BUDGET ALLOCATION MANAGEMENT MODEL FOR SEISMIC REHABILITATION OF INFRASTRUCTURE ASSETS

MOHAMMADREZA YADOLLAHI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Civil Engineering)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

FEBRUARY 2013

Dedicated to

My Beloved **Mother**

Who I owe her so much for her

Everlasting Love, Inspiration, and Encouragement

ACKNOWLEDMENT

I would like to express my sense of appreciation to my supervisor Dr. Rosli Mohamad Zin for his consistent support and guidance for my research. This work would not have been completed without his technical comments, patience and understanding. I also would like to appreciate my Co-supervisor Professor Azlan Adnan for his constructive advices.

My deepest gratitude goes to my beloved mother, for her endless love, prayers and encouragement. Thank you very much.

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ABSTRACT

Economic efficiency is an important factor in seismic rehabilitation planning for infrastructure assets. An inventory of structures is screened to identify seismically susceptible parts and prioritize them in the order of need for rehabilitation purposes. In most cases, the financial resources for rehabilitation of infrastructure assets are limited. Therefore, there is a need to efficiently allocate such resources to various projects. The main goal of this research is to develop a budget allocation management model for rehabilitation of infrastructure projects, when there isn't sufficient budget to allocate to all projects. Accordingly, a decision support system is developed and exercised in this research to optimize the budget for rehabilitation projects in three categories of road structures. To accomplish this, a computer-based Multiple Strategy Budget Allocation decision support System (MSBAS©) was developed to identify (including selection and prioritization) the best configuration (package) of seismic rehabilitation projects across existing structures. This system employs a multi-criteria assessment module that takes into account desirable criteria to estimate the financial needs for rehabilitation based on the existing budget constraints in a fiscal year. To select the optimal package of projects, a Genetic Algorithm (GA) optimization module is also developed. Multi-objective decision making is conducted under a specific decision strategy with solving a 0-1 Knapsack Problem. To demonstrate the applicability of the GA-based approach, a hypothetical decision making problem is presented. Using this system, managers can compare their decisions for different strategies and significantly improve management efficiency.

ABSTRAK

Kecekapan ekonomi merupakan satu faktor penting dalam perancangan rehabilitasi sismik bagi asset infrastruktur. Inventori struktur akan ditapis untuk mengenalpasti bahagian sismik yang bermasalah dan seterusnya disusun mengikut keperluan rehabilitasi. Dalam kebanyakan kes, sumber kewangan untuk rehabilitasi infrastruktur adalah terhad. Oleh yang demikian, sumber tersebut perlu diagihkan secara cekap bagi pelbagai projek rehabilitasi. Matlamat utama kajian ini adalah untuk membangunkan model pengurusan pengagihan bajet untuk projek rehabilitasi, khususnya apabila bajet adalah tidak mencukupi untuk diagihkan kesemua projek rehabilitasi. Sehubungan dengan itu, sistem sokongan keputusan dibangunkan dan digunapakai bagi mengoptimum bajet projek rehabilitasi dalam tiga kategori infrastruktur jalanraya. Untuk mencapai hasrat ini, satu Sistem bantuan pembuat keputusan Peruntukan Bajet Pelbagai Strategi (MSBAS©) berasaskan komputer telah dibangunkan bagi mengenalpasti (termasuk pemilihan dan pengutamaan) konfigurasi (pakej) terbaik projek rehabilitasi sismik sedia ada dalam rangkaian jalanraya. Sistem ini mengunapakai modul penilaian pelbagai-kriteria yang mengambilkira kriteria berbeza untuk menganggar keperluan kewangan untuk rehabilitasi, berdasarkan kekangan bajet yang sedia bajet dalam tahun fiskal. Bagi memilih pakej projek yang optimum, satu modul pengoptimuman Algoritma Genetik (GA) juga telah dibentuk. Keputusan pelbagai-objektif telah dibuat di bawah strategi yang tertentu dengan Pemasalan Knapsack (0-1). Bagi membuktikan kebolehgunaan pendekatan Algoritma Genetik, satu pemasalan pembuatan keputusan hipotikal ditunjukkan. Dengan penggunaan sistem ini, pengurus dapat membandingkan keputusan mereka bagi strategi yang berbeza dan memperbaiki secara signifikan kecekapan pengurusan projek rahabilitasi.

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LIST OF ABBREVIATIONS

AASHTO	-	American Association of State Highway and Transportation Officials
AHP	-	Analytical Hierarchy Process
AI	-	Artificial Intelligence
AMC	-	Average Mean of Criteria
ANN	-	Artificial Neural Network
ASCE	-	American Society for Civil Engineers
ATC	-	Applied Technology Council
AVR	-	Abutment Vulnerability Rating
AVR	-	Abutment Vulnerability Rating
BMS	-	Bridge Management System
CBA	-	Cost-Benefit Analysis
CI	-	Consistency Index
CR	-	Consistency Ratio
CTI	-	Critical Transportation Infrastructure
CVR	-	Columns Vulnerability Rating
DOT	-	Department of Transportation
DP	-	Dynamic Programming
DRSA	-	Dominance-Based Rough Set Approach
DS	-	Decision Strategy
DSS	-	Decision Support System
EA	-	Evolutionary Algorithm

ERC	-	Effective Rehabilitation criteria
FEMA	-	Federal Emergency Management Agency
FHWA	-	Federal Highway Administration
GA	-	Genetic Algorithm
GP	-	Goal Programming
GS	-	General Score
GUI	-	Graphical User Interface
HAZUS	-	Hazard US
IM	-	Indices Method
IOE	-	Intensity of Effectiveness
KP	-	Knapsack Problem
LVR	-	Liquefaction Vulnerability Rating
MCDM	-	Multi-Criteria Decision Making
MCE	-	Maximum Credible Earthquake
MCPS	-	Multi-Criteria Priority Scoring
MRT	-	Ministry of Road and Transportation
MS	-	Mean Score
MSBAS	-	Multi-Strategy Budget Allocation System
NP	-	Non-deterministic Polynomial
PGA	-	Peak Ground Acceleration
PGV	-	Peak Ground Velocity
PS	-	Priority Score
RVS	-	Rapid Visual Screening
SD	-	Standard Deviation
SPSS	-	Statistical Package for Social Science
SPT	-	Standard Penetration Test
SVF	-	Seismic Vulnerability Factor

SVS	-	Seismic Vulnerability Score
SVSA	-	Seismic Vulnerability Score Assignment
TD	-	Temporal Difference
TRI	-	Transportation Research Institute
USGS	-	United States Geological Survey
VF	-	Validation Factor
VM	-	Value Management
VS	-	Value Score

LIST OF SYMBOLS

b_1	-	lower threshold for budget
b_2	-	upper threshold for budget
B	-	Total available budget at network level
C	-	Criteria vector
$\hat{C}_i$	-	i^{th} identified rehabilitation criterion
$\mathbb{C}_i$	-	Estimated rehabilitation cost for project *i*
E	-	Seismic hazard rating.
i	-	index marking project
j	-	index marking criteria
k	-	index marking infrastructures' category
m	-	Total number of identified criteria
$\acute{m}$	-	Total number of relative importance criteria
n	-	Total number of rehabilitation projects
Ñ	-	number of projects in the final package
N_k	-	number of projects in each category of infrastructures
Θ	-	Occurrence rate within the population
PS_i	-	Priority score for project *i*
PS_i^*	-	Priority score based on new weighted criteria for project *i*
P_f	-	Possibility that the criterion does not belong to the ERC
R_n	-	Rank based on other factors
R_s	-	Rank based on structural vulnerability

S	-	Matrix of vulnerability evaluation scores
s_i	-	Structural vulnerability factors for structure *i*
t	-	number of infrastructures categories
V	-	Structural vulnerability rating
VS_i	-	Value score for project *i*
W	-	Weighted criteria matrix
w_i	-	Relative weights of factors for structure *i*
X_i	-	Indicator variable (X_i=1 if project i exists in the final package X_i=0 if project i does not exist in the final package).
z	-	Score associated with the confidence level required
λ_{max}	-	Eigenvalue
$\mu_{\hat{A}}(x_i)$	-	Degree of membership for each criterion in each category

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Road transportation network provides services that are critical to public welfare. Previous damages due to the natural disasters revealed that any malfunction of road components can negatively interrupt traffic flows, economy of the region, and post-earthquake emergency response and recovery (Shiraki et al., 2007). If any of the natural disasters such as earthquake occurs, it is important to ensure that the network remains operational. Road network includes critical elements such as pavements, bridges, tunnels, retaining walls and buildings. The loss of functionality of these components within the system clearly affects the vulnerability, serviceability, reliability, functionality and performance of the whole network.

The negative effects of earthquakes damages on road infrastructure are comprehensive and seriously disruptive. In this regard, one of the important responsibility of the transportation authority's is to take mitigation and preparedness measures against natural hazards and try to reduce the possible risks and consequences of damages for existing road structures. Hence, one of the important targets of transportation decision makers, especially in earthquake prone regions, is to manage the risk of this hazard by taking the appropriate measures such as preparedness, mitigation, reduction or reconstruction. Maintenance, repair and rehabilitation activities (include structural repair, renovation, retrofitting or strengthening) for road structures are of the fundamental and vital requirements to achieve the abovementioned target.

Traditionally, seismic rating of road infrastructures for rehabilitation prioritization has been implemented based on seismic factors. However, consideration of non-seismic factors is necessary for reliable rehabilitation prioritization. Non-seismic factors include socioeconomic factors, determining the value of an infrastructure to its user's community. Based on the information obtained from a questionnaire survey and literature review, this study identifies a set of effective rehabilitation criteria to determine a priority score for each structure that is used to find the rehabilitation priority. This procedure is presented for different road infrastructures such as bridges, tunnels, retaining walls, and road buildings. The identified criteria can be generalized to provide valuable insights for policy makers concerned with budget allocation for seismic rehabilitation, especially in seismic-prone countries where budget is often a constraint.

Another important issue in seismic rehabilitation process is the lack of financial resources (Yen, 2010). Therefore, there is a need to efficiently allocate such resources to various projects. Applying the weighted rehabilitation criteria, this study presents a computer-based multi-strategy decision support system (DSS) for seismic rehabilitation budget allocation across existing projects. This system employs a multi-criteria assessment module that takes into account different criteria based on the budget constraints in a fiscal year. To select the optimal package of projects, a Genetic Algorithm (GA) optimization module is also developed. Multi-objective decision making is conducted under a specific decision strategy with solving a (0-1) Knapsack Problem (KP). To demonstrate the applicability of the GA-based approach, a hypothetical decision making problem is presented. Using this system, managers can compare their decisions for different strategies and significantly improve management efficiency.

1.2 Background and Justification

Disaster risk management in transportation network is a comparatively new area of social concern and practice which has great influence on the development of countries. In disaster risk management, "Risk Reduction" is a practical and acceptable worldwide measure for reducing the vulnerability against future disasters (FEMA 273, 1997; FEMA 356, 2000; NCHRP, 2007). Risk reduction involves activities to reduce the vulnerability to specific hazards. In this sense, seismic rehabilitation is the most conventional seismic risks mitigation approach for road structures against earthquakes.

Past experiences demonstrated that natural disasters have been devastating increasing numbers of road infrastructure, destroyed transportation assets and restrain the sustainable development (see some historical data in Section 1.6). For instance, unpredictable earthquake damages can cause serious effects to bridges in earthquake-prone areas. The risk of disasters can be also expected to rise in the future (ISDR, 2008), particularly in seismic-prone countries. Increase in extreme natural events and vulnerability of structures are two main reasons in this regard.

In addition, the probable economic and social earthquake damages to road transportation structures or their components are divided into direct and indirect categories. While direct damages are estimated through cost and time consumed for reconstruction of structures, estimation of indirect damages, which are mostly much higher than direct damages, is more complicated and may require the implementation of detailed economic analyses. Just after any disastrous earthquake, the functionality of such critical road structures decrease suddenly where highlights their importance in two main aspects; disruption at network regarding the normal traffic and cause delay for the emergency response activities. In addition, because of the loss of transportation serviceability just after an earthquake and before the normal situation, the disaster managers require to alternate the roads in such a way that an acceptable level of communication exists and the whole network remain operational.

An earthquake may result in various damages ranging from minor cracks on the top surface to completely ruptured road structures (Tung, 2004). Structures like bridges, tunnels, retaining structures, and all those buildings located on the roads are most vulnerable components in road networks. Not to mention that these structures are main connectors of road network and dispersion or improper performance of them especially in emergency times makes the relief, recovery and reconstruction activities very difficult.

The first earthquake design legislation was enacted in 1933 for schools in California (FEMA 398, 2004). However, considering the years of first published guidelines for the seismic rehabilitation process for different structures (NEHRP Report-FEMA 273, 1997), it can be concluded that the knowledge in seismic rehabilitation is quite a new topic in the world. In addition, in many seismic-prone countries, this area of researches has just recently been considered. The major aims of the seismic rehabilitation are to recover original function of the structures and to prepare measures against possible stronger earthquakes (Fukuyama and Sugano, 2005). However, budgetary constraints are mostly prohibitive and lead to replacing it with a new structure. Alternatively, doing nothing (abandoning the project) and accepting the consequences of damage is another possible option.

On the other hand, there not often exists a reliable and suitable infrastructure database as well as sufficient knowledge about the seismic rehabilitation expenditures. In addition, the probability nature of earthquakes, the damages resulted from delayed rehabilitation projects and the estimated benefits resulted from rehabilitation activities add to the decision makers' complexities. Not to mention that earthquakes leave considerable damages to the road structures that major part of these damages will be borne by the governments.

Therefore, planning for maintenance, repair or rehabilitation of the mentioned structures is one of the vital requirements for management and planning authorities. In recent decade, a growing operational and technical emphasis has been given to seismic rehabilitation of structures with particular attention given to lifeline facilities and the physical infrastructure. While economical evaluation in order to find the best strategy is an important issue, in most of the traditional methods, the issue of different management objectives and strategies are not investigated. Hence, most of the traditional techniques for seismic rehabilitation budget allocation are not very useful for solving the problem efficiently. Considering all previous approaches, this study develops a computerized DSS for optimal budget allocation among seismic rehabilitation projects. To achieve this goal, the most effective rehabilitation criteria for the seismic rehabilitation of road infrastructures in terms of numeric weighted values and other prerequisites for module development should be settled in advance.

1.3 Problem Statement

Budget allocation decision making for seismic rehabilitation projects of road structures is a kind of combinatorial problem include different criteria, objectives and strategies which make the problem solving complex. This complexity can be evaluated form different points of view as discussed in the flowing paragraphs; First, one of the most significant requirements for seismic rehabilitation process is to apply an applicable vulnerability assessment method across all existing projects. In most cases, due to the vast area of road network and large number of various structures, the detailed seismic vulnerability assessment according to existing manuals and current design codes is extremely costly and time consuming. Not to mention that seismic rehabilitation for road structures is relatively a new subject in the world (FEMA 398, 2004). In some cases, there are also other factors which clarify the difficulty in seismic vulnerability assessment; these factors include variety of projects characteristics, the old age of many of the structures (especially in the seismic-prone countries), lack of structural database (containing adequate knowledge and information about structures) and uncertainties about available data.

Second, in prioritization procedure for seismic rehabilitation, other than seismic-structural criteria, non-seismic-structural criteria should also be taken into account. Existing manuals and codes of practice do not provide a comprehensive list of effective rehabilitation criteria for this purpose. Moreover, in order to implement these criteria for prioritization purposes, their relative weights need to be determined. Therefore, the lack of numeric weights for the effective rehabilitation criteria illustrates another aspect of the problem.

Third, most of the governmental transportation departments that are responsible for rehabilitation planning have limited economic and human resources to perform these tasks. Accordingly, the available budgets for rehabilitation tasks are mostly not sufficient to cover all the projects. This type of problem often includes multiple objectives and strategies that contribute to decision making. Each strategy results in selecting different package of projects. Although there are a variety of budget allocation approaches and systems for selecting the best package, appropriate strategies have not been developed or compared for different purposes.

In addition, available commercial optimization software packages are specifically developed for one type of structures, such as bridges. In most cases, to purchase the software license of such commercial packages requires considerable amount of fund and requires large amount of data. Furthermore, these packages are mainly compatible and developed based on life cycle of the structures and are not so practical for network project level. The speed, accuracy, robustness, and simplicity of selected system are other issues.

To sum up, one of the lessons drawn from abovementioned problems is that there is no sufficient methodology for an effective budget allocation among dissimilar rehabilitation projects in road infrastructure. This realization led the researcher to think for a multi-strategy budget allocation DSS for seismic rehabilitation projects. This system can be applied effectively by the transportation managers or other decision makers who are involved in infrastructure planning.

Consequently, to enhance the cost-effectiveness of government spending, the use of practical and appropriate prioritization method will help to identify and rank the rehabilitation projects and allocate the budget efficiently. Since the budget allocation problem is a combinatorial optimization problem, develop a methodology which seeks to maximize the benefit of rehabilitation projects without exceeding its budget is beneficial. An accompanying software package will be developed for this purpose in this study to facilitate implementation of the methodology.

1.4 Aim and Objectives

The main aim of this research is to develop a DSS for optimal budget allocation among seismic rehabilitation projects for road structures, when constraints are budgetary limitations or objective criteria. This system results in risk reduction by effective budget allocation approach so that total vulnerability of selected project will be minimized. The most important objectives of this research are as follows:

- To identify seismic-structural vulnerability assessment methods for road structures;
- To identify effective rehabilitation criteria and their relative weights for seismic rehabilitation process;

- To develop a multi-criteria priority assessment method for rehabilitation projects;
- To establish the decision strategies for budget allocation in rehabilitation projects; and,
- To develop a computer-based decision support system for optimal budget allocation.

1.5 Scope and Limitation

Although there are various types of damages to different types of road structures, the scope of this study is limited to evaluate the hazard of earthquake. In addition, only seismic vulnerability assessment of bridges, tunnels, retaining walls and road buildings in road network are overviewed in this study. This means for other hazard and structures, further investigations need to done. In addition, the proposed methodology is specifically based on rapid visual screening procedure and limited to only four types of road structures. Weight assignment of criteria is based on questionnaire survey and also interviews with experienced experts, managers and specialists. The types of data in this study are subjective-based which then will convert to the quantifiable values for assessing the weights of rehabilitation criteria and will be the basis for developing the optimization method.

Vulnerability assessment method will be conducted for only main components of the given structures. For more precise ranking of road structures, detailed evaluation of different components and network analysis should be done, which definitely, will add to the total cost. In optimization process, objective functions are established for the most effective rehabilitation criteria and other criteria are not considered. This is because increasing the objective functions in selected optimization method reduces the computational speed and accuracy. However, other desirable criteria can also be modelled as objective functions and introduced into system. Established decision strategies are classified according the previous experiences, literature review and expert recommendations. This study only covers six strategies for optimal budget allocation which are assumed as the most typical and common approaches in the scope of the study.

1.6 Significance of Research

The role of transportation lifelines in the economic, social and cultural development is undeniable. They have dominant role in the national and regional economic circulation and great effects on man's daily life and management of economic systems. Correspondingly, transportation elements (such as bridges in road network) facilitate the society's activities from economic, cultural and social points of view. Therefore the society and the end users expect high serviceability of the network.

Risk reduction through seismic rehabilitation process is mainly under the responsibility of the public authorities. Because of high cost of road infrastructure rehabilitation projects, economic considerations are highly influential, especially in seismic-prone countries. Without a quantitative measurement of projects' vulnerabilities, it is difficult for transportation decision makers to select the appropriate structures and allocate the budget. Following this, fiscal commitments need to be specified in national budgets (ISDR, 2003). In order to highlight the significance of research regarding the high number of budget that is invested on seismic rehabilitation projects every year, some records are highlighted in this section.

- "Between the late 1980s and late 1990s, California's Northridge Earthquake of 1994 was one of the most costly natural disasters in the United States. It was resulted in a total of $20 billion in infrastructure damages (Yen, 2010)."
- "From 1993-1996, the United States spent an average of approximately $250 million per week responding to the impacts of natural disasters, with earthquakes, hurricanes, and floods being the major causes of monetary losses (Yen, 2010)."
- "In 2005, according to Congress Act (SAFETEA-LU), Federal Highway Administration (FHWA) spent $12.5 million in seismic research to work with the bridge engineering community and enhance the earthquake resistance of U.S. highway bridges (Yen, 2010)."

In 2009, the status of US critical infrastructure system was taken into account by American Society for Civil Engineers (ASCE). The structural conditions of the most US bridges was evaluated as poor while it was emphasized that there are no sufficient budget to fulfill all maintenance activities in this area. At the same time, ASCE announced that "$17 billion annual investment was needed to substantially improve current bridge conditions; however, only $10.5 billion was spent annually on the construction and maintenance of bridges" (Gokey et al., 2009). Thereafter, infrastructure deterioration has been focused by US Congress and the Act of American Recovery and Reinvestment allocates $120 billion towards infrastructure investment (Gokey et al., 2009).

The cost of rehabilitation process is more critical in seismic-prone countries. For instance, Iran Ministry of road and transportation spent more than $2.5 million from 2002 to 2004 only on 40 important bridges on preliminary stage of retrofitting, includes site surveys, providing as-built designs and rehabilitation strategy approaches. These 40 bridges were selected out of more than 36000 bridges only in railroads network. This high number of costs is just a very small portion of budget needed for other parts of transportation network include road infrastructures.

Such extensive spending illustrates just a small portion of budget needed every year for rehabilitation tasks in transportation infrastructures in different countries. Therefore, because of lack of resources available for this purpose, systematic approaches for allocating funds to the various rehabilitation projects becomes more pronounced which can help the decision makers practically. The developed multi-strategy budget allocation system resulting from the present study is intended to be used by various road infrastructure managers at transportation departments involving planning, prioritizing, scheduling and selecting of rehabilitation activities. This system considers minimizing the total vulnerability score and so that the total rehabilitation cost remains controllable.

1.7 Research Methodology

In order to allocate the rehabilitation budget optimally, the use of prioritization methods that allow to quick ranking the project is extremely important. In an attempt to achieve the aim and objectives of the study, activities involved in each stage are briefly discussed. The first stage includes literature review related to different aspects of the problem. This stage also requires information about methods of seismic vulnerability assessments for four critical elements of road transportation structures namely; bridges, tunnels, retaining walls and buildings. The information in this stage helps us to find a seismic vulnerability assessment method for road structures. At the end of this stage, seismic vulnerability scores are determined for each structure.

The second stage includes the identification of effective seismic rehabilitation criteria as well as criteria definition and criteria weight assessment for the abovementioned structures. This stage evaluates a wide range of factors and criteria which directly or indirectly contribute to rehabilitation decision making. By making use of statistical analysis, this part analyses various criteria extracted from pilot survey and literature review to build the methodology. The identified criteria in this stage help transportation managers and other relative practitioners for ranking the road structures based on their priority scores. In third stage, a multiple criteria priority scoring method is proposed to assign a priority score to each project.

Financial considerations for rehabilitation of the structures according to the existing methods are discussed in fourth stage which leads to establishing the common desirable decision strategies for budget allocating. Because many methods are available for budget allocation, decision strategy approaches are classified to cover most of the available and the relative methods. Finally in Stage 5, considering all criteria, objectives and strategies, a computer-based system is developed for budget distribution among rehabilitation projects. The main goal of this flexible system is to develop an optimization method for the formulation and implementation of various policies and strategies to allocate the budget optimally. In addition, the technical aspects of the system are checked in this stage using comments of managers and experts regarding the ranking (pilot survey) and the efficiency of the system is improved by feedback results.

1.8 Outline of Dissertation

This study consists of nine chapters. Different aspects of problem statement, background and motivation of the research along with the objectives and scope of the study were presented in previous sections, in Chapter 1. In Chapter 2, a literature review associated with the brief description of seismic rehabilitation procedure of structures is carried out. Meanwhile, the commonly used procedures for seismic rehabilitation of bridges, tunnels, retaining walls and buildings are discussed. This review also includes the definition of critical transportation infrastructures, relative importance criteria in rehabilitation of road structures and common methods for financial considerations and budget allocation optimization approaches in rehabilitation decision making.

Chapter 3 presents research methodology and shows the five essential stages for conducting the research including five objectives. In an attempt to achieve the aim and objectives of the study, activities involved in each stage are briefly discussed. For four types of road structures, seismic vulnerability score assignment procedure and the application of vulnerability functional form are discussed in Chapter 4. To improve the simplicity and usefulness of results and using vulnerability functional form, Chapter 4 develops an incremental methodology for assigning a numeric score to seismic vulnerability of structures. This model applies the existing methodologies for calculating the structure rank based on seismic rating method using indices.

Chapter 5 evaluates a wide range of factors and criteria which directly or indirectly contribute to rehabilitation decision making. By making use of statistical methods, a set of criteria identified from pilot survey and literature review are analysed. The most effective rehabilitation criteria and their pertinent weights are then resulted. In order to prioritize the projects, a multi-criteria priority scoring model is developed in Chapter 6. This model is based on multi-criteria decision making approach. Chapter 7 details common decision strategies that are taken by mangers to distribute the existing budget. Six decision strategies are established in this chapter. After finding the priority scores of rehabilitation projects through seismic vulnerability scores and weighted importance criteria, with the help of a computer-based programming, the optimization process is conducted. This is an accompanying software package which is developed to facilitate the implementation of the whole methodology. This System is a DSS for budget allocation in the preliminary stage of seismic rehabilitation process and is developed in Chapter 8. In addition, this chapter provides a pilot survey, sensitivity analysis and validation test for the output results. Finally, Chapter 9 presents conclusions and possible directions for future researches.

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