



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم

بسم الله الرحمن الرحيم



HANAA ALY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم



شبكة المعلومات الجامعية التوثيق الإلكتروني والميكروفيلم



HANAA ALY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم

جامعة عين شمس

التوثيق الإلكتروني والميكروفيلم

قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها
علي هذه الأقراص المدمجة قد أعدت دون أية تغيرات



يجب أن

تحفظ هذه الأقراص المدمجة بعيدا عن الغبار



HANAA ALY



Cairo University

VULNERABILITY BASED INFRASTRUCTURE FUND ALLOCATION OPTIMIZATION MODEL

By

Mohamed Ahmed Bahaa EL-Din Ahmed El-Khayat

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Structural Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2021

VULNERABILITY BASED INFRASTRUCTURE FUND ALLOCATION OPTIMIZATION MODEL

By
Mohamed Ahmed Bahaa EL-Din Ahmed El-Khayat

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Structural Engineering

Under the Supervision of

Prof. Dr. Hesham Maged Osman

Dr. Dina Atef Saad

.....

.....

Professor of Construction Engineering
and Management,
Structural Engineering Department, Cairo
University

Assistant Professor,
Structural Engineering Department, Cairo
University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2021

VULNERABILITY BASED INFRASTRUCTURE FUND ALLOCATION OPTIMIZATION MODEL

By
Mohamed Ahmed Bahaa EL-Din Ahmed El-Khayat

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Structural Engineering

Approved by the
Examining Committee

Prof. Dr. Hesham Maged Osman

Thesis Main Advisor

Prof. Dr. Dina Atef Saad

Advisor

Prof. Dr. Maged Ezzat Georgy

Internal Examiner

Prof. Dr. Hesham Ahmed Bassiouny

Arab Academy for Science, Technology
and Maritime Transport

External Examiner

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2021

Engineer's Name: Mohamed Ahmed Bahaa EL-Din Ahmed EL-Khayat
Date of Birth: 02/09/1991
Nationality: Egyptian
E-mail: Mohamedbahaaa2@Gmail.com
Phone: 002-01068902524
Address: 2 El-Zobeer Ibn EL-Awam St, Old Cairo
Registration Date: 1/10/2015
Awarding Date: ---/---/2021
Degree: Master of Science
Department: Structural Engineering



Supervisors:

Prof. Dr. Hesham Maged Osman
Prof. Dr. Dina Atef Saad

Examiners:

Prof. Dr. Hesham Maged Osman (Thesis main advisor)
Prof. Dr. Dina Atef Saad (advisor)
Prof. Dr. Maged Ezzat Georgy (Internal examiner)
Prof. Dr. Hesham Ahmed Bassiouny (External examiner)
Arab Academy for Science, Technology
and Maritime Transport

Title of Thesis:

Vulnerability Based Infrastructure Fund Allocation Optimization Model

Key Words:

Optimization; Funding Decisions; Vulnerability; Deterioration Modeling; Infrastructure Rehabilitation.

Summary:

Infrastructure bills are in permanent increase due to the continuous deterioration with time, and the presence of a gap between the infrastructure rehabilitation needs and the available fund. Accordingly, a fund allocation model became necessary to be created to face this everlasting problem. Many budget allocation models were created, but all these efforts failed to face the fast deterioration rates for infrastructure assets due to neglecting the effect of some factors that accelerate the deterioration rates beyond the expected. The research purpose is to develop a new fund allocation optimization model which maximizes the assets overall physical conditions and with the presence of funding constrains taking in consideration the effect of normal deterioration rates and the vulnerability factors effect by using Markov Chains stochastic deterioration modeling.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: Mohamed Ahmed Bahaa EL-Din Ahmed

Date: / /2021

Signature:

Dedication

*To My Mother &
Father*

Acknowledgments

Foremost, I would like to express my sincere gratitude to my supervisors Dr. Prof. Hesham Osman, and Dr. Dina Atef Saad, for their valuable supervision, continuous support, and guidance throughout all stages of my MSc. thesis progress. Their academic and technical experience directed me to make the current thesis achievable, which made me very thankful to them. I would also like to gratefully thank all the participated interviewees for their valuable time providing me with the relevant information and necessary data required to build the thesis model.

Moreover, I would like to express my appreciation to my managers Eng. Muhammad Yahia; Chief Executive Officer of Porto Group Holding Company and Eng. Ali EL-Hadidi; Deputy Manager of Porto Group Holding Company for their continuous support and allowing time for completing the thesis, along with providing me the relevant documents that support the research. In addition, I wish to express my deep thanks to the person who has always stood side by side, day and night beside me, in addition to providing me with adequate advices, patience and support; my closet friend and brother, Hossam EL-Din Refaat.

Nobody has been more important to me in the pursuit of this project than the members of my family. I would like to thank my parents and my sister whose love and guidance are with me in whatever I pursue. They are the ultimate role models. Finally, I express my regards to everyone who participated in the current research and supported me in any respect of the study.

Thank you all...

Table of Contents

DISCLAIMER	I
DEDICATION	II
ACKNOWLEDGMENTS.....	III
TABLE OF CONTENTS	IV
LIST OF TABLES.....	VI
LIST OF FIGURES.....	VII
ABSTRACT	VIII
CHAPTER 1 : INTRODUCTION.....	1
1.1. <i>Background.....</i>	<i>1</i>
1.2. <i>Research Motivation</i>	<i>3</i>
1.2.1. Infrastructure Accelerated Deterioration.....	3
1.2.2. Overlooking Of Infrastructure’s Vulnerability in Funding Models	3
1.3. <i>Research Objective</i>	<i>4</i>
1.4. <i>Research methodology.....</i>	<i>4</i>
1.5. <i>Research organization</i>	<i>5</i>
CHAPTER 2 : LITERATURE REVIEW	6
2.1. <i>Introduction.....</i>	<i>6</i>
2.2. <i>Infrastructure Asset Management & Optimization Models</i>	<i>6</i>
2.3. <i>Infrastructure Vulnerability.....</i>	<i>8</i>
2.4. <i>Infrastructure Deterioration</i>	<i>10</i>
2.4.1 Road Deterioration Factors.....	12
2.5. <i>Stochastic Deterioration behavior Modeling.....</i>	<i>15</i>
2.6. <i>Genetic Algorithms Optimization.....</i>	<i>17</i>
2.7. <i>Summary</i>	<i>18</i>
CHAPTER 3 : PROPOSED METHODOLOGY.....	19
3.1. <i>Introduction.....</i>	<i>19</i>
3.2. <i>Research Framework.....</i>	<i>19</i>
3.2.1. Roads Inventory.....	21
3.2.2. Roads Condition Assessment.....	21
3.2.3. Vulnerability Effects Assessments'	21
3.2.4. Stochastic Deterioration Modeling	22
3.2.5. Life Cycle Cost Analysis	23
3.2.6. Fund Allocation Optimization	24
3.3. <i>Summary</i>	<i>25</i>
CHAPTER 4 : VULNERABILITY-BASED DETERIORATION BEHAVIOR MODELLING.....	26
4.1. <i>Introduction.....</i>	<i>26</i>
4.2. <i>Infrastructure Assets Vulnerability.....</i>	<i>26</i>
4.3. <i>Vulnerability Factors Assessment.....</i>	<i>27</i>
4.4. <i>Vulnerability Factors Assurance</i>	<i>33</i>
4.5. <i>Vulnerability Index.....</i>	<i>39</i>
4.6. <i>Markov Chains Stochastic Deterioration Model</i>	<i>40</i>
4.7. <i>Summary</i>	<i>44</i>

CHAPTER 5 : MATHEMATICAL FORMULATIONS OF THE FUND-ALLOCATION MODEL AND THE OPTIMIZATION PARAMETERS	45
5.1. <i>Introduction.....</i>	45
5.2. <i>Optimization Model Computation.....</i>	45
5.2.1. Estimating Yearly Difference in Condition Index	46
5.2.2. Estimating Yearly Rehabilitation and Maintenance Costs.....	48
5.2.3. Optimization Model Parameters	48
5.2.4. Assigning Optimization Model Constrains	49
5.2.5. Assigning Optimization Model Variables.....	50
5.2.6. Generic Algorithms Solver Application.....	50
5.2.7. Analyze the Optimization Model Results	51
5.3. <i>Summary</i>	52
CHAPTER 6 : CASE STUDY	53
6.1. <i>Introduction.....</i>	53
6.2. <i>Case Study Description.....</i>	53
6.2.1. Road Network Details.....	53
6.2.2. Road Network Actual Physical Condition	54
6.2.3. Markov Chains Deterioration Modeling	55
6.3. <i>Case Study Results and Analysis.....</i>	61
6.4. <i>Summary</i>	62
CHAPTER 7 : CONCLUSIONS	63
7.1. <i>Summary</i>	63
7.2. <i>Research contribution.....</i>	64
7.3. <i>Limitations and Future research work.....</i>	65
REFERENCES	66
APPENDIX A: SAMPLE QUESTIONNAIRE.....	78
APPENDIX B: QUESTIONNAIRE RESPONSES	84
APPENDIX C: QUESTIONNAIRE ANALYSIS	92

List of Tables

Table 1-Countries Expenditure in the Infrastructure Department According to (Shaw G., et al., 2012).	1
Table 2-Vulnerability factors and their measuring units.....	32
Table 3-Deterioration Factors Table	34
Table 4-Road Network Details	53
Table 5-Road Network IRI Readings	54
Table 6-IRI Categories and score values.....	55
Table 7-Value of Vulnerability Factors Weights	56
Table 8-Interventions Costs.....	58
Table 9-Results Summary of the Optimization Experiments	61
Table 10-Appendix B - Experts Information.....	85
Table 11-Appendix B - Vulnerability Factors Codes.....	86
Table 12-Appendix B - Experts Responses On Vulnerability Factors Influence.....	87
Table 13-Appendix B - Experts Responses On Vulnerability Factors Weights	88
Table 14-Appendix B - Experts Responses On Yearly Transition Probability Matrix..	89
Table 15- Appendix C - Experts Responses Results and Analysis on Vulnerability Factors	93
Table 16-- Appendix C - Experts Responses Results and Analysis on Transition Probability Matrix	93

List of Figures

Figure 1-Deterioration Factors Categories According to (Hossein Alzubaidi and Rolf Magnusson, 2002)	14
Figure 2-Deterioration Factors Categories According to (Sharad S. Adlinge and Prof. A.K. Gupta, 2009)	15
Figure 3- Optimization Model Frame Work Phases.....	20
Figure 4-Relation Between Road Physical Condition and Intervention Cost	24
Figure 5-Vulnerability Factors Categories	27
Figure 6-Flooding in Egypt	29
Figure 7-Example for Markov Chains Transition Probability Techniques	40
Figure 8-Impact of asset's vulnerability on the deterioration behavior	40
Figure 9-Intervention Magnitude	46
Figure 10-Improvement Effect Illustration Diagram	47
Figure 11- Intervention Methodology	47
Figure 12-Three Intervention Methodologies	49
Figure 13-Optimization Model Variables	50
Figure 14-Initial Condition Rating Using IRI Categories and score values.....	55
Figure 15-1-Year Deterioration Matrix Without Vulnerability Effect.....	56
Figure 16-Vulnerability Factors Score	57
Figure 17-1-Year Deterioration Matrix Under Vulnerability Effect.....	57
Figure 18-Expected Condition Rating Without Intervention after 1-year.....	57
Figure 19-Intervention Categories.....	58
Figure 20-Optimization Model Objective Function	59
Figure 21- Optimization Model Constrains.....	59
Figure 22- Optimization Model Decision Variables	60

Abstract

Infrastructure assets are one of the essential assets in any community for its sustainability and livability. Like any asset, infrastructure ones deteriorate with time, thus their bills are in continuous increase. Due to the massive needs for many assets to be intervened after deterioration with the presence of budget constraints, decision makers may take many rehabilitation decisions that may be effective and maybe not. Many efforts were made in order to help those who take the rehabilitation decisions to select the best and effective assets to be rehabilitated, however, most of these decisions weren't effective because most of these efforts didn't consider the fast deterioration of infrastructure assets due to its vulnerability to external factors. Accordingly, a fund-allocation optimization model that maximizes the physical performance of infrastructure, while considering budget constraints and infrastructure vulnerability factors using stochastic modeling is proposed in this research. Before developing the model, the vulnerability factors were previously selected knowing the degree of influence for each one, after that model will calculate the vulnerability index for each asset as differs from an asset to another. The vulnerability index is then used in the stochastic deterioration model using Markov chain in order to develop the yearly expected condition index for each asset under the vulnerability effect. To measure the performance of the model, it is applied to a road network as one type of infrastructure. Thus, the unexpected factors that accelerates road deterioration by increasing its vulnerability were captured using this study, including excessive traffic loading, neighboring disturbance, climate change, etc. Applying the model and comparing it against the existing models, results demonstrated rationality behind the generated funding decisions using the proposed model, and the cumbersome consequences of ignoring vulnerability. Thus, the model can help policymakers make realistic funding decisions to maintain infrastructure performance.