide a better way to manage and process the different types of procedures of the model.

- The proposed RRP model provides a clear structured procedure for data collection and transforms it into parameters to be used in the presented model. Although a few road recovery researches have discussed the importance of data and information in the road reconstruction process, the road recovery literature lacks providing and adopting structured methods according these data to identify the priority of roads for recovery. The new RRP model provides structured procedures to capture data of the road reconstruction projects, transform them into parameters and use these parameters and information to create and structure the proposed model.
- The new model proposes a structured feedback collection mechanism by the conducted questionnaire to capture comments about the RRP model performance, ease of use and usefulness. This can help road reconstruction organisations to identify new factors and idea for capturing and sharing in the proposed model. The new RRP model provides a structured procedure for enhancing its performance using the outputs of the model's evaluation process, and the feedback collected about the model's use.
- The presented research combines activities and components required for designing and implementation of the RRP model. The new RRP model provides a relatively comprehensive method that includes important components and proposes clear relationship flows within and between the different parts.

- The proposed RRP model provides a good level of detail that makes implementation and using of the model easier. This can help to encourage more research efforts to provide structured methods to provide further details and guidelines which are important for the model's processes, methods and tools. Therefore; the proposed model is flexible to include more performance objectives needed.
- The proposed RRP model shows the importance of appointing and/or providing roles to road reconstruction engineering team members and workers in the process of structuring the RRP model. Representing these roles in the RRP model can help to provide better understanding of the processes of the RRP model, enhance awareness about priority of recovering damaged roads after natural/man-made disasters. This can show the importance of the road reconstruction organisations to assist in the building and evaluating of the RRP model and can help to provide a more structured comprehensive method for RRP adoption.
- The proposed RRP model pinpoints the controlling factors and groups of factors that may affect the implementation and application of the RRP model. These factors can be motives to RRP adoption and of use in the road reconstruction projects. The RRP model shows the importance of monitoring and adapting these factors and groups to be appropriate for RRP adoption, and suggests activities and procedures to use them in the building of the presented model.
- The research links, evaluates and prioritises the RRP model components according to the results of the conducted questionnaires and interviews. These results have encouraged the structuring of the model's components. The results support and add value to the proposed RRP model by testing and indicating the

importance, usefulness of the RRP model in the road reconstruction and rehabilitation organisations.

- The new proposed RRP model aims at comprising all the issues and components that play an important role in the successful implementation and application of RRP in road reconstruction projects. They were investigated through an extensive review of literatures, and enhanced through evaluations and estimations of the model's parameters by conducting interviews and questionnaires. Furthermore, the developed RRP model was designed to overcome deficiencies that can be found in the area of prioritising damaged roads for recovery.
- The proposed RRP model can help to easily identify further new controlling factors and groups of factors and thus the presented RRP model can be enhanced to successfully manage them. Providing an ultimate comprehensive RRP model for identifying the recovery priority of roads damaged by natural/man-made disasters may be quite complex due to the continuous changes in data, influencing factors and reconstruction domains over time. This study provides a platform for further development and modification of the RRP model so that the proposed model can be used in practice more efficiently and effectively.
- The proposed model is a tool which is capable of ranking or prioritising roads (segment of roads) for high level management objectives according to a multi-criteria need for rehabilitation.

6.7 Summary

In this chapter, the details of a final structure of the RRP model developed throughout the research stages are described. The proposed RRP model is developed by following methodologies to fill the gaps of existing models or the lack of such model and to provide a useful and practical method for recovery priority of damaged roads in reconstruction and rehabilitation projects.

The proposed model encompasses four phases, which are: identifying factors and factor groups that may affect activities and components of the RRP; deciding the required procedures and mathematical equations to successfully deal with the controlling factors and to achieve required goals and strategies; estimation and calculation of the model's parameters which are presented in the proposed equations of the model; and finally, application and testing of the presented model for road recovery priority and put into consideration further improvements.

Controlling factors and groups of factors that may affect RRP implementation and application are discussed, and categorised to simplify understanding and managing them. The controlling factors and groups are categorised according to their importance level (impact weight) in the results of the questionnaire survey. Useful solutions, procedures and mathematical equations that may help to deal successfully with these controlling factors are suggested.

A field survey was carried out to collect data which are essential to determine the input parameters in the model application. The questionnaire survey of the research has shown that controlling factors and groups with highest impact weight and the roads with highest input data regarding each factor within each group will result in a highest priority index for recovery.

The RRP model measures how critical a given road (or segment of road) for recovery is to the overall number of roads damaged by natural/man-made disasters. A road (or segment of road) is more critical and needs a first priority for recovery if its RRPI results in a relatively higher number compared to the less critical road (or segment of road) for recovery which results in a relatively low value of RRPI.

The RRP model shows the relationships among the different stages and components. It helps to show how damaged road data transforms from one shape to another during the different stages of RRP.

The proposed RRP model overcomes shortcomings of the existing such models and provides a structured, comprehensive and easy to use it for road reconstruction and rehabilitation organisations. The advantages of this RRP model include characteristics such as differentiating between controlling factors and factor groups, providing structured processing procedures for damaged road data, providing clear monitoring and evaluation these data, presenting stages, procedures and equations for RRP model implementation and application.

RRP model users can help to provide feedback and evaluation about the use of the RRP model in order to identify opportunities for improvement and overcome shortcomings and bottlenecks. A continuous process of identifying and processing new types of RRP models is important to update, validate and add value to the RRP model. So, the proposed RRP model is flexible enough to meet the changing demands and can be regularly improved to satisfy the changes and improvements in road rehabilitation. The new experiences and methods can be used to modify, update and validate the contents of the RRP model.

The application of this model may solve the problem of decision making in road recovery priority determination in a hierarchical manner so that recovery process can be accomplished from an urgent repair need road to a less recovery priority road.

There is a need for more effort from the organisations' pavement management to enhance the employees' awareness about RRP model benefits, build trust among employees, and provide more time for employees for sharing data and information. The pavement management system should also provide a performance appraisal method that appreciates and rewards RRP activities and applies modifications to the work processes and activities of the proposed model by embedding new activities and processes into them.

The methodological aspects involved in the road recovery priority index construction process can be further elaborated. Other techniques, such as fuzzy preference relations, can be planned for future research on this topic.

This chapter is dedicated to discuss the components of the research developed RRP model and its advantages compared to other existing models. The next chapter will present the application of the proposed model in four case studies from the road reconstruction to evaluate it in terms of usability and usefulness.

CHAPTER SEVEN

CASE STUDIES AND MODEL APPLICATION

7.1 Introduction

Vanier *et al.* (2006) stated that it is necessary to have adequate or reliable data to compare various criteria, to state clearly the institutional objectives, to harmonise and normalise data from different sources, to quantify subjective preferences such as risk aversion, and to keep the decision-making strategy consistent over a number of years into the future. Halpern and Fagin (1992) noted that data aggregation is not a problem of mathematics rather it is a problem of judgment. For researchers in the field of decision-making and infrastructure management, there is a lot of work ahead to make this happen.

This chapter will initially describe the objectives of the conducted case studies. The application and testing of the road recovery priority RRP model developed in this research is carried out using collected field data. The development of the proposed RRP model was explained in the previous chapter. This chapter attempts to apply this model to data collected from Baghdad, Iraq. The aim of this exercise is to study the model evaluation in usability and usefulness terms.

The case studies presented in this study will cover collected data and background information of selected roads, description of the implementation, application and procedures of the developed RRP model, and finally, analysis and discussion of the obtained results regarding each case study. At the end of this chapter, final findings and results will be concluded for the case studies.

7.2 Objectives

The specific objectives of the conducted case studies are as follows:

- To assess the performance of the proposed RRP model in solving problems related to decision making that can help road reconstruction organisations to choose the first priority roads for recovery in areas exposed to natural/man-made disasters.
- To summarise the model application procedures by providing a sample of calculation through the model procedures that can lead at the end to the results required from applying the presented model.
- To demonstrate various types of input data needed regarding the four groups of factors which are estimated in this study and their effects on road recovery priority and the sub-factors included within each factor group.

7.3 General Description of the Study Areas

Baghdad city in Iraq is chosen as the case study field because many roads in it were damaged and suffered considerable problems caused by the last war and the armed conflict in Iraq. Baghdad city is divided into 55 sectors or zones as shown in Figure F.1 in Appendix F. The case studies will conduct data collection at four parts which can be considered as comprehensive to the most important parts in Baghdad city. These parts will involve all types of roads (bridge, highway, primary and secondary road), all types of areas (urban and rural area), different population (highly and lowly populated area) and different numbers and types of critical socio-economic facilities. The variance in the case studies will cover all types of input data in the proposed model in order to test the model's suitability for any applying data according to the different condition of road, area, population, damage, etc. A brief description of the four selected case studies is as follows:

1. Case study 1: Mohammed Al-Qasim Highway which is within Zones 11-17, 19, 20, 23 and 51, and it is considered as the major highway in Baghdad city.

2. Case study 2: A comparison between two damaged bridges; the first one is located at Zones 8 and 17 and the second at Zones 1, 2, 10 and 13. These bridges separate between the two parts of Baghdad city; Al-Rusaffa and Al-Karkh.

3. Case study 3: Al-Karada Road which is within Zones 3, 10, 11, 13, 14 and 23. It is located in Al-Karada area which is the largest commerce place in Baghdad city.

4. Case study 4: A rural road which is within Zones 51 and 52. It is located in suburbs of Baghdad city which is a rural and lowly populated area.

For network-level planning, low intensity sampling is adequate whereas, for engineering design of projects at the preparation stage, intensive sampling is needed with full coverage of the project area (Robinson *et al.*, 1998). The number of zones which will be used in the case study in Baghdad will be 17 zones out of 55 in total zones. So, the coverage percent will be 30.9%.

Descriptions, details of collected data, applying these input data in the proposed RRP model, discussion of results and conclusions are described in details for case study 1 in section 7.4. Case studies 2, 3 and 4 are briefly introduced in sections 7.5, 7.6 and 7.7 respectively.

7.4 Case Study 1

7.4.1 Study Area

The selected road is Mohammed Al-Qasim Highway in Baghdad city, the capital of Iraq, which is an urban area. This road is the major highway crossing the entire city from the north to the south passing through the centre of the city which is the busiest and most crowded part of Iraq. This highway serves a large number of critical socio-economic facilities especially government institutions, factories, hospitals and companies. It also serves the University of Technology and Baghdad University, which are the most important universities in Iraq. In addition, a big part of the damage caused by the last war in Iraq took place in this highway. The location and borders of Mohammed Al-Qasim Highway are illustrated in Figure F.2 in Appendix F.

7.4.2 Collected Data

The first and most basic function of a PMS is to provide a complete and structured inventory of the pavement network to be managed. This is accomplished by dividing the network into relatively small units called sections. These sections represent the minimum fraction of the network for which major maintenance and rehabilitation, M&R, decisions are made. Each section is defined in order to exhibit consistent characteristics, such as pavement structure, construction history, functional classification, traffic volumes and mixes, and condition (Shahin, 1980; Butt, 1991). The network inventory also includes the identification number and area of each section.

To complete the inventory of the network, the managing agency needs to perform an evaluation of the present condition of the different pavement sections under its responsibility. This evaluation will then serve as one of the main inputs in the decision process that will determine the M&R activities to be carried out. It is therefore a crucial element of any PMS. Without accurate data, PMS outputs would not be very reliable (Gendreau and Soriano, 1998). Sun and Gu (2011) stated that, generally, a highway network is divided into a number of road segments. Road segments with low ratings will have a high likelihood to be scheduled for maintenance and rehabilitation, depending on the availability of funds and the importance of the road.

Therefore, the selected highway, which is 16.3 km in length, has been divided into five segments. Their lengths and origin/destination are given in Table 7.1.

Table 7.1: Length and O/D of Case study 1 segments

Segment	Length (km)	Origin/Destination
A	5.0	Al-Rabee district/Al-Nida'a mosque intersection
B	2.6	Al-Nida'a mosque intersection/Bab Al-Muadham intersection
C	2.9	Bab Al-Muadham intersection/East Gate intersection
D	2.8	East Gate intersection/Al-Andalus intersection
E	3.0	Al-Andalus intersection/Dora expressway

So, five parts of data were collected regarding each segment. And each part of data is divided into four factor groups as discussed below.

7.4.2.1 Socio-Economic Factor Group

First, a type and a number of socio-economic buildings, such as hospitals, government institutes, universities, factories and banks, included in each specified road segment has been defined. Then, for each specified building, data regarding area of the building and number of persons in each building has been collected. This in turn helps in determining the capacity of each building. Later, the number of critical socio-economic buildings, the area of these buildings and their capacity included in each segment has been accumulated to identify the total number, total area and total capacity of these buildings. The detailed data regarding socio-economic facility type, area of these facility buildings, number of persons in each building and the capacity of these buildings has been listed in Tables G.1 to G.5 in Appendix G for each segment.

Also, the type of area (whether it is urban or rural), population and area served by the road has been determined for each segment. A summary of the collected data of the socio-economic group for the five segments of the highway is presented in Table 7.2.

Shamshiry *et al.* (2011) stated that the advanced technology across remote sensing and geographical information system (GIS) and sciences are becoming very powerful tools to manage natural disasters, urban studies, etc. throughout day events in the world. The GIS can be a platform to store several layers of information and can attain a major part of goals in crisis management. By executing spatial overlays, using logical relationship and manipulation of overlaying information, certain decisions can be made. Overall, the application of the GIS in crisis management is about making some proper decisions based on valid information.

Sinha (2008) stated that a promising tool for disaster management is the use of the GIS which can be used for storage, retrieval, mapping and analysis of geographic data. In the planning process, the GIS can be used to identify and pinpoint risk prone locations of priorities for mitigation.

The use of satellite data and the GIS has opened the door for immense opportunities in large-scale mapping, 3D analysis, updating of existing maps, projects planning and decision making (Parsons and Frost, 2002). The GIS is a platform for storage, maintenance, management and analysis of geographic information and is designed to handle such data which have a spatial and descriptive nature simultaneously. What makes data handling in the GIS different from others is the existence of spatial data. Moreover, because of the very strong user interface in the GIS, it can be used for visualisation of explored knowledge. The GIS in recent years has emerged as a powerful tool. It has integrated capabilities of spatial analysis database management and graphic visualisation and has been widely adopted for building geotechnical expert systems (Forst and Chameau, 1993; Shamshiry *et al.*, 2011).

The Arc GIS 9 (Arc Map Version 9.3) computer programme has been used in this research to help in some points of the data collection. For this factor group, it has been used to help in locating the socio-economic buildings and aid, sometimes, in determining areas of these building and areas served by the road (segment).

Table 7.2: A summary of the collected data for group 1 – Case study 1

Case Study: 1 **Road Zone(s): 11-17, 19, 20, 23 and 51** **Type of Area: Urban**					
Road Segment	A	B	C	D	E
Total Number of Socio-Economic buildings	36	45	62	54	46
Total Area of Socio-Economic Buildings (m^2)	181050	262550	891230	580410	784980
Total Number of Persons in Socio-Economic Buildings	32295	57770	118660	62490	108570
Total Capacity of Socio-Economic Buildings (person/m^2)	0.178	0.220	0.133	0.108	0.138
Population (habitant)	630,000	680,000	1,400,000	1,300,000	1,100,000
Area Served by a Segment (km^2)	20	23	25	31	38

7.4.2.2 Road Network Factor Group

In addition to the recorded data in the road organisations and field observation, the Arc GIS 9 computer programme has been used to identify road (segment) lengths, number of lanes, number of nodes and number of links for each segment of the studied highway. The collected data regarding this group of factors can be summarised in Table 7.3. The pavement structure for this highway is rigid pavement resurfaced with a flexible overlay.

Table 7.3: A summary of the collected data for group 2 – Case study 1

Case Study: 1 Type of Road: Highway					
Road Segment	A	B	C	D	E
Number of nodes	5	3	4	3	6
Number of links	4	2	3	2	5
Length (km)	5.0	2.6	2.9	2.8	3.0
Number of lanes	3 lanes in each direction				
Pavement structure	2 layers of rigid pavement with a flexible overlay				

7.4.2.3 Traffic Factor Group

As discussed in Chapter six, the traffic in this study has been classified into three classes and their types and description are as presented previously in Table 6.16. In order to manually count vehicles according to their classes and types during an hour, five observers were located in each segment to calculate the number of vehicles with different classes and different types for four days. The peak hour was 7:30–8:30 in the morning and 2:30–3:30 in the afternoon. This process was repeated four times, twice in the morning and twice in the afternoon, in order to achieve accurate results. Then, the summation of vehicles within each class and the total number of vehicles for all classes and types for each observer can be calculated. A detailed collected data regarding type and number of vehicles corresponding to each class has been given in Tables G.6 to G.10 in Appendix G for segments A to E respectively.

Vehicles within each class and the total number of vehicles for all classes and types for the four times have been gathered and the average number of vehicles for each class and the average summation for all vehicles classes has been obtained for each road segment and are listed in Tables G.11 to G.15 in Appendix G. The total average number of vehicles can be then used to obtain the traffic flow in vehicle/day (vpd) for each road segment.

Data related to delay time, additional trip length and reduction in average speed has been collected by driving along each segment by the observers many times in order to obtain the average of each factor data. Also, the number of vehicles in a queue has been counted by the field observation in order to determine the queue length for each segment using Eq. (6.12) discussed previously in Chapter six. LOS for each segment has been collected from the recorded data available in the road organisations. The final summary of the collected data regarding the traffic group of factors for each road segment is shown in Table 7.4.

Table 7.4: A summary of the collected data for group 3 – Case study 1

Case Study: 1					
Road Segment	**A**	**B**	**C**	**D**	**E**
Percentage of Vehicles (Class 1) (%)	86.00	87.94	92.26	90.56	88.66
Traffic Flow (vpd)	65832	88776	242064	258264	215688
Delay Time (min.)	0.9	1.1	15.1	14.2	13.7
Additional Trip Length (km)	0.5	2.3	4.0	8.0	6.8
Number of Vehicles in a Queue	10	30	130	150	110
Number of Open Lanes	3	3	1	2	2
Queue Length (m)	40.64	121.92	1584.96	914.4	670.56
LOS (Before)	A	A	C	C	B
LOS (After)	C	D	F	F	F
Average Speed (Before) (km/hr)	80	80	80	80	80
Average Speed (After) (km/hr)	65	60	30	45	55
Reduction in Average Speed (km/hr)	15	20	50	35	25
Traffic Control Pattern	No electric traffic signals				

7.4.2.4 Damage Factor Group

The five segments of the highway suffered from different types of damage. In order to determine the severity of damage for each segment, damage type and description were first illustrated as shown in Table 7.5.

Table 7.5: Damage type and description for highway segments

Case Study: 1	
Road Segment	**Damage Description**
A	Uncomfortable riding, longitudinal unevenness, fencing damage
B	Uncomfortable riding, longitudinal unevenness, fencing damage
C	Structural damage of the pavement layers, bomb explosion, complete collapse, failure due to excessive vehicles weight, fencing damage
D	Structural damage of the pavement layers, bomb explosion, complete collapse, failure due to excessive vehicles weight, fencing damage
E	Surface rutting, cracking, spalling, bomb explosion, failure due to excessive vehicles weight, fencing damage

According to damage type, severity of damage for each segment can then be identified. The length of a damaged area has been determined, so the per cent of damaged road can be calculated by dividing the damaged area length by the actual segment length. The number of damaged lanes and number of damaged layers has been identified by field observation. Finally, ΔPSI has been specified for each segment according to the recorded data in the road organisations and by using Eq. (6.13). A summary of the collected data for the damage group of factors is presented in Table 7.6.

Table 7.6: A summary of the collected data for group 4 – Case study 1

Case Study: 1					
Road Segment	**A**	**B**	**C**	**D**	**E**
Length of Damaged Area (km)	1.0	1.0	2.1	1.8	1.2
Percentage of Damaged Road (%)	20.0	38.5	72.4	64.3	40.0
Type of Damage	Roughness	Roughness	Surface distress, Structural defect	Surface distress, Structural defect	Surface distress
Severity of Damage	Minor	Minor	Major, Severe	Major, Severe	Major
Number of Open Lanes	3	3	1	2	2
Number of Damaged Layers	1	1	3	2	2
P_o	4.5	4.5	4.5	4.5	4.5
P_t	3.5	3.5	0.5	1.5	2.5
ΔPSI	1.0	1.0	4.0	3.0	2.0

7.4.3 Model Application and Results

By applying the proposed mathematical model on the collected data for segments A, B, C, D and E, the road recovery priority index value $RRPI_n$ for each segment can be obtained. By inputting the variable values of the hierarchy $H_{g,f}$ for each factor within each group in combined with the estimated values of impact weight of each factor $W_{g,f}$ and impact weight W_g which were obtained from the questionnaire and the estimated value of the scale of each factor $S_{g,f}$; Eqs. (6.8, 6.6, 6.9 and 6.10) are used to calculate the group priority index value GPI_g for each factor group of each segment within the road. By using Eq. (6.11), the road recovery priority index value for each segment

$RRPI_{segment}$ can be calculated in order to make a final decision regarding the road segment recovery hierarchy.

Excel spreadsheets are used here to list the input data and to use the mathematical equations of the proposed model for doing the required calculations in order to obtain the output results for each road (road segment).

Detailed inputs, calculations and results are presented in Tables 7.7, 7.8, 7.9, 7.10 and 7.11 for segments A, B, C, D and E respectively. A comparison is then made between the values of road recovery priority index for each segment $RRPI_{segment}$ in order to decide of which segment needs to be first recovered. A result summary of each group priority index GPI_g within each segment, the resulted $RRPI_{segment}$ and the final decision to determine the recovery hierarchy for each segment is presented in Table 7.12.

A sample of calculation is as follows:

For the socio-economic factor group, the total number of socio-economic facilities for segment A is 36. So, by using Figure 6.2, the hierarchy value for this factor $H_{1,1}$= 3.96 and the scale value $S_{1,1}$ = 7.

Similarly, by using Figures 6.3, 6.4, 6.5, 6.6 and 6.7:

$H_{1,2}$ = 3.19, $S_{1,2}$ = 7, $H_{1,3}$= 5.11, $S_{1,3}$= 6, $H_{1,4}$ = 2.233, $S_{1,4}$= 6,

$H_{1,5}$= 4.0, $S_{1,5}$ = 7, $H_{1,6}$ = 1.0, $S_{1,6}$= 2

The rating for each factor can be calculated by Eq. (6.8).

$$R_{1,1} = \frac{3.96}{7} = 0.56571$$

Similarly

$R_{1,2}$ = 0.45571, $R_{1,3}$ = 0.85167, $R_{1,4}$= 0.37217, $R_{1,5}$ = 0.57143, $R_{1,6}$ = 0.5

Values of the impact weight for each factor within this group are obtained from the questionnaire results and are as follows:

$W_{1,1}$= 0.216, $W_{1,2}$ = 0.102, $W_{1,3}$= 0.130, $W_{1,4}$= 0.214, $W_{1,5}$= 0.150, $W_{1,6}$= 0.188

Then, by using Eq. (6.6), the significance level for this group can be obtained.

$$SL_1 = 0.216 \times 0.56571 + 0.102 \times 0.45571 + 0.130 \times 0.85167 + 0.214 \times 0.37217 + 0.150 \times 0.57143 + 0.188 \times 0.5 = 0.53875$$

Then, group indicator for group 1 can be calculated by applying Eq. (6.9).

$$GI_1 = 1 - 0.53875 = 0.46125$$

The impact weight value for this group which is obtained from the questionnaire is W_1 = 0.258

Then, Eq. (6.10) is used to calculate the group priority index value for group 1.

$$GPI_1 = 0.46125 \times 0.258 = 0.11900$$

Similarly, for the other groups:

GPI_2= 0.08535, GPI_3= 0.06554, GPI_4= 0.04474

Finally, the road recovery priority index value for segment A can be calculated using Eq. (6.11).

$RRPI_A = 0.11900 + 0.08535 + 0.06554 + 0.04474 = 0.31463$

Similarly

$RRPI_B$= 0.33182, $RRPI_C$= 0.54596, $RRPI_D$= 0.49505, $RRPI_E$= 0.46538

Table 7.7: Detailed inputs, calculations and results for segment A – Case study 1

Group and Factor No. (*g*,*f*)	$W_{g,f}$	$S_{g,f}$	$H_{g,f}$	$R_{g,f}$	$W_{g,f}$* $R_{g,f}$	SL_g	GI_g	W_g	GPI_g	$RRPI_A$
1,1	0.216	7	3.96	0.56571	0.12219	0.53875	0.46125	0.258	0.11900	**0.31463**
1,2	0.102	7	3.19	0.45571	0.04648					
1,3	0.13	6	5.11	0.85167	0.11072					
1,4	0.214	6	2.233	0.37217	0.07964					
1,5	0.15	7	4	0.57143	0.08571					
1,6	0.188	2	1	0.50000	0.09400					
2,1	0.204	5	3	0.60000	0.12240	0.62403	0.37597	0.227	0.08535	
2,2	0.168	7	4.5	0.64286	0.10800					
2,3	0.165	7	4.5	0.64286	0.10607					
2,4	0.175	6	3.667	0.61117	0.10695					
2,5	0.171	5	3	0.60000	0.10260					
2,6	0.117	3	2	0.66667	0.07800					
3,1	0.119	7	2.4	0.34286	0.04080	0.74398	0.25602	0.256	0.06554	
3,2	0.135	7	3.283	0.46900	0.06332					
3,3	0.138	5	4.82	0.96400	0.13303					
3,4	0.124	7	6.5	0.92857	0.11514					
3,5	0.126	7	5.742	0.82029	0.10336					
3,6	0.128	6	4	0.66667	0.08533					
3,7	0.126	7	5.5	0.78571	0.09900					
3,8	0.104	2	2	1.00000	0.10400					
4,1	0.23	6	5	0.83333	0.19167	0.82725	0.17275	0.259	0.04474	
4,2	0.236	3	3	1.00000	0.23600					
4,3	0.197	6	4	0.66667	0.13133					
4,4	0.151	4	3	0.75000	0.11325					
4,5	0.186	6	5	0.83333	0.15500					

Table 7.8: Detailed inputs, calculations and results for segment B – Case study 1

Group and Factor No. (g,f)	$W_{g,f}$	$S_{g,f}$	$H_{g,f}$	$R_{g,f}$	$W_{g,f}$* $R_{g,f}$	SL_g	GI_g	W_g	GPI_g	$RRPI_B$
1,1	0.216	7	3.6	0.51429	0.11109	0.50556	0.49444	0.258	0.12757	**0.33182**
1,2	0.102	7	2.687	0.38386	0.03915					
1,3	0.130	6	4.9	0.81667	0.10617					
1,4	0.214	6	2.067	0.34450	0.07372					
1,5	0.150	7	3.8	0.54286	0.08143					
1,6	0.188	2	1	0.50000	0.09400					
2,1	0.204	5	3	0.60000	0.12240	0.72551	0.27449	0.227	0.06231	
2,2	0.168	7	6	0.85714	0.14400					
2,3	0.165	7	6	0.85714	0.14143					
2,4	0.175	6	4.7	0.78333	0.13708					
2,5	0.171	5	3	0.60000	0.10260					
2,6	0.117	3	2	0.66667	0.07800					
3,1	0.119	7	2.206	0.31514	0.03750	0.65616	0.34384	0.256	0.08802	
3,2	0.135	7	2.875	0.41071	0.05545					
3,3	0.138	5	4.78	0.95600	0.13193					
3,4	0.124	7	4.85	0.69286	0.08591					
3,5	0.126	7	4.854	0.69343	0.08737					
3,6	0.128	6	3	0.50000	0.06400					
3,7	0.126	7	5	0.71429	0.09000					
3,8	0.104	2	2	1.00000	0.10400					
4,1	0.230	6	4.075	0.67917	0.15621	0.79179	0.20821	0.259	0.05393	
4,2	0.236	3	3	1.00000	0.23600					
4,3	0.197	6	4	0.66667	0.13133					
4,4	0.151	4	3	0.75000	0.11325					
4,5	0.186	6	5	0.83333	0.15500					

Table 7.9: Detailed inputs, calculations and results for segment C – Case study 1

Group and Factor No. (g,f)	$W_{g,f}$	$S_{g,f}$	$H_{g,f}$	$R_{g,f}$	$W_{g,f}$* $R_{g,f}$	SL_g	GI_g	W_g	GPI_g	$RRPI_C$
1,1	0.216	7	2.95	0.42143	0.09103	0.43653	0.56347	0.258	0.14537	**0.54596**
1,2	0.102	7	1.181	0.16871	0.01721					
1,3	0.130	6	5.335	0.88917	0.11559					
1,4	0.214	6	1.125	0.18750	0.04013					
1,5	0.150	7	3.667	0.52386	0.07858					
1,6	0.188	2	1	0.50000	0.09400					
2,1	0.204	5	3	0.60000	0.12240	0.67357	0.32643	0.227	0.07410	
2,2	0.168	7	5	0.71429	0.12000					
2,3	0.165	7	5	0.71429	0.11786					
2,4	0.175	6	4.55	0.75833	0.13271					
2,5	0.171	5	3	0.60000	0.10260					
2,6	0.117	3	2	0.66667	0.07800					
3,1	0.119	7	1.774	0.25343	0.03016	0.39716	0.60284	0.256	0.15433	
3,2	0.135	7	1.386	0.19800	0.02673					
3,3	0.138	5	2.993	0.59860	0.08261					
3,4	0.124	7	4	0.57143	0.07086					
3,5	0.126	7	1.415	0.20214	0.02547					
3,6	0.128	6	1	0.16667	0.02133					
3,7	0.126	7	2	0.28571	0.03600					
3,8	0.104	2	2	1.00000	0.10400					
4,1	0.230	6	2.38	0.39667	0.09123	0.33532	0.66468	0.259	0.17215	
4,2	0.236	3	1	0.33333	0.07867					
4,3	0.197	6	2	0.33333	0.06567					
4,4	0.151	4	1	0.25000	0.03775					
4,5	0.186	6	2	0.33333	0.06200					

Table 7.10: Detailed inputs, calculations and results for segment D – Case study 1

Group and Factor No. (*g*,*f*)	$W_{g,f}$	$S_{g,f}$	$H_{g,f}$	$R_{g,f}$	$W_{g,f}$* $R_{g,f}$	SL_g	GI_g	W_g	GPI_g	$RRPI_D$
1,1	0.216	7	3.24	0.46286	0.09998	0.45162	0.54838	0.258	0.14148	**0.49505**
1,2	0.102	7	1.699	0.24271	0.02476					
1,3	0.130	6	5.46	0.91000	0.11830					
1,4	0.214	6	1.25	0.20833	0.04458					
1,5	0.150	7	3.267	0.46671	0.07001					
1,6	0.188	2	1	0.50000	0.09400					
2,1	0.204	5	3	0.60000	0.12240	0.72260	0.27740	0.227	0.06297	
2,2	0.168	7	6	0.85714	0.14400					
2,3	0.165	7	6	0.85714	0.14143					
2,4	0.175	6	4.6	0.76667	0.13417					
2,5	0.171	5	3	0.60000	0.10260					
2,6	0.117	3	2	0.66667	0.07800					
3,1	0.119	7	1.944	0.27771	0.03305	0.41883	0.58117	0.256	0.14878	
3,2	0.135	7	1.278	0.18257	0.02465					
3,3	0.138	5	3.08	0.61600	0.08501					
3,4	0.124	7	2.75	0.39286	0.04871					
3,5	0.126	7	2.171	0.31014	0.03908					
3,6	0.128	6	1	0.16667	0.02133					
3,7	0.126	7	3.5	0.50000	0.06300					
3,8	0.104	2	2	1.00000	0.10400					
4,1	0.230	6	2.785	0.46417	0.10676	0.45243	0.54758	0.259	0.14182	
4,2	0.236	3	1	0.33333	0.07867					
4,3	0.197	6	3	0.50000	0.09850					
4,4	0.151	4	2	0.50000	0.07550					
4,5	0.186	6	3	0.50000	0.09300					

Table 7.11: Detailed inputs, calculations and results for segment E – Case study 1

Group and Factor No. (g,f)	$W_{g,f}$	$S_{g,f}$	$H_{g,f}$	$R_{g,f}$	$W_{g,f}$* $R_{g,f}$	SL_g	GI_g	W_g	GPI_g	$RRPI_E$
1,1	0.216	7	3.56	0.50857	0.10985	0.45390	0.54610	0.258	0.14089	**0.46538**
1,2	0.102	7	1.358	0.19400	0.01979					
1,3	0.13	6	5.31	0.88500	0.11505					
1,4	0.214	6	1.5	0.25000	0.05350					
1,5	0.15	7	2.88	0.41143	0.06171					
1,6	0.188	2	1	0.50000	0.09400					
2,1	0.204	5	3	0.60000	0.12240	0.62454	0.37546	0.227	0.08523	
2,2	0.168	7	4	0.57143	0.09600					
2,3	0.165	7	4	0.57143	0.09429					
2,4	0.175	6	4.5	0.75000	0.13125					
2,5	0.171	5	3	0.60000	0.10260					
2,6	0.117	3	2	0.66667	0.07800					
3,1	0.119	7	2.134	0.30486	0.03628	0.46132	0.53868	0.256	0.13790	
3,2	0.135	7	1.562	0.22314	0.03012					
3,3	0.138	5	3.13	0.62600	0.08639					
3,4	0.124	7	3.067	0.43814	0.05433					
3,5	0.126	7	2.659	0.37986	0.04786					
3,6	0.128	6	1	0.16667	0.02133					
3,7	0.126	7	4.5	0.64286	0.08100					
3,8	0.104	2	2	1.00000	0.10400					
4,1	0.23	6	4	0.66667	0.15333	0.60867	0.39133	0.259	0.10136	
4,2	0.236	3	2	0.66667	0.15733					
4,3	0.197	6	3	0.50000	0.09850					
4,4	0.151	4	2	0.50000	0.07550					
4,5	0.186	6	4	0.66667	0.12400					

Table 7.12: A result summary and decision making – Case study 1

Segment	GPI_g				$RRPI_{segment}$	Final Decision (Recovery Hierarchy)
	1	2	3	4		
A	0.11900	0.08535	0.06554	0.04474	**0.31463**	**5**
B	0.12757	0.06231	0.08802	0.05393	**0.33182**	**4**
C	0.14537	0.07410	0.15433	0.17215	**0.54596**	**1**
D	0.14148	0.06297	0.14878	0.14182	**0.49505**	**2**
E	0.14089	0.08523	0.13790	0.10136	**0.46538**	**3**

7.4.4 Discussion of Results

The obtained results of group priority index values GPI_g for each factor group for all road segments are shown in Figures 7.1, 7.2, 7.3 and 7.4 for factor groups 1, 2, 3 and 4 respectively.

Figure 7.1 shows the obtained group priority index values GPI_1 of the socio-economic factor group for all segments. It can be found from this figure that these values are proximate for segments C, D and E. The highest GPI value is for segment C (GPI_1=0.14537) because the total number of socio-economic facilities, area of socio-economic buildings and population served by this segment are much higher than those for the other segments. However, the socio-economic situations are close to each other for segments C, D and E and these segments need the first priority for recovery from the standpoint of the socio-economic group of factors. On the contrary, segment A has the lowest GPI_1 value (0.11900) because all of the input values' factors are smaller than those for the other segments.

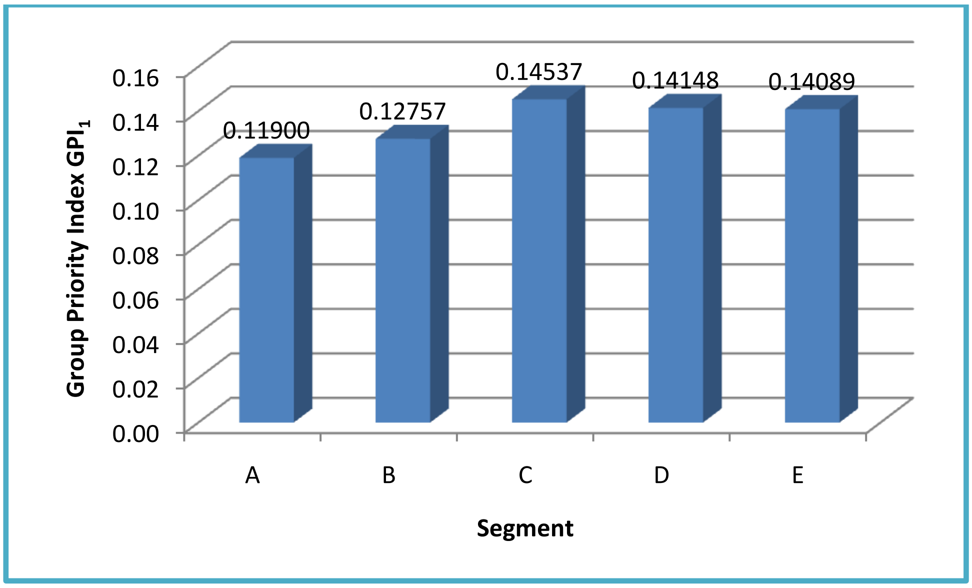

Figure 7.1: Group priority index values GPI_1 for group 1 for all segments – Case study 1

The obtained group priority index values GPI_2 of road network factor group given in Figure 7.2 demonstrate that segment A has the highest value of GPI_2 (0.08535), because it has a longer length of segment then segment E (GPI_2= 0.08523), because it has a higher number of nodes and links compared with other segments. Hence, according to the road network factors, segments A and E have the first recovery priority, while segments B (0.06231) and D (0.06297) have the lowest GPI_2 value as they have the lowest number of nodes and links and smallest segment length.

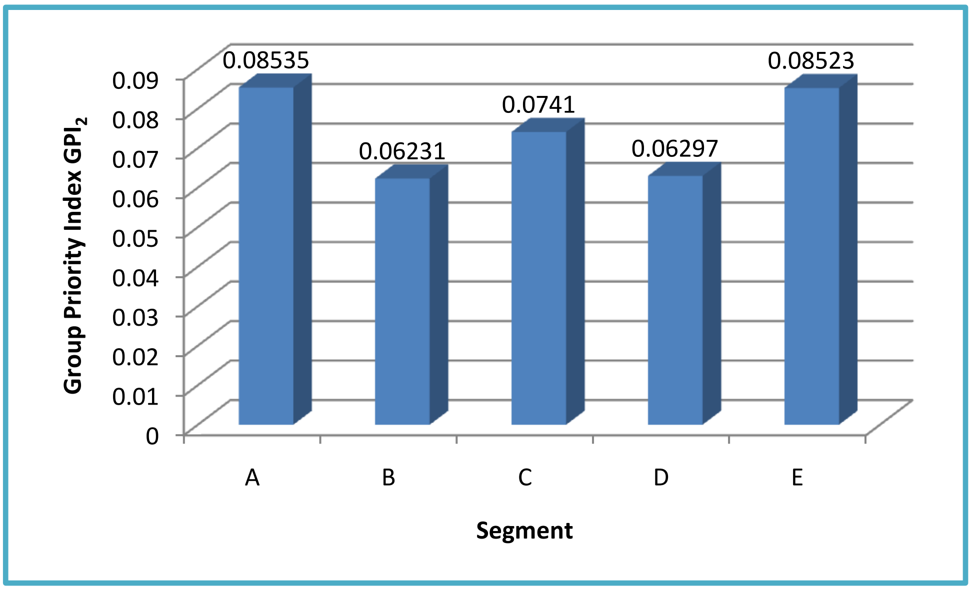

Figure 7.2: Group priority index values GPI_2 for group 2 for all segments – Case study 1

The input data of the traffic factor group for all segments give the group priority index values GPI_3 which are represented in Figure 7.3. It can be noticed from this figure that there is a big gap in the GPI_3 values between segments C, D and E on the first hand and segments A and B on the other hand. Segment C has the highest GPI_3 value (0.15433). The reason for that is that segment C has the highest delay time, longest queue length and largest reduction in average speed in comparison with other road segments. On the other hand, all the input data for segment A are much lower than that for other segments, so that segment A has the lowest GPI_3 value (0.06554). Segments D (GPI_3= 0.14878) and E (GPI_3= 0.1379) are almost identical in their values of GPI_3 because they have very similar input factor values. Therefore, from the traffic factors point of view, segment C needs to be recovered first and recovery for segments A and B can be postponed.

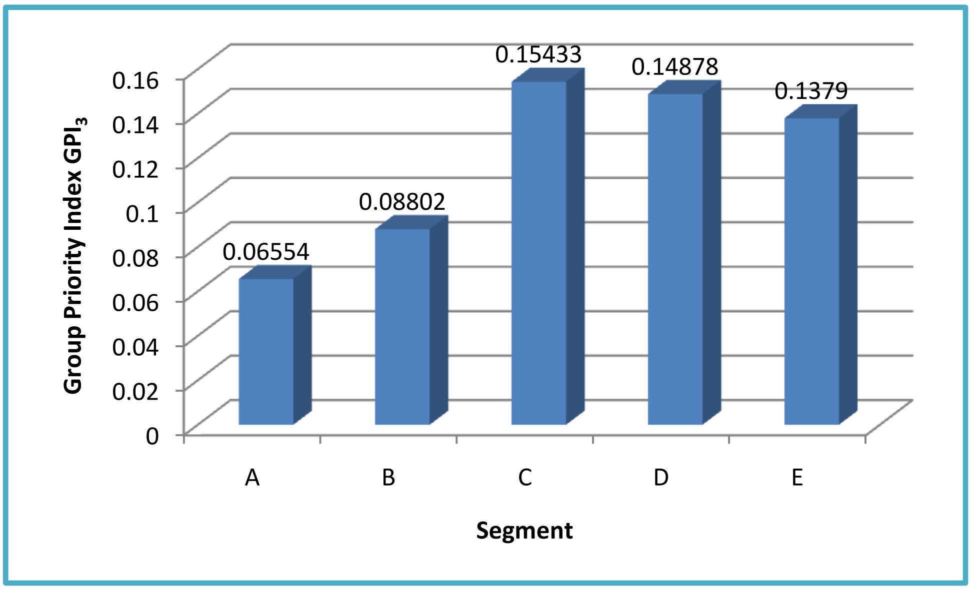

Figure 7.3: Group priority index values GPI_3 for group 3 for all segments – Case study 1

Regarding the damage factor group, Figure 7.4 demonstrates that segment C has a marked value of group priority index (GPI_4=0.17215) and it is much greater than the corresponding values for other segments. This is because the damage was much higher for this segment. It has the highest percent of damage, the lowest number of open lanes and the highest value of present serviceability index and all layers were damaged. For this reason it is required to recover it first according to the damage group of factors. Conversely, the damage for segments A and B was much less, so that segments A and B have the lowest GPI_4 value (GPI_4=0.04474 and 0.05393 respectively).

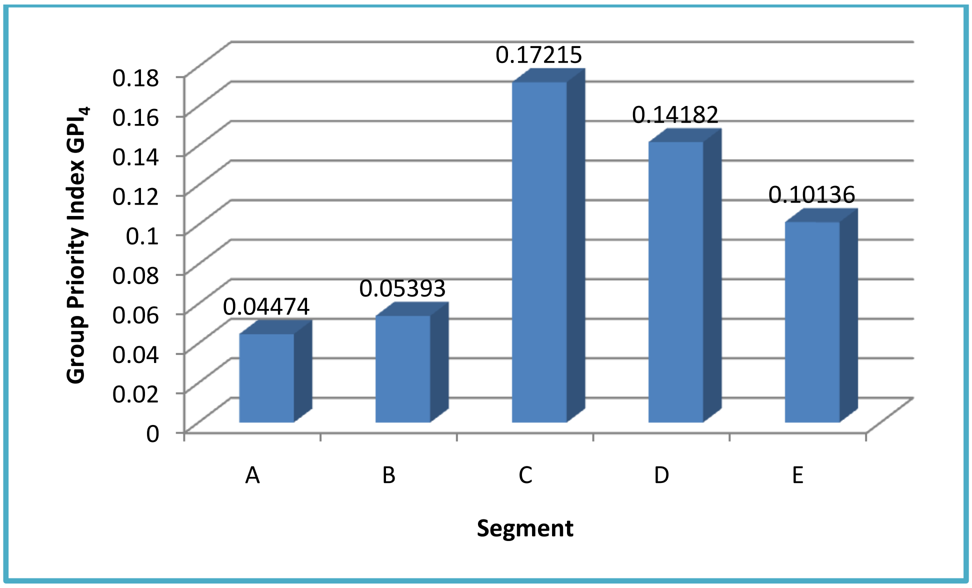

Figure 7.4: Group priority index values GPI_4 for group 4 for all segments – Case study 1

To conclude, the final road recovery priority index values for each segment can be demonstrated in Figure 7.5. From these values of each segment, it can be noticed that segment C has the highest $RRPI$ value (0.54596) because it is controlling in three groups as it has the highest group priority index in the socio-economic, traffic and damage groups, while segment A has the lowest one ($RRPI_A$=0.31463). It can thus be concluded that segment C needs an urgent repair while the repair for segment A can be postponed until repairing the other four segments of this highway.

Figure 7.6 shows a summary of the obtained group priority index values GPI for each group and the final road recovery priority index values $RRPI$ for each segment.

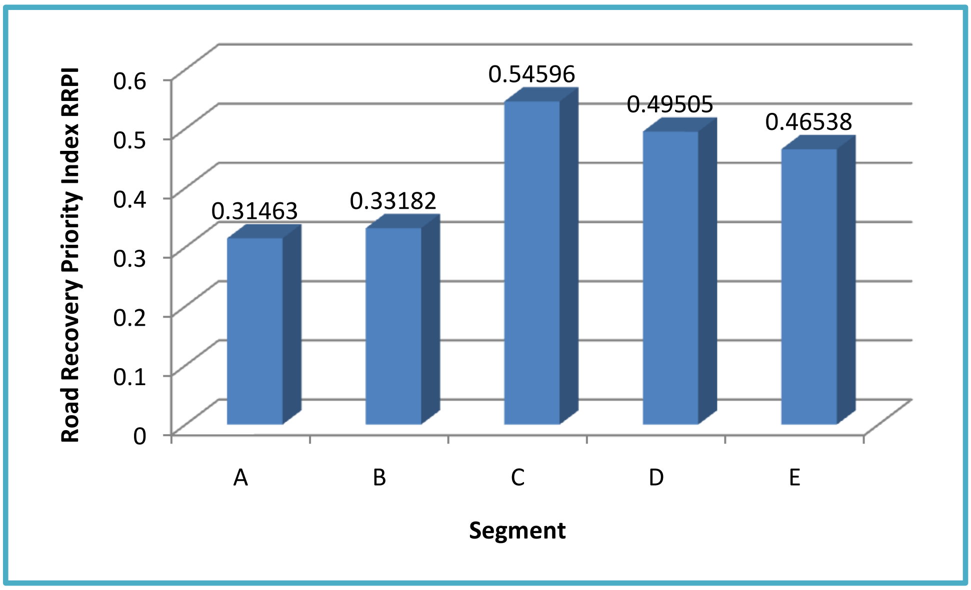

Figure 7.5: Final RRPI values for each segment – Case study 1

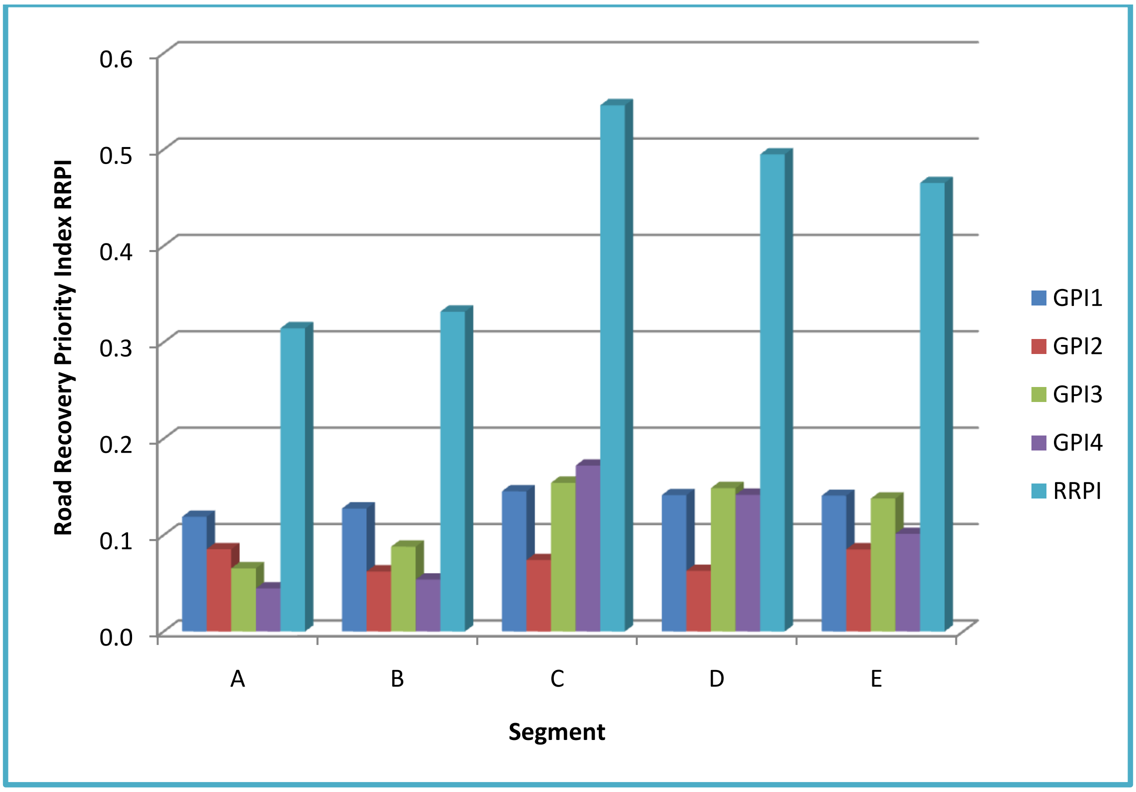

Figure 7.6: A summary of group priority index values GPI for each group and the final road recovery priority index values RRPI for each segment – Case study 1

7.5 Case Study 2

7.5.1 Study Area

This case study demonstrates a comparison between two damaged bridges: Al-Sarrafia and Al-Mualaq (14^{th} July) Bridge. These bridges separate between the two parts of Baghdad city; Al-Rusaffa and Al-Karkh.

The Al-Sarrafia Bridge is located in the northern part of Baghdad city. It connects between the western parts of the city on one hand; which is associated with the transport network of south of Iraq bordering Euphrates River; and east of the city on the other hand; which is associated with Mohammed Al-Qasim Highway leading to the south of country in addition to the northern cities. The Al-Mua'alaq Bridge connects east and south east of Baghdad areas on one hand and south Baghdad areas and the areas which borders to the Tigris River leading to north Baghdad on the other hand. It works with the Two Storeys Bridge as a crossover to the south of the city. It serves as people and goods transportation. It serves many important government institutions in the Green Zone in which the presidential mansions are located.

Figures F.3 and F.4 in Appendix F present the Al-Sarafia and Al-Mua'alaq Bridge maps respectively. Their lengths and origin/destination are given in Table 7.13.

Table 7.13: Length and O/D of Case study 2 bridges

Bridge No.	Name	Length (km)	Origin/Destination
1	Al-Sarrafia	0.75	Al-Sarrafia (Al-Resaffa) /Al-Etafia (Al-Karkh)
2	Al-Mualaq (14^{th} July)	0.47	Al-Karadda (Al-Resaffa)/Green Zone (Al-Karkh)

7.5.2 Collected Data

7.5.2.1 Socio-Economic Factor Group

Tables G.16 to G.17 in Appendix G for Bridge No.1 and 2 respectively list detailed data regarding socio-economic facility type, area of these facility buildings, number of persons in each building and the capacity of these buildings. A summary of the collected data of the socio-economic group for the two bridges is presented in Table 7.14.

Table 7.14: A summary of the collected data for group 1 – Case study 2

Case Study: 2 **Road Zone(s): 1, 2, 8, 10, 13 and 17**	**Type of Area: Urban**	
Bridge No.	**1**	**2**
Total Number of Socio-Economic buildings	68	94
Total Area of Socio-Economic Buildings (m^2)	984800	2894500
Total Number of Persons in Socio-Economic Buildings	200220	386980
Total Capacity of Socio-Economic Buildings (person/m^2)	0.203	0.134
Population (habitant)	1,100,000	1,400,000
Area Served by a Segment (km^2)	8.3	17.5

7.5.2.2 Road Network Factor Group

The collected data regarding this group of factors is summarised and given in Table 7.15.

Table 7.15: A summary of the collected data for group 2 – Case study 2

Case Study: 2 Type of Road: Bridge		
Bridge No.	**1**	**2**
Number of nodes	2	2
Number of links	1	1
Length (km)	0.75	0.47
Number of lanes in each direction	1	2
Pavement structure	Rigid pavement	

7.5.2.3 Traffic Factor Group

A detailed collected data regarding type and number of vehicles corresponding to each class has been given in Tables G.18 and G.19 in Appendix G for Bridge No.1 and 2 respectively and the average summation for all vehicles classes has been obtained for each bridge and are listed in Tables G.20 and G.21. The final summary of the collected data regarding the traffic group of factors for each bridge is shown in Table 7.16.

Table 7.16: A summary of the collected data for group 3 – Case study 2

Case Study: 2		
Bridge No.	**1**	**2**
Percentage of Vehicles (Class 1) (%)	96.6	99.5
Traffic Flow (vpd)	32064	44760
Delay Time (min.)	45	30
Additional Trip Length (km)	4.4	10.2
Number of Vehicles in a Queue	170	150
Number of Open Lanes	0	1
Queue Length (m)	1036	610
LOS (Before)	A	A
LOS (After)	F	E
Average Speed (Before) (km/hr)	55	55
Average Speed (After) (km/hr)	0	20
Reduction in Average Speed (km/hr)	55	35
Traffic Control Pattern	No electric traffic signals	

7.5.2.4 Damage Factor Group

A summary of the collected data for the damage group of factors is presented in Table 7.17.

Table 7.17: A summary of the collected data for group 4 – Case study 2

Case Study: 2		
Bridge No.	**1**	**2**
Length of Damaged Area (km)	0.75	0.22
Percentage of Damaged Road (%)	100	47
Type of Damage	Complete collapse	Bomb explosion, structural damage
Severity of Damage	Severe	Major
Number of Open Lanes	0	1
Number of Damaged Layers	All	All
P_o	4.5	4.5
P_t	0	1.5
ΔPSI	4.5	3.0

7.5.3 Model Application and Results

The calculation procedure for the model application is the same as case study 1. Detailed inputs, calculations and results are presented in Tables 7.18 and 7.19 for Bridge No.1 and 2 respectively. Then a comparison is made between the values of road recovery priority index for each bridge $RRPI_{Bridge}$ in order to decide which bridge needs to be first recovered. A result summary of each group priority index GPI_g within each bridge, the resulted $RRPI_{Bridge}$ and the final decision to determine the recovery hierarchy for each bridge is presented in Table 7.20.

Table 7.18: Detailed inputs, calculations and results for Bridge No. 1 – Case study 2

Group and Factor No. (*g,f*)	$W_{g,f}$	$S_{g,f}$	$H_{g,f}$	$R_{g,f}$	$W_{g,f}* R_{g,f}$	SL_g	GI_g	W_g	GPI_g	$RRPI_1$
1,1	0.216	7	2.8	0.40000	0.08640	0.47127	0.52873	0.258	0.13641	**0.53535**
1,2	0.102	7	1.025	0.14643	0.01494					
1,3	0.130	6	4.985	0.83083	0.10801					
1,4	0.214	6	1.5	0.25000	0.05350					
1,5	0.150	7	5.34	0.76286	0.11443					
1,6	0.188	2	1	0.50000	0.09400					
2,1	0.204	5	2	0.40000	0.08160	0.78866	0.21134	0.227	0.04797	
2,2	0.168	7	7	1.00000	0.16800					
2,3	0.165	7	7	1.00000	0.16500					
2,4	0.175	6	5.625	0.93750	0.16406					
2,5	0.171	5	5	1.00000	0.17100					
2,6	0.117	3	1	0.33333	0.03900					
3,1	0.119	7	1.34	0.19143	0.02278	0.40392	0.59608	0.256	0.15260	
3,2	0.135	7	3.959	0.56557	0.07635					
3,3	0.138	5	1.5	0.30000	0.04140					
3,4	0.124	7	3.867	0.55243	0.06850					
3,5	0.126	7	1.964	0.28057	0.03535					
3,6	0.128	6	1	0.16667	0.02133					
3,7	0.126	7	1.9	0.27143	0.03420					
3,8	0.104	2	2	1.00000	0.10400					
4,1	0.230	6	1	0.16667	0.03833	0.23408	0.76592	0.259	0.19837	
4,2	0.236	3	1	0.33333	0.07867					
4,3	0.197	6	1	0.16667	0.03283					
4,4	0.151	4	1	0.25000	0.03775					
4,5	0.186	6	1.5	0.25000	0.04650					

Table 7.19: Detailed inputs, calculations and results for Bridge No. 2 – Case study 2

Group and Factor No. (g,f)	$W_{g,f}$	$S_{g,f}$	$H_{g,f}$	$R_{g,f}$	$W_{g,f}$* $R_{g,f}$	SL_g	GI_g	W_g	GPI_g	$RRPI_2$
1,1	0.216	7	2.15	0.30714	0.06634	0.42159	0.57841	0.258	0.14923	**0.47772**
1,2	0.102	7	1	0.14286	0.01457					
1,3	0.130	6	5.33	0.88833	0.11548					
1,4	0.214	6	1.125	0.18750	0.04013					
1,5	0.150	7	4.25	0.60714	0.09107					
1,6	0.188	2	1	0.50000	0.09400					
2,1	0.204	5	2	0.40000	0.08160	0.75855	0.24145	0.227	0.05481	
2,2	0.168	7	7	1.00000	0.16800					
2,3	0.165	7	7	1.00000	0.16500					
2,4	0.175	6	5.765	0.96083	0.16815					
2,5	0.171	5	4	0.80000	0.13680					
2,6	0.117	3	1	0.33333	0.03900					
3,1	0.119	7	1.05	0.15000	0.01785	0.44318	0.55682	0.256	0.14255	
3,2	0.135	7	3.705	0.52929	0.07145					
3,3	0.138	5	2	0.40000	0.05520					
3,4	0.124	7	2.2	0.31429	0.03897					
3,5	0.126	7	2.78	0.39714	0.05004					
3,6	0.128	6	2	0.33333	0.04267					
3,7	0.126	7	3.5	0.50000	0.06300					
3,8	0.104	2	2	1.00000	0.10400					
4,1	0.230	6	3.65	0.60833	0.13992	0.49367	0.50633	0.259	0.13114	
4,2	0.236	3	2	0.66667	0.15733					
4,3	0.197	6	2	0.33333	0.06567					
4,4	0.151	4	1	0.25000	0.03775					
4,5	0.186	6	3	0.50000	0.09300					

Table 7.20: A result summary and decision making – Case study 2

Bridge No.	GPI_g				$RRPI_{Bridge}$	**Final Decision (Recovery Hierarchy)**
	1	**2**	**3**	**4**		
1	0.13641	0.04797	0.15260	0.19837	**0.53535**	**1**
2	0.14923	0.05481	0.14255	0.13114	**0.47772**	**2**

7.5.4 Discussion of Results

The obtained results of group priority index values GPI_g for each factor group for the two bridges are shown in Figures 7.7, 7.8, 7.9 and 7.10 for factor groups 1, 2, 3 and 4 respectively.

For the socio-economic group, Bridge No.2 has higher value of GPI than Bridge No.1, as shown in Figure 7.7, as it has more socio-economic buildings, more area for these buildings, more population and area served by the bridge. This needs the first priority for recovery for Bridge No.2.

From the road network point of view, Bridge No.2 also needs the first recovery priority as it has a higher GPI than Bridge No.1 as presented in Figure 7.8. The input road network data for both bridges are almost identical but Bridge No.2 has two lanes in each direction compared to one lane for Bridge No.1 which requires first priority for recovery.

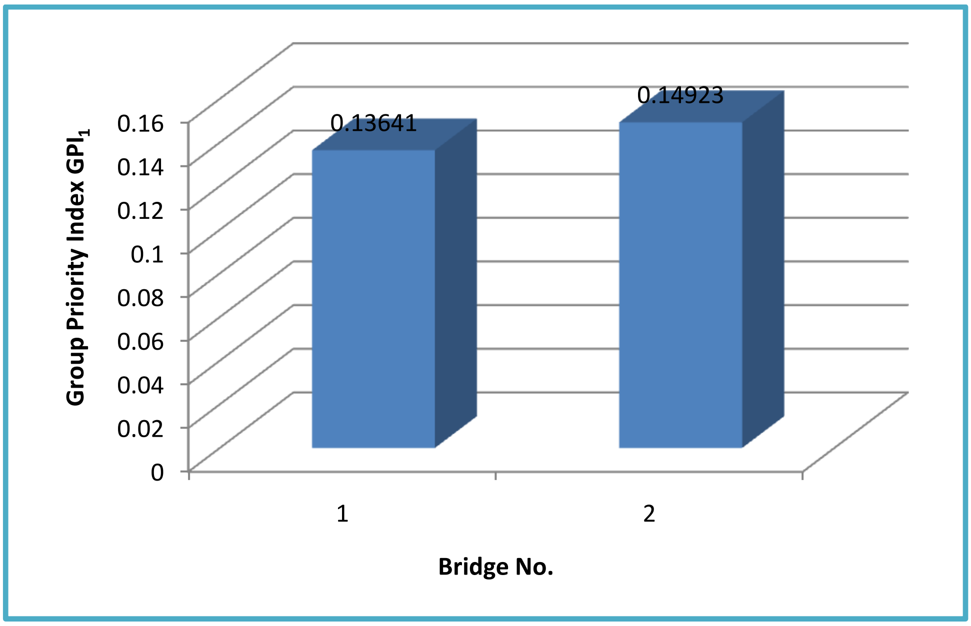

Figure 7.7: Group priority index values GPI_1 for group 1 for all segments – Case study 2

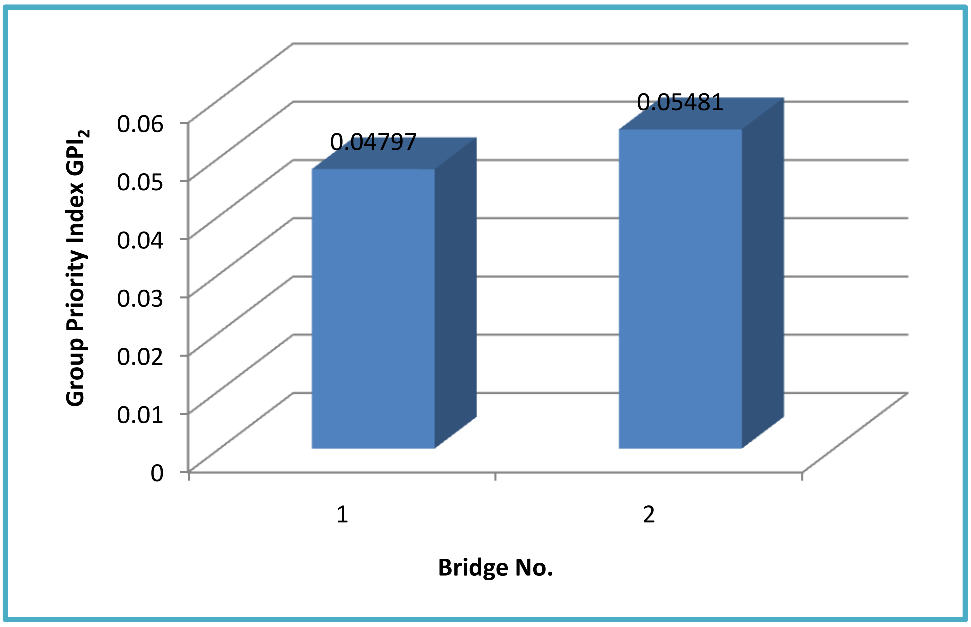

Figure 7.8: Group priority index values GPI_2 for group 2 for all segments – Case study 2

Conversely to group 1 and 2, Bridge No.1 has a higher GPI than Bridge No.2 for group 3 (traffic factors) as shown in Figure 7.9 because it has more delay time, queue length, reduction in speed, worse LOS and has no open lanes. So this indicates that the recovery should be first done for Bridge No.1.

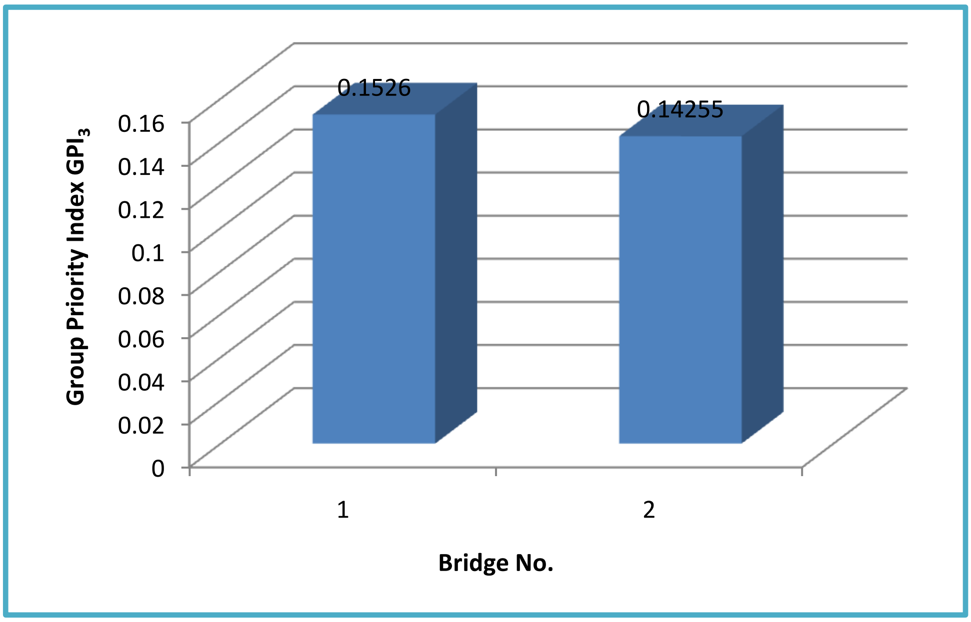

Figure 7.9: Group priority index values GPI_3 for group 3 for all segments – Case study 2

It can be noticed from Figure 7.10 for the damage group that Bridge No.1 requires the first priority recovery as it has a higher value of GPI than Bridge No.2. Here there is a significant difference in the GPI values as the per cent and severity of damage is much more for Bridge No.1 than for Bridge No.2.

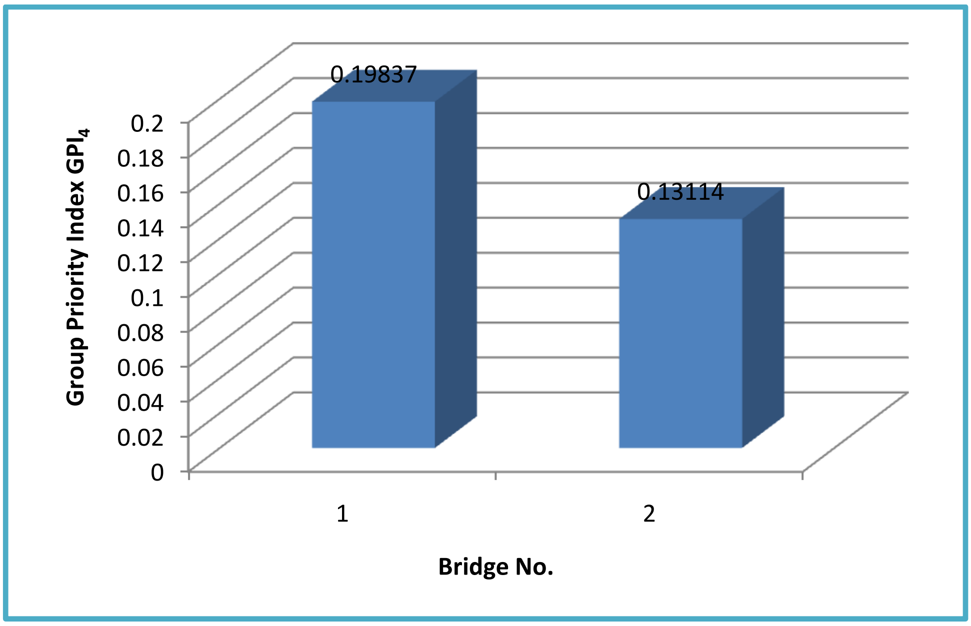

Figure 7.10: Group priority index values GPI_4 for group 4 for all segments – Case study 2

By taking a look on the collected data for the two chosen bridges, it looks like Bridge No.2 is more important as it is located in a busiest area, has more lanes and traffic flow and also serves more population and area than Bridge No.1. So as a general rule Bridge No.2 needs to be recovered first. But here the decision making is made by the help of the presented RRP model and the conclusion may not be the same as mentioned. Here, after the application of the RRP model, Bridge No.1 controls in the traffic and damage groups and Bridge No.2 controls in the socio-economic and road network factor groups (as it has highest group priority index GPI). However, the road recovery priority index $RRPI$ is higher for Bridge No.1 than 2, as shown in Figure 7.11. This is because the difference in the GPI values for the damage group is much higher than those for the socio-economic and road network groups between the two bridges. Therefore, according to the results produced from RRP model, the road recovery should be first done to Bridge No.1.

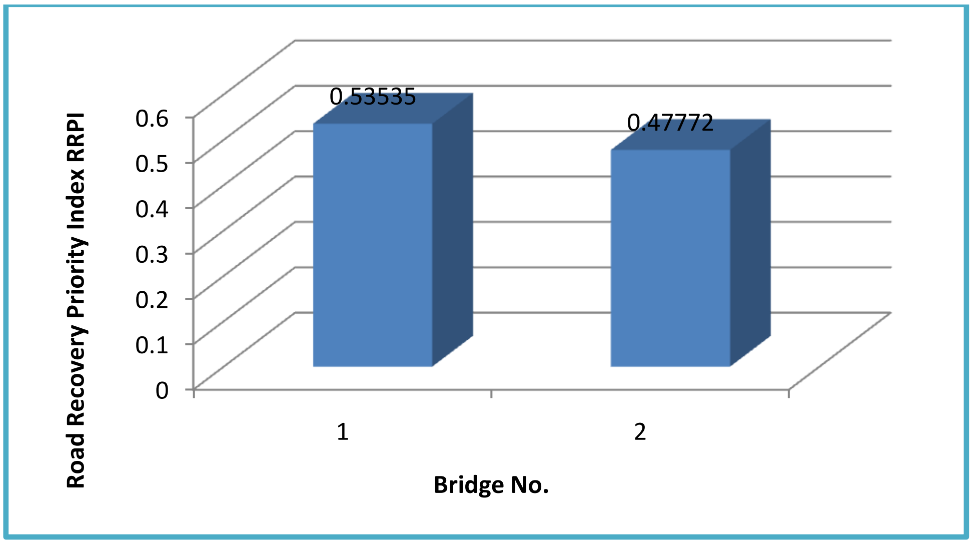

Figure 7.11: Final RRPI values for each bridge – Case study 2

Figure 7.12 shows a summary of the obtained group priority index values GPI for each group and the final road recovery priority index values $RRPI$ for each segment.

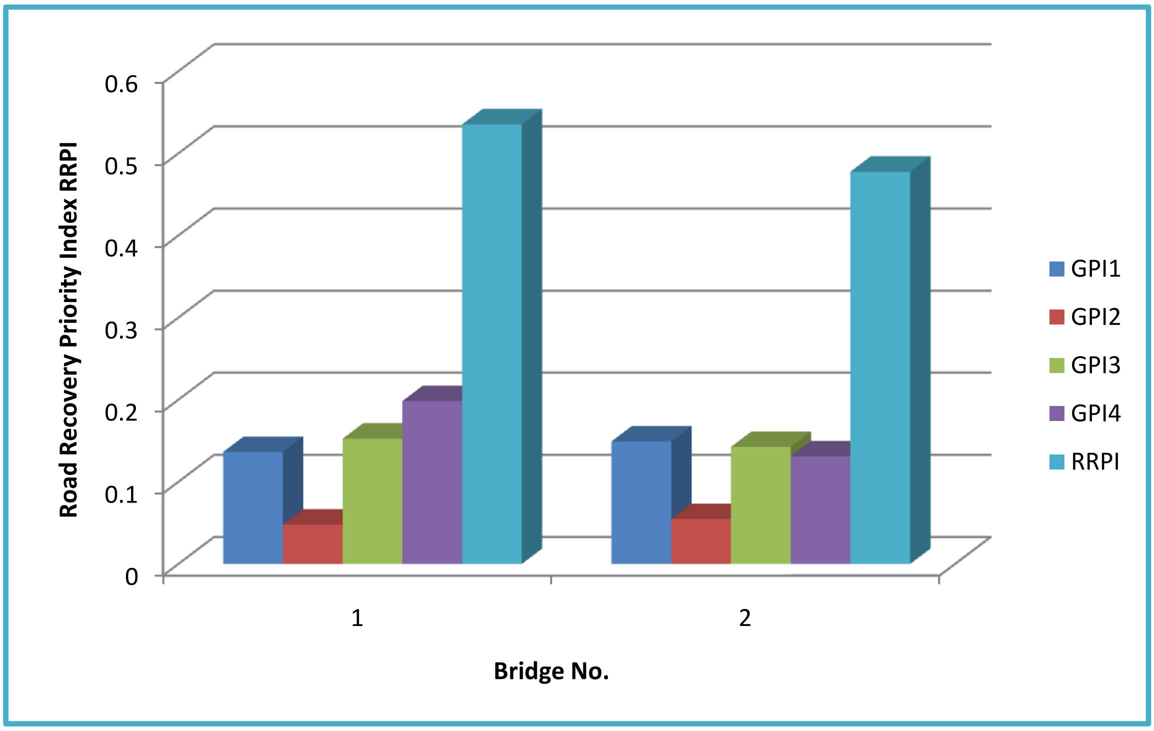

Figure 7.12: A summary of group priority index values GPI for each group and the final road recovery priority index values RRPI for each bridge – Case study 2

7.6 Case Study 3

7.6.1 Study Area

The third selected road is Outer Karadda road which is located in the south east of Baghdad city. It is a commercial road and contains on its extension many of the most important commerce centres in Baghdad. It leads from the south end to the road that connects Baghdad with the southern governorates. Also, it leads to four important bridges (Al-Jaderia, Al-Mua'alaq, Two Storeys and Al-Dura Bridge) which connect the two sides of Baghdad, Al-Rusafa and Al-Karkh. In addition, Baghdad University which is the largest university in Iraq is located at its end from the south. Moreover, it is the most crowded and busiest road in the city. The location and borders of Al-Karadda road are as shown in Figure F.5 in Appendix F. The selected road, which is 6.8 km in length, has been divided into three segments. The lengths and the O/D for these segments are given in Table 7.21.

Table 7.21: Length and O/D of Case study 3 segments

Segment	Length (km)	Origin/Destination
A	1.5	Al-Amana Intersection/Ukba Square
B	3.1	Ukba Square/Al-Hurria Square
C	2.2	Al-Hurria Square/Baghdad University

7.6.2 Collected Data

7.6.2.1 Socio-Economic Factor Group

The detailed data regarding socio-economic facility type, area of these facility buildings, number of persons in each building and the capacity of these buildings is given in Tables G.22, G.23 and G.24 in Appendix G for segment A, B and C respectively. A summary of the collected data of the socio-economic group for the three segments of the road is presented in Table 7.22.

Table 7.22: A summary of the collected data for group 1 – Case study 3

Case Study: 3 **Road Zone(s): 3, 10, 13, 14 and 23** **Type of Area: Urban**			
Road Segment	A	B	C
Total Number of Socio-Economic buildings	129	195	92
Total Area of Socio-Economic Buildings (m^2)	1714550	1999650	1757350
Total Number of Persons in Socio-Economic Buildings	232890	287700	230410
Total Capacity of Socio-Economic Buildings (person/m^2)	0.136	0.144	0.131
Population (habitant)	900,000	1,400,000	1,100,000
Area Served by a Segment (km^2)	14	13	17

7.6.2.2 Road Network Factor Group

Table 7.23 lists a summary of the collected data regarding this group of factors.

Table 7.23: A summary of the collected data for group 2 – Case study 3

Case Study: 3 **Type of Road: Primary**			
Road Segment	A	B	C
Number of nodes	4	34	14
Number of links	3	33	13
Length (km)	1.5	3.1	2.2
Number of lanes	3 lanes in each direction		
Pavement structure	Flexible pavement		

7.6.2.3 Traffic Factor Group

Tables G.25, G.26 and G.27 in Appendix G list detailed collected data regarding type and number of vehicles corresponding to each class for segments A, B and C respectively and the average summation for all vehicle classes has been obtained for each bridge and are listed in Tables G.28, G.29 and G.30 for each segment. The final summary of the collected data regarding the traffic group of factors for each bridge is shown in Table 7.24.

Table 7.24: A summary of the collected data for group 3 – Case study 3

Case Study: 3			
Road Segment	**A**	**B**	**C**
Percentage of Vehicles (Class 1) (%)	97.59	97.14	97.26
Traffic Flow (vpd)	88608	70560	79656
Delay Time (min.)	20	10	15
Additional Trip Length (km)	3.0	5.0	6.5
Number of Vehicles in a Queue	80	95	110
Number of Open Lanes	1	3	2
Queue Length (m)	975.36	386.08	670.56
LOS (Before)	B	B	B
LOS (After)	F	D	E
Average Speed (Before) (km/hr)	55	55	55
Average Speed (After) (km/hr)	10	40	30
Reduction in Average Speed (km/hr)	45	15	25
Traffic Control Pattern	Electric traffic signals		

7.6.2.4 Damage Factor Group

Table 7.25 lists a summary of the collected data for the damage group of factors.

Table 7.25: A summary of the collected data for group 4 – Case study 3

Case Study: 3			
Road Segment	**A**	**B**	**C**
Length of Damaged Area (km)	0.8	1.0	0.9
Percentage of Damaged Road (%)	53.33	32.26	40.91
Type of Damage	Surface distress, bomb explosion	Roughness	Roughness
Severity of Damage	Major	Minor	Minor
Number of Open Lanes	1	3	2
Number of Damaged Layers	2	0	1
$\mathbf{P_o}$	4.5	4.5	4.5
$\mathbf{P_t}$	1.5	2.5	2.0
∆PSI	3.0	2.0	2.5

7.6.3 Model Application and Results

Detailed inputs, calculations and results are presented in Tables 7.26, 7.27 and 7.28 for segments 1, 2 and 3 respectively. Then a comparison is made between the values of road recovery priority index for each segment $RRPI_{Segment}$ in order to decide of which segment needs to be first recovered. A result summary of each group priority index GPI_g within each segment, the resulted $RRPI_{segment}$ and the final decision to determine the recovery hierarchy for each segment is listed in Table 7.29.

Table 7.26: Detailed inputs, calculations and results for segment A – Case study 3

Group and Factor No. (g,f)	$W_{g,f}$	$S_{g,f}$	$H_{g,f}$	$R_{g,f}$	$W_{g,f}$* $R_{g,f}$	SL_g	GI_g	W_g	GPI_g	$RRPI_A$
1,1	0.216	7	2.775	0.39643	0.08563	0.47045	0.52955	0.258	0.13662	**0.46989**
1,2	0.102	7	1	0.14286	0.01457					
1,3	0.130	6	5.32	0.88667	0.11527					
1,4	0.214	6	1.75	0.29167	0.06242					
1,5	0.150	7	4.6	0.65714	0.09857					
1,6	0.188	2	1	0.50000	0.09400					
2,1	0.204	5	4	0.80000	0.16320	0.77378	0.22622	0.227	0.05135	
2,2	0.168	7	5	0.71429	0.12000					
2,3	0.165	7	5	0.71429	0.11786					
2,4	0.175	6	5.25	0.87500	0.15313					
2,5	0.171	5	3	0.60000	0.10260					
2,6	0.117	3	3	1.00000	0.11700					
3,1	0.119	7	1.241	0.17729	0.02110	0.38512	0.61488	0.256	0.15741	
3,2	0.135	7	2.877	0.41100	0.05549					
3,3	0.138	5	2.667	0.53340	0.07361					
3,4	0.124	7	4.5	0.64286	0.07971					
3,5	0.126	7	2.049	0.29271	0.03688					
3,6	0.128	6	1	0.16667	0.02133					
3,7	0.126	7	2.5	0.35714	0.04500					
3,8	0.104	2	1	0.50000	0.05200					
4,1	0.230	6	3.333	0.55550	0.12777	0.51927	0.48074	0.259	0.12451	
4,2	0.236	3	2	0.66667	0.15733					
4,3	0.197	6	2	0.33333	0.06567					
4,4	0.151	4	2	0.50000	0.07550					
4,5	0.186	6	3	0.50000	0.09300					

Table 7.27: Detailed inputs, calculations and results for segment B – Case study 3

Group and Factor No. (g,f)	$W_{g,f}$	$S_{g,f}$	$H_{g,f}$	$R_{g,f}$	$W_{g,f}$* $R_{g,f}$	SL_g	GI_g	W_g	GPI_g	$RRPI_B$
1,1	0.216	7	2.25	0.32143	0.06943	0.43324	0.56676	0.258	0.14622	**0.41748**
1,2	0.102	7	1	0.14286	0.01457					
1,3	0.130	6	5.28	0.88000	0.11440					
1,4	0.214	6	1.125	0.18750	0.04013					
1,5	0.150	7	4.7	0.67143	0.10071					
1,6	0.188	2	1	0.50000	0.09400					
2,1	0.204	5	4	0.80000	0.16320	0.56016	0.43984	0.227	0.09984	
2,2	0.168	7	1	0.14286	0.02400					
2,3	0.165	7	1	0.14286	0.02357					
2,4	0.175	6	4.45	0.74167	0.12979					
2,5	0.171	5	3	0.60000	0.10260					
2,6	0.117	3	3	1.00000	0.11700					
3,1	0.119	7	1.286	0.18371	0.02186	0.52213	0.47787	0.256	0.12233	
3,2	0.135	7	3.189	0.45557	0.06150					
3,3	0.138	5	3.5	0.70000	0.09660					
3,4	0.124	7	3.667	0.52386	0.06496					
3,5	0.126	7	3.456	0.49371	0.06221					
3,6	0.128	6	3	0.50000	0.06400					
3,7	0.126	7	5.5	0.78571	0.09900					
3,8	0.104	2	1	0.50000	0.05200					
4,1	0.230	6	4.387	0.73117	0.16817	0.81050	0.18950	0.259	0.04908	
4,2	0.236	3	3	1.00000	0.23600					
4,3	0.197	6	4	0.66667	0.13133					
4,4	0.151	4	4	1.00000	0.15100					
4,5	0.186	6	4	0.66667	0.12400					

Table 7.28: Detailed inputs, calculations and results for segment C – Case study 3

Group and Factor No. (g,f)	$W_{g,f}$	$S_{g,f}$	$H_{g,f}$	$R_{g,f}$	$W_{g,f}$* $R_{g,f}$	SL_g	GI_g	W_g	GPI_g	$RRPI_C$
1,1	0.216	7	3.0	0.42857	0.09257	0.46259	0.53741	0.258	0.13865	**0.45402**
1,2	0.102	7	1	0.14286	0.01457					
1,3	0.130	6	5.345	0.89083	0.11581					
1,4	0.214	6	1.5	0.25000	0.05350					
1,5	0.150	7	4.3	0.61429	0.09214					
1,6	0.188	2	1	0.50000	0.09400					
2,1	0.204	5	4	0.80000	0.16320	0.57329	0.42671	0.227	0.09686	
2,2	0.168	7	1	0.14286	0.02400					
2,3	0.165	7	1	0.14286	0.02357					
2,4	0.175	6	4.9	0.81667	0.14292					
2,5	0.171	5	3	0.60000	0.10260					
2,6	0.117	3	3	1.00000	0.11700					
3,1	0.119	7	1.274	0.18200	0.02166	0.44208	0.55792	0.256	0.14283	
3,2	0.135	7	3.007	0.42957	0.05799					
3,3	0.138	5	3	0.60000	0.08280					
3,4	0.124	7	3.167	0.45243	0.05610					
3,5	0.126	7	2.659	0.37986	0.04786					
3,6	0.128	6	2	0.33333	0.04267					
3,7	0.126	7	4.5	0.64286	0.08100					
3,8	0.104	2	1	0.50000	0.05200					
4,1	0.230	6	3.954	0.65900	0.15157	0.70782	0.29218	0.259	0.07567	
4,2	0.236	3	3	1.00000	0.23600					
4,3	0.197	6	3	0.50000	0.09850					
4,4	0.151	4	3	0.75000	0.11325					
4,5	0.186	6	3.5	0.58333	0.10850					

Table 7.29: A result summary and decision making – Case study 3

Segment	GPI_g				$RRPI_{segment}$	**Final Decision (Recovery Hierarchy)**
	1	**2**	**3**	**4**		
A	0.13662	0.05135	0.15741	0.12451	**0.46989**	**1**
B	0.14622	0.09984	0.12233	0.04908	**0.41748**	**3**
C	0.13865	0.09686	0.14283	0.07567	**0.45402**	**2**

7.6.4 Discussion of Results

The obtained results of group priority index values GPI_g for each factor group for all segments are shown in Figures 7.13, 7.14, 7.15 and 7.16 for factor groups 1, 2, 3 and 4 respectively.

Due to the situation of segment B that it has more socio-economic buildings, more area of these buildings, and more capacity of such buildings and also serves more population, this made its GPI value more than those for other segments as illustrated in Figure 7.13. This in turn puts segment B in the first priority for recovery compared to other segments of this road.

Segment B needs also to be recovered first from the standpoint of the road network group as it has a higher GPI value than those values for other segments as can be seen in Figure 7.14. This is because it has a higher number of nodes, links and segment length.

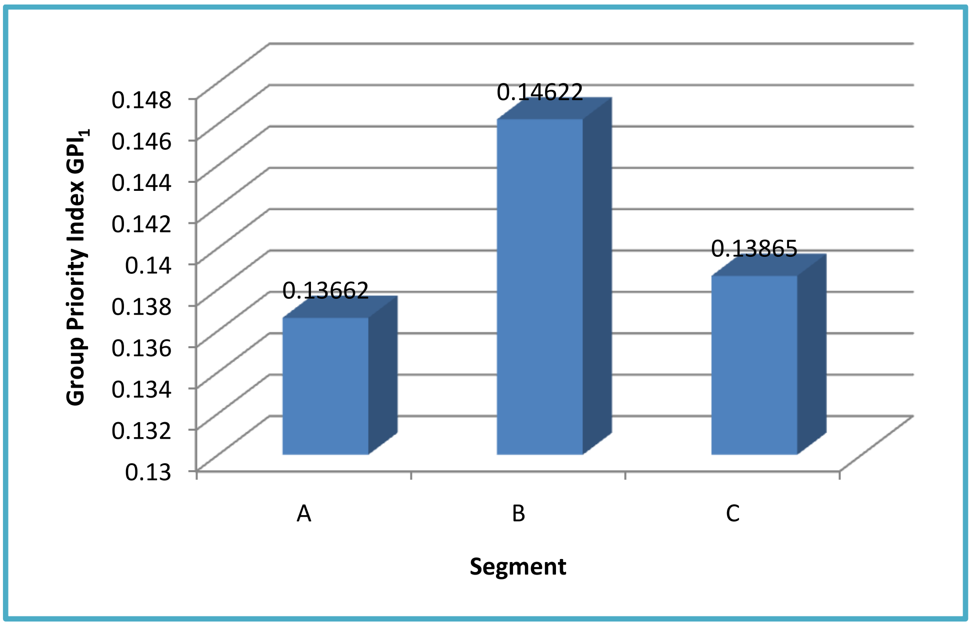

Figure 7.13: Group priority index values GPI_1 for group 1 for all segments – Case study 3

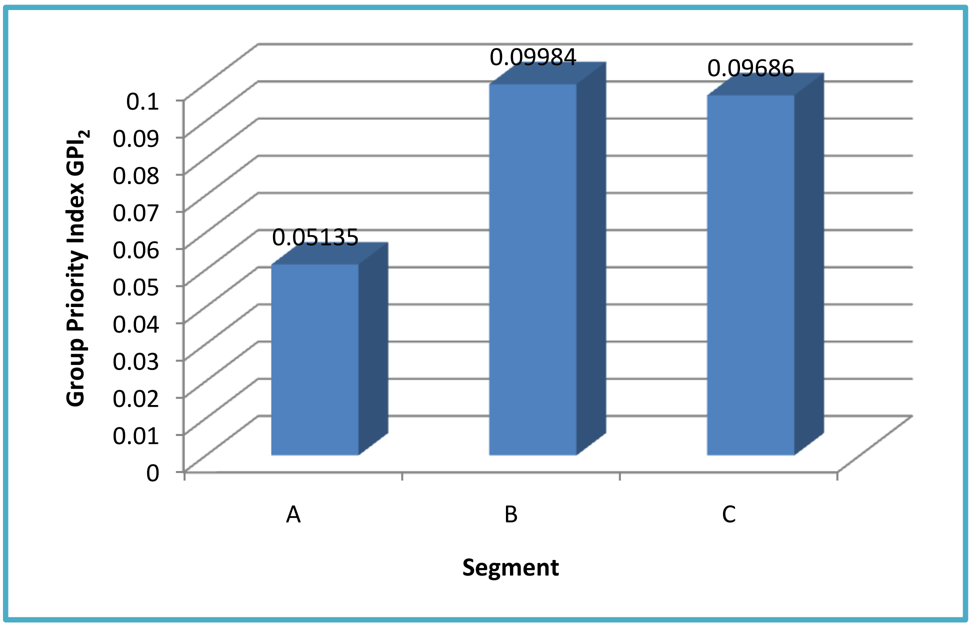

Figure 7.14: Group priority index values GPI_2 for group 2 for all segments – Case study 3

As shown in Figure 7.15 for the traffic factor group, segment A has the highest GPI due to the highest traffic flow, delay time, queue length, reduction in vehicle speed and the worse level of service compared to other segments. Therefore segment A should be recovered first according to the traffic group of factors.

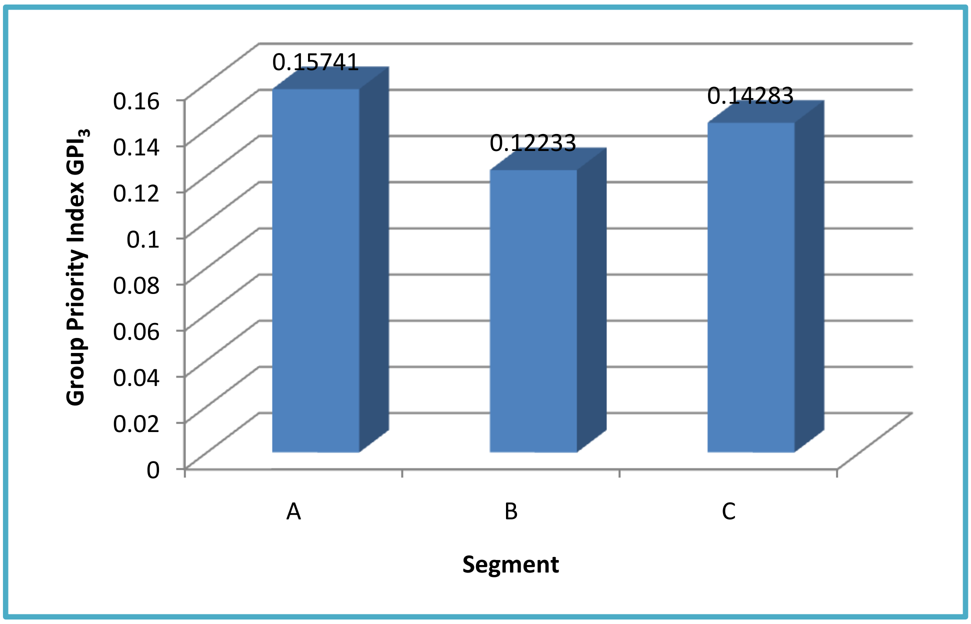

Figure 7.15: Group priority index values GPI_3 for group 3 for all segments – Case study 3

Finally, segment A is considered as the first priority to be recovered as it has the highest GPI. As presented in Figure 7.16, there is a marked difference in the GPI between segment A and other segments. The reason is that more damage had happened in this segment due to the higher percentage of damaged road, greater severity of damage, more damaged layers, less open lanes and less PSI compared to other segments.

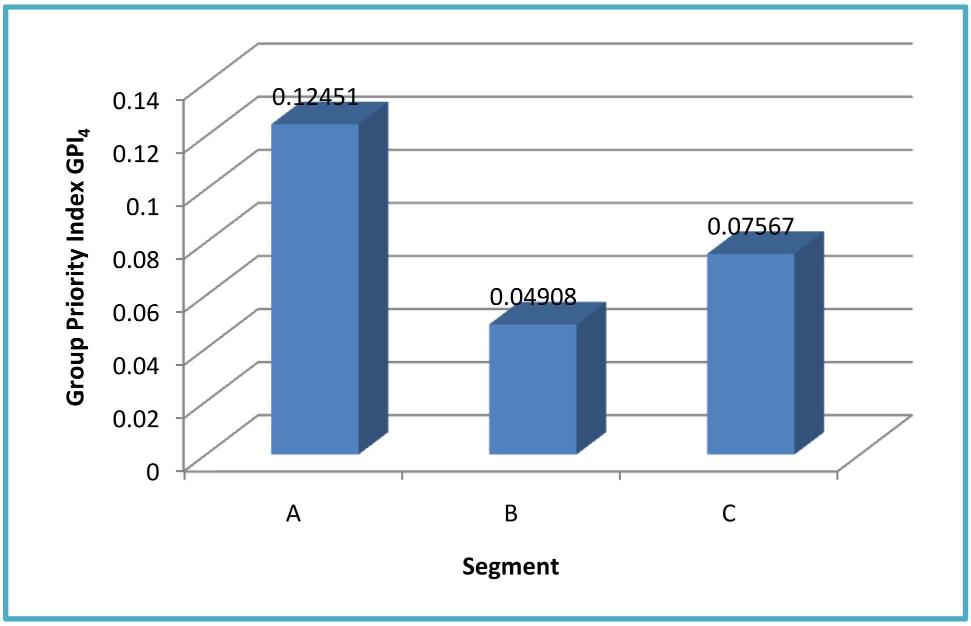

Figure 7.16: Group priority index values GPI_4 for group 4 for all segments – Case study 3

To conclude, the final road recovery priority index values for each segment can be demonstrated in Figure 7.17. From these values of each segment, it can be noticed that segment A has the highest $RRPI$ value (0.46989) because it is controlling in two groups as it has the higher group priority index in the traffic and damage groups. Although segment B is controlling in two groups as it has the higher GPI for the socio-economic and road network groups, it has the lowest resulted $RRPI$ (0.41748) because it has a very small value of GPI for the damage group. Thus, it can be concluded that segment A needs an urgent repair while segments C and B are considered to be in the second and third recovery priority respectively.

Figure 7.18 shows a summary of the obtained group priority index values GPI for each group and the final road recovery priority index values $RRPI$ for each segment.

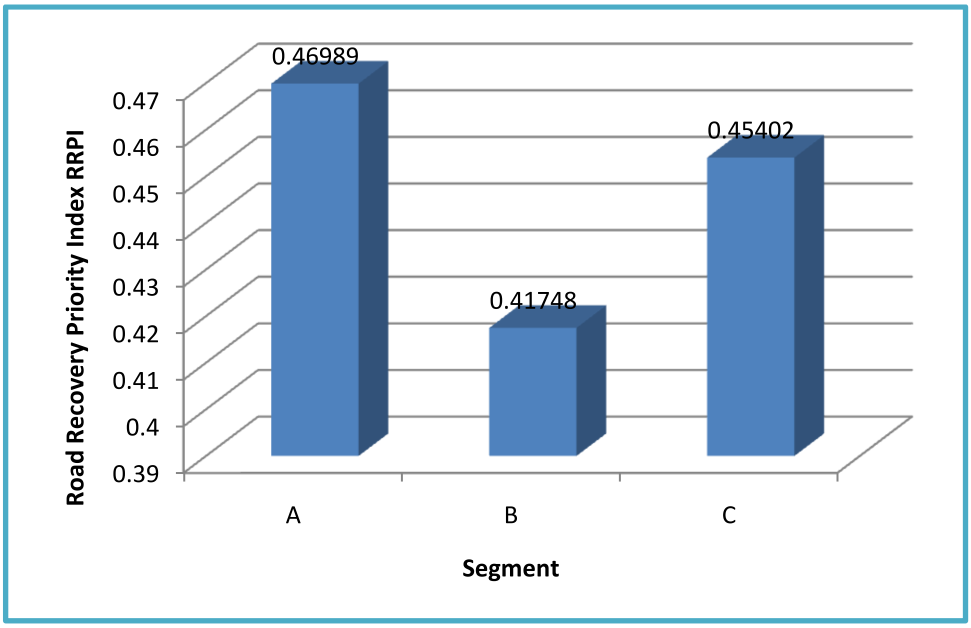

Figure 7.17: Final RRPI values for each segment – Case study 3

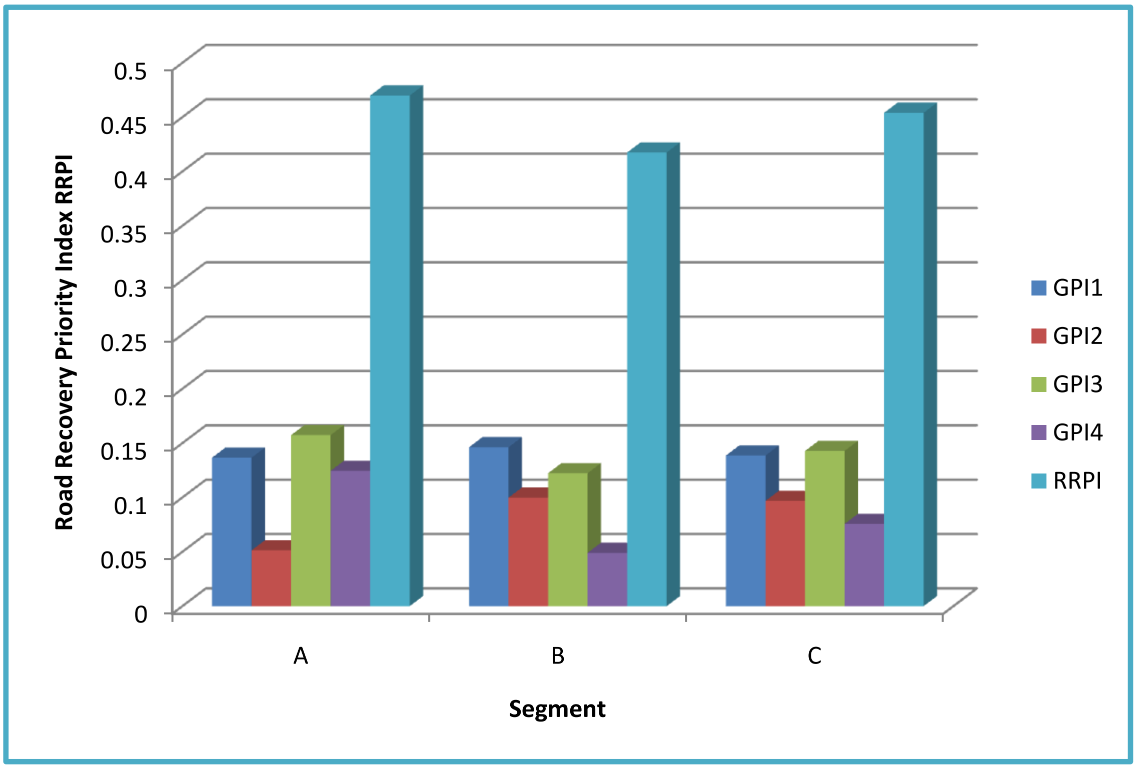

Figure 7.18: A summary of group priority index values GPI for each group and the final road recovery priority index values RRPI for each segment – Case study 3

7.7 Case Study 4

7.7.1 Study Area

The last selected road is a rural road located in the north-west of Baghdad city, adjacent to the Tigris River. It serves agricultural areas (gardening and vegetable). It is the road which leads to one of the biggest tourist areas in Baghdad, Tourism Baghdad Island. It serves a number of schools, a few government institutions and a number of small health services (clinics). It leads to the main general road which links Baghdad with the northern governorates. In addition, it connects with Al-Muthana Bridge which leads to the roads which go through the southern governorates. Also, this road leads to Mohammed Al-Qasim Highway which is the major highway crossing the entire city. The location and borders of case study 4 are given in Figure F.6 in Appendix F. The total length of the road for this case study is 14.6 km and has been divided into three segments. Table 7.30 shows the segment lengths and origin/destination for this road.

Table 7.30: Length and O/D of Case study 4 segments

Segment	Length (km)	Origin/Destination
A	3.3	Al-Muthana Bridge/Baghdad Island
B	5.1	Baghdad Island/Abu-Daly
C	6.2	Abu-Daly/Al-Rashedia

7.7.2 Collected Data

7.7.2.1 Socio-Economic Factor Group

Tables G.31, G.32 and G.33 in Appendix G present detailed data regarding socio-economic facility type, area of these facility buildings, number of persons in each building and the capacity of these buildings for each segment. Table 7.31 lists a summary of the collected data for the socio-economic factor group.

Table 7.31: A summary of the collected data for group 1 – Case study 4

Case Study: 4 **Road Zone(s): 51 and 52** **Type of Area: Rural**			
Road Segment	A	B	C
Total Number of Socio-Economic buildings	11	14	28
Total Area of Socio-Economic Buildings (m^2)	15730	9410	37770
Total Number of Persons in Socio-Economic Buildings	2870	3110	12220
Total Capacity of Socio-Economic Buildings (person/m^2)	0.182	0.330	0.324
Population (habitant)	240,000	280,000	180,000
Area Served by a Segment (km^2)	16	10	20

7.7.2.2 Road Network Factor Group

The collected data regarding this factor group is presented in Table 7.32.

Table 7.32: A summary of the collected data for group 2 – Case study 4

Case Study: 4 **Type of Road: Secondary**			
Road Segment	A	B	C
Number of nodes	7	4	9
Number of links	6	3	8
Length (km)	3.3	5.1	6.2
Number of lanes	1 lane in each direction		
Pavement structure	Flexible pavement		

7.7.2.3 Traffic Factor Group

A detailed collected data regarding type and number of vehicles corresponding to each class has been given in Tables G.34, G.35 and G.36 in Appendix G for segments A, B and C respectively and the average summation for all vehicles classes has been obtained for each segment and are listed in Tables G.37, G.38 and G.39. Table 7.33 presents the final summary of the collected data regarding the traffic group of factors for each segment.

Table 7.33: A summary of the collected data for group 3 – Case study 4

Case Study: 4			
Road Segment	**A**	**B**	**C**
Percentage of Vehicles (Class 1) (%)	38.40	40.16	41.61
Traffic Flow (vpd)	22560	21456	18168
Delay Time (min.)	10	5	8
Additional Trip Length (km)	8	13	22
Number of Vehicles in a Queue	60	40	30
Number of Open Lanes	1	1	1
Queue Length (m)	731.52	487.68	365.76
LOS (Before)	C	B	B
LOS (After)	F	D	D
Average Speed (Before) (km/hr)	60	60	60
Average Speed (After) (km/hr)	20	30	40
Reduction in Average Speed (km/hr)	40	30	20
Traffic Control Pattern	No electric traffic signals		

7.7.2.4 Damage Factor Group

A summary of the collected data for the damage factor group is given in Table 7.34.

Table 7.34: A summary of the collected data for group 4 – Case study 4

Case Study: 4			
Road Segment	**A**	**B**	**C**
Length of Damaged Area (km)	2.1	1.2	1.7
Percentage of Damaged Road (%)	63.64	23.53	27.42
Type of Damage	Structural defect	Roughness, Surface distress	Roughness, Surface distress
Severity of Damage	Major	Minor	Minor
Number of Open Lanes	1	1	1
Number of Damaged Layers	2	1	1
P_o	4.5	4.5	4.5
P_t	1.5	2.5	2.5
∆PSI	3.0	2.0	2.0

7.7.3 Model Application and Results

Detailed inputs, calculations and results are presented in Tables 7.35, 7.36 and 7.37 for segments 1, 2 and 3 respectively. Then a comparison is made between the values of road recovery priority index for each segment $RRPI_{Segment}$ in order to decide of which segment needs to be first recovered. A result summary of each group priority index GPI_g within each segment, the resulted $RRPI_{segment}$ and the final decision to determine the recovery hierarchy for each segment is listed in Table 7.38.

Table 7.35: Detailed inputs, calculations and results for segment A – Case study 4

Group and Factor No. (g,f)	$W_{g,f}$	$S_{g,f}$	$H_{g,f}$	$R_{g,f}$	$W_{g,f}$* $R_{g,f}$	SL_g	GI_g	W_g	GPI_g	$RRPI_A$
1,1	0.216	7	5.9	0.84286	0.18206	0.79550	0.20450	0.258	0.05276	**0.34270**
1,2	0.102	7	5.857	0.83671	0.08534					
1,3	0.130	6	5.09	0.84833	0.11028					
1,4	0.214	6	3.8	0.63333	0.13553					
1,5	0.150	7	4.4	0.62857	0.09429					
1,6	0.188	2	2	1.00000	0.18800					
2,1	0.204	5	5	1.00000	0.20400	0.78931	0.21069	0.227	0.04783	
2,2	0.168	7	3.5	0.50000	0.08400					
2,3	0.165	7	3.667	0.52386	0.08644					
2,4	0.175	6	4.35	0.72500	0.12688					
2,5	0.171	5	5	1.00000	0.17100					
2,6	0.117	3	3	1.00000	0.11700					
3,1	0.119	7	6.232	0.89029	0.10594	0.56057	0.43943	0.256	0.11249	
3,2	0.135	7	4.372	0.62457	0.08432					
3,3	0.138	5	3.5	0.70000	0.09660					
3,4	0.124	7	2.75	0.39286	0.04871					
3,5	0.126	7	2.537	0.36243	0.04567					
3,6	0.128	6	1	0.16667	0.02133					
3,7	0.126	7	3	0.42857	0.05400					
3,8	0.104	2	2	1.00000	0.10400					
4,1	0.230	6	2.818	0.46967	0.10802	0.49952	0.50048	0.259	0.12962	
4,2	0.236	3	2	0.66667	0.15733					
4,3	0.197	6	2	0.33333	0.06567					
4,4	0.151	4	2	0.50000	0.07550					
4,5	0.186	6	3	0.50000	0.09300					

Table 7.36: Detailed inputs, calculations and results for segment B – Case study 4

Group and Factor No. (*g*,*f*)	$W_{g,f}$	$S_{g,f}$	$H_{g,f}$	$R_{g,f}$	$W_{g,f}$* $R_{g,f}$	SL_g	GI_g	W_g	GPI_g	$RRPI_B$
1,1	0.216	7	5.6	0.80000	0.17280	0.77888	0.22112	0.258	0.05705	**0.26120**
1,2	0.102	7	6.059	0.86557	0.08829					
1,3	0.130	6	4.35	0.72500	0.09425					
1,4	0.214	6	3.6	0.60000	0.12840					
1,5	0.150	7	5	0.71429	0.10714					
1,6	0.188	2	2	1.00000	0.18800					
2,1	0.204	5	5	1.00000	0.20400	0.83582	0.16418	0.227	0.03727	
2,2	0.168	7	5	0.71429	0.12000					
2,3	0.165	7	5	0.71429	0.11786					
2,4	0.175	6	3.633	0.60550	0.10596					
2,5	0.171	5	5	1.00000	0.17100					
2,6	0.117	3	3	1.00000	0.11700					
3,1	0.119	7	6.197	0.88529	0.10535	0.62750	0.37250	0.256	0.09536	
3,2	0.135	7	4.427	0.63243	0.08538					
3,3	0.138	5	4	0.80000	0.11040					
3,4	0.124	7	1.778	0.25400	0.03150					
3,5	0.126	7	3.049	0.43557	0.05488					
3,6	0.128	6	3	0.50000	0.06400					
3,7	0.126	7	4	0.57143	0.07200					
3,8	0.104	2	2	1.00000	0.10400					
4,1	0.230	6	4.824	0.80400	0.18492	0.72384	0.27616	0.259	0.07153	
4,2	0.236	3	3	1.00000	0.23600					
4,3	0.197	6	2	0.33333	0.06567					
4,4	0.151	4	3	0.75000	0.11325					
4,5	0.186	6	4	0.66667	0.12400					

Table 7.37: Detailed inputs, calculations and results for segment C – Case study 4

Group and Factor No. (g,f)	$W_{g,f}$	$S_{g,f}$	$H_{g,f}$	$R_{g,f}$	$W_{g,f}$* $R_{g,f}$	SL_g	GI_g	W_g	GPI_g	$RRPI_C$
1,1	0.216	7	4.467	0.63814	0.13784	0.73357	0.26643	0.258	0.06874	**0.29877**
1,2	0.102	7	5.306	0.75800	0.07732					
1,3	0.130	6	4.38	0.73000	0.09490					
1,4	0.214	6	4.2	0.70000	0.14980					
1,5	0.150	7	4	0.57143	0.08571					
1,6	0.188	2	2	1.00000	0.18800					
2,1	0.204	5	5	1.00000	0.20400	0.72201	0.27799	0.227	0.06310	
2,2	0.168	7	2.667	0.38100	0.06401					
2,3	0.165	7	3	0.42857	0.07071					
2,4	0.175	6	3.267	0.54450	0.09529					
2,5	0.171	5	5	1.00000	0.17100					
2,6	0.117	3	3	1.00000	0.11700					
3,1	0.119	7	6.168	0.88114	0.10486	0.63492	0.36508	0.256	0.09346	
3,2	0.135	7	4.592	0.65600	0.08856					
3,3	0.138	5	3.7	0.74000	0.10212					
3,4	0.124	7	1	0.14286	0.01771					
3,5	0.126	7	3.537	0.50529	0.06367					
3,6	0.128	6	3	0.50000	0.06400					
3,7	0.126	7	5	0.71429	0.09000					
3,8	0.104	2	2	1.00000	0.10400					
4,1	0.230	6	4.629	0.77150	0.17745	0.71636	0.28364	0.259	0.07346	
4,2	0.236	3	3	1.00000	0.23600					
4,3	0.197	6	2	0.33333	0.06567					
4,4	0.151	4	3	0.75000	0.11325					
4,5	0.186	6	4	0.66667	0.12400					

Table 7.38: A result summary and decision making – Case study 4

Segment	GPI_g				$RRPI_{segment}$	**Final Decision (Recovery Hierarchy)**
	1	**2**	**3**	**4**		
A	0.05276	0.04783	0.11249	0.12962	**0.34270**	**1**
B	0.05705	0.03727	0.09536	0.07153	**0.26120**	**3**
C	0.06874	0.06310	0.09346	0.07346	**0.29877**	**2**

7.7.4 Discussion of Results

The obtained results of group priority index values GPI_g for each factor group for all segments are shown in Figures 7.19, 7.20, 7.21 and 7.22 for factor groups 1, 2, 3 and 4 respectively.

As indicated in Figure 7.19, there is a small difference in the GPI_1 values for road segments. Segment C has the highest group priority index regarding the socio-economic group of factors as there are more socio-economic critical buildings, more area of such buildings within this segment and more area served by this segment in comparison with other segments. This requires a first priority of recovery for segment C before the recovery of other segments.

Regarding the second group, the road network, a marked difference in the GPI_2 values can be noticed for the road segments. The same as group 1 needs to be done as segment C has a higher number of nodes and links and a greater length than those for other segments. This in turn leads to the highest group priority index as shown in Figure 7.20. Segment B has the lowest input values for group factors which generate less GPI and that means its recovery can be postponed until recovering the other segments.

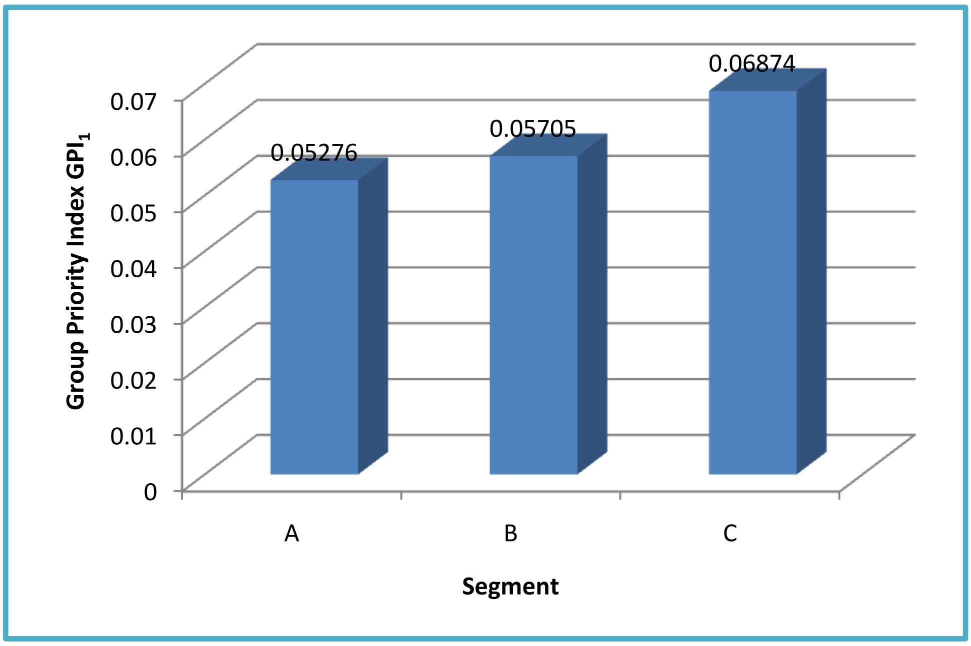

Figure 7.19: Group priority index values GPI_1 for group 1 for all segments – Case study 4

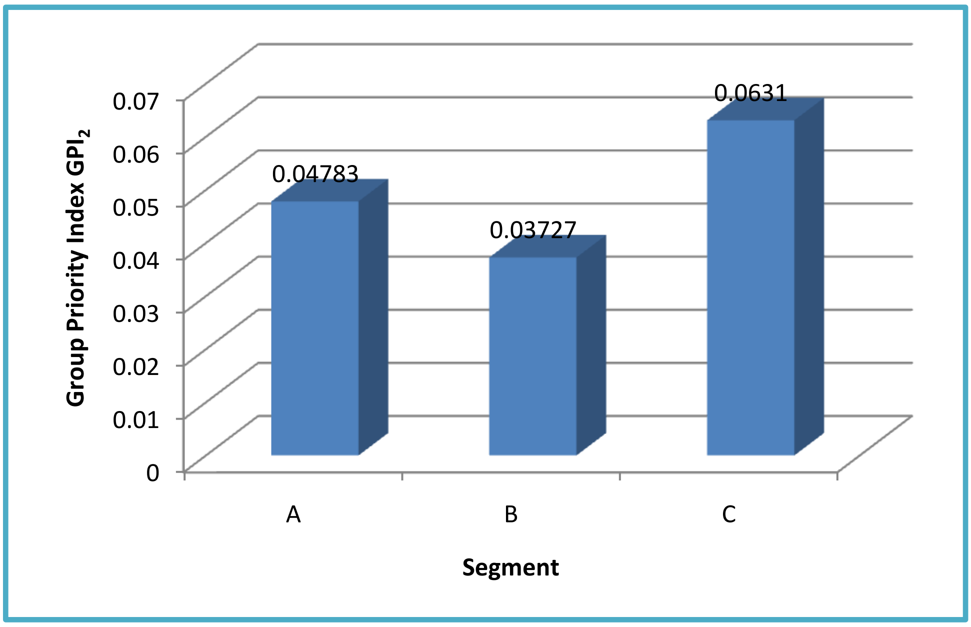

Figure 7.20: Group priority index values GPI_2 for group 2 for all segments – Case study 4

Due to the condition of segment A from the standpoint of the traffic group of factors, as it has more traffic flow, more delay time, more queue length, more reduction in average speed and worse level of service, so the resulted GPI is more than those for segments B and C as presented in Figure 7.21. This puts segment A as the first recovery priority.

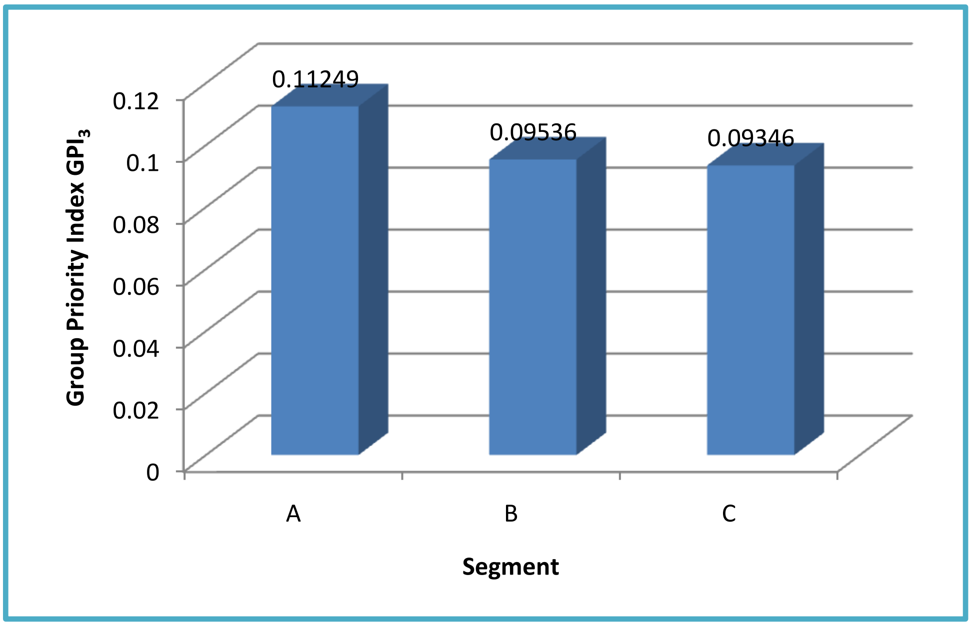

Figure 7.21: Group priority index values GPI_3 for group 3 for all segments – Case study 4

Finally, Figure 7.22 shows that there is a significant difference in the GPI values for segments regarding the damage factor group. Segment A is also in the first place for recovery, then segments C and B. It can be noticed by the collected input data for this group that segment A has a higher percentage of damage, more damaged layers, more severity of damage and less present serviceability index compared to other segments.

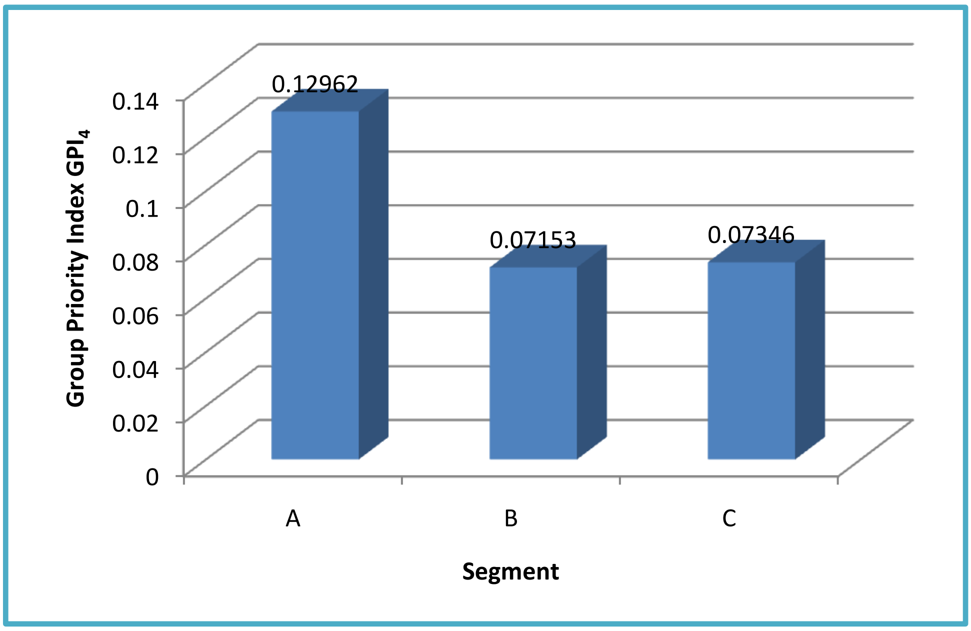

Figure 7.22: Group priority index values GPI_4 for group 4 for all segments – Case study 4

At the end and as a result for all groups, segment C is controlling in the socio-economic and road network factor groups (as it has highest group priority index GPI) while segment A is controlling in the traffic and damage group of factors. However, the road recovery priority index $RRPI$ is higher for segment A rather than those for other segments, as shown in Figure 7.23. This is because the difference in the GPI values for the damage group is much higher than those for the socio-economic and road network group between all segments. Therefore, according to the application of the $RRPI$ model, road recovery should be first done to segment A and then to C and B respectively.

Figure 7.24 shows a summary of the obtained group priority index values GPI for each group and the final road recovery priority index values $RRPI$ for each segment.

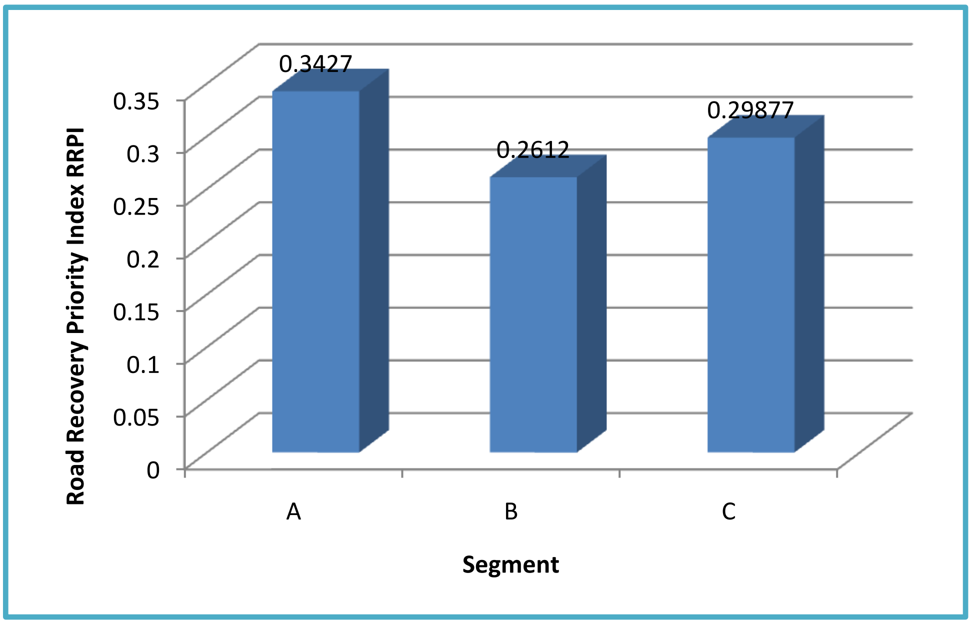

Figure 7.23: Final RRPI values for each segment – Case study 4

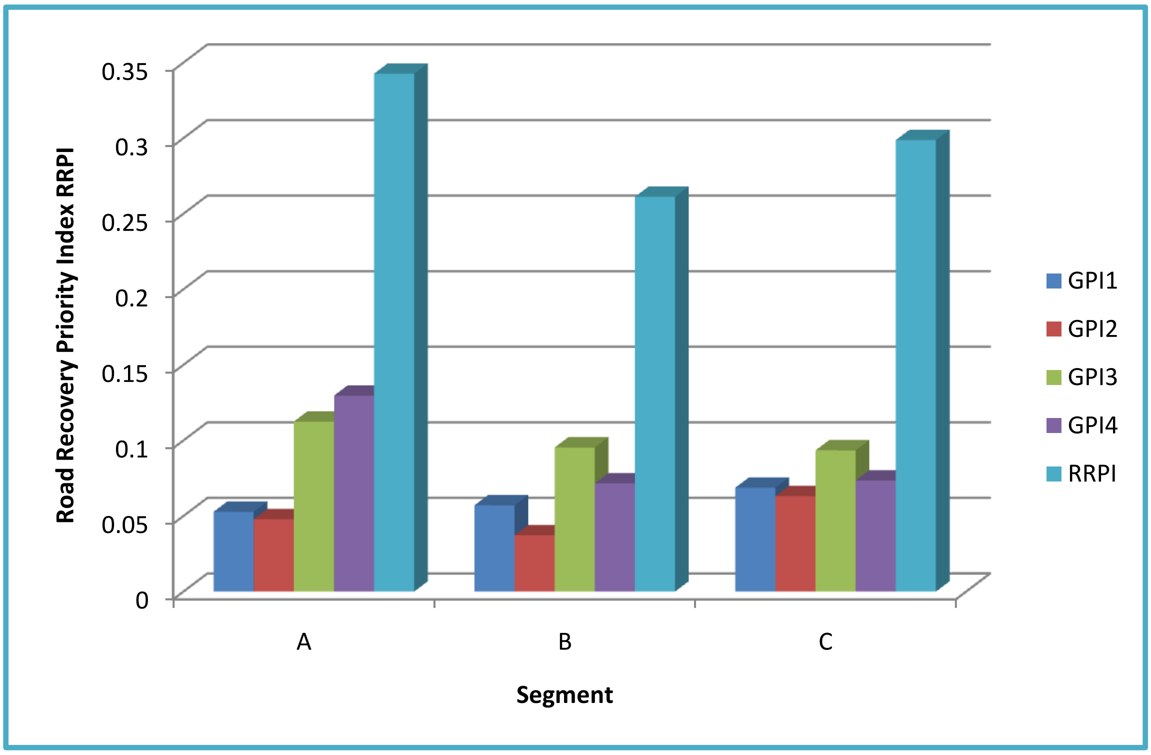

Figure 7.24: A summary of group priority index values GPI for each group and the final road recovery priority index values RRPI for each segment – Case study 4

7.8 Summary of Findings

A road rehabilitation planning and prioritisation model was developed to enable an efficient and effective rehabilitation process for transportation networks which were damaged by natural/man-made disasters. This chapter presents four case studies that aim at investigating and demonstrating the usability and usefulness of the proposed RRP model for road reconstruction and rehabilitation organisations. Case study 1 involved a major highway in Baghdad which crosses the entire city passing through the centre. A comparison between two damaged bridges has been covered in case study 2, while case study 3 examined the application of the RRP model on a primary road within a commercial area. Finally, the proposed model has dealt with a secondary rural road within an agricultural area. The case studies can be considered as comprehensive to the different types of input values for the proposed model. These involved all types of roads (bridge, highway, primary and secondary road), all types of areas (urban and rural area), different population (highly and lowly populated area) and different numbers and types of critical socio-economic facilities.

A field survey was carried out to collect data which are essential to determine the input parameters in the model application. The application of this model may solve the problem of decision making in road recovery priority determination in a hierarchical manner so that road recovery process can be accomplished from those which are urgent to those which are less urgent.

An application example is analysed to evaluate the implementation procedures and performance of the developed model, illustrate its use and demonstrate its capabilities in gathering different affecting components in a comprehensive model. These capabilities are demonstrated in the ability of the developed rehabilitation priority model to consider a number of practical road rehabilitation requirements, including: socio-economic, road network, traffic and damage considerations. These new and unique capabilities should prove useful to decision makers and planners in departments of roads reconstruction and should contribute to enhancing the planning of recovery priority efforts for roads damaged by disasters.

The mathematical road recovery priority model was developed and improved to be applicable, from input data, analysis steps to the decision making, anywhere. The final results concluded from the conducted case studies can be summarised as follows:

- For the socio-economic group, a slight difference in the group priority index values between case study segments was noticed. Calculation results show that the segment with the highest GPI value was according to the highest total number of socio-economic buildings, area of these buildings and population served by this segment. Results show that the group priority index GPI_1 value presents 25 per cent from the road recovery priority index.
- For the road network group, there is an obvious variance in the GPI results for each case study segments. The results show that the length of road (segment) has an important effect on the recovery priority which leads to a high value of GPI. According to the related results, the group priority index GPI_2 value approximately presents 15 per cent from the road recovery priority index. It has a lower level of impact compared to other groups.
- Model application for the traffic group of factors indicated that there is a considerable and marked difference in the GPI_3 values between case study segments. The results demonstrate that the adverse impact of natural/man-made

disasters on traffic movement such as delay time, long queue length and reduction in average speed, put the road segment in the first priority for recovery. Calculations show that this group contributes nearly 30 per cent of the final $RRPI$ value for each case study.

- For the damage factor group, the obtained results showed that there is a very big difference between each case study segment in the GPI values. This significant difference in GPI_4 is caused by the variance in the damage considerations between road segments, especially per cent of damage road, severity of damage and the number of open lanes. This group contributes more than 30 per cent of the final $RRPI$ value for each case study. So, it is the most important group as it has the highest impact level compared to other groups.
- It can be noticed that, for each case study, the segment with the highest resulted group priority index for the damage group is the segment that resulted in the highest road recovery priority index. This supports the idea that the damage group is the most important group in the proposed RRP model. So we can conclude that the segment with the highest damage group priority index will almost be the first priority segment for recovery.
- The obtained results indicated the importance of the traffic and damage groups for all case studies as they have a great impact on the resulted $RRPI$ value, while socio-economic and road network groups were of less importance.
- The hierarchy of the input value for a specified factor has an important effect on the resulted $RRPI$ value and can change the obtained result in an obvious form. If the input value of data for a single factor corresponding to a specific road is high, this

means that it is a critical case and then it is given a first hierarchy. Conversely, a lower hierarchy is to be considered when the input value of data is low.

- The presented RRP model provides adequate components and details, while dividing the controlling components into four main groups to simplify understanding and following. Providing detailed and structured processes helps the organisation to identify required procedures and components during the implementation and application stages of the RRP model.
- The ranking of damaged roads (road segments) is based on a decision model which provides a systematic way of competing attributes to fulfil the multiple objectives in ranking process. This decision model enables ranking of damaged roads by decision makers with different priorities based on dealing with different group of factors which are taken into consideration in the proposed RRP model. The results have shown that adopting the presented model in the sector of road rehabilitation is highly usable and useful.
- The key to successful implementation and application of the model is a good database of the road network and related components in the area. The database should include all factors and groups included in the presented model. This database should be well maintained so that accurate information is available in the event of a disaster.
- The implementation of the model can be applied by road reconstruction and rehabilitation companies in several contexts. The first is for the spending of maintenance budgets on the most important and first priority roads. If the priority routes are chosen, maintenance budgets could be spent first on the identified routes to improve their ability to sustain damage and remain viable. This could reduce

both the damage sustained to the transportation components and the repair times after a disaster. The model could also be usefully implemented to save time on decision-making after a disaster.

This chapter presents the results of four case studies, which are conducted to investigate RRP model application in the variety of road conditions by using different input values in order to evaluate the usability and usefulness of the proposed model in road reconstruction projects. The next chapter will discuss the final findings and achievements of this study, and provide recommendations for future research.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The research has achieved its main goal of developing an integrated comprehensive road recovery priority RRP model by following a process of research methodologies. The research has proved that the proposed RRP model can successfully help decision makers in road reconstruction and rehabilitation organisations to easily select the first priority road (roads) damaged by natural/man-made disasters for recovery. The achievements of this research can be summarised as follows:

- The objective of providing required background to simplify understanding and developing the RRP model of the research and to identify the various areas of recovery priority of roads that may require more research and investigation has been achieved. This has been accomplished through conducting an extensive review of RRP literature that highlights main concepts and discusses managerial aspects of RRP implementation and application in the context of road reconstruction and rehabilitation projects. The research has started with an investigation into the impact of natural/man-made disasters on generally different life sectors and then specifically on road networks. The research has investigated the most critical factors and factor groups that may affect on RRP adoption. Moreover, the research has discussed the important RRP principles, concepts and methods in order to develop the proposed model.

- The objective of investigating shortcomings of existing models related to the recovery priority of damaged roads has been accomplished through an extensive review of such RRP models in the literature. This has helped the researcher to investigate problems of existing models and identify opportunities for development of a new RRP model. The results have shown that those models still have many shortcomings that prevent them from being used successfully in road rehabilitation projects. For example, many of these RRP models may lack necessary affecting components and factors or may not consider the problem from different aspects such as socio-economic, road network, traffic and damage which have been taken into consideration in this research to fulfil the requirements of road organisations in the rehabilitation sector.

- A preliminary conceptual RRP model has been developed on the basis of reviewing and analysing road recovery priority literature to identify the main components required in the proposed RRP model. The review and analysis of previous models and the generation of a dummy data have helped to address the key characteristics and the important affecting factors required in the RRP model in order to overcome shortcomings of other models and to provide a useful method for RRP in road rehabilitation projects.

- A further effort has been made to accomplish the aim of transferring the preliminary conceptual RRP model into a final, refined, improved RRP model. Interviews and questionnaires have been conducted with a sufficient number of people who have wide experience in road maintenance and rehabilitation and in pavement management to explore the most important affecting components and factors and to investigate the impact weight (level of importance) for each factor and each factor group included in the proposed RRP model. The incorporation of recommendations and findings resulted from the questionnaires, interviews and further review of literature has helped to refine and enhance the proposed RRP model in terms of ease of use, comprehensiveness, usefulness, reliability, applicability and alignment with the characteristics of road reconstruction and rehabilitation projects.

- The result of this study has demonstrated that the estimated factors and groups and the obtained weight values can provide engineers, managers and decision makers with useful information that can be used in performing recovery processes for roads damaged by natural disasters/armed conflicts.

- A final enhanced RRP model has been developed to fulfil the research objectives of providing a structured and practical method for RRP implementation and application in road rehabilitation and reconstruction projects. It includes all important components with sufficient details required for a successful adoption of the RRP model in road organisations. It can solve problems of the previous RRP models, such as the lack of important affecting factors. Also, it includes many factors which have been adopted in the proposed model to overcome the problem of including only two or three affecting factors.

- In order to fulfil the aim of the research to evaluate and test the developed RRP model in terms of its usability and usefulness, an extensive investigation through four case studies has been conducted in the context of road recovery priority after man-made disasters. The application and implementation of the proposed RRP model on four different types of collected real data in the selected case studies have shown that the RRP model is favourably recommended for its applicability and usefulness in road rehabilitation projects. The case studies have provided useful understanding and clarification of RRP practices, and have shown how the proposed model can be used in order to conclude the final decision of the first priority road (roads) to be recovered.

The benefits that may be received from the proposed RRP model for potential stakeholders can be summarised as follows:

- In this work, effort has been made to take important influential factors into consideration in the proposed RRP model which can more comprehensively estimate the performance of the damaged road network and provide reliable results and information that can help in determining the first priority roads for recovery after natural/man-made disasters. Therefore, the model will help road reconstruction organisations to identify the most important factors that may be taken into consideration in the decision making when prioritising damaged roads for recovery.

- The proposed road recovery priority model presented in this study enables decision makers in the road management, reconstruction and rehabilitation organisations to better understand the evaluation process after natural/man-made disasters which provides an accurate, effective, efficient and systematic decision support method and tool.

- It is anticipated that the presented RRP model will improve road reconstruction management performance that may have an economic impact by eliminating wasted time and resources and by concentrating on rehabilitation of the first priority roads.

- The new RRP model provides structured procedures to capture data on road reconstruction projects, transform them into parameters and use these parameters and information to make a decision regarding the priority of recovering damaged roads. This model also provides a clearer map and useful guideline for appropriate RRP processes and procedures in road reconstruction projects.

- In addition to using the proposed model for recovery prioritisation of roads damaged by natural/man-made disasters, it is also possible to use the proposed model to manage the maintenance priority for roads which are needed to be maintained and rehabilitated depending on the estimated factors and/or any other required factors.

- The proposed RRP model provides a good level of detail that makes implementation and use of the model easier by the road reconstruction and rehabilitation organisations. This helps to encourage more research efforts to provide structured methods for providing further details and guidelines which are important in the modelling processes, methods and tools. Therefore, the proposed model can include more performance objectives needed and can be used according to any specified factors or groups of factors in order to best fit with requirements and needs. So, it is possible to include and/or exclude any factor (factors) or group (groups) if there is a special or different need for some countries regarding the factors relevant to the road recovery priority issue.

- The proposed RRP model is flexible enough to meet the changing demands and can be regularly improved to satisfy the changes and improvements in road rehabilitation. The new experiences and methods can be used to modify, update and validate the contents of the RRP model.

8.2 Recommendations for Future Research

The proposed RRP model of the research is designed to provide a useful structured method that solves problems of other models, and facilitates and encourages RRP initiatives to help to successfully adopt the RRP model in road reconstruction and rehabilitation projects. However, as with any other research, recommendations and suggestions for further investigation, improvement and refinement of the proposed RRP model are provided in order to improve its implementation and application in the road organisations.

The achievements of research themselves are important, but more important is that the achievements provide a basis for future research to extend the understanding on the subject. Therefore, the following are some major aspects in which further work needs to be considered based on the presented studies:

- This study provides a platform for further development and modification of the RRP model so that the proposed RRP model can be used in practice more efficiently and effectively.

- More efforts can also be conducted to enhance the awareness of using such a model in the road reconstruction and rehabilitation organisations and to emphasise the importance of the RRP model in order to encourage more implementation and application of RRP models in this sector.

- The costs need to be investigated. It is essential for efficient transport measures to take the cost consideration into account. Total costs caused by natural/man-made disasters include direct losses such as re-construction/repair construction for the damaged roads, and indirect losses caused by transport networks disruption such as time-dependent costs. Financial factors and costs (such as reconstruction cost, time cost, unemployment cost, business interruption cost, fuel consumption cost) are a complicated task because it needs a lot of work and time. This requires a considerable amount of time (perhaps years) to be accomplished. A financial group of factors has been included in the interview and questionnaire surveys in order to estimate its impact weight in the proposed RRP model and also included in the structure of the proposed model. However, it is not included in the model application as a detailed collected data is required regarding this group. Thus, this cannot be achieved within the limited time extent of this research and, therefore, the financial group of factors require further research.

- The proposed model supplies a reference for the road recovery priority issue. But it is worth transferring it to a computer-aided programme based on the achieved results of this study in order that this programme can provide ease, quickness and effectiveness in the process of inputting data, determining the hierarchy values of factors and performing the calculations in order to obtain the RRPI values which are required for the decision-making.

- A continuous process of identifying and processing new controlling factors needs to be carried out. The proposed RRP model provides flexibility to update, validate and add value onto it which enhances to successfully manage any new identified factors. Therefore, the proposed RRP model is flexible to be updated based on the needs of industry to satisfy the changes and improvements in road rehabilitation.

- The methodological aspects involved in the road recovery priority index construction process can be further elaborated. Other techniques, such as fuzzy preference relations, can be planned for future research on this topic.

- In case of a re-application of the proposed model for the same recovered and unrecovered roads, further investigation needs to be carried out to collect data and information on road performance. These data will be used as input information to improve the proposed model so that improvement/reconstruction of the road network and consideration of making the model more dynamic can be taken into account. It is important to take into consideration the situation of the highway network after the recovery/improvement which is conducted by the application of the model and the subsequent influence of the recovered road (roads) on the priority for further rehabilitation/reconstruction. Examples of new collected data may be required regarding the traffic and damage group of factors for the recovered road to re-apply the model after the first application in order to achieve the recovery for the non recovered roads or further recovery for the recovered roads.

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APPENDIX A

INTERVIEW FORM

UNIVERSITY OF BIRMINGHAM

INVESTIGATION AND EVALUATION OF A ROAD RECOVERY PRIORITY (RRP) MODEL FOR ROAD RECONSTRUCTION AND REHABILITATION PROJECTS

A. Background and General Information

Name:

Address:

Date of Interview:

Position:

Experiences in road construction and maintenance sector:

B. Road Recovery Priority (RRP)

1. Do you use or plan to use a Pavement Management System (PMS) in your highway department?

2. What do you understand by the term Road Recovery Priority (RRP)?

3. What is the stimulus/reason for practicing RRP?

4. What factors are important and critical in RRP?

5. What are the results and outcomes required from the implementation of RRP?

6. Are there any other issues that you would like to mention regarding RRP?

C. Model Evaluation

I would be grateful for your comments on the following RRP model with regards to criteria such as ease of understanding and use, comprehensiveness, applicability, feasibility, structure, etc.

This model is designed to help highway institutions taking the first step into prioritising roads for recovery after natural/man-made disasters, by providing a general guide for road reconstruction and rehabilitation organisations to identify what factors are available and important to their organisations and where it is found, what stages and activities can be followed to develop and apply a successful RRP, what tools and services can be provided by an effective and efficient RRP, how users can benefit from the RRP, and what challenges and factors can be faced throughout the implementation and application of the RRP model. This model can be considered as a general guide for road reconstruction and rehabilitation organisations, while more specific details will be left to be decided by the organisations to support their special characteristics.

The main components of the RRP model developed in the research are shown in Figure 1. Five estimated groups of factors have been included in this study to be influenced on the road priority for recovery. I would be also grateful for your comments and opinions about what are the influencing and controlling factors within each group from your point of view.

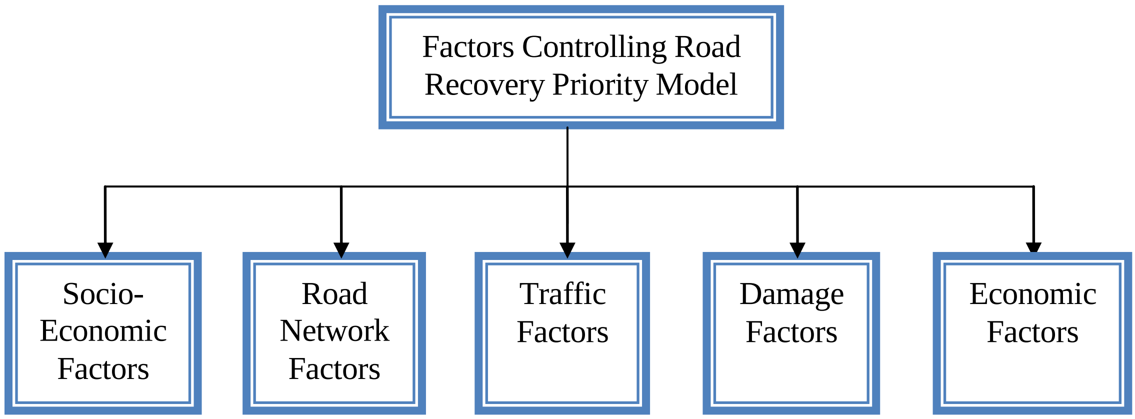

Figure 1: Components of the proposed RRP model for reconstruction and rehabilitation projects

APPENDIX B

QUESTIONNAIRE FORM

UNIVERSITY OF BIRMINGHAM

QUESTIONNAIRE

FACTORS AFFECTING ROAD RECOVERY PRIORITY (RRP) AFTER NATURAL DISASTERS/ARMED CONFLICTS

I am undertaking a research as a partial fulfilment of the requirements for the PhD degree in Highways Engineering in the University of Birmingham in the U.K. My research is about roads recovery priority after natural/man-made disasters. The outcomes of my research will principally benefit the roads sector in Iraq but the knowledge gain can be used for other countries in which their roads are damaged or destroyed by natural/man-made disasters. This questionnaire represents one part of the survey process in my research and it is, however, a very vital part of this research. The aim of this questionnaire is to estimate the impact weight (percentage) of each different factor given subsequently on road recovery priority after natural/man-made disasters. The information that you will provide will help me to carry out my research. This information will only be used for the purpose of the research.

Thank you for taking the time to complete this questionnaire.

Section 1: General Information (Please feel free not to fill all this)

Interviewee (Respondent) (Optional): …..……………………………………

Company/Institution (Optional): ….…………………………………………..

Responsibility (Optional): …….………..…………………………………..

Date: ….…………………………………………………………………..

Experience Years: ………………………………………………………..

Section 2: Level of importance of each factor within each group

2.1 Please decide the level of importance (rate of impact) of each of the following socio-economic factors on road recovery priority after natural/man-made disasters.

Please use this scale: 1 = very low 2 = low 3 = medium 4 = high 5 = very high

Factor	Description	Rating (Weighting)				
		1	**2**	**3**	**4**	**5**
Number of critical socio-economic factors	Number of critical socio-economic buildings served by a road. These include government offices, hospitals, schools, universities, banks, mosques, churches, hotels, museums, police stations, factories, grocery stores, centre of commerce and services institutions (water, power, gas, and sewage), etc.					
Area of socio-economic buildings	The total area of the socio-economic buildings served by a road (in m^2).					
Capacity of socio-economic buildings	Total number of persons in the socio-economic buildings divided by the total area of these buildings (in person/m^2).					
Population	Number of people served by a road (habitant).					
Area served by a road	Total area served by a road (in km^2).					
Type of area	Whether it is urban or rural.					
Other	State……..					
Other	State……..					

2.2 Please decide the level of importance (rate of impact) of each of the following road network factors on road recovery priority after natural/man-made disasters.

Please use this scale: 1 = very low 2 = low 3 = medium 4 = high 5 = very high

Factor	Description	Rating (Weighting)				
		1	2	3	4	5
Type of road	The different types of roads (interstate, bridge, highway, primary and secondary routes).					
Number of nodes	Number of traffic loading/ unloading points to/ from a road.					
Number of links	Number of road segments connecting different nodes within a road.					
Length of road	Length of the entire road (in km).					
Number of lanes	Number of lanes for each road in each direction.					
Pavement structure	Whether a pavement is rigid or flexible, and whether a pavement with an overlay or not.					
Other	State……..					
Other	State……..					

2.3 Please decide the level of importance (rate of impact) of each of the following traffic factors on road recovery priority after natural/man-made disasters.

Please use this scale: 1 = very low 2 = low 3 = medium 4 = high 5 = very high

Factor	Description	Rating (Weighting)				
		1	2	3	4	5
Traffic classification	Traffic classification in terms of vehicle types. These include cars, light commercial vehicles, mini-buses, buses, light trucks, medium trucks, heavy trucks and articulated vehicles.					
Traffic flow	Traffic volume actually travelling on the road (in vpd).					
Delay time	The additional delay time caused by congestion and a longer trip length (in min.).					
Additional trip length	The increase in the trip length caused by traffic diversion onto alternative routes to avoid blocked roads and queuing on links (in km).					
Queue length	The length of queue at a specific time caused by congestion (m).					
Level of service (LOS)	The decline in the level of service caused by the event.					
Reduction in average speed	The reduction in vehicle speed caused by the queuing of other vehicles (in km/hr).					
Traffic control pattern	Whether it is worked with electric traffic signals or not.					
Other	State……..					
Other	State……..					

2.4 Please decide the level of importance (rate of impact) of each of the following damage factors on road recovery priority after natural/man-made disasters.

Please use this scale: 1 = very low 2 = low 3 = medium 4 = high 5 = very high

Factor	Description	Rating (Weighting)				
		1	2	3	4	5
Percentage of damaged road	The percentage of a damaged length road out of the road length.					
Severity of damage	It is classified as minor, major or severe according to type of damage (roughness, surface distress, structural defect).					
Number of open lanes	Number of open lanes in each direction.					
Number of damaged layers	Number of layers damaged in each direction.					
PSI	The decline in the present serviceability index after the event.					
Other	State……..					
Other	State……..					

2.5 Please decide the level of importance (rate of impact) of each of the following financial factors on road recovery priority after natural/man-made disasters.

Please use this scale: 1 = very low 2 = low 3 = medium 4 = high 5 = very high

Factor	Description	Rating (Weighting)				
		1	2	3	4	5
Direct cost	Cost of road reconstruction or maintenance (materials, labours and equipments).					
Time cost	Cost of time due to congestion, longer trip length and delay time.					
Fuel consumption	Cost of extra fuel consumption caused by congestion, longer trip length and delay time.					
Effect on economic	The decline in economic caused by the delay to works, extra budget for road maintenance, etc.					
Other	State……..					
Other	State……..					

Section 3: Level of importance of each group

Please decide the level of importance (rate of impact) of each of the following factor groups on road recovery priority after natural/man-made disasters.

Please use this scale: 1 = very low 2 = low 3 = medium 4 = high 5 = very high

Factor	Description	Rating (Weighting)				
		1	2	3	4	5
Socio-economic factors	Number of critical socio-economic facilities, area of socio-economic buildings, capacity of socio-economic buildings, population, area served by a road and type of area.					
Road network factors	Type of road, number of nodes, number of links, length of road, number of lanes and pavement structure.					
Traffic factors	Traffic classification, traffic flow, delay time, additional trip length, queue length, level of service, reduction in average speed and traffic control pattern.					
Damage factors	Percentage of damaged road, severity of damage, number of open lanes, number of damaged layers and PSI.					
Financial factors	Direct cost, time cost, fuel consumption and effect on economic.					
Other	State……..					
Other	State……..					

Section 4: Evaluation of Success

4.1 To what extent do you consider the availability of road recovery priority (RRP) model according to the critical estimated factor groups and their included factors presented earlier to be successful in prioritising roads which have been damaged by natural/man-made disasters for recovery and rehabilitation? ☐

Please use this scale: 1 = unsuccessful at all 2 = slightly successful
3 = moderately successful 4 = successful
5 = very successful 6 = extremely successful

4.2 To what extent do you consider your institution (company) use (or plan to use) the road recovery priority (RRP) model or a similar model in its road reconstruction and rehabilitation projects? ☐

Please use this scale: 1 = not used at all 2 = planned to use 3 = slightly used
4 = moderately used 5 = very used 6 = extremely used

End of the pre-interview questionnaire, and thank you

Comments: ……………………………………………………………….…………….

Once again, thank you for taking the time to complete the questionnaire.

Section 5: Researcher Contacts

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APPENDIX C

QUESTIONNAIRE FEEDBACK SAMPLE

UNIVERSITY OF BIRMINGHAM

QUESTIONNAIRE

FACTORS AFFECTING ROAD RECOVERY PRIORITY (RRP) AFTER NATURAL DISASTERS/ARMED CONFLICTS

I am undertaking a research as a partial fulfilment of the requirements for the PhD degree in Highways Engineering in the University of Birmingham in the U.K. My research is about roads recovery priority after natural/man-made disasters. The outcomes of my research will principally benefit the roads sector in Iraq but the knowledge gain can be used for other countries in which their roads are damaged or destroyed by natural/man-made disasters. This questionnaire represents one part of the survey process in my research and it is, however, a very vital part of this research. The aim of this questionnaire is to estimate the impact weight (percentage) of each different factor given subsequently on road recovery priority after natural/man-made disasters. The information that you will provide will help me to carry out my research. This information will only be used for the purpose of the research.

Thank you for taking the time to complete this questionnaire.

Section 1: General Information (Please feel free not to fill all this)

Interviewee (Respondent):

Company/Institution:

Responsibility:

Date: 07 / 07 / 2010

Experience Years: 7 Years

Section 2: Level of importance of each factor within each group

2.1 Please decide the level of importance (rate of impact) of each of the following socio-economic factors on road recovery priority after natural/man-made disasters.

Please use this scale: 1 = very low 2 = low 3 = medium 4 = high 5 = very high

Factor	Description	Rating (Weighting)				
		1	2	3	4	5
No. of critical socio-economic factors	Number of critical socio-economic buildings served by a road. These include government offices, hospitals, schools, universities, banks, mosques, churches, hotels, museums, police stations, factories, grocery stores, centre of commerce and services institutions (water, power, gas, and sewage),…etc.				√	
Area of socio-economic buildings	The total area of the socio-economic buildings served by a road (in m^2).		√			
Capacity of socio-economic buildings	Total number of persons in the socio-economic buildings divided by the total area of these buildings (in person/m^2).			√		
Population	Number of people served by a road (habitant).					√
Area served by a road	Total area served by a road (in km^2).		√			
Type of area	Whether it is urban or rural.				√	
Other	State……..					
Other	State……..					

2.2 Please decide the level of importance (rate of impact) of each of the following road network factors on road recovery priority after natural/man-made disasters.

Please use this scale: 1 = very low 2 = low 3 = medium 4 = high 5 = very high

Factor	Description	Rating (Weighting)				
		1	2	3	4	5
Type of road	The different types of roads (interstate, bridge, highway, primary and secondary routes).					√
Number of nodes	Number of traffic loading/ unloading points to/ from a road.	√				
Number of links	Number of road segments connecting different nodes within a road.				√	
Length of road	Length of the entire road (in km).				√	
Number of lanes	Number of lanes for each road in each direction.			√		
Pavement structure	Whether a pavement is rigid or flexible, and whether a pavement with an overlay or not.	√				
Other	State……..					
Other	State……..					

2.3 Please decide the level of importance (rate of impact) of each of the following traffic factors on road recovery priority after natural/man-made disasters.

Please use this scale: 1 = very low 2 = low 3 = medium 4 = high 5 = very high

Factor	Description	Rating (Weighting)				
		1	2	3	4	5
Traffic classification	Traffic classification in terms of vehicle types. These include cars, light commercial vehicles, mini-buses, buses, light trucks, medium trucks, heavy trucks and articulated vehicles.			√		
Traffic flow	Traffic volume actually travelling on the road (in vpd).				√	
Delay time	The additional delay time caused by congestion and a longer trip length (in min.).					√
Additional trip length	The increase in the trip length caused by traffic diversion onto alternative routes to avoid blocked roads and queuing on links (in km).				√	
Queue length	The length of queue at a specific time caused by congestion (m).					√
Level of service (LOS)	The decline in the level of service caused by the event.			√		
Reduction in average speed	The reduction in vehicle speed caused by the queuing of other vehicles (in km/hr).					√
Traffic control pattern	Whether it is worked with electric traffic signals or not.				√	
Other	State……..					
Other	State……..					

2.4 Please decide the level of importance (rate of impact) of each of the following damage factors on road recovery priority after natural/man-made disasters.

Please use this scale: 1 = very low 2 = low 3 = medium 4 = high 5 = very high

Factor	Description	Rating (Weighting)				
		1	2	3	4	5
Percentage of damaged road	The percentage of a damaged length road out of the road length.				√	
Severity of damage	It is classified as minor, major or severe according to type of damage (roughness, surface distress, structural defect).				√	
Number of open lanes	Number of open lanes in each direction.					√
Number of damaged layers	Number of layers damaged in each direction.			√		
PSI	The decline in the present serviceability index after the event.				√	
Other	State……..					
Other	State……..					

2.5 Please decide the level of importance (rate of impact) of each of the following financial factors on road recovery priority after natural/man-made disasters.

Please use this scale: 1 = very low 2 = low 3 = medium 4 = high 5 = very high

Factor	Description	Rating (Weighting)				
		1	2	3	4	5
Direct cost	Cost of road reconstruction or maintenance (materials, labours and equipments).				√	
Time cost	Cost of time due to congestion, longer trip length and delay time.			√		
Fuel consumption	Cost of extra fuel consumption caused by congestion, longer trip length and delay time.			√		
Effect on economic	The decline in economic caused by the delay to works, extra budget for road maintenance, etc….					√
Other	State……..					
Other	State……..					

Section 3: Level of importance of each group

Please decide the level of importance (rate of impact) of each of the following factor groups on road recovery priority after natural/man-made disasters.

Please use this scale: 1 = very low 2 = low 3 = medium 4 = high 5 = very high

Factor	Description	Rating (Weighting)				
		1	2	3	4	5
Socio-economic factors	Number of critical socio-economic facilities, area of socio-economic buildings, capacity of socio-economic buildings, population, area served by a road and type of area.		√			
Road network factors	Type of road, number of nodes, number of links, length of road, number of lanes and pavement structure.				√	
Traffic factors	Traffic classification, traffic flow, delay time, additional trip length, queue length, level of service, reduction in average speed and traffic control pattern.					√
Damage factors	Percentage of damaged road, severity of damage, number of open lanes, number of damaged layers and PSI.				√	
Financial factors	Direct cost, time cost, fuel consumption and effect on economic.					√
Other	State……..					
Other	State……..					

Section 4: Evaluation of Success

4.1 To what extent do you consider the availability of road recovery priority (RRP) model according to the critical estimated factor groups and their included factors presented earlier to be successful in prioritising roads which have been damaged by natural/man-made disasters for recovery and rehabilitation? [5]

Please use this scale: 1 = unsuccessful at all 2 = slightly successful
3 = moderately successful 4 = successful
5 = very successful 6 = extremely successful

4.2 To what extent do you consider your institution (company) use (or plan to use) the road recovery priority (RRP) model or a similar model in its road reconstruction and rehabilitation projects? [1]

Please use this scale: 1 = not used at all 2 = planned to use 3 = slightly used
4 = moderately used 5 = very used 6 = extremely used

End of the pre-interview questionnaire, and thank you

Comments: Put into consideration the effect of the security check point's factor.

Once again, thank you for taking the time to complete the questionnaire.

Section 5: Researcher Contacts

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APPENDIX D

QUESTIONNAIRE DATA BASE

Appendix D.1 Respondent's Evaluation for Section 2 of the Questionnaire

Table D.1 Respondent's evaluation for factors in group 1 (Socio-economic factor group)

No.	Experience Years (E)	Weight for E	Respondent's Evaluation					
			$F_{1,1}$	$F_{1,2}$	$F_{1,3}$	$F_{1,4}$	$F_{1,5}$	$F_{1,6}$
1	17	0.5	5	3	4	5	2	3
2	9	0.3	4	3	4	5	3	3
3	11	0.5	4	3	4	3	2	4
4	22	0.5	4	2	3	4	3	5
5	18	0.5	5	2	3	4	2	3
6	4	0.2	5	4	3	5	2	5
7	12	0.5	5	1	2	4	4	2
8	23	0.5	4	1	2	5	5	5
9	16	0.5	4	2	1	3	3	4
10	15	0.5	4	3	4	5	1	4
11	8	0.3	4	2	3	3	5	4
12	25	0.5	5	1	2	5	4	5
13	13	0.5	4	3	3	4	4	3
14	10	0.3	4	4	4	5	2	4
15	17	0.5	5	1	2	5	4	4
16	17	0.5	4	1	2	4	1	1
17	5	0.2	4	2	2	5	2	4
18	11	0.5	4	3	3	3	4	4
19	19	0.5	5	3	4	5	3	5
20	14	0.5	4	3	4	3	3	4
21	3	0.2	3	4	5	4	3	4
22	20	0.5	5	2	3	4	2	3
23	20	0.5	5	2	3	4	5	5
24	17	0.5	5	2	2	5	3	4
25	14	0.5	4	1	1	5	3	4
26	9	0.3	5	1	1	5	3	4
27	9	0.3	5	1	2	4	2	5
28	10	0.3	4	1	2	3	2	3
29	13	0.5	4	1	2	4	1	5
30	19	0.5	3	2	3	4	4	3
31	12	0.5	5	1	1	5	4	4
32	5	0.2	3	2	3	4	2	2
33	21	0.5	4	1	2	4	3	5
34	6	0.3	5	3	3	5	4	4
35	18	0.5	4	1	2	5	2	5

No.	Experience Years (E)	Weight for E	Respondent's Evaluation					
			$F_{1,1}$	$F_{1,2}$	$F_{1,3}$	$F_{1,4}$	$F_{1,5}$	$F_{1,6}$
36	11	0.5	1	3	4	3	3	1
37	10	0.3	3	1	2	2	3	4
38	8	0.3	5	4	5	3	3	2
39	9	0.3	5	5	4	4	4	2
40	17	0.5	5	3	4	5	4	5
41	17	0.5	3	1	2	5	5	4
42	22	0.5	5	3	3	4	3	5
43	30	0.5	5	1	2	5	3	5
44	28	0.5	5	2	1	4	2	4
45	8	0.3	4	3	3	4	1	4
46	16	0.5	5	2	3	4	3	4
47	16	0.5	4	1	2	4	2	2
48	4	0.2	3	1	1	4	2	4
49	11	0.5	5	1	1	4	2	4
50	11	0.5	3	2	3	4	3	4
51	11	0.5	3	1	2	4	1	2
52	19	0.5	4	2	2	4	3	3
53	19	0.5	5	1	1	5	4	2
54	20	0.5	5	3	3	5	3	4
55	18	0.5	5	2	3	4	2	5
56	12	0.5	5	3	3	5	4	4
57	8	0.3	3	1	2	4	2	1
58	8	0.3	5	1	1	3	5	4
59	9	0.3	3	1	1	4	4	5
60	5	0.2	1	2	3	2	4	1
61	13	0.5	4	2	2	5	2	5
62	13	0.5	5	2	3	4	3	4
63	27	0.5	4	2	2	4	1	4
64	15	0.5	4	2	2	5	2	3
65	15	0.5	5	3	4	5	4	3
66	14	0.5	4	4	5	4	3	5
67	8	0.3	4	1	2	5	2	4
68	11	0.5	4	1	1	4	3	4
69	6	0.3	5	5	5	3	3	4
70	19	0.5	5	4	4	4	3	5
71	9	0.3	3	3	4	2	4	3
72	12	0.5	3	1	2	5	4	2
73	18	0.5	4	2	3	4	4	5
74	23	0.5	5	1	1	4	3	4
75	17	0.5	5	2	2	5	3	5

No.	Experience Years (E)	Weight for E	Respondent's Evaluation					
			$F_{1,1}$	$F_{1,2}$	$F_{1,3}$	$F_{1,4}$	$F_{1,5}$	$F_{1,6}$
76	17	0.5	5	3	4	5	3	5
77	7	0.3	4	2	3	5	2	4
78	16	0.5	4	2	2	4	2	3
79	19	0.5	5	2	3	3	1	4
80	20	0.5	5	1	2	4	4	2
81	6	0.3	5	3	3	4	4	4
82	10	0.3	4	1	2	5	5	4
83	10	0.3	4	1	1	4	2	1
84	4	0.2	3	1	1	4	2	4
85	9	0.3	3	2	2	5	5	3
86	16	0.5	5	1	2	5	4	1

Table D.2 Respondent's evaluation for factors in group 2 (Road network factor group)

No.	Experience Years (E)	Weight for E	Respondent's Evaluation					
			$F_{2,1}$	$F_{2,2}$	$F_{2,3}$	$F_{2,4}$	$F_{2,5}$	$F_{2,6}$
1	17	0.5	4	5	5	2	4	1
2	9	0.3	5	3	3	2	2	2
3	11	0.5	4	3	3	2	3	4
4	22	0.5	3	2	2	3	1	2
5	18	0.5	5	1	1	1	3	3
6	4	0.2	5	3	4	3	5	4
7	12	0.5	5	4	5	4	4	3
8	23	0.5	5	4	4	4	4	3
9	16	0.5	4	3	3	4	4	2
10	15	0.5	3	3	2	3	2	1
11	8	0.3	5	4	4	3	3	4
12	25	0.5	5	3	3	2	3	2
13	13	0.5	4	4	3	3	2	3
14	10	0.3	3	4	4	5	4	4
15	17	0.5	5	4	4	4	4	2
16	17	0.5	4	3	3	4	4	1
17	5	0.2	4	5	4	4	4	1
18	11	0.5	4	3	2	3	4	2
19	19	0.5	5	3	3	2	3	4
20	14	0.5	5	4	4	4	3	3
21	3	0.2	3	3	4	3	3	2
22	20	0.5	5	2	2	3	4	2
23	20	0.5	4	4	4	4	3	4
24	17	0.5	5	4	3	3	3	2
25	14	0.5	4	3	3	2	3	1
26	9	0.3	5	3	3	4	4	2
27	9	0.3	5	4	5	4	4	2
28	10	0.3	5	2	3	4	4	3
29	13	0.5	5	5	4	4	5	3
30	19	0.5	4	3	3	5	3	4
31	12	0.5	5	4	3	3	4	4
32	5	0.2	4	2	2	4	2	3
33	21	0.5	5	2	3	5	4	1
34	6	0.3	4	3	3	5	4	4
35	18	0.5	4	5	5	5	5	2
36	11	0.5	3	3	4	5	4	1
37	10	0.3	5	5	4	5	3	2
38	8	0.3	5	2	3	3	3	4

No.	Experience Years (E)	Weight for E	Respondent's Evaluation					
			$F_{2,1}$	$F_{2,2}$	$F_{2,3}$	$F_{2,4}$	$F_{2,5}$	$F_{2,6}$
39	9	0.3	5	4	4	2	3	2
40	17	0.5	5	4	4	3	4	1
41	17	0.5	3	4	3	3	3	4
42	22	0.5	5	4	4	4	5	2
43	30	0.5	4	5	4	5	5	3
44	28	0.5	5	5	4	4	4	2
45	8	0.3	4	5	4	4	5	2
46	16	0.5	5	3	3	4	3	1
47	16	0.5	3	2	2	2	3	2
48	4	0.2	5	3	3	5	4	4
49	11	0.5	5	4	4	4	4	3
50	11	0.5	4	5	5	4	4	4
51	11	0.5	3	4	4	4	3	1
52	19	0.5	4	3	4	4	4	4
53	19	0.5	3	4	4	4	4	2
54	20	0.5	4	4	4	5	4	1
55	18	0.5	5	4	4	5	4	4
56	12	0.5	3	3	5	2	3	3
57	8	0.3	4	3	3	3	3	2
58	8	0.3	5	3	3	3	5	1
59	9	0.3	4	4	3	3	2	3
60	5	0.2	1	1	2	1	3	2
61	13	0.5	5	4	4	4	4	3
62	13	0.5	4	3	4	5	4	3
63	27	0.5	4	4	2	5	5	2
64	15	0.5	5	3	4	5	4	2
65	15	0.5	5	4	3	3	3	1
66	14	0.5	4	4	3	4	3	2
67	8	0.3	4	4	3	2	3	4
68	11	0.5	4	3	5	5	4	3
69	6	0.3	4	5	3	4	3	4
70	19	0.5	3	4	4	5	5	1
71	9	0.3	4	4	3	2	5	4
72	12	0.5	5	4	4	3	4	3
73	18	0.5	5	3	4	5	5	3
74	23	0.5	4	3	3	5	4	2
75	17	0.5	5	3	2	4	2	1
76	17	0.5	4	4	3	2	3	4
77	7	0.3	5	1	4	4	3	1
78	16	0.5	3	4	5	3	2	3

No.	Experience Years (E)	Weight for E	Respondent's Evaluation					
			$F_{2,1}$	$F_{2,2}$	$F_{2,3}$	$F_{2,4}$	$F_{2,5}$	$F_{2,6}$
79	19	0.5	5	3	4	4	4	4
80	20	0.5	5	4	3	4	4	2
81	6	0.3	4	4	2	4	4	1
82	10	0.3	5	2	1	5	4	2
83	10	0.3	4	5	4	5	3	2
84	4	0.2	4	3	5	5	3	3
85	9	0.3	4	5	4	5	5	1
86	16	0.5	4	3	3	2	2	3

Table D.3 Respondent's evaluation for factors in group 3 (Traffic factor group)

No.	Experience Years (E)	Weight for E	Respondent's Evaluation							
			$F_{3,1}$	$F_{3,2}$	$F_{3,3}$	$F_{3,4}$	$F_{3,5}$	$F_{3,6}$	$F_{3,7}$	$F_{3,8}$
1	17	0.5	2	5	5	5	5	5	5	4
2	9	0.3	2	4	5	3	4	3	4	2
3	11	0.5	4	5	4	5	5	5	4	3
4	22	0.5	1	3	3	2	3	3	3	2
5	18	0.5	4	5	3	3	4	2	2	1
6	4	0.2	5	5	3	2	3	5	3	5
7	12	0.5	4	5	4	4	4	3	3	3
8	23	0.5	4	4	5	5	5	5	5	4
9	16	0.5	5	4	5	4	3	3	3	3
10	15	0.5	2	3	3	4	4	3	4	3
11	8	0.3	4	4	4	4	4	3	5	5
12	25	0.5	5	4	5	4	3	5	4	3
13	13	0.5	5	4	3	4	3	4	4	3
14	10	0.3	4	4	4	5	5	2	4	3
15	17	0.5	4	5	4	4	4	4	3	3
16	17	0.5	3	3	4	5	4	3	5	4
17	5	0.2	3	4	5	5	4	5	5	5
18	11	0.5	5	4	4	3	4	4	4	3
19	19	0.5	3	4	5	4	3	5	4	3
20	14	0.5	3	5	5	3	4	5	4	4
21	3	0.2	3	4	3	3	3	3	5	3
22	20	0.5	3	5	4	4	4	5	4	2
23	20	0.5	4	5	5	4	5	5	5	5
24	17	0.5	4	5	4	4	3	4	3	3
25	14	0.5	5	4	4	3	3	5	4	4
26	9	0.3	4	4	5	5	4	5	5	5
27	9	0.3	2	5	5	5	5	4	4	4
28	10	0.3	4	5	5	5	5	3	5	2
29	13	0.5	5	5	5	5	5	5	4	4
30	19	0.5	3	4	4	3	4	5	4	4
31	12	0.5	3	4	5	5	4	3	5	4
32	5	0.2	3	4	4	3	3	4	4	4
33	21	0.5	4	5	5	5	5	5	5	5
34	6	0.3	4	5	5	5	5	5	5	5
35	18	0.5	5	5	5	5	5	5	5	5
36	11	0.5	5	4	5	5	5	4	4	4
37	10	0.3	5	5	5	4	4	5	5	3
38	8	0.3	4	4	5	3	3	4	4	3

No.	Experience Years (E)	Weight for E	Respondent's Evaluation							
			$F_{3,1}$	$F_{3,2}$	$F_{3,3}$	$F_{3,4}$	$F_{3,5}$	$F_{3,6}$	$F_{3,7}$	$F_{3,8}$
39	9	0.3	5	4	5	3	4	5	5	3
40	17	0.5	4	5	5	4	5	4	4	3
41	17	0.5	3	4	5	3	3	4	4	3
42	22	0.5	4	5	4	4	5	3	3	2
43	30	0.5	5	4	5	3	4	4	2	1
44	28	0.5	4	5	5	5	4	4	5	4
45	8	0.3	3	4	5	5	5	4	5	4
46	16	0.5	5	4	4	4	5	3	4	4
47	16	0.5	2	2	4	3	2	4	4	2
48	4	0.2	3	5	5	4	5	3	4	3
49	11	0.5	5	4	4	4	4	3	4	5
50	11	0.5	4	4	5	5	4	4	5	4
51	11	0.5	3	5	4	5	5	4	5	4
52	19	0.5	4	4	3	2	4	4	4	4
53	19	0.5	5	5	5	5	5	4	5	5
54	20	0.5	4	5	5	5	4	5	5	4
55	18	0.5	4	5	4	5	5	4	5	4
56	12	0.5	4	4	5	3	5	5	5	3
57	8	0.3	3	3	3	4	2	4	4	2
58	8	0.3	3	5	5	3	4	4	4	4
59	9	0.3	4	4	5	4	3	5	5	4
60	5	0.2	1	5	4	3	2	4	1	1
61	13	0.5	5	5	5	4	5	5	4	4
62	13	0.5	2	5	4	4	5	4	3	3
63	27	0.5	4	5	5	4	3	5	4	3
64	15	0.5	5	4	4	5	4	4	5	4
65	15	0.5	4	4	5	4	4	5	4	5
66	14	0.5	4	5	5	5	3	4	5	3
67	8	0.3	4	5	3	5	3	5	4	3
68	11	0.5	3	5	4	3	5	4	4	4
69	6	0.3	5	4	5	4	4	4	5	3
70	19	0.5	3	4	4	3	4	3	4	2
71	9	0.3	3	4	4	3	4	4	5	3
72	12	0.5	3	5	5	5	3	4	4	3
73	18	0.5	4	4	5	5	5	3	4	2
74	23	0.5	4	4	5	4	4	5	3	1
75	17	0.5	5	2	5	3	4	4	3	4
76	17	0.5	5	5	4	4	5	5	3	4
77	7	0.3	3	4	5	4	5	3	5	4
78	16	0.5	4	4	5	5	2	5	4	2

No.	Experience Years (E)	Weight for E	Respondent's Evaluation							
			$F_{3,1}$	$F_{3,2}$	$F_{3,3}$	$F_{3,4}$	$F_{3,5}$	$F_{3,6}$	$F_{3,7}$	$F_{3,8}$
79	19	0.5	5	5	5	2	5	3	4	3
80	20	0.5	4	4	4	3	4	4	3	4
81	6	0.3	3	3	5	4	4	4	3	3
82	10	0.3	2	5	4	5	5	5	3	2
83	10	0.3	4	5	4	4	3	4	3	4
84	4	0.2	1	5	3	4	4	5	5	4
85	9	0.3	4	4	3	4	3	4	3	1
86	16	0.5	5	4	4	3	4	4	4	1

Table D.4 Respondent's evaluation for factors in group 4 (Damage factor group)

No.	Experience Years (E)	Weight for E	Respondent's Evaluation				
			$F_{4,1}$	$F_{4,2}$	$F_{4,3}$	$F_{4,4}$	$F_{4,5}$
1	17	0.5	5	4	2	3	4
2	9	0.3	4	4	2	4	2
3	11	0.5	3	4	4	3	3
4	22	0.5	5	5	4	3	4
5	18	0.5	4	4	3	3	3
6	4	0.2	3	5	3	2	3
7	12	0.5	5	5	4	3	3
8	23	0.5	4	5	4	3	4
9	16	0.5	5	4	4	4	3
10	15	0.5	3	4	3	3	3
11	8	0.3	5	5	2	1	4
12	25	0.5	5	4	4	4	3
13	13	0.5	4	4	4	1	3
14	10	0.3	4	4	4	2	3
15	17	0.5	3	4	3	3	4
16	17	0.5	5	5	4	3	4
17	5	0.2	4	4	2	4	4
18	11	0.5	5	5	2	1	4
19	19	0.5	5	4	4	1	3
20	14	0.5	5	4	3	2	3
21	3	0.2	4	4	3	4	4
22	20	0.5	4	5	3	3	4
23	20	0.5	3	4	4	1	4
24	17	0.5	4	2	3	3	4
25	14	0.5	5	4	4	5	4
26	9	0.3	4	5	3	3	4
27	9	0.3	4	5	2	1	1
28	10	0.3	5	5	3	2	2
29	13	0.5	5	5	5	4	4
30	19	0.5	3	2	4	1	3
31	12	0.5	2	4	4	2	5
32	5	0.2	3	2	4	4	3
33	21	0.5	4	4	2	3	4
34	6	0.3	4	4	4	2	3
35	18	0.5	4	5	2	3	5
36	11	0.5	4	3	4	2	4
37	10	0.3	4	4	4	3	5
38	8	0.3	4	4	3	1	3

No.	Experience Years (E)	Weight for E	Respondent's Evaluation				
			$F_{4,1}$	$F_{4,2}$	$F_{4,3}$	$F_{4,4}$	$F_{4,5}$
39	9	0.3	4	3	4	3	3
40	17	0.5	5	5	5	3	4
41	17	0.5	4	4	4	3	3
42	22	0.5	4	3	4	4	4
43	30	0.5	5	2	2	3	5
44	28	0.5	4	4	2	3	3
45	8	0.3	4	5	4	4	5
46	16	0.5	4	5	2	3	4
47	16	0.5	3	5	3	3	3
48	4	0.2	5	4	5	3	4
49	11	0.5	5	4	4	4	4
50	11	0.5	4	3	3	3	4
51	11	0.5	3	4	4	3	4
52	19	0.5	4	5	4	4	3
53	19	0.5	5	5	2	3	4
54	20	0.5	5	4	4	1	2
55	18	0.5	4	4	4	2	2
56	12	0.5	2	5	5	1	2
57	8	0.3	4	4	3	2	3
58	8	0.3	5	4	3	4	4
59	9	0.3	4	4	3	3	4
60	5	0.2	2	4	3	1	1
61	13	0.5	4	5	2	3	2
62	13	0.5	5	4	3	2	4
63	27	0.5	4	4	3	3	1
64	15	0.5	4	5	4	1	2
65	15	0.5	3	4	3	1	4
66	14	0.5	5	5	4	2	3
67	8	0.3	4	4	3	4	2
68	11	0.5	5	4	5	3	3
69	6	0.3	5	4	3	2	5
70	19	0.5	5	4	5	3	3
71	9	0.3	5	5	3	3	2
72	12	0.5	3	3	4	2	3
73	18	0.5	2	4	4	3	4
74	23	0.5	3	4	4	4	3
75	17	0.5	4	3	4	3	3
76	17	0.5	4	5	4	3	3
77	7	0.3	4	4	5	3	4
78	16	0.5	5	5	4	2	3

No.	Experience Years (E)	Weight for E	Respondent's Evaluation				
			$F_{4,1}$	$F_{4,2}$	$F_{4,3}$	$F_{4,4}$	$F_{4,5}$
79	19	0.5	4	4	3	3	3
80	20	0.5	3	5	4	3	4
81	6	0.3	5	5	3	1	3
82	10	0.3	4	5	5	2	1
83	10	0.3	5	4	4	3	2
84	4	0.2	3	4	3	3	4
85	9	0.3	5	5	4	2	3
86	16	0.5	3	5	3	3	1

Table D.5 Respondent's evaluation for factors in group 5 (Financial factor group)

No.	Experience Years (E)	Weight for E	Respondent's Evaluation			
			$F_{5,1}$	$F_{5,2}$	$F_{5,3}$	$F_{5,4}$
1	17	0.5	4	3	2	5
2	9	0.3	4	4	3	4
3	11	0.5	4	4	4	5
4	22	0.5	4	3	3	4
5	18	0.5	4	2	2	5
6	4	0.2	3	3	3	4
7	12	0.5	5	4	3	3
8	23	0.5	4	3	2	5
9	16	0.5	5	4	2	3
10	15	0.5	3	4	2	4
11	8	0.3	4	2	1	5
12	25	0.5	4	4	2	5
13	13	0.5	5	4	3	3
14	10	0.3	4	4	3	5
15	17	0.5	3	4	4	4
16	17	0.5	4	3	3	5
17	5	0.2	4	2	3	4
18	11	0.5	5	4	4	4
19	19	0.5	5	4	2	3
20	14	0.5	4	3	4	3
21	3	0.2	3	4	3	4
22	20	0.5	4	3	2	4
23	20	0.5	4	2	1	5
24	17	0.5	5	3	4	5
25	14	0.5	2	3	3	3
26	9	0.3	5	2	1	5
27	9	0.3	3	3	3	4
28	10	0.3	5	4	2	4
29	13	0.5	3	3	3	4
30	19	0.5	4	3	3	4
31	12	0.5	4	2	2	3
32	5	0.2	4	3	3	4
33	21	0.5	4	2	3	5
34	6	0.3	4	3	3	4
35	18	0.5	5	2	1	4
36	11	0.5	3	2	1	5
37	10	0.3	4	4	1	4
38	8	0.3	5	1	2	5

No.	Experience Years (E)	Weight for E	Respondent's Evaluation			
			$F_{5,1}$	$F_{5,2}$	$F_{5,3}$	$F_{5,4}$
39	9	0.3	5	4	1	5
40	17	0.5	4	2	3	4
41	17	0.5	5	4	1	5
42	22	0.5	5	4	4	5
43	30	0.5	5	2	1	5
44	28	0.5	5	3	2	5
45	8	0.3	4	2	1	5
46	16	0.5	5	4	3	4
47	16	0.5	2	2	1	5
48	4	0.2	5	2	1	5
49	11	0.5	5	4	2	4
50	11	0.5	4	3	2	5
51	11	0.5	4	2	1	5
52	19	0.5	4	3	3	4
53	19	0.5	5	5	1	5
54	20	0.5	5	2	2	5
55	18	0.5	5	1	2	5
56	12	0.5	3	1	2	5
57	8	0.3	4	4	3	4
58	8	0.3	5	3	2	5
59	9	0.3	4	2	4	5
60	5	0.2	5	2	3	4
61	13	0.5	5	2	1	5
62	13	0.5	4	4	2	4
63	27	0.5	4	2	2	4
64	15	0.5	5	4	3	5
65	15	0.5	3	4	2	5
66	14	0.5	4	4	2	5
67	8	0.3	5	2	1	5
68	11	0.5	5	3	3	4
69	6	0.3	4	2	1	4
70	19	0.5	5	4	3	5
71	9	0.3	5	3	2	4
72	12	0.5	4	3	3	3
73	18	0.5	5	1	3	4
74	23	0.5	3	3	2	5
75	17	0.5	5	3	3	4
76	17	0.5	4	2	2	3
77	7	0.3	4	3	3	5
78	16	0.5	3	2	3	4

No.	Experience Years (E)	Weight for E	Respondent's Evaluation			
			$F_{5,1}$	$F_{5,2}$	$F_{5,3}$	$F_{5,4}$
79	19	0.5	4	3	1	4
80	20	0.5	3	4	2	5
81	6	0.3	5	3	2	4
82	10	0.3	4	2	1	5
83	10	0.3	5	3	3	5
84	4	0.2	5	4	2	4
85	9	0.3	3	2	1	5
86	16	0.5	4	4	1	5

Appendix D.2 Respondent's Evaluation for Section 3 of the Questionnaire

Table D.6 Respondent's evaluation for all groups

No.	Experience Years (E)	Weight for E	Respondent's Evaluation				
			G_1	G_2	G_3	G_4	G_5
1	17	0.5	5	5	3	2	5
2	9	0.3	3	4	5	4	4
3	11	0.5	4	3	4	4	5
4	22	0.5	5	4	4	4	4
5	18	0.5	5	4	4	5	4
6	4	0.2	4	4	3	4	5
7	12	0.5	5	4	4	4	5
8	23	0.5	5	4	4	4	5
9	16	0.5	5	3	4	4	3
10	15	0.5	3	2	3	4	4
11	8	0.3	5	5	5	5	5
12	25	0.5	5	3	4	4	3
13	13	0.5	4	4	5	3	3
14	10	0.3	4	4	4	4	5
15	17	0.5	5	3	4	4	3
16	17	0.5	3	3	3	5	5
17	5	0.2	4	4	5	4	4
18	11	0.5	5	4	4	3	4
19	19	0.5	5	3	4	4	3
20	14	0.5	5	4	5	4	4
21	3	0.2	3	3	4	4	5
22	20	0.5	3	4	5	5	4
23	20	0.5	3	4	4	5	5
24	17	0.5	4	3	3	2	5
25	14	0.5	4	3	5	5	4
26	9	0.3	4	4	4	5	4
27	9	0.3	4	4	5	5	4
28	10	0.3	4	3	5	5	4
29	13	0.5	4	4	4	4	3
30	19	0.5	5	3	4	3	2
31	12	0.5	2	1	3	5	4
32	5	0.2	4	3	3	3	2
33	21	0.5	5	5	5	4	5
34	6	0.3	4	4	4	5	5
35	18	0.5	5	4	5	5	4
36	11	0.5	3	4	4	5	4

No.	Experience Years (E)	Weight for E	Respondent's Evaluation				
			G_1	G_2	G_3	G_4	G_5
37	10	0.3	2	5	5	5	4
38	8	0.3	5	4	4	3	5
39	9	0.3	4	2	3	4	5
40	17	0.5	5	5	4	5	3
41	17	0.5	4	4	5	5	5
42	22	0.5	4	4	5	4	5
43	30	0.5	5	5	4	4	5
44	28	0.5	4	4	5	4	5
45	8	0.3	4	4	5	4	5
46	16	0.5	5	4	4	4	4
47	16	0.5	4	2	2	3	4
48	4	0.2	4	4	5	5	5
49	11	0.5	4	4	3	4	4
50	11	0.5	4	4	5	4	5
51	11	0.5	4	4	5	4	5
52	19	0.5	4	4	2	4	4
53	19	0.5	5	4	4	5	5
54	20	0.5	5	4	4	5	5
55	18	0.5	4	4	5	4	5
56	12	0.5	4	5	5	5	4
57	8	0.3	4	3	3	4	4
58	8	0.3	3	4	5	5	5
59	9	0.3	3	3	4	4	5
60	5	0.2	5	4	3	2	5
61	13	0.5	3	4	5	5	5
62	13	0.5	4	3	5	5	4
63	27	0.5	5	4	4	4	4
64	15	0.5	4	3	4	4	5
65	15	0.5	5	1	3	4	5
66	14	0.5	3	3	3	5	3
67	8	0.3	2	5	5	4	5
68	11	0.5	5	4	4	5	5
69	6	0.3	4	4	5	2	3
70	19	0.5	5	4	4	5	5
71	9	0.3	4	5	5	5	3
72	12	0.5	4	4	4	5	5
73	18	0.5	4	4	3	5	4
74	23	0.5	4	3	5	4	4
75	17	0.5	4	3	4	3	3
76	17	0.5	5	4	5	5	4

No.	Experience Years (E)	Weight for E	Respondent's Evaluation				
			G_1	G_2	G_3	G_4	G_5
77	7	0.3	2	4	5	4	5
78	16	0.5	4	3	4	4	3
79	19	0.5	5	4	5	3	4
80	20	0.5	4	3	4	5	5
81	6	0.3	5	4	4	4	3
82	10	0.3	4	4	4	4	5
83	10	0.3	5	3	3	5	5
84	4	0.2	5	2	4	5	3
85	9	0.3	5	5	5	3	4
86	16	0.5	3	3	4	4	5

Appendix D.3 Respondent's Evaluation for Section 4 of the Questionnaire

Table D.7 Respondent's evaluation for section 4 of the questionnaire

No.	Experience Years (E)	Weight for E	Respondent's Evaluation	
			Question 1	Question 2
1	17	0.5	6	1
2	9	0.3	5	1
3	11	0.5	4	1
4	22	0.5	5	2
5	18	0.5	6	2
6	4	0.2	5	2
7	12	0.5	5	2
8	23	0.5	3	2
9	16	0.5	6	2
10	15	0.5	6	2
11	8	0.3	6	3
12	25	0.5	6	3
13	13	0.5	6	1
14	10	0.3	6	1
15	17	0.5	5	1
16	17	0.5	4	1
17	5	0.2	6	1
18	11	0.5	3	3
19	19	0.5	5	2
20	14	0.5	6	2
21	3	0.2	5	2
22	20	0.5	6	2
23	20	0.5	5	2
24	17	0.5	6	2
25	14	0.5	5	2
26	9	0.3	5	2
27	9	0.3	5	2
28	10	0.3	5	1
29	13	0.5	5	1
30	19	0.5	5	1
31	12	0.5	6	1
32	5	0.2	6	3
33	21	0.5	4	1
34	6	0.3	6	1
35	18	0.5	2	1
36	11	0.5	5	1

No.	Experience Years (E)	Weight for E	Respondent's Evaluation	
			Question 1	Question 2
37	10	0.3	3	2
38	8	0.3	6	2
39	9	0.3	6	4
40	17	0.5	6	2
41	17	0.5	4	2
42	22	0.5	5	2
43	30	0.5	4	2
44	28	0.5	5	2
45	8	0.3	5	2
46	16	0.5	5	2
47	16	0.5	4	2
48	4	0.2	5	2
49	11	0.5	4	2
50	11	0.5	6	1
51	11	0.5	6	1
52	19	0.5	5	1
53	19	0.5	5	2
54	20	0.5	3	2
55	18	0.5	5	2
56	12	0.5	5	2
57	8	0.3	4	2
58	8	0.3	4	2
59	9	0.3	6	2
60	5	0.2	6	2
61	13	0.5	6	2
62	13	0.5	4	2
63	27	0.5	5	2
64	15	0.5	4	2
65	15	0.5	5	3
66	14	0.5	3	2
67	8	0.3	6	2
68	11	0.5	5	2
69	6	0.3	4	2
70	19	0.5	5	2
71	9	0.3	5	2
72	12	0.5	6	2
73	18	0.5	5	2
74	23	0.5	5	2
75	17	0.5	5	2
76	17	0.5	6	1

No.	Experience Years (E)	Weight for E	Respondent's Evaluation	
			Question 1	Question 2
77	7	0.3	5	1
78	16	0.5	3	1
79	19	0.5	6	1
80	20	0.5	5	1
81	6	0.3	5	1
82	10	0.3	4	1
83	10	0.3	6	2
84	4	0.2	5	2
85	9	0.3	5	2
86	16	0.5	6	2

APPENDIX E

RELIABILITY, VALIDITY AND CORRELATION RESULTS BY USING SPSS PROGRAMME

Appendix E.1 Reliability Results by using SPSS Programme

Group 1

Case Processing Summary

		N	%
Cases	Valid	86	100.0
	Excluded	0	.0
	Total	86	100.0

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.846	.845	6

Item Statistics

	Mean	Std. Deviation	N
FACTOR1	1.8163	.64331	86
FACTOR2	.8535	.45185	86
FACROR3	1.0907	.52527	86
FACTOR4	1.7930	.59740	86
FACTOR5	1.2605	.56906	86
FACTOR6	1.5767	.68060	86

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	1.398	.853	1.816	.963	2.128	.155	6
Item Variances	.340	.204	.463	.259	2.269	.009	6

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
FACTOR1	6.5744	4.414	.768	.704	.790
FACTOR2	7.5372	5.587	.520	.763	.840
FACROR3	7.3000	5.241	.576	.771	.830
FACTOR4	6.5977	4.676	.724	.690	.801
FACTOR5	7.1302	5.249	.510	.319	.842
FACTOR6	6.8140	4.483	.679	.507	.811

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
8.3907	6.903	2.62735	6

Group 2

Case Processing Summary

		N	%
Cases	Valid	86	100.0
	Excluded	0	.0
	Total	86	100.0

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.884	.882	6

Item Statistics

	Mean	Std. Deviation	N
FACTOR1	1.8209	.57520	86
FACTOR2	1.4965	.56390	86
FACTOR3	1.4674	.56661	86
FACTOR4	1.5558	.62017	86
FACTOR5	1.5233	.55639	86
FACTOR6	1.0477	.52597	86

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	1.485	1.048	1.821	.773	1.738	.062	6
Item Variances	.323	.277	.385	.108	1.390	.001	6

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
FACTOR1	7.0907	5.167	.712	.542	.861
FACTOR2	7.4151	5.073	.775	.670	.850
FACTOR3	7.4442	5.030	.791	.689	.847
FACTOR4	7.3558	5.049	.691	.584	.865
FACTOR5	7.3884	5.062	.794	.691	.847
FACTOR6	7.8640	6.002	.420	.249	.903

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
8.9116	7.360	2.71299	6

Group 3

Case Processing Summary

		N	%
Cases	Valid	86	100.0
	Excluded	0	.0
	Total	86	100.0

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.945	.946	8

Item Statistics

	Mean	Std. Deviation	N
FACTOR1	1.6221	.65823	86
FACTOR2	1.8442	.57222	86
FACTOR3	1.8791	.57988	86
FACTOR4	1.6988	.59240	86
FACTOR5	1.7233	.60637	86
FACTOR6	1.7442	.57775	86
FACTOR7	1.7256	.54690	86
FACTOR8	1.4140	.58915	86

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	1.706	1.414	1.879	.465	1.329	.021	8
Item Variances	.349	.299	.433	.134	1.449	.002	8

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
FACTOR1	12.0291	12.329	.739	.586	.943
FACTOR2	11.8070	12.483	.833	.761	.936
FACTOR3	11.7721	12.289	.874	.795	.933
FACTOR4	11.9523	12.439	.811	.705	.937
FACTOR5	11.9279	12.343	.814	.726	.937
FACTOR6	11.9070	12.569	.800	.705	.938
FACTOR7	11.9256	12.652	.830	.762	.936
FACTOR8	12.2372	12.771	.727	.613	.943

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
13.6512	16.180	4.02243	8

Group 4

Case Processing Summary

		N	%
Cases	Valid	86	100.0
	Excluded	0	.0
	Total	86	100.0

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.848	.848	5

Item Statistics

	Mean	Std. Deviation	N
FACTOR1	1.7337	.57836	86
FACTOR2	1.7814	.56662	86
FACTOR3	1.4860	.55924	86
FACTOR4	1.1360	.51630	86
FACTOR5	1.4070	.56021	86

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	1.509	1.136	1.781	.645	1.568	.069	5
Item Variances	.310	.267	.334	.068	1.255	.001	5

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
FACTOR1	5.8105	3.027	.724	.539	.799
FACTOR2	5.7628	3.104	.698	.522	.806
FACTOR3	6.0581	3.241	.628	.415	.825
FACTOR4	6.4081	3.407	.601	.375	.832
FACTOR5	6.1372	3.227	.635	.418	.823

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
7.5442	4.819	2.19527	5

Group 5

Case Processing Summary

		N	%
Cases	Valid	86	100.0
	Excluded	0	.0
	Total	86	100.0

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.802	.801	4

Item Statistics

	Mean	Std. Deviation	N
FACTOR1	1.7767	.56333	86
FACTOR2	1.2628	.54364	86
FACTOR3	.9686	.48852	86
FACTOR4	1.8616	.55839	86

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	1.467	.969	1.862	.893	1.922	.181	4
Item Variances	.291	.239	.317	.079	1.330	.001	4

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
FACTOR1	4.0930	1.593	.710	.526	.703
FACTOR2	4.6070	1.706	.647	.427	.737
FACTOR3	4.9012	1.976	.514	.306	.798
FACTOR4	4.0081	1.729	.599	.435	.761

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
5.8698	2.920	1.70881	4

All Groups

Case Processing Summary

		N	%
Cases	Valid	86	100.0
	Excluded	0	.0
	Total	86	100.0

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.904	.906	5

Item Statistics

	Mean	Std. Deviation	N
GROUP1	1.773	.6169	86
GROUP2	1.557	.5212	86
GROUP3	1.756	.5476	86
GROUP4	1.783	.5821	86
GROUP5	1.807	.5700	86

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	1.735	1.557	1.807	.250	1.161	.010	5
Item Variances	.323	.272	.381	.109	1.401	.002	5

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
GROUP1	6.902	3.711	.737	.560	.889
GROUP2	7.119	3.956	.779	.644	.880
GROUP3	6.920	3.822	.804	.672	.874
GROUP4	6.893	3.803	.749	.600	.886
GROUP5	6.869	3.853	.744	.571	.887

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
8.676	5.843	2.4171	5

Appendix E.2 Validity Results by using SPSS Programme

All Factors

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	G5F4, G2F6, G1F2, G5F3, G3F8, G1F5, G4F4, G2F4, G5F2, G4F2, G4F5, G1F6, G4F3, G2F2, G3F1, G4F1, G3F6, G3F4, G2F5, G2F3, G5F1, G1F1, G1F4, G3F2, G2F1, G3F7, G3F5, G3F3, G1F3[a]	.	Enter

a. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.851[a]	.724	.581	.429208

a. Predictors: (Constant), G5F4, G2F6, G1F2, G5F3, G3F8, G1F5, G4F4, G2F4, G5F2, G4F2, G4F5, G1F6, G4F3, G2F2, G3F1, G4F1, G3F6, G3F4, G2F5, G2F3, G5F1, G1F1, G1F4, G3F2, G2F1, G3F7, G3F5, G3F3, G1F3

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	27.100	29	.934	5.073	.000[a]
	Residual	10.316	56	.184		
	Total	37.416	85			

a. Predictors: (Constant), G5F4, G2F6, G1F2, G5F3, G3F8, G1F5, G4F4, G2F4, G5F2, G4F2, G4F5, G1F6, G4F3, G2F2, G3F1, G4F1, G3F6, G3F4, G2F5, G2F3, G5F1, G1F1, G1F4, G3F2, G2F1, G3F7, G3F5, G3F3, G1F3

b. Dependent Variable: EVALUATION OF SUCCESS

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.225	.208		1.080	.285
	G1F1	.048	.194	.047	.249	.804
	G1F2	.385	.287	.262	1.344	.184
	G1F3	-.050	.253	-.040	-.198	.844
	G1F4	.400	.180	.361	2.219	.031
	G1F5	.020	.127	.017	.161	.873
	G1F6	-.354	.121	-.363	-2.931	.005
	G2F1	.294	.207	.255	1.418	.162
	G2F2	.143	.181	.122	.794	.431
	G2F3	-.201	.179	-.172	-1.122	.267
	G2F4	-.040	.142	-.038	-.282	.779
	G2F5	-.267	.175	-.224	-1.521	.134
	G2F6	.195	.126	.155	1.548	.127
	G3F1	-.105	.134	-.104	-.780	.438
	G3F2	.346	.203	.298	1.705	.094
	G3F3	.275	.211	.241	1.305	.197
	G3F4	-.122	.176	-.109	-.694	.490

	G3F5	.234	.203	.214	1.156	.252
	G3F6	-.167	.175	-.146	-.953	.345
	G3F7	-.047	.214	-.039	-.219	.827
	G3F8	.053	.151	.047	.348	.729
	G4F1	-.070	.163	-.061	-.430	.669
	G4F2	-.087	.163	-.074	-.532	.597
	G4F3	.137	.139	.115	.982	.330
	G4F4	.440	.161	.342	2.738	.008
	G4F5	-.053	.143	-.044	-.367	.715
	G5F1	.043	.179	.037	.242	.809
	G5F2	-.094	.136	-.077	-.692	.492
	G5F3	.072	.146	.053	.496	.622
	G5F4	-.061	.168	-.052	-.365	.717

a. Dependent Variable: EVALUATION OF SUCCESS

All Groups

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	GROUP5, GROUP1, GROUP3, GROUP4, GROUP2[a]	.	Enter

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.708[a]	.501	.470	.402413

a. Predictors: (Constant), GROUP5, GROUP1, GROUP3, GROUP4, GROUP2

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	13.026	5	2.605	16.087	.000[a]
	Residual	12.955	80	.162		
	Total	25.981	85			

a. Predictors: (Constant), GROUP5, GROUP1, GROUP3, GROUP4, GROUP2

b. Dependent Variable: EVALUATION OF SUCCESS

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.372	.163		2.278	.025
	GROUP1	.252	.107	.281	2.360	.021
	GROUP2	-.074	.140	-.070	-.530	.597
	GROUP3	.262	.139	.260	1.884	.063
	GROUP4	.105	.119	.110	.883	.380
	GROUP5	.227	.117	.234	1.940	.056

a. Dependent Variable: EVALUATION OF SUCCESS

Appendix E.3 Correlation Results by using SPSS Programme

Group 1

Correlations

		F1	F2	F3	F4	F5	F6
F1	Pearson Correlation	1	.378**	.419**	.798**	.496**	.681**
	Sig. (2-tailed)		.000	.000	.000	.000	.000
	N	86	86	86	86	86	86
F2	Pearson Correlation	.378**	1	.865**	.264*	.204	.380**
	Sig. (2-tailed)	.000		.000	.014	.059	.000
	N	86	86	86	86	86	86
F3	Pearson Correlation	.419**	.865**	1	.366**	.281**	.411**
	Sig. (2-tailed)	.000	.000		.001	.009	.000
	N	86	86	86	86	86	86
F4	Pearson Correlation	.798**	.264*	.366**	1	.549**	.630**
	Sig. (2-tailed)	.000	.014	.001		.000	.000
	N	86	86	86	86	86	86
F5	Pearson Correlation	.496**	.204	.281**	.549**	1	.414**
	Sig. (2-tailed)	.000	.059	.009	.000		.000
	N	86	86	86	86	86	86
F6	Pearson Correlation	.681**	.380**	.411**	.630**	.414**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	
	N	86	86	86	86	86	86

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Group 2

Correlations

		F1	F2	F3	F4	F5	F6
F1	Pearson Correlation	1	.604**	.575**	.558**	.687**	.429**
	Sig. (2-tailed)		.000	.000	.000	.000	.000
	N	86	86	86	86	86	86
F2	Pearson Correlation	.604**	1	.788**	.599**	.678**	.387**
	Sig. (2-tailed)	.000		.000	.000	.000	.000
	N	86	86	86	86	86	86
F3	Pearson Correlation	.575**	.788**	1	.638**	.681**	.426**
	Sig. (2-tailed)	.000	.000		.000	.000	.000
	N	86	86	86	86	86	86
F4	Pearson Correlation	.558**	.599**	.638**	1	.737**	.234*
	Sig. (2-tailed)	.000	.000	.000		.000	.030
	N	86	86	86	86	86	86
F5	Pearson Correlation	.687**	.678**	.681**	.737**	1	.318**
	Sig. (2-tailed)	.000	.000	.000	.000		.003
	N	86	86	86	86	86	86
F6	Pearson Correlation	.429**	.387**	.426**	.234*	.318**	1
	Sig. (2-tailed)	.000	.000	.000	.030	.003	
	N	86	86	86	86	86	86

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Group 3

Correlations

		F1	F2	F3	F4	F5	F6	F7	F8
F1	Pearson Correlation	1	.682**	.727**	.606**	.658**	.647**	.589**	.561**
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.000
	N	86	86	86	86	86	86	86	86
F2	Pearson Correlation	.682**	1	.764**	.736**	.798**	.735**	.666**	.582**
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.000	.000
	N	86	86	86	86	86	86	86	86
F3	Pearson Correlation	.727**	.764**	1	.763**	.739**	.796**	.771**	.625**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000	.000
	N	86	86	86	86	86	86	86	86
F4	Pearson Correlation	.606**	.736**	.763**	1	.695**	.666**	.777**	.623**
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000	.000
	N	86	86	86	86	86	86	86	86
F5	Pearson Correlation	.658**	.798**	.739**	.695**	1	.626**	.701**	.655**
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000	.000
	N	86	86	86	86	86	86	86	86
F6	Pearson Correlation	.647**	.735**	.796**	.666**	.626**	1	.709**	.620**
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000	.000
	N	86	86	86	86	86	86	86	86
F7	Pearson Correlation	.589**	.666**	.771**	.777**	.701**	.709**	1	.750**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000		.000
	N	86	86	86	86	86	86	86	86
F8	Pearson Correlation	.561**	.582**	.625**	.623**	.655**	.620**	.750**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	

N	86	86	86	86	86	86	86	86

**. Correlation is significant at the 0.01 level (2-tailed).

Group 4

Correlations

		F1	F2	F3	F4	F5
F1	Pearson Correlation	1	.655**	.539**	.525**	.565**
	Sig. (2-tailed)		.000	.000	.000	.000
	N	86	86	86	86	86
F2	Pearson Correlation	.655**	1	.592**	.465**	.499**
	Sig. (2-tailed)	.000		.000	.000	.000
	N	86	86	86	86	86
F3	Pearson Correlation	.539**	.592**	1	.438**	.461**
	Sig. (2-tailed)	.000	.000		.000	.000
	N	86	86	86	86	86
F4	Pearson Correlation	.525**	.465**	.438**	1	.530**
	Sig. (2-tailed)	.000	.000	.000		.000
	N	86	86	86	86	86
F5	Pearson Correlation	.565**	.499**	.461**	.530**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	86	86	86	86	86

**. Correlation is significant at the 0.01 level (2-tailed).

Group 5

Correlations

		F1	F2	F3	F4
F1	Pearson Correlation	1	.573**	.462**	.644**
	Sig. (2-tailed)		.000	.000	.000
	N	86	86	86	86
F2	Pearson Correlation	.573**	1	.513**	.487**
	Sig. (2-tailed)	.000		.000	.000
	N	86	86	86	86
F3	Pearson Correlation	.462**	.513**	1	.328**
	Sig. (2-tailed)	.000	.000		.002
	N	86	86	86	86
F4	Pearson Correlation	.644**	.487**	.328**	1
	Sig. (2-tailed)	.000	.000	.002	
	N	86	86	86	86

**. Correlation is significant at the 0.01 level (2-tailed).

All Groups

Correlations

		GROUP1	GROUP2	GROUP3	GROUP4	GROUP5
GROUP1	Pearson Correlation	1	.694**	.663**	.594**	.613**
	Sig. (2-tailed)		.000	.000	.000	.000
	N	86	86	86	86	86
GROUP2	Pearson Correlation	.694**	1	.748**	.604**	.632**
	Sig. (2-tailed)	.000		.000	.000	.000
	N	86	86	86	86	86
GROUP3	Pearson Correlation	.663**	.748**	1	.703**	.638**
	Sig. (2-tailed)	.000	.000		.000	.000
	N	86	86	86	86	86
GROUP4	Pearson Correlation	.594**	.604**	.703**	1	.693**
	Sig. (2-tailed)	.000	.000	.000		.000
	N	86	86	86	86	86
GROUP5	Pearson Correlation	.613**	.632**	.638**	.693**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	86	86	86	86	86

**. Correlation is significant at the 0.01 level (2-tailed).

APPENDIX F

MAPS

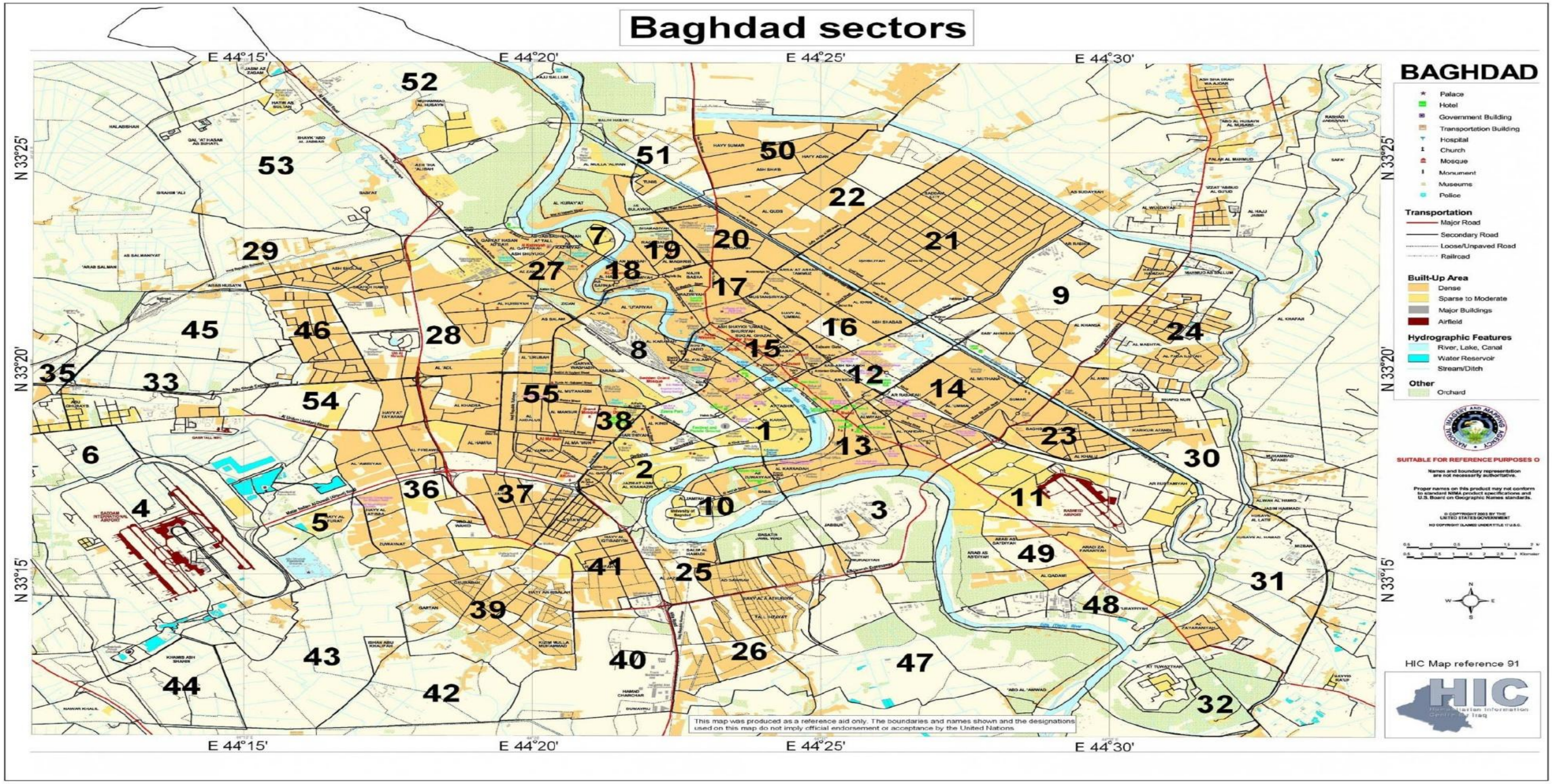

Figure F.1: Baghdad Sectors' Map

(http://www.globalsecurity.org/jhtml/jframe.html#http://www.globalsecurity.org/military/world/iraq/images/baghdad_sectors.jpg)

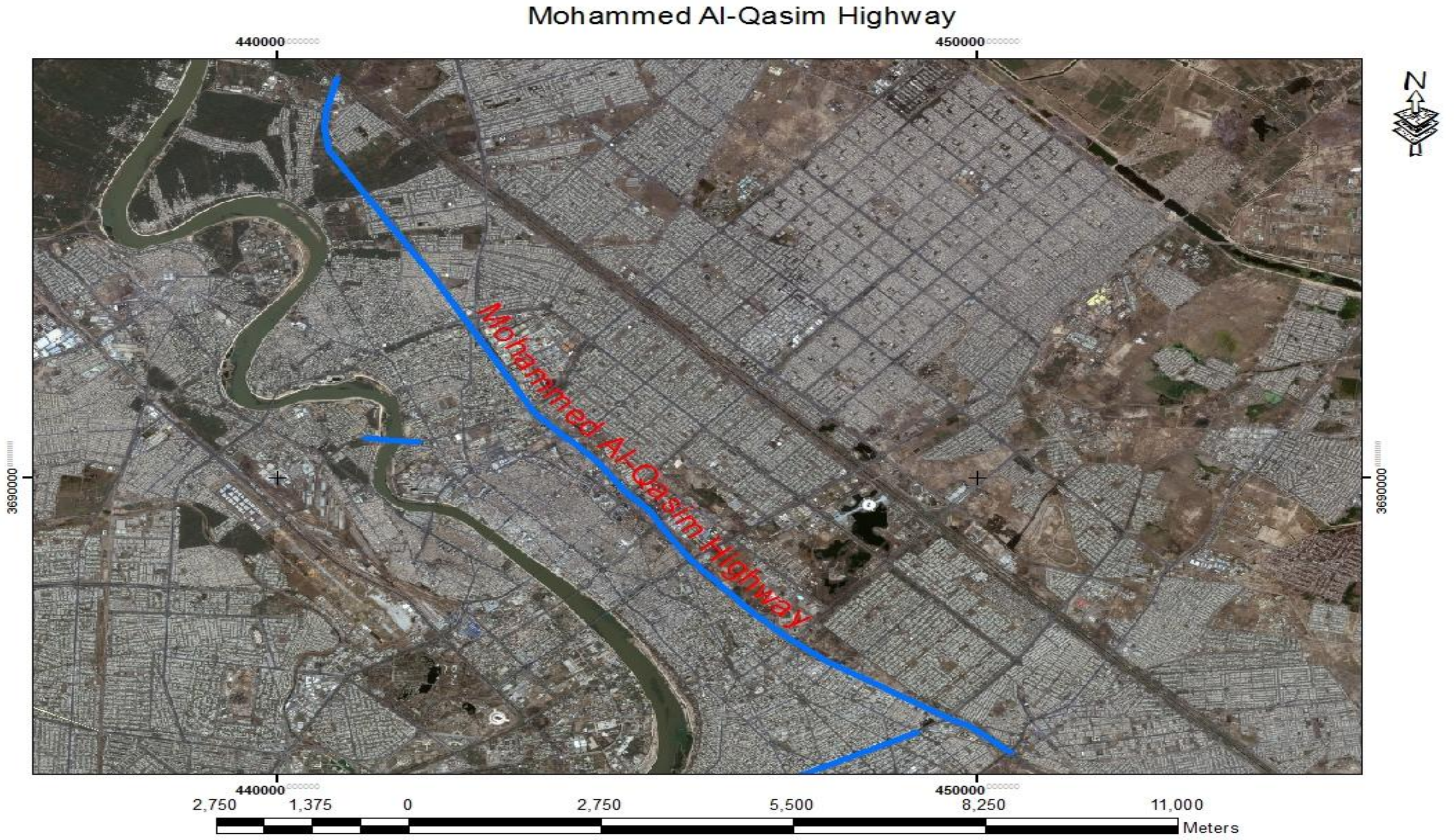

Figure F.2: Case study 1 – Mohammed Al-Qasim Highway

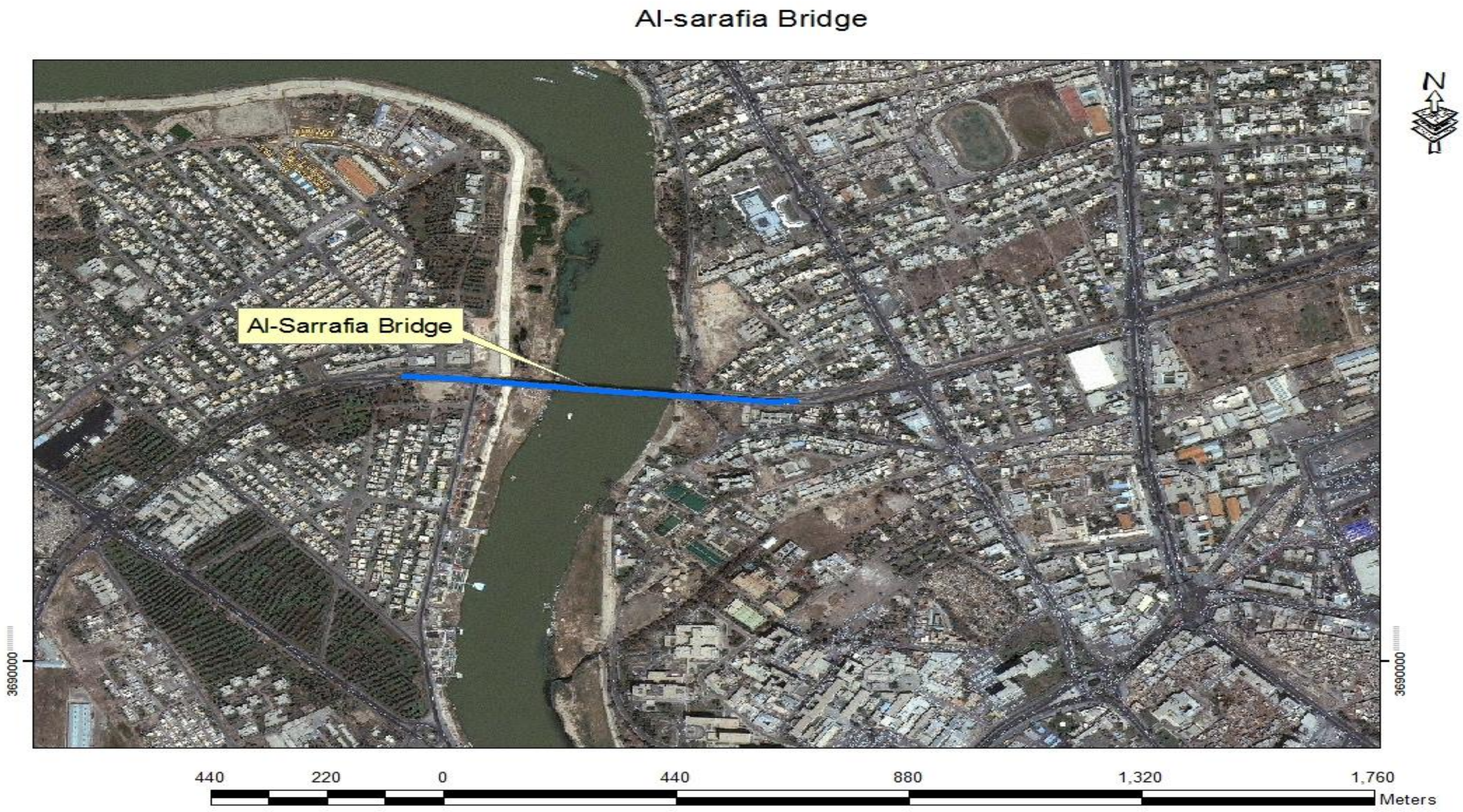

Figure F.3: Case study 2 – Al-Sarafia Bridge

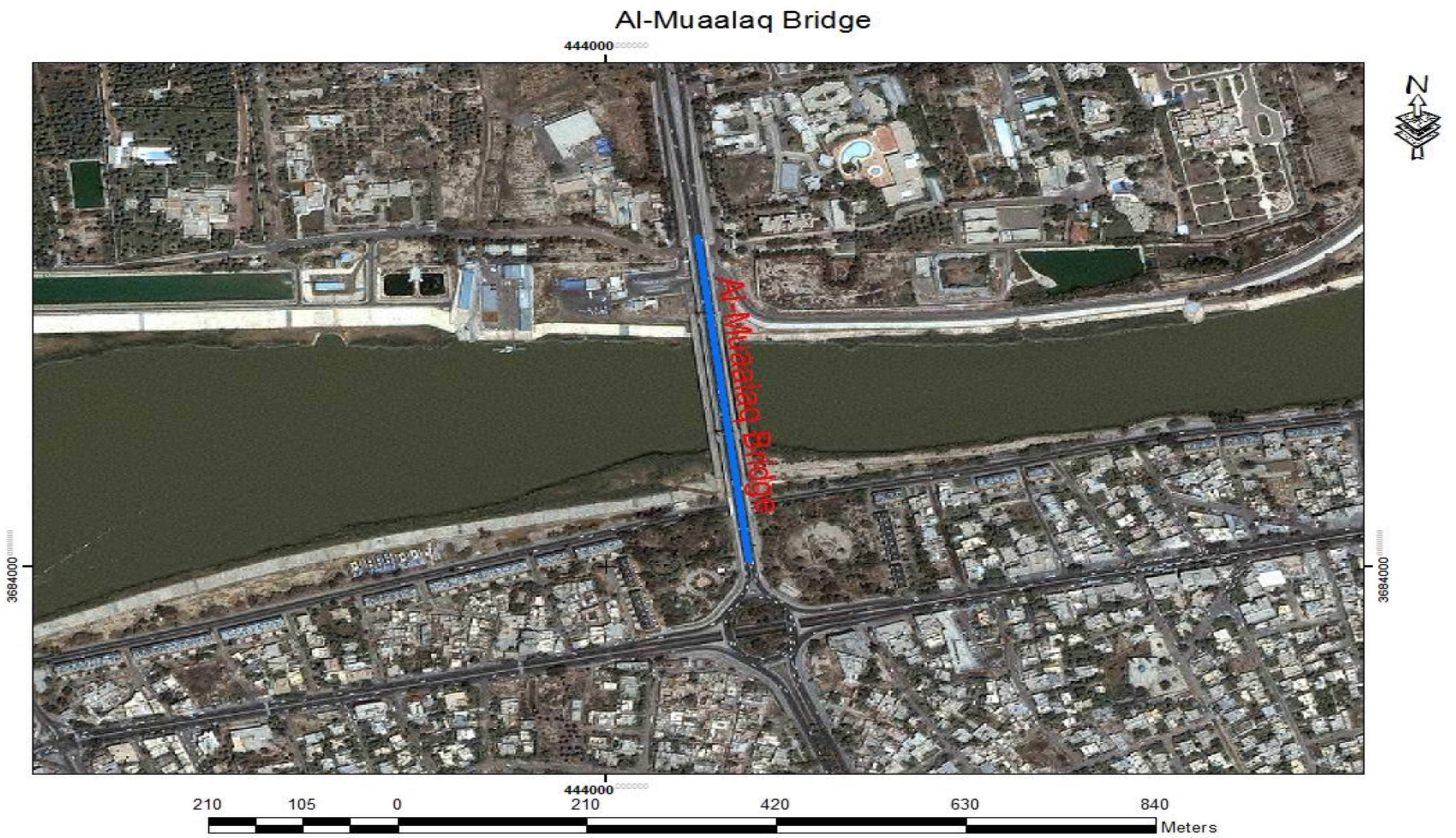

Figure F.4: Case study 2 – Al-Mua'alaq Bridge

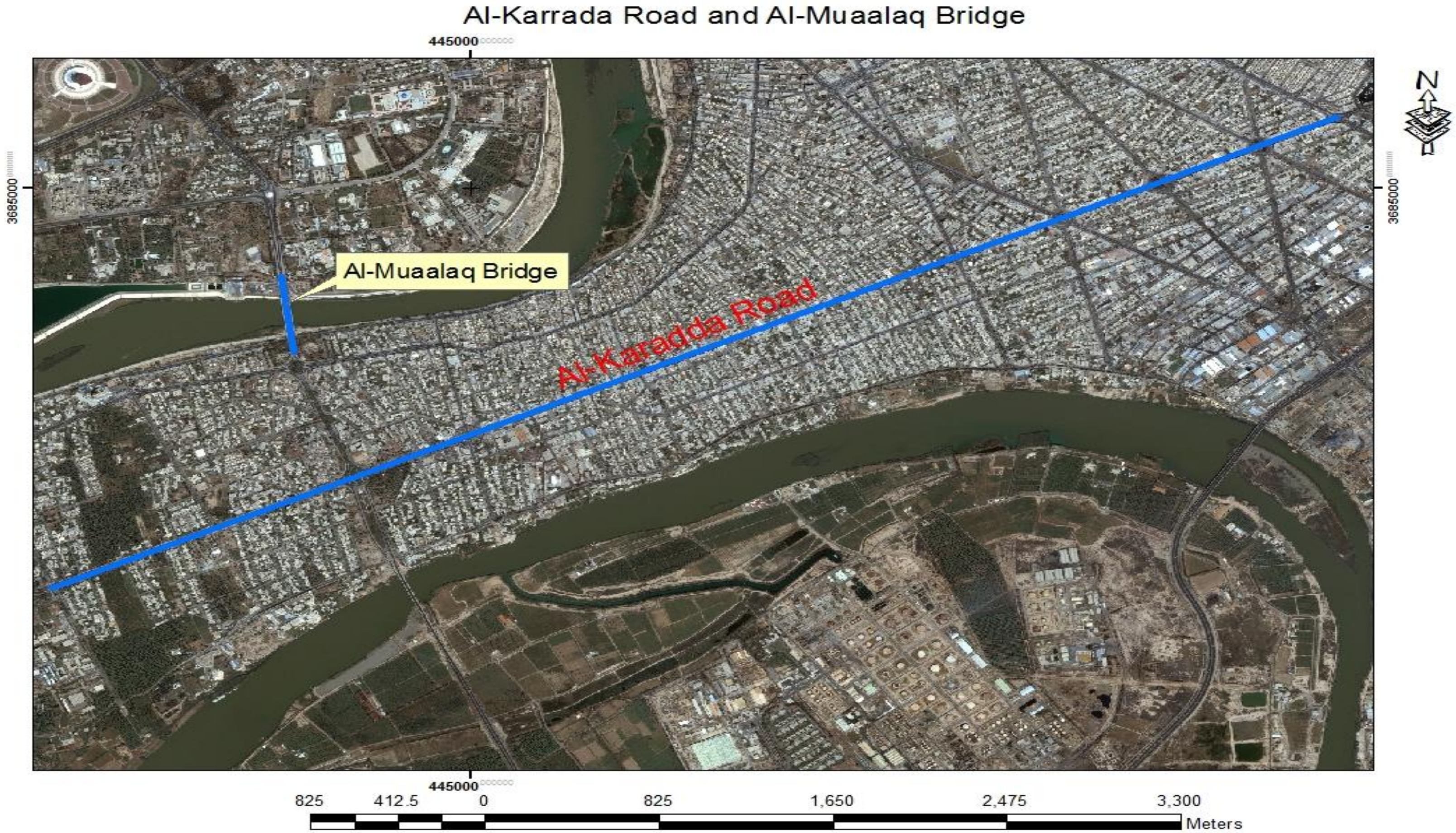

Figure F.5: Case study 3 – Al-Karadda Road

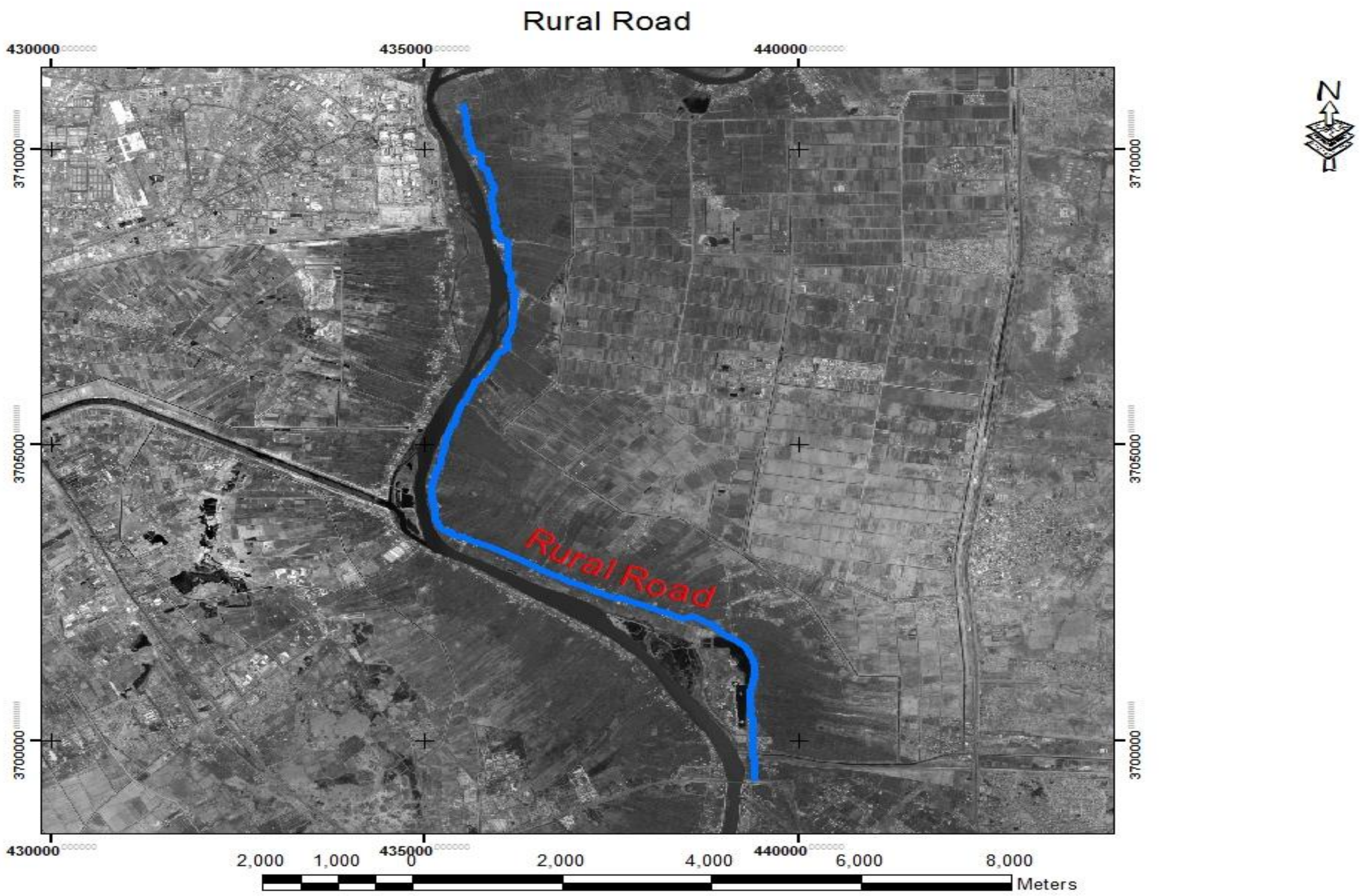

Figure F.6: Case study 4 – Rural Road

APPENDIX G

DETAILED COLLECTED DATA

Appendix G.1 Detailed Collected Data – Case Study 1

Socio-Economic Factor Group

Table G.1: Detailed collected data of socio-economic group for segment A – Case study 1

Case Study: 1 Road Segment: A			**Road Zone(s): 19, 20 and 51 Type of Area: Urban**	
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
1	Hospital 1	3000	230	0.077
2	Hospital 2	8000	1000	0.125
3	Hospital 3	1500	200	0.133
4	Government institute 1	2500	450	0.180
5	Government institute 2	2300	320	0.139
6	Government institute 3	2000	250	0.125
7	Service institute 1	1250	280	0.329
8	Service institute 2	1100	250	0.347
9	Service institute 3	500	80	0.320
10	Police station 1	850	110	0.129
11	Police station 2	750	135	0.187
12	University 1	20000	3500	0.175
13	University 2	30000	6000	0.200
14	University 3	18000	3200	0.178
15	University 4	15000	1800	0.120
16	School 1	3000	750	0.250
17	School 2	2800	650	0.232
18	School 3	2500	660	0.264
19	Mosque 1	1900	350	0.368
20	Mosque 2	4500	1000	0.222
21	Mosque 3	4500	800	0.400
22	Commerce centre 1	5200	1200	0.286
23	Commerce centre 2	5800	1100	0.229
24	Commerce centre 3	4300	900	0.273
25	Commerce centre 4	3800	800	0.222
26	Factory 1	2300	250	0.109
27	Factory 2	1200	130	0.108
28	Factory 3	1500	200	0.133
29	Factory 4	1400	100	0.071
30	Grocery store 1	5600	1200	0.462
31	Grocery store 2	6400	1250	0.391
32	Grocery store 3	3100	600	0.375

Case Study: 1 **Road Segment: A**		**Road Zone(s): 19, 20 and 51** **Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
33	Bank 1	5600	850	0.304
34	Bank 2	3400	700	0.292
35	Bank 3	2900	600	0.231
36	Bank 4	2600	400	0.222
Total	36	181050	32295	0.178

Table G.2: Detailed collected data of socio-economic group for segment B – Case study 1

Case Study: 1 **Road Segment: B**		**Road Zone(s): 17** **Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building ($person/m^2$)**
1	Hospital 1	12000	2000	0.167
2	Hospital 2	2000	200	0.100
3	Hospital 3	1500	180	0.120
4	Hospital 4	1500	150	0.100
5	Government institute 1	6900	1800	0.261
6	Government institute 2	10000	1200	0.120
7	Government institute 3	2800	900	0.321
8	Service institute 1	750	270	0.360
9	Service institute 2	1100	250	0.227
10	Service institute 3	550	130	0.236
11	Service institute 4	400	90	0.225
12	Service institute 5	550	140	0.255
13	Police station 1	700	90	0.129
14	Police station 2	800	110	0.138
15	University 1	75000	15000	0.200
16	University 2	8500	2500	0.294
17	University 3	7000	2100	0.300
18	University 4	3200	2000	0.625
19	University 5	6000	1800	0.300
20	School 1	4000	750	0.188
21	School 2	6000	1200	0.200
22	School 3	7500	2000	0.267
23	Mosque 1	2100	450	0.214
24	Mosque 2	800	220	0.275
25	Church 1	1000	150	0.150
26	Commerce centre 1	21000	5500	0.262
27	Commerce centre 2	12000	3500	0.292
28	Commerce centre 3	6500	1500	0.231
29	Commerce centre 4	4500	1100	0.244
30	Commerce centre 5	8000	1700	0.213
31	Factory 1	1000	100	0.100
32	Factory 2	1200	120	0.100
33	Factory 3	1600	130	0.081
34	Factory 4	2100	190	0.090
35	Factory 5	2300	240	0.104
36	Factory 6	2300	250	0.109

Case Study: 1 **Road Segment: B**		**Road Zone(s): 17** **Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
37	Factory 7	2500	350	0.140
38	Factory 8	2700	410	0.152
39	Grocery store 1	6000	1600	0.267
40	Grocery store 2	4000	1400	0.351
41	Grocery store 3	3800	900	0.237
42	Grocery store 4	2500	700	0.280
43	Bank 1	3400	900	0.265
44	Bank 2	8000	950	0.119
45	Bank 3	4500	550	0.122
Total	45	262550	57770	0.220

Table G.3: Detailed collected data of socio-economic group for segment C – Case study 1

Case Study: 1 **Road Segment: C**			**Road Zone(s): 15 and 16** **Type of Area: Urban**	
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
1	Hospital 1	10000	1700	0.170
2	Hospital 2	5000	700	0.140
3	Hospital 3	3000	250	0.083
4	Hospital 4	2000	200	0.100
5	Hospital 5	1500	150	0.100
6	Hospital 6	1800	170	0.094
7	Hospital 7	3500	450	0.129
8	Hospital 8	2800	350	0.125
9	Government institute 1	4100	900	0.220
10	Government institute 2	4600	1000	0.217
11	Government institute 3	4800	1400	0.292
12	Government institute 4	9000	1800	0.200
13	Government institute 5	15500	2100	0.135
14	Government institute 6	11000	2000	0.182
15	Government institute 7	9000	2100	0.233
16	Government institute 8	8600	2400	0.279
17	Government institute 9	10200	2800	0.275
18	Government institute 10	25000	3000	0.120
19	Service institute 1	1500	230	0.153
20	Service institute 2	460	90	0.196
21	Service institute 3	300	80	0.267
22	Service institute 4	300	70	0.233
23	Service institute 5	550	110	0.200
24	Service institute 6	620	130	0.210
25	Service institute 7	2100	450	0.214
26	Service institute 8	3200	590	0.184
27	Police station 1	600	120	0.200
28	Police station 2	750	180	0.240
29	University 1	500000	50000	0.100
30	University 2	35000	3200	0.091
31	University 3	15000	3000	0.200
32	University 4	19500	3000	0.154
33	School 1	5200	1000	0.192
34	School 2	6400	1100	0.172
35	School 3	7600	1800	0.237
36	School 4	6900	1900	0.275

Case Study: 1		**Road Zone(s): 15 and 16**		
Road Segment: C		**Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
37	Mosque 1	5000	800	0.160
38	Mosque 2	1400	250	0.179
39	Church 1	2000	200	0.100
40	Church 2	800	70	0.088
41	Commerce centre 1	7000	1200	0.171
42	Commerce centre 2	6500	1700	0.262
43	Commerce centre 3	11500	2800	0.243
44	Commerce centre 4	16500	3200	0.194
45	Commerce centre 5	25000	4200	0.168
46	Commerce centre 6	31000	5500	0.177
47	Factory 1	1000	100	0.100
48	Factory 2	1200	100	0.083
49	Factory 3	1500	170	0.113
50	Factory 4	1800	180	0.100
51	Factory 5	2000	350	0.175
52	Factory 6	2100	400	0.190
53	Factory 7	2200	480	0.218
54	Factory 8	2400	530	0.221
55	Factory 9	2700	580	0.215
56	Factory 10	3000	580	0.193
57	Grocery store 1	6500	1000	0.154
58	Grocery store 2	7000	1200	0.171
59	Bank 1	1300	300	0.231
60	Bank 2	1850	400	0.216
61	Bank 3	6500	850	0.131
62	Bank 4	5100	1000	0.196
Total	62	891230	118660	0.133

Table G.4: Detailed collected data of socio-economic group for segment D – Case study 1

Case Study: 1 Road Segment: D		**Road Zone(s): 12 Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
1	Hospital 1	1800	180	0.100
2	Hospital 2	2200	280	0.127
3	Hospital 3	3100	320	0.103
4	Hospital 4	3600	690	0.192
5	Hospital 5	4000	700	0.175
6	Hospital 6	4500	800	0.178
7	Hospital 7	3900	700	0.179
8	Hospital 8	4400	800	0.182
9	Government institute 1	4500	1000	0.222
10	Government institute 2	5600	1400	0.250
11	Government institute 3	6800	1400	0.206
12	Government institute 4	8400	1800	0.214
13	Government institute 5	4400	1000	0.227
14	Government institute 6	8700	2000	0.230
15	Government institute 7	14800	2900	0.196
16	Government institute 8	15200	3000	0.197
17	Service institute 1	540	100	0.185
18	Service institute 2	750	120	0.160
19	Service institute 3	1100	250	0.227
20	Service institute 4	720	150	0.208
21	Service institute 5	1050	250	0.238
22	Service institute 6	2600	550	0.212
23	Service institute 7	3300	750	0.227
24	Police station 1	650	80	0.123
25	Police station 2	1500	290	0.193
26	University 1	12500	3100	0.248
27	University 2	11000	3000	0.273
28	School 1	10000	1000	0.100
29	School 2	6000	1200	0.200
30	School 3	9000	1700	0.189
31	School 4	7500	2000	0.267
32	Mosque 1	1200	300	0.250
33	Mosque 2	1900	400	0.211
34	Church 1	1800	180	0.100
35	Commerce centre 1	7000	1200	0.171
36	Commerce centre 2	30000	3200	0.107

Case Study: 1 **Road Segment: D**		**Road Zone(s): 12** **Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
37	Commerce centre 3	17000	4000	0.235
38	Commerce centre 4	27000	5800	0.215
39	Commerce centre 5	280000	6000	0.021
40	Factory 1	1000	100	0.100
41	Factory 2	1200	120	0.100
42	Factory 3	1300	250	0.192
43	Factory 4	2100	360	0.171
44	Factory 5	2500	400	0.160
45	Factory 6	3000	420	0.140
46	Factory 7	3100	460	0.148
47	Factory 8	3300	560	0.170
48	Factory 9	3500	650	0.186
49	Factory 10	3700	770	0.208
50	Grocery store 1	3800	1000	0.263
51	Bank 1	3200	450	0.141
52	Bank 2	8000	1200	0.150
53	Bank 3	4500	460	0.102
54	Bank 4	6200	700	0.113
Total	54	580410	62490	0.108

Table G.5: Detailed collected data of socio-economic group for segment E – Case study 1

Case Study: 1 **Road Segment: E**			**Road Zone(s): 11, 13, 14 and 23** **Type of Area: Urban**	
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
1	Hospital 1	2200	180	0.082
2	Hospital 2	2900	460	0.159
3	Hospital 3	3800	650	0.171
4	Government institute 1	9000	2000	0.667
5	Government institute 2	8600	2300	0.548
6	Government institute 3	6400	1400	0.438
7	Government institute 4	8500	1800	0.450
8	Government institute 5	5800	1500	0.517
9	Government institute 6	7500	1900	0.500
10	Government institute 7	6300	1500	0.536
11	Service institute 1	510	110	0.355
12	Service institute 2	780	180	0.375
13	Service institute 3	1500	350	0.467
14	Police station 1	610	80	0.131
15	Police station 2	1380	290	0.426
16	University 1	500000	50000	1.000
17	University 2	55000	10000	0.500
18	School 1	6000	1100	0.733
19	School 2	9600	1800	0.563
20	School 3	6000	1300	0.684
21	School 4	5800	1400	0.500
22	Mosque 1	1300	300	0.231
23	Mosque 2	1600	400	0.250
24	Church 1	1800	180	0.100
25	Church 2	850	80	0.094
26	Church 3	1750	160	0.091
27	Church 4	1100	120	0.109
28	Commerce centre 1	6100	1500	0.536
29	Commerce centre 2	20000	3800	0.776
30	Commerce centre 3	24000	5600	0.467
31	Commerce centre 4	14000	3100	0.646
32	Commerce centre 5	17000	3600	0.600
33	Factory 1	1000	120	0.120
34	Factory 2	1300	200	0.154
35	Factory 3	2000	280	0.140
36	Factory 4	2200	390	0.177

Case Study: 1 **Road Segment: E**		**Road Zone(s): 11, 13, 14 and 23** **Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
37	Factory 5	2600	410	0.158
38	Factory 6	3000	430	0.143
39	Factory 7	3100	500	0.161
40	Factory 8	3400	600	0.176
41	Factory 9	3700	700	0.189
42	Factory 10	4000	800	0.200
43	Grocery store 1	7600	2500	0.694
44	Grocery store 2	8000	1500	0.600
45	Bank 1	3000	400	1.333
46	Bank 2	2400	600	0.923
Total	46	784980	108570	0.138

Traffic Factor Group

Table G.6: Detailed collected data of vehicles' class, type and number for segment A – Case study 1

Case Study: 1 **Road Segment: A** **Observer: A-1**		**Date: Monday 26/07/2010** **Time: 7:30 – 8:30** **Name of observer:**	
Class	**Type**	**Number of vehicles counted by observer**	**Total number of vehicles for each class**
1	Cars	2388	2388
2	-Light commercial vehicles	23	349
	-Mini-buses	21	
	-Buses	305	
3	-Light trucks	35	56
	-Medium trucks	10	
	-Heavy trucks	47	
	-Articulated vehicles	4	
Total number of vehicles for all classes and types			2793

Table G.7: Detailed collected data of vehicles' class, type and number for segment B – Case study 1

Case Study: 1 **Road Segment: B** **Observer: B-1**		**Date: Monday 26/07/2010** **Time: 7:30 – 8:30** **Name of observer:**	
Class	**Type**	**Number of vehicles counted by observer**	**Total number of vehicles for each class**
1	Cars	3266	3266
2	-Light commercial vehicles	33	375
	-Mini-buses	27	
	-Buses	315	
3	-Light trucks	41	67
	-Medium trucks	12	
	-Heavy trucks	9	
	-Articulated vehicles	5	
Total number of vehicles for all classes and types			3708

Table G.8: Detailed collected data of vehicles' class, type and number for segment C – Case study 1

Case Study: 1 **Road Segment: C** **Observer: C-1**		**Date: Monday 26/07/2010** **Time: 7:30 – 8:30** **Name of observer:**	
Class	**Type**	**Number of vehicles counted by observer**	**Total number of vehicles for each class**
1	Cars	9294	9294
2	-Light commercial vehicles	81	642
	-Mini-buses	76	
	-Buses	485	
3	-Light trucks	85	138
	-Medium trucks	22	
	-Heavy trucks	20	
	-Articulated vehicles	11	
Total number of vehicles for all classes and types			10074

Table G.9: Detailed collected data of vehicles' class, type and number for segment D – Case study 1

Case Study: 1 **Road Segment: D** **Observer: D-1**		**Date: Monday 26/07/2010** **Time: 7:30 – 8:30** **Name of observer:**	
Class	**Type**	**Number of vehicles counted by observer**	**Total number of vehicles for each class**
1	Cars	9721	9721
2	-Light commercial vehicles	156	781
	-Mini-buses	98	
	-Buses	527	
3	-Light trucks	142	221
	-Medium trucks	33	
	-Heavy trucks	31	
	-Articulated vehicles	15	
Total number of vehicles for all classes and types			10723

Table G.10: Detailed collected data of vehicles' class, type and number for segment E – Case study 1

Case Study: 1 **Road Segment: E** **Observer: E-1**		**Date: Monday 26/07/2010** **Time: 7:30 – 8:30** **Name of observer:**	
Class	**Type**	**Number of vehicles counted by observer**	**Total number of vehicles for each class**
1	Cars	7956	7956
2	-Light commercial vehicles	167	760
	-Mini-buses	81	
	-Buses	512	
3	-Light trucks	158	266
	-Medium trucks	38	
	-Heavy trucks	42	
	-Articulated vehicles	28	
Total number of vehicles for all classes and types			8982

Table G.11: Average detailed collected data of vehicles' class and number for segment A – Case study 1

Case Study: 1 **Road Segment: A**			**Duration: 1 hour**		
Class	**Number of vehicles counted by each observer**				**Average**
	A-1	**A-2**	**A-3**	**A-4**	
1	2388	2306	2325	2415	2359
2	349	297	309	358	328
3	56	51	54	61	56
Total	2793	2654	2688	2834	2743

Table G.12: Average detailed collected data of vehicles' class and number for segment B – Case study 1

Case Study: 1 **Road Segment: B**			**Duration: 1 hour**		
Class	**Number of vehicles counted by each observer**				**Average**
	B-1	**B-2**	**B-3**	**B-4**	
1	3266	3214	3229	3302	3253
2	375	381	369	392	379
3	67	62	71	69	67
Total	3708	3657	3669	3763	3699

Table G.13: Average detailed collected data of vehicles' class and number for segment C – Case study 1

Case Study: 1 Road Segment: C		**Duration: 1 hour**			
Class	**Number of vehicles counted by each observer**				**Average**
	C-1	**C-2**	**C-3**	**C-4**	
1	9294	9327	9318	9280	9305
2	642	631	650	643	642
3	138	141	149	129	139
Total	10074	10099	10117	10052	10086

Table G.14: Average detailed collected data of vehicles' class and number for segment D – Case study 1

Case Study: 1 Road Segment: D		**Duration: 1 hour**			
Class	**Number of vehicles counted by each observer**				**Average**
	D-1	**D-2**	**D-3**	**D-4**	
1	9721	9788	9752	9717	9745
2	781	796	785	754	779
3	221	265	248	215	237
Total	10723	10849	10785	10686	10761

Table G.15: Average detailed collected data of vehicles' class and number for segment E – Case study 1

Case Study: 1 Road Segment: E		**Duration: 1 hour**			
Class	**Number of vehicles counted by each observer**				**Average**
	E-1	**E-2**	**E-3**	**E-4**	
1	7956	8027	7991	7897	7968
2	760	725	743	771	750
3	266	254	275	281	269
Total	8982	9006	9009	8949	8987

Appendix G.2 Detailed Collected Data – Case Study 2

Socio-Economic Factor Group

Table G.16: Detailed collected data of socio-economic group for Bridge No. 1 – Case study 2

Case Study: 2 Bridge No.: 1		**Road Zone(s): 8 and 17 Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building ($person/m^2$)**
1	Hospital 1	75000	14000	0.187
2	Hospital 2	12000	2500	0.208
3	Hospital 3	6500	1700	0.262
4	Hospital 4	8000	1600	0.200
5	Hospital 5	7000	1100	0.157
6	Hospital 6	10000	1800	0.180
7	Government institute 1	30000	6500	0.217
8	Government institute 2	7000	1200	0.171
9	Government institute 3	10000	1900	0.190
10	Government institute 4	9000	1800	0.200
11	Service institute 1	28000	3000	0.107
12	Service institute 2	1300	200	0.154
13	Service institute 3	800	120	0.150
14	Service institute 4	1000	180	0.180
15	Service institute 5	5000	1200	0.240
16	Service institute 6	4000	750	0.188
17	Service institute 7	2500	600	0.240
18	Service institute 8	3500	650	0.186
19	Service institute 9	70000	21000	0.300
20	Police station 1	650	110	0.169
21	Police station 2	750	140	0.187
22	Police station 3	1000	190	0.190
23	Police station 4	800	140	0.175
24	University 1	150000	20000	0.133
25	University 2	20000	4500	0.225
26	University 3	200000	30000	0.150
27	University 4	55000	12000	0.218
28	School 1	5000	850	0.170
29	School 2	6500	1200	0.185
30	School 3	8000	1800	0.225
31	School 4	5000	900	0.180
32	School 5	5500	1100	0.200
33	School 6	3500	700	0.200
34	Mosque 1	30000	8000	0.267
35	Mosque 2	3500	750	0.214
36	Mosque 3	2200	500	0.227
37	Mosque 4	900	320	0.356

Case Study: 2 **Bridge No.: 1**		**Road Zone(s): 8 and 17** **Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
38	Church 1	1000	160	0.160
39	Commerce centres (15)	140000	43000	0.307
40	Factory 1	1000	160	0.160
41	Factory 2	1600	250	0.156
42	Factory 3	1800	150	0.083
43	Factory 4	2500	400	0.160
44	Factory 5	2800	350	0.125
45	Factory 6	1400	250	0.179
46	Grocery store 1	15000	4200	0.280
47	Grocery store 2	4000	1100	0.275
48	Grocery store 3	3800	900	0.237
49	Grocery store 4	2600	600	0.231
50	Grocery store 5	3200	850	0.266
51	Grocery store 6	2800	600	0.214
52	Bank 1	3400	1000	0.294
53	Bank 2	4000	550	0.138
54	Bank 3	5000	700	0.140
Total	68	984800	200220	0.203

Table G.17: Detailed collected data of socio-economic group for Bridge No. 2 – Case study 2

Case Study: 2 **Bridge No.: 2**			**Road Zone(s): 1, 2, 10 and 13** **Type of Area: Urban**	
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
1	Hospital 1	11000	2400	0.218
2	Hospital 2	3600	700	0.194
3	Hospital 3	4500	800	0.178
4	Government institute 1	10000	2100	0.210
5	Government institute 2	8000	1500	0.188
6	Government institute 3	9000	2000	0.222
7	Government institute 4	100000	18000	0.180
8	Government institute 5	4400	1200	0.273
9	Government institute 6	8700	2300	0.264
10	Government institute 7	600000	45000	0.075
11	Government institute 8	90000	8000	0.089
12	Government institute 9	60000	5000	0.083
13	Service institute 1	550	100	0.182
14	Service institute 2	750	120	0.160
15	Service institute 3	1100	200	0.182
16	Service institute 4	700	170	0.243
17	Service institute 5	1400	230	0.164
18	Service institute 6	450	100	0.222
19	Service institute 7	350	80	0.229
20	Police station 1	650	90	0.138
21	Police station 2	1500	280	0.187
22	Police station 3	750	180	0.240
23	University 1	200000	25000	0.125
24	University 2	20000	6000	0.300
25	University 3	1100000	100000	0.091
26	University 4	30000	8000	0.267
27	University 5	20000	6000	0.300
28	School 1	9000	1700	0.189
29	School 2	7500	2000	0.267
30	School 3	7000	1800	0.257
31	School 4	6500	2000	0.308
32	School 5	7500	1800	0.240
33	School 6	5400	1100	0.204
34	School 7	6400	1500	0.234
35	Mosque 1	1200	300	0.250
36	Mosque 2	1700	400	0.235
37	Mosque 3	1400	360	0.257
38	Church 1	1000	150	0.150
39	Church 2	2000	400	0.200
40	Commerce centres (35)	450000	120000	0.267
41	Factory 1	1300	260	0.200
42	Factory 2	2600	450	0.173

Case Study: 2 **Bridge No.: 2**			**Road Zone(s): 1, 2, 10 and 13** **Type of Area: Urban**	
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
43	Factory 3	3100	500	0.161
44	Factory 4	3500	650	0.186
45	Factory 5	3700	770	0.208
46	Factory 6	3000	400	0.133
47	Factory 7	2700	350	0.130
48	Factory 8	1800	210	0.117
49	Grocery store 1	3800	1000	0.263
50	Grocery store 2	3000	950	0.317
51	Grocery store 3	6500	1200	0.185
52	Grocery store 4	10000	2800	0.280
53	Bank 1	3500	550	0.157
54	Bank 2	6500	800	0.123
55	Bank 3	8000	1200	0.150
56	Bank 4	4500	480	0.107
57	Bank 5	6000	700	0.117
58	Hotel 1	8000	1650	0.206
59	Hotel 2	10000	1800	0.180
60	Hotel 3	9000	1200	0.133
Total	94	2894500	386980	0.134

Traffic Factor Group

Table G.18: Detailed collected data of vehicles' class, type and number for Bridge No.1 – Case study 2

Case Study: 2 Bridge No.: 1 Observer: 1-1		**Date: Monday 28/07/2010 Time: 7:30 – 8:30 Name of observer:**	
Class	**Type**	**Number of vehicles counted by observer**	**Total number of vehicles for each class**
1	Cars	1324	1324
2	-Light commercial vehicles	16	48
	-Mini-buses	32	
	-Buses	0	
3	-Light trucks	1	1
	-Medium trucks	0	
	-Heavy trucks	0	
	-Articulated vehicles	0	
Total number of vehicles for all classes and types			1373

Table G.19: Detailed collected data of vehicles' class, type and number for Bridge No.2 – Case study 2

Case Study: 2 Bridge No.: 2 Observer: 2-1		**Date: Monday 28/07/2010 Time: 7:30 – 8:30 Name of observer:**	
Class	**Type**	**Number of vehicles counted by observer**	**Total number of vehicles for each class**
1	Cars	1826	1826
2	-Light commercial vehicles	3	7
	-Mini-buses	4	
	-Buses	0	
3	-Light trucks	2	2
	-Medium trucks	0	
	-Heavy trucks	0	
	-Articulated vehicles	0	
Total number of vehicles for all classes and types			1835

Table G.20: Average detailed collected data of vehicles' class and number for Bridge No.1 – Case study 2

Case Study: 2 Bridge No.: 1	**Duration: 1 hour**				
Class	**Number of vehicles counted by each observer**				**Average**
	1-1	**1-2**	**1-3**	**1-4**	
1	1324	1197	1388	1256	1291
2	48	47	39	40	44
3	1	2	0	1	1
Total	1373	1246	1427	1297	1336

Table G.21: Average detailed collected data of vehicles' class and number for Bridge No.2 – Case study 2

Case Study: 2 Bridge No.: 2	**Duration: 1 hour**				
Class	**Number of vehicles counted by each observer**				**Average**
	2-1	**2-2**	**2-3**	**2-4**	
1	1826	1787	1914	1891	1855
2	7	6	10	8	8
3	2	2	3	2	2
Total	1835	1795	1927	1901	1865

Appendix G.3 Detailed Collected Data – Case Study 3

Socio-Economic Factor Group

Table G.22: Detailed collected data of socio-economic group for segment A – Case study 3

Case Study: 3 Road Segment: A		**Road Zone(s): 11, 14 and 23 Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building ($person/m^2$)**
1	Hospital 1	5000	1200	0.240
2	Hospital 2	11000	2400	0.218
3	Hospital 3	6500	1800	0.277
4	Government institute 1	2600	550	0.212
5	Government institute 2	2200	420	0.191
6	Government institute 3	6000	1100	0.183
7	Government institute 4	10000	2100	0.210
8	Government institute 5	8000	1500	0.188
9	Government institute 6	9000	2000	0.222
10	Government institute 7	4500	800	0.178
11	Government institute 8	3000	650	0.217
12	Service institute 1	1100	340	0.309
13	Service institute 2	1300	250	0.192
14	Service institute 3	600	80	0.133
15	Service institute 4	950	180	0.189
16	Police station 1	650	110	0.169
17	Police station 2	750	140	0.187
18	University 1	200000	25000	0.125
19	University 2	20000	6000	0.300
20	University 3	1100000	100000	0.091
21	University 4	30000	8000	0.267
22	School 1	4000	850	0.213
23	School 2	6500	1300	0.200
24	School 3	7500	1800	0.240
25	School 4	5000	1100	0.220
26	School 5	6000	1100	0.183
27	School 6	3500	750	0.214
28	Mosque 1	2200	500	0.227
29	Mosque 2	900	220	0.244
30	Church 1	1000	150	0.150
31	Church 2	2000	400	0.200
32	Church 3	1000	100	0.100
33	Church 4	800	150	0.188
34	Commerce centres (20)	175000	55000	0.314
35	Factory 1	1000	150	0.150
36	Factory 2	1600	200	0.125
37	Factory 3	2100	150	0.071

Case Study: 3 **Road Segment: A**		**Road Zone(s): 11, 14 and 23** **Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
38	Factory 4	3000	400	0.133
39	Factory 5	2700	350	0.130
40	Grocery store 1	10000	2800	0.280
41	Grocery store 2	4000	1200	0.300
42	Grocery store 3	3700	900	0.243
43	Grocery store 4	2500	600	0.240
44	Bank 1	3400	800	0.235
45	Bank 2	4000	450	0.113
46	Bank 3	5000	600	0.120
47	Hotel 1	8000	1650	0.206
48	Hotel 2	6000	1600	0.267
49	Hotel 3	10000	1800	0.180
50	Hotel 4	9000	1200	0.133
Total	69	1714550	232890	0.136

Table G.23: Detailed collected data of socio-economic group for segment B – Case study 3

Case Study: 3 **Road Segment: B**		**Road Zone(s): 3 and 13** **Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
1	Hospital 1	5000	1200	0.240
2	Hospital 2	11000	2400	0.218
3	Hospital 3	6500	1800	0.277
4	Government institute 1	10000	2100	0.210
5	Government institute 2	8000	1500	0.188
6	Government institute 3	9000	2000	0.222
7	Government institute 4	12000	2100	0.175
8	Government institute 5	11000	2000	0.182
9	Government institute 6	8500	1800	0.212
10	Government institute 7	11000	2800	0.255
11	Government institute 8	100000	18000	0.180
12	Service institute 1	1500	230	0.153
13	Service institute 2	450	90	0.200
14	Service institute 3	350	70	0.200
15	Service institute 4	600	140	0.233
16	Service institute 5	2100	400	0.190
17	Police station 1	600	130	0.217
18	Police station 2	750	190	0.253
19	University 1	200000	25000	0.125
20	University 2	20000	6000	0.300
21	University 3	1100000	100000	0.091
22	University 4	30000	8000	0.267
23	School 1	5200	1100	0.212
24	School 2	6400	1400	0.219
25	School 3	7000	1800	0.257
26	School 4	6500	2000	0.308
27	School 5	7500	1800	0.240
28	School 6	5000	1100	0.220
29	School 7	6000	1100	0.183
30	Mosque 1	1100	400	0.364
31	Mosque 2	1400	350	0.250
32	Church 1	2000	300	0.150
33	Church 2	800	100	0.125
34	Church 3	1000	150	0.150
35	Church 4	2000	400	0.200
36	Commerce centres (35)	300000	80000	0.267
37	Factory 1	3000	400	0.133
38	Factory 2	2700	350	0.130
39	Factory 3	1800	210	0.117
40	Factory 4	1800	250	0.139
41	Factory 5	2000	350	0.175
42	Factory 6	2100	400	0.190

Case Study: 3 Road Segment: B		**Road Zone(s): 3 and 13 Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building ($person/m^2$)**
43	Factory 7	2200	500	0.227
44	Factory 8	2400	530	0.221
45	Grocery store 1	6500	1000	0.154
46	Grocery store 2	7000	1200	0.171
47	Grocery store 3	10000	2800	0.280
48	Grocery store 4	4000	1200	0.300
49	Bank 1	3200	450	0.141
50	Bank 2	8000	1200	0.150
51	Bank 3	4500	460	0.102
52	Bank 4	6200	700	0.113
53	Hotel 1	8000	1650	0.206
54	Hotel 2	5000	1100	0.220
55	Hotel 3	10000	1800	0.180
56	Hotel 4	9000	1200	0.133
Total	90	1999650	287700	0.144

Table G.24: Detailed collected data of socio-economic group for segment C – Case study 3

Case Study: 3 Road Segment: C		**Road Zone(s): 3, 10 and 13 Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
1	Hospital 1	11000	2400	0.218
2	Hospital 2	3600	700	0.194
3	Hospital 3	4500	800	0.178
4	Government institute 1	10000	2100	0.210
5	Government institute 2	8000	1500	0.188
6	Government institute 3	9000	2000	0.222
7	Government institute 4	100000	18000	0.180
8	Government institute 5	4400	1200	0.273
9	Government institute 6	8700	2300	0.264
10	Government institute 7	15000	2900	0.193
11	Government institute 8	1500	320	0.213
12	Service institute 1	550	100	0.182
13	Service institute 2	750	120	0.160
14	Service institute 3	1100	200	0.182
15	Service institute 4	700	170	0.243
16	Police station 1	650	90	0.138
17	Police station 2	1500	280	0.187
18	University 1	200000	25000	0.125
19	University 2	20000	6000	0.300
20	University 3	1100000	100000	0.091
21	University 4	30000	8000	0.267
22	School 1	9000	1700	0.189
23	School 2	7500	2000	0.267
24	School 3	7000	1800	0.257
25	School 4	6500	2000	0.308
26	School 5	7500	1800	0.240
27	Mosque 1	1200	300	0.250
28	Mosque 2	1700	400	0.235
29	Church 3	1000	150	0.150
30	Church 4	2000	400	0.200
31	Commerce centres (18)	115000	33000	0.287
32	Factory 1	1300	260	0.200
33	Factory 2	2600	450	0.173
34	Factory 3	3100	500	0.161
35	Factory 4	3500	650	0.186
36	Factory 5	3700	770	0.208
37	Grocery store 1	3800	1000	0.263
38	Grocery store 2	3000	950	0.317
39	Bank 1	3500	550	0.157
40	Bank 2	6500	800	0.123
41	Hotel 1	8000	1650	0.206
42	Hotel 2	20000	3700	0.185

Case Study: 3 **Road Segment: C**		**Road Zone(s): 3, 10 and 13** **Type of Area: Urban**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
43	Hotel 3	9000	1400	0.156
Total	60	1757350	230410	0.131

Traffic Factor Group

Table G.25: Detailed collected data of vehicles' class, type and number for segment A – Case study 3

Case Study: 3 **Road Segment: A** **Observer: A-1**		**Date: Monday 01/08/2010** **Time: 7:30 – 8:30** **Name of observer:**	
Class	**Type**	**Number of vehicles counted by observer**	**Total number of vehicles for each class**
1	Cars	3523	3523
2	-Light commercial vehicles	16	76
	-Mini-buses	36	
	-Buses	24	
3	-Light trucks	12	19
	-Medium trucks	7	
	-Heavy trucks	0	
	-Articulated vehicles	0	
Total number of vehicles for all classes and types			3618

Table G.26: Detailed collected data of vehicles' class, type and number for segment B – Case study 3

Case Study: 3 **Road Segment: B** **Observer: B-1**		**Date: Monday 01/08/2010** **Time: 7:30 – 8:30** **Name of observer:**	
Class	**Type**	**Number of vehicles counted by observer**	**Total number of vehicles for each class**
1	Cars	2818	2818
2	-Light commercial vehicles	11	71
	-Mini-buses	36	
	-Buses	24	
3	-Light trucks	10	16
	-Medium trucks	6	
	-Heavy trucks	0	
	-Articulated vehicles	0	
Total number of vehicles for all classes and types			2905

Table G.27: Detailed collected data of vehicles' class, type and number for segment C – Case study 3

Case Study: 3 Road Segment: C Observer: C-1		Date: Monday 01/08/2010 Time: 7:30 – 8:30 Name of observer:	
Class	**Type**	**Number of vehicles counted by observer**	**Total number of vehicles for each class**
1	Cars	3171	3171
2	-Light commercial vehicles	12	72
	-Mini-buses	36	
	-Buses	24	
3	-Light trucks	11	19
	-Medium trucks	8	
	-Heavy trucks	0	
	-Articulated vehicles	0	
Total number of vehicles for all classes and types			3262

Table G.28: Average detailed collected data of vehicles' class and number for segment A – Case study 3

Case Study: 3 Road Segment: A		Duration: 1 hour			
Class	**Number of vehicles counted by each observer**				**Average**
	A-1	**A-2**	**A-3**	**A-4**	
1	3523	3702	3606	3581	3603
2	76	65	70	62	68
3	19	22	18	25	21
Total	3618	3789	3694	3668	3692

Table G.29: Average detailed collected data of vehicles' class and number for segment B – Case study 3

Case Study: 3 Road Segment: B		Duration: 1 hour			
Class	**Number of vehicles counted by each observer**				**Average**
	B-1	**B-2**	**B-3**	**B-4**	
1	2818	2906	2878	2822	2856
2	71	68	62	59	65
3	16	20	18	23	19
Total	2905	2994	2958	2904	2940

Table G.30: Average detailed collected data of vehicles' class and number for segment C – Case study 3

Case Study: 3 Road Segment: C		**Duration: 1 hour**			
Class	**Number of vehicles counted by each observer**				**Average**
	C-1	**C-2**	**C-3**	**C-4**	
1	3171	3297	3245	3198	3228
2	72	67	65	75	70
3	19	23	17	24	21
Total	3262	3387	3327	3297	3319

Appendix G.4 Detailed Collected Data – Case Study 4

Socio-Economic Factor Group

Table G.31: Detailed collected data of socio-economic group for segment A – Case study 4

Case Study: 4 Road Segment: A			**Road Zone(s): 51 and 52 Type of Area: Rural**	
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
1	Service institute 1	250	60	0.240
2	Service institute 2	400	140	0.350
3	Police station	550	90	0.164
4	School 1	900	380	0.422
5	School 2	400	140	0.350
6	Mosque 1	1000	300	0.300
7	Mosque 2	800	280	0.350
8	Mosque 3	650	210	0.323
9	Tourist area	10,000	1000	0.100
10	Grocery store 1	300	120	0.400
11	Grocery store 2	480	150	0.313
Total	11	15730	2870	0.182

Table G.32: Detailed collected data of socio-economic group for segment B – Case study 4

Case Study: 4 **Road Segment: B**			**Road Zone(s): 51 and 52** **Type of Area: Rural**	
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
1	Service institute 1	220	50	0.227
2	Service institute 2	300	90	0.300
3	Service institute 3	600	160	0.267
4	Medical clinic 1	300	50	0.167
5	Medical clinic 2	250	30	0.120
6	School 1	1500	700	0.467
7	School 2	800	150	0.188
8	School 3	1400	550	0.393
9	Mosque 1	900	280	0.311
10	Mosque 2	750	300	0.400
11	Mosque 3	600	200	0.333
12	Mosque 4	850	250	0.294
13	Grocery store 1	440	140	0.318
14	Grocery store 2	500	160	0.320
Total	14	9410	3110	0.330

Table G.33: Detailed collected data of socio-economic group for segment C – Case study 4

Case Study: 4 **Road Segment: C**		**Road Zone(s): 51 and 52** **Type of Area: Rural**		
No.	**Socio-economic facility type**	**Area of the building (m^2)**	**No. of persons in the building**	**Capacity of the building (person/m^2)**
1	Hospital	3000	450	0.150
2	Medical clinic	400	70	0.175
3	Government institute 1	2000	800	0.400
4	Government institute 2	1200	250	0.208
5	Service institute 1	4000	1500	0.375
6	Service institute 2	650	280	0.431
7	Police station 1	550	100	0.182
8	Police station 2	650	110	0.169
9	School 1	1600	750	0.469
10	School 2	2100	700	0.333
11	School 3	2200	720	0.327
12	School 4	900	350	0.389
13	School 5	850	300	0.353
14	School 6	950	380	0.400
15	Mosque 1	750	240	0.320
16	Mosque 2	850	280	0.329
17	Mosque 3	550	180	0.327
18	Mosque 4	400	150	0.375
19	Mosque 5	600	210	0.350
20	Commerce centre 1	3000	1100	0.367
21	Commerce centre 2	1800	800	0.444
22	Factory 1	1200	150	0.125
23	Factory 2	1400	180	0.129
24	Factory 3	950	120	0.126
25	Grocery store 1	520	180	0.346
26	Grocery store 2	2000	800	0.400
27	Grocery store 3	1800	750	0.417
28	Grocery store 4	900	320	0.356
Total	28	37770	12220	0.324

Traffic Factor Group

Table G.34: Detailed collected data of vehicles' class, type and number for segment A – Case study 4

Case Study: 4 **Road Segment: A** **Observer: A-1**		**Date: Monday 03/08/2010** **Time: 7:30 – 8:30** **Name of observer:**	
Class	**Type**	**Number of vehicles counted by observer**	**Total number of vehicles for each class**
1	Cars	368	368
2	-Light commercial vehicles	36	393
	-Mini-buses	357	
	-Buses	0	
3	-Light trucks	119	183
	-Medium trucks	63	
	-Heavy trucks	0	
	-Articulated vehicles	1	
Total number of vehicles for all classes and types			944

Table G.35: Detailed collected data of vehicles' class, type and number for segment B – Case study 4

Case Study: 4 **Road Segment: B** **Observer: B-1**		**Date: Monday 03/08/2010** **Time: 7:30 – 8:30** **Name of observer:**	
Class	**Type**	**Number of vehicles counted by observer**	**Total number of vehicles for each class**
1	Cars	352	352
2	-Light commercial vehicles	31	388
	-Mini-buses	357	
	-Buses	0	
3	-Light trucks	103	158
	-Medium trucks	54	
	-Heavy trucks	0	
	-Articulated vehicles	1	
Total number of vehicles for all classes and types			898

Table G.36: Detailed collected data of vehicles' class, type and number for segment C – Case study 4

Case Study: 4 **Road Segment: C** **Observer: C-1**	**Date: Monday 03/08/2010** **Time: 7:30 – 8:30** **Name of observer:**		
Class	**Type**	**Number of vehicles counted by observer**	**Total number of vehicles for each class**
1	Cars	309	309
2	-Light commercial vehicles	27	384
	-Mini-buses	357	
	-Buses	0	
3	-Light trucks	32	61
	-Medium trucks	29	
	-Heavy trucks	0	
	-Articulated vehicles	0	
Total number of vehicles for all classes and types			754

Table G.37: Average detailed collected data of vehicles' class and number for segment A – Case study 4

Case Study: 4 **Road Segment: A**		**Duration: 1 hour**			
Class	**Number of vehicles counted by each observer**				**Average**
	A-1	**A-2**	**A-3**	**A-4**	
1	368	359	377	341	361
2	393	401	409	388	398
3	183	170	178	192	181
Total	944	930	964	921	940

Table G.38: Average detailed collected data of vehicles' class and number for segment B – Case study 4

Case Study: 4 **Road Segment: B**		**Duration: 1 hour**			
Class	**Number of vehicles counted by each observer**				**Average**
	B-1	**B-2**	**B-3**	**B-4**	
1	352	366	346	371	359
2	388	378	382	379	382
3	158	149	143	163	153
Total	898	893	871	913	894

Table G.39: Average detailed collected data of vehicles' class and number for segment C – Case study 4

Case Study: 4 **Road Segment: C**		**Duration: 1 hour**			
Class	**Number of vehicles counted by each observer**				**Average**
	C-1	**C-2**	**C-3**	**C-4**	
1	309	322	331	298	315
2	384	379	378	386	382
3	61	57	69	52	60
Total	754	758	778	736	757