

2010-08-10



Methodology to Assess the Reliability of Transport Networks under Disaster Conditions

By

Varuna Viraj Adikariwattage



University of Moratuwa, Sri Lanka.

Electronic Theses & Dissertations

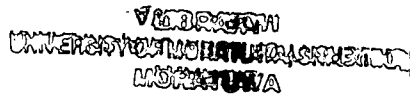
This thesis was submitted to the Department of

www.lib.mru.ac.lk

Transport and Logistics Management of the University of Moratuwa in
partial fulfillment of the requirements for the Degree of Master of Science

Supervised by

Professor J.M.S.J Bandara



Department of Transport and Logistics Management

University of Moratuwa

University of Moratuwa

Sri Lanka



92978

September 2008

92978

92978

656 "os"

656(043)

T.H

Dedication:

To my dear

Father, Mother and Brothers



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Declaration

I, Varuna Viraj Adikariwattage hereby declare that the content of this thesis is the output of original research work carried out over a period of 15 months at the Department of Transport and Logistics Management, University of Moratuwa, Sri Lanka. Whenever others' work is included in this thesis, it is appropriately acknowledged as a reference.

V. Adikariwattage

Varuna Viraj Adikariwattage

Department of Transport and Logistics Management,

University of Moratuwa,

Sri Lanka.



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

J.M.S.J. Bandara

Prof. J.M.S.J Bandara,

Department of Transport and Logistics Management,

University of Moratuwa,

Sri Lanka.

Abstract

Transportation research and development covers a multitude of topics regarding all areas in transportation. Transportation reliability and vulnerability studies are a new area that has started to draw a lot of attention particularly about its possible applications to help disaster management practices. But unfortunately transportation network risk and vulnerability assessment has not received due recognition so far when formulating preparedness policies in disaster management operations. There are various types of studies such as environmental impact assessment, cost benefit studies for transportation infrastructure where a wide variety of features are looked at, but risk and vulnerability analysis of the transportation network has not yet been considered with much importance. One major reason for this can be highlighted as the lack of established terminology and associated means of analysis that can be specifically adopted for the purpose. And further more it is difficult to draw a firm consensus on available methods due to various disparities among the concepts proposed.



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

The aim of this research is to develop a methodology to evaluate the state of transportation networks in terms of accessibility and connectivity under disaster situations. A new methodology is proposed based on concepts of both vulnerability and reliability assessment of transportation networks. The proposed method expresses the state of the network using an index defined as the Preparedness Index that is used as a measurement of the state of the network against possible threats and degradation due to damage.

The proposed preparedness index has two components, one to assess the quality or the effectiveness of the connection in terms of distance covered, travel time or LOS provided, and the other component to assess the probability of maintaining the connection that takes in to account the prevailing uncertainty in the network. With the proposed concept it was possible to achieve a good balance in the measurement regarding the state of the network without any one component, either network structural aspects or predictability and probability aspects dominating the analysis. Therefore this proposed index has the potential to overcome some of the drawbacks identified with conventional methods.

Acknowledgement

First and foremost I wish to express my deep and sincere gratitude to my supervisor, Professor J.M.S.J Bandara, University of Moratuwa for giving me the opportunity to undertake this research study. I am deeply indebted to my supervisor whose guidance, constructive comments and all the other support that helped me to successfully complete the research and writing of this thesis.

I would also like to gratefully acknowledge the important comments given by Professor Amal S. Kumarage, University of Moratuwa, coordinator of my research and Dr. I.M.S Sathyaprasad, University of Peradeniya, Sri Lanka. Their ideas and constructive comments enormously helped me in achieving the objectives of my research.

I have furthermore to thank the staff of the Department of Transport and Logistics Management, University of Moratuwa for their support in the course of my study.



University of Moratuwa, Sri Lanka
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

I owe a very special gratitude to Dr. M.A.W Kumara and the fellow research students at the Transportation Engineering Division of the Department of Civil Engineering University of Moratuwa. I want to thank them for all their support, interest and valuable comments.

Finally I would like to take this opportunity to extend my heartfelt gratitude to all the academic and non academic staff of the University of Moratuwa, who has contributed to my work in numerous ways.

V:V Adikariwattage

Table of contents

CHAPTER 01

INTRODUCTION	1
1.1 GENERAL	1
1.2 AIM OF THE RESEARCH	4
1.3 OBJECTIVES	4
1.4 METHODOLOGY	4

CHAPTER 02

LITERATURE REVIEW	6
2.1 GENERAL	6
2.2 RELIABILITY	7
2.2.1 Connectivity reliability	9
2.2.2 Travel time reliability	15
2.2.2.1 Cause based multimodal (GBMM) model (Haitham et al, 2006)	17
2.2.3 Capacity reliability	18
2.3 VULNERABILITY	20
2.3.1 Measuring vulnerability	21
2.3.2 Vulnerability and risk assessment for disaster management	24
2.4 RISK	25
2.4.1 Estimating the occurrence of natural hazards	25
2.4.2 Hazard mapping	26
2.4.3 Criticality and importance	26
2.5 SURVIVABILITY	28

CHAPTER 03

CONCEPTUAL FRAMEWORK FOR ANALYZING THE NETWORK RELIABILITY	29
3.1 INTRODUCTION	29
3.1.1 Vulnerability versus reliability	31
3.2 PREPAREDNESS INDEX	31

3.3 PREPAREDNESS INDEX (PI) - CONCEPT	33
3.3.1 Connecting length ratio	33
3.3.1.1 Accounting for traffic flow	36
3.3.2 Uncertainty	38
3.3.2.1 Connectivity probability	40
3.4 PREPAREDNESS INDEX AS A MEASUREMENT OF VULNERABILITY	43
3.5 IDENTIFYING IMPORTANT LINKS AND CRITICAL LINKS	50
3.5.1 Link importance	50
3.5.2 Criticality	51
3.6 ILLUSTRATIVE EXAMPLE	51
3.6.1 Procedure to search all feasible paths between the O-D pair	53
3.6.1.1 Dijkstra's algorithm	53
3.6.1.2 Proposed algorithm to search all paths between an O-D pair	56
3.6.2 Calculating connecting length ratio	59
3.6.3 Calculating link importance	62
3.6.4 Calculating connectivity probability	68
3.6.5 Network connectivity	69
CHAPTER 04	
CASE STUDY	74
4.1 INTRODUCTION	74
4.2 SIMPLIFIED NETWORK	76
4.3 ESTIMATING UNCERTAINTY	78
4.4 CALCULATION OF THE PREPAREDNESS INDEX FOR INDIVIDUAL O-D PARES	79
4.4.1 Rathnapura - Ehaliyagoda	79
4.4.2 Rathnapura-Balangoda	83
4.5 EVALUATING NETWORK CONNECTIVITY	87
CHAPTER 05	
CONCLUSION AND FUTURE WORK	91
5.1 GENERAL	91
5.2 FUTURE WORK	94
APPENDIX	95
REFERENCES	100



List of figures

Figure 2.1: Probability distribution of traffic flow	10
Figure 2.2: Series connected links	11
Figure 2.3: Parallel configuration	11
Figure 2.4: A parallel path set of a network	12
Figure 2.5: A series cut set of a network	12
Figure 2.6: Schematic road network	12
Figure 2.7: Event tree of link states (Min liu, 2005)	13
Figure 2.8: Elements of network vulnerability	22
Figure 2.9: Landslides hazard map of Kagall district	27
Figure 3.1: Example network	34
Figure 3.2: Network with multiple connections	38
Figure 3.3: Network with single connection	39
Figure 3.4: Series connected links	40
Figure 3.5: Parallel connected links	41
Figure 3.6: Parallel and series combination	41
Figure 3.7: Standard network configuration	44
Figure 3.8: Network with $PI > 1$	45
Figure 3.9: Network with $PI < 1$	46
Figure 3.10: Factors affecting PI	48
Figure 3.11: Identification of critical links	51
Figure 3.12: Example network	52
Figure 3.13: Flowchart for Dijkstra's algorithm	55
Figure 3.14: Flowchart for the proposed algorithm to search paths	58
Figure 3.15: Registering paths on an Excel work sheet	59
Figure 3.16: Connecting length ratio Vs Path distance limit	61
Figure 3.17: Link importance for accessibility of (1-13)	65
Figure 3.18: Link importance for accessibility of nodes (1, 13) with restricted paths	65
Figure 3.19: Link importance for accessibility of nodes (1, 13) with restricted paths	66
Figure 3.20: Change of link importance with level of path distance limit	67

Figure 3.21: Probability of having at least one connection in the network	68
Figure 3.22: Preparedness index variation	69
Figure 3.23: Network connectivity	71
Figure 3.24: Link importance for network connectivity	73
Figure 4.1: Selected road network in the Rathnapura district	75
Figure 4.2: Simplified network	76
Figure 4.3: Landslides hazards map of Rathnapura	78
Figure 4.4: PI variation with each link closed	81
Figure 4.5: Connectivity probability & connecting length ratio	81
Figure 4.6: Link importance	82
Figure 4.7: PI variation with each link closed	84
Figure 4.8: Connectivity probability & Connecting length ratio	85
Figure 4.9: Link importance	85
Figure 4.10: Link Importance for network connectivity	89



List of tables

Table 2.1: Causes, effects and link probabilities (Haitham et al, 2006)	17
Table 3.1: Network paths of the example network	34
Table 3.2: Path distance weighting	34
Table 3.3: Link weighted connections	35
Table 3.4: Standard network- I	39
Table 3.5: Standard network-I 1	39
Table 3.6: Standard network	44
Table 3.7: Calculation of weighted path values	45
Table 3.8: Calculation of weighted path values	46
Table 3.9: Standard network	47
Table 3.10: Link numbers and lengths	52
Table 3.11: Network link details (considering the entire network)	60
Table 3.12: Change in weighted connections of links after link 12 closed	62
Table 3.13: Change in weighted connections of links after link 18 closed	63
Table 3.14: Link importance	64
Table 3.15: Connectivity probability	68
Table 3.16: Network connectivity	72
Table 4.1: Link uncertainty	79
Table 4.2: Calculation of network path weightings for Rathnapura-Ehaliyagoda	80
Table 4.3: Calculation of network path weightings for Rathnapura-Balangoda	83
Table 4.4: Preparedness index of each O-D pair	86
Table 4.5: O-D pair weightings	87
Table 4.6: Weighted average of weighted connections using link-1	87
Table 4.7: link weighted connection for network connectivity	88
Table 4.8: Critical links	90