AN OVERVIEW OF DECISION SUPPORT SYSTEMS FOR HIGHWAY ASSET MANAGEMENT

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DATE – May 15th, 2010

3290 words + 3 figures + 1 table = 4290 words
ABSTRACT

The challenge of maintaining the infrastructures at the best possible condition by investing the minimum amount of money keeps transportation agencies continually searching for innovative approaches to eventually provide optimum benefits to taxpayers. Highway infrastructure, as a significant part of the public asset, plays a special role to ensure the mobility of citizens and transportation of goods. Therefore, special attention should be placed in maintaining highway assets. Moreover, the limited and constrained available budget along with old aging infrastructure in nation magnifies the role of strategic decision making for maintenance, rehabilitation and repair (MR&R) of highways. Research aims to answer to the questions of which asset item needs and should receive an action, what MR&R actions should be applied and when should the work be done. The goal for one of the decision making categories, multi-objective decision making, is to find the best compromise between multiple and conflicting objectives in the asset management field. Considering all objectives in these problems there will be more than one solution that optimizes simultaneously all the objectives and there is no distinct superiority between these solutions. Usually there is not a single best solution being better than the remainder with respect to every objective. Another category of decision making techniques is Multi Criteria Decision making (MCDA) which is a discipline aimed at supporting decisions that are faced with numerous and conflicting evaluations. MCDA highlights these conflicts in order to derive a way to come to a compromise in a transparent process. The present paper is an overview of decision support systems application in highway asset management. Finally, the expected result of this research would be a decision support system to identify the list of assets in need of action, prioritizing the action list and recommending the MR&R actions that should be applied.
A MULTI-CRITERIA DECISION SUPPORT SYSTEM FOR HIGHWAY ASSET MANAGEMENT

INTRODUCTION

The challenge of maintaining the infrastructures at the best possible condition by investing the minimum amount of money keeps transportation agencies continually searching for innovative approaches to eventually provide optimum benefits to taxpayers (1). In a developed society satisfactory performance of civil infrastructure can guarantee the economic growth and social development (2). Highway infrastructure as a significant part of the public asset plays a special role to ensure the mobility of citizens and transportation of goods. Therefore, special attention should be placed in maintaining highway assets. The old aging infrastructure and the limited available budgets magnify the role of strategic decision making for maintenance, rehabilitation and repair (MR&R) of highways.

The decision making used for selecting and prioritizing necessary actions to maintain a facility or a system to function within an acceptable level of service and safety, while considering budget constraints is called infrastructure management. There are many reported successful application of decision support systems in the construction industry. For example the system developed by Hawk et al. (3) for MR&R of bridges. They have helped engineers, practitioners and decision makers through improved identification of infrastructure assets information, methodologies developed for needs assessment and analytical tools for the evaluation of possible solutions (4).

There have been many studies around the world for the management of highway infrastructure. During the last decades various types of individual highway asset items management systems such as bridge management system and pavement management system have been developed. Research in these areas is still ongoing with new findings and progress (5). To mention some out of many for instance Abu Dabous et al. (2) developed a decision support method for multi-criteria selection of bridge rehabilitation strategy. They report that current decision-making approach for bridge management is life cycle cost optimization and this single criterion decision making process which does not consider the indirect impact of MR&R should be improved. They propose a bridge decision managing system considering multiple and conflicting criteria. This study eventually develops a comprehensive decision support system for bridges which are one individual asset item of highways.

Selih et al. (6) developed a high level multiple-criteria decision support system for highway infrastructure management. They developed a DSS (Decision Support System) to determine the priority ranking of asset rehabilitation projects. They present the results for a selected case study consisting 27 overpasses for a highway section. They believe the proposed system meets best the pre-defined combination of several criteria and therefore yields the maximized overall benefit.

These examples are a few evidences of many studies reported of developing a decision support system for bridge management, pavement management and other major highway assets but there remain much room for a research that takes into account various asset items simultaneously in highway area to develop a comprehensive decision support system. The present research aims at developing a decision support system for highway asset management to select optimal MR&R techniques while taking into account limited available budget. Also it is of interest to find the budget needed to optimally MR&R the highway in order for the assets to reach the target level. Moreover, developed decision support system will prioritize the asset MR&R in highways in a way that projects for MR&R of highway assets can be optimally ranked.

Therefore, research seeks to answer the questions of which asset item needs and should receive an action, what MR&R actions should be applied and when should the work be done. Therefore the main questions that will be addresses by the proposed research are:
• Considering various asset items in highways which asset items are in need of action and what MR&R actions should be applied to take the optimal advantage of allocated budget?
• What is the required budget in order for the highway assets to undergo MR&R and meet the target level?

The research is in progress and in the next sections the possible methods for highway asset management will be reviewed.

DEcision MAKING TECHNIQUES
There are two main categories of decision making techniques; (1) Multi-Criteria Decision Making (MCDM) (2) Multi-Objective Decision Making (MODM). The goal for MODM techniques is to find the best compromise between multiple and conflicting objectives in the asset management field. Considering all objectives in these problems there will be more than one solution that optimizes simultaneously all the objectives and there is no distinct superiority between these solutions. Usually there is not a single best solution being better than the others with respect to every objective. Therefore, there will be a set of solutions which are better than other solutions called Pareto front. Another category of decision making techniques is Multi Criteria Decision making (MCDA) which aims at supporting decisions that are faced with numerous and conflicting alternatives. MCDA highlights these conflicts in order to derive a way to come to a compromise in a transparent process.

In both MODM and MCDM categories various techniques along with their application in highway area are reported, such as application of Analytic Hierarchy Process (AHP) for highway asset management (6), application of multi objective optimization for time-cost-quality optimization in highways (7), application of a modified AHP technique for bridge management (2). these techniques need to be analyzed to identify the most appropriate techniques in modeling the current problem.

Multi Criteria Decision Making (MCDM)

Analytic Hierarchy Process (AHP)
There are many techniques reported in the category of Multi-criteria decision making among which application of one of these techniques, Analytic Hierarchy Process (AHP), in roadway asset management will be verified herein. The AHP technique may be utilized to facilitate the process of selecting facilities to undergo a maintenance, rehabilitation and repair. The selected decision making technique, AHP, is a method to derive ratio scales from paired comparisons. The input can be obtained from actual measurement or from subjective opinion. The result of the decision process is a set of assets selected for the MR&R actions to increase the performance of the assets and maintaining desired performance level(8). Selih et.al. (6) developed a framework for multi criteria decision making using AHP.

The structure of their methodology is represented schematically in FIGURE 1. Several steps have to be carried out in order to maintain the adequate performance and functionality of assets. The first step is creating an asset inventory system to identify all assets. Then, field inspection, condition assessment and consequent rating of asset items should be done. The final result of rating process will be a set of scores and an aggregated total score for each asset. Following this rating phase a decision process with different criteria can be employed. Prior to the decision process the criteria and relative importance have to be determined. The result of the decision process will be a set of assets selected for the MR&R actions. Once these projects are completed, the performance of the asset is increased.
FIGURE 1 Schematic presentation of the infrastructure management methodology(6)

Application of Modified AHP for bridge rehabilitation technology selection

Saleh et al. (2008) (4) have developed a modified AHP technique for the selection of bridge rehabilitation strategy. They reported that using deterministic numbers to define the relative importance of the different elements of the decision-making problem can be difficult due to uncertainty in the behavior of the different elements under consideration. Therefore, a modified AHP technique has been developed to overcome this problem of uncertainty in pairwise comparison stage of AHP process. In the proposed AHP first the alternatives and decision criteria are identified and problem will be decomposed into hierarchy. Then the comparative judgment between the elements in the same level of hierarchy considering the scale of relative importance as shown in TABLE 1 will be performed. The next step is evaluating vectors of priority using Monte Carlo simulation and performing consistency checks for each matrix developed. Finally overall weight of the different alternatives will be computed (2).

The hierarchy structure for the problem as an application of the modified AHP in the selection of bridge rehabilitation strategy is shown in FIGURE 2. It clarifies the goal, criteria and alternatives structure in the current case.
A proposed range of values for the intensity of relative importance as an extension for the scale of relative importance developed by Saaty (9) is presented in TABLE 1. The purpose of this approach is to account for the uncertainty in the value of relative importance between the compared elements while making judgments. The range of values reflects the decision maker’s confidence regarding the value of the relative importance between the compared elements (2).

<table>
<thead>
<tr>
<th>Definition</th>
<th>Description</th>
<th>Pessimistic</th>
<th>Most likely</th>
<th>Optimistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal importance</td>
<td>Two activities contribute equally to the objective</td>
<td>0.5</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>Weak importance of one over another</td>
<td>Experience and judgement slightly favour one activity over another</td>
<td>2.5</td>
<td>3</td>
<td>3.5</td>
</tr>
<tr>
<td>Essential or strong importance</td>
<td>Experience and judgement strongly favour one activity over another</td>
<td>4.5</td>
<td>5</td>
<td>5.5</td>
</tr>
<tr>
<td>Demonstrated importance</td>
<td>An activity is strongly favoured and its dominance demonstrated in practice</td>
<td>6.5</td>
<td>7</td>
<td>7.5</td>
</tr>
<tr>
<td>Absolute importance</td>
<td>The evidence favouring one activity over another is of the highest possible order of affirmation</td>
<td>8.5</td>
<td>9</td>
<td>9.5</td>
</tr>
</tbody>
</table>

**Analytic Network Process (ANP)**

The Analytic Network Process (ANP) was proposed to overcome the problem of interdependence and feedback between criteria or alternatives (10). The previous explained technique, AHP, is the specific form of the analytic network process (ANP). This technique aims to release the restriction of hierarchical structure in the AHP technique. The first step in of ANP technique is comparing the criteria in whole system to from the supermatrix. Pairwise comparison is done to form this matrix and the relative importance can be determined using a scale such as 1 to 9 scale (11).

This is of importance for the problems that cannot be structured hierarchically when the interaction of higher level elements with lower level elements and their dependency should be taken into account. In the ANP it is not only the importance of the criteria that determines the importance of alternatives but also importance of the alternatives themselves determines the importance of the criteria (12). Therefore, many problems can be modeled using a diagram called a network as presented in FIGURE 3.
Network models do not have a hierarchical structure, which means they do not have to be linear from the top to the bottom. In fact the ANP technique a network is being used for which it is not necessary to specify levels, as in a hierarchy (12). Therefore the term level in AHP is replaced by the term cluster in ANP. The network model has cycles connecting its clusters of elements and loops that connect a cluster to itself.

The similarity between ANP and AHP is in the comparative judgment phase but they differ in the synthesizing phase. In the ANP, ratio scale priority vectors derived from pairwise comparison matrices are not synthesized linearly as in AHP. Saaty has developed an improved “supermatrix” technique to synthesize ratio scales. Each ratio scale is appropriately introduced as a column in a matrix to represent the impact of elements in a cluster on an element in another cluster or on elements of the cluster itself. In that case, the supermatrix is composed of several submatrices, each of whose columns is a principal eigenvector that represents the impact of all elements in a cluster on each of the elements in another (or the same) cluster. The supermatrix, which is composed of ratio scale priority vectors derived from pairwise comparison matrices and the zero vectors, must be stochastic to obtain meaningful limiting results. The supermatrix has clusters. Each block of column vectors are weighted by the priority of the corresponding cluster, with their elements displayed vertically on the left side of the matrix and horizontally at the top of the matrix. To make sure that this matrix is stochastic we need to compare clusters themselves that are on the left with respect to their impact on each cluster at the top. The resulting priorities of the clusters are then used to weight column vector clusters on the left with respect to the corresponding cluster on the top. Thus, the supermatrix is column stochastic (11).

Multi Objective Decision Making (MODM)

Many problems of the real-life are optimization of more than one objective function at the same time. The fact of optimizing several objectives simultaneously has made the problem-solving more complicated in multi-objective optimization. The existence of many multi-objective problems in the real-world, their intrinsic complexity and the advantages of meta heuristic procedures to deal with them has strongly developed this research area in the recent years (13).

The goal of multi objective optimization problem is to find the best compromise between multiple and conflicting objectives. Considering all objectives in these problem there will be more than one solution that optimizes simultaneously all the objectives and there is no distinct superiority between these solutions. Usually there is not a single best solution being better than remainder with respect to every objective. Among the feasible solutions, solutions belonging to Pareto front are known as nondominated solutions, while the remainder solutions are known as dominated. Since none of the pareto set solutions is absolutely better than the other nondominated solutions, all of them are equally acceptable as regards the satisfaction of all the objectives.

One of reported applications of MODM is for highway time-cost-quality optimization. El-Rayes et al. (7) have utilized a multi objective approach for time-cost-quality trade-off analysis in highway projects. Their model is designed to search for optimal resource utilization plans that minimize
construction time and cost while maximizing its quality. In the optimization process first the model is formulated which incorporates all major decision variables and objectives. Then the quality in the project is quantified in order for the quality objective to be considered in optimization problem. Finally model is implemented in which a multi objective Genetic Algorithm (GA) is utilized for highway construction and rehabilitation to enable the simultaneous optimization of time, cost and quality. They analyze an application example to show the capabilities of the model (7).

CONCLUSION

Highways as one of the most important assets play an important role in each society. Every year large amounts of money are spent for their maintenance, rehabilitation, repair and reconstruction. There has been many research works for improving the asset management process. These studies have been resulted in development of management systems such as pavement management system, bridge management system, safety management system and some other management systems which are mainly designed to maintain the target level of state agencies with minimum cost. However these various management systems are acceptably functioning but there should be a comprehensive management system in order for decision makers to decide considering all asset items not only considering the individual asset item. In this paper some of the decision making techniques along with their application is evaluated and are about to be used in the developed model of the research.

The expected result of this research on one hand would be a decision support system to identify the list of assets in need of action, prioritizing the action list and recommending the MR&R actions that should be applied. Of course all the decisions in the model should consider the limited available budget. On the other hand, the model would be able to calculate the required budget for MR&R of highway assets to meet the target level

ACKNOWLEDGMENTS

The research reported in this paper was conducted at Center for Highway Asset Management Programs (CHAMPS) and funded by the Virginia Department of Transportation (VDOT). Any opinions, findings or conclusions are those of the authors and do not necessarily reflect the views of VDOT.

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