MANAGING THE MAINTENANCE OF VIRGINIA’S ROADS AND HIGHWAYS

Student Team: John Robinson, Justin Rousseau, Alex Uhl, and Chad Warner

Faculty Advisor: Yacov Y. Haimes
Department of Systems and Information Engineering

Client Advisor: Dan Roosevelt
Virginia Transportation Research Council
Charlottesville, VA
RooseveltDS@vdot.state.va.us

KEYWORDS: Asset management, maintenance prioritization, multiobjective decision analysis, Pareto optimality, risk fingerprinting.

ABSTRACT

The Virginia Department of Transportation (VDOT) maintains the third largest road system in the United States. Moreover, the system is growing old and requires an increasing amount of restoration. In order to assist in utilizing maintenance funds to their maximum capabilities, this project implemented risk analysis and multiobjective modeling techniques to develop a process for evaluating maintenance strategies for Virginia’s roads and bridges.

Current budget allocations for maintaining Virginia’s transportation assets are mostly determined by historical data. As a result, maintenance funds are not reaching the assets that need them the most. Evaluating the conditions of assets and their corresponding maintenance alternatives allows for more efficient budget prioritization.

Current asset management systems lack the ability to track and compare multiple objectives. This project used systems engineering approaches to identify sources of risk and several major objectives inherent in highway maintenance programs. Multiobjective analysis focused on determining and comparing the costs and benefits of different maintenance policies for a single asset over an extended period of time. The model allows for the filtering and prioritization of these policies for eventual aggregation into large scale maintenance management strategies.

The risk-cost-benefit model and analysis framework focused primarily on initial maintenance policy evaluation at the residency level. The proposed methodology ultimately continues up the VDOT organizational ladder until a complete need-based budget is developed, resulting in a more efficient use of maintenance spending.

INTRODUCTION

The Virginia Department of Transportation (VDOT) maintains and operates all road systems in 93 of the 95 counties in the state. The state’s maintenance expenditure was $837 million in fiscal year 2001, a tremendous increase from $480 million in 1990 (Haimes and Lambert 2001). The increase in maintenance costs is expected to continue, and, due to transportation funding limitations, the potential impacts of these growing maintenance costs will seriously influence future resource allocation decisions. Clearly, the primary goal of maintaining the state’s roads and bridges is to ensure that the system is sound, safe, and reliable; however, with VDOT’s current process and the lack of additional funding, Virginia may be faced with the necessities of reducing new construction and cutting back on maintenance.

Findings of the National Council on Public Works Improvement in 1988 highlighted the debilitating, aging physical infrastructure in the U.S. (and all over the world), by stating, “After two years of study, the National Council on Public Works Improvement (the Council) has found convincing evidence that the quality of America’s infrastructure is barely adequate to fulfill current requirements, and insufficient to meet the demands of future economic growth and development.”

A recent study commissioned by the Federal Highway Administration (FHWA) in 2001 states that more than a quarter of the nation’s bridges are too weak, rundown, or overburdened for current traffic loads. The study also found that the government rated as many as 167,993 out of the nation’s 585,755 bridges (29%) as “structurally deficient” or “functionally obsolete.” According to their 1998 data, Virginia’s bridges are directly in line with this national record with 3,690 of
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12,584 (29%) falling into the same category. Clearly, these poor conditions under current rehabilitation strategies call for a principled assessment of VDOT’s asset management program (Haimes and Lambert 2001).

RISK MANAGEMENT

This project introduces improved methods of highway maintenance management through the implementation of ‘risk-based decision making’. This is a term frequently used to indicate that some systematic process that addresses uncertainties is being used to formulate policy options and assess their various distributional impacts and ramifications (Haimes and Lambert 2001). These techniques are becoming increasingly more popular throughout all disciplines of the professional world.

To be effective and meaningful, risk management must be an integral part of the overall management of a system (Haimes 1998). ‘Risk assessment’ is the process of determining what can go wrong, what the likelihood is that it will go wrong, and what the consequences are. ‘Risk management’ builds on the risk assessment process by determining how to best handle exposure to risk. This process includes determining how the system is affected in the short-term and in the long-term in terms of what actions can be taken; what the risks, costs, and benefits are of the various alternatives; and what their tradeoffs are (Haimes 1998). The methodology used for this project implemented every one of these aspects of risk assessment and risk management.

Figure 1 demonstrates the application of risk management to the problem of highway maintenance. While the cost of maintenance with risk management may be slightly higher initially, cost is reduced over time because the impacts of current decisions on future policy options are evaluated through multiobjective tradeoff analysis.

Risks, costs, and benefits are often measured in different units; nevertheless, to manage the system, an acceptable balance is required (Center for Risk Management 2002). Multiobjective tradeoff analysis is at the heart of risk management. Problems may be solved in a shorter amount of time or measures may be taken in anticipation of a possible failure. This project offers a framework for state officials to assess road and bridge conditions and uses risk management approaches to obtain a more efficient budget allocation.

Figure 2. Current Budget Allocation Process

A more efficient maintenance and budgeting process would work from the bottom up, assessing the actual needs of the local residencies to result in the proper allocation of funds (Figure 3). Each residency proposes a set of prioritized maintenance strategies to the district level, where they are aggregated with strategies from other residencies. Finally, the Maintenance Program Leadership Group (MPLG), which determines initial
allocation to the districts, aggregates all VDOT strategies in order to create the statewide budget. Consequently, VDOT would no longer rely so heavily on historical data in its budget allocation but could rely on the needs of the residencies receiving the funds.

**METHODOLOGY**

The team used risk management concepts and methodologies in the design and development of the model prototype. They include Hierarchical Holographic Modeling (HHM), Multiobjective Decision Tree (MODT) Analysis, and Risk Fingerprinting.

**Hierarchical Holographic Modeling (HHM)**

A hierarchical holographic model can generate a highly organized chart in which each column represents the risks associated with one of the specific aspects describing the system’s requirements (Haimes 1998). Rather than simply constructing a list for the entire system or organization, it breaks risk down into subsystems (Haimes 1981). For instance, obtaining a full understanding of the risks involved in managing the maintenance of roads and highways demands identifying sources of risk resulting from drastically different perspectives, such as budget allocation, cost, the environment, local politics, safety, equipment, and data gathering (Figure 4).

The team created an HHM early in the modeling process in order to investigate all possible areas of risk in the VDOT transportation system. The results from the HHM were used to later define the most important areas of focus for the metrics on which to prioritize maintenance activities.

**Multiobjective Decision Tree (MODT) Analysis**

Decision trees map out a process over time with respect to various decision options and the possible events resulting from these decisions. Single-objective decision trees produce a single optimal policy recommendation, and they “are today considered by many to be unrealistic, too restrictive, and often inadequate for most real-world problems” (Haimes 1998). Thus, the tool used to model different maintenance scenarios, while addressing the multiple objectives of this project is the Multiobjective Decision-Tree. The three primary objectives are as follows:

- Minimize short-term (current-year) cost
- Minimize long-term cost (via net present value)
- Maximize long-term condition state

Each decision tree maps out the maintenance alternatives available for a single asset over a given time horizon. Every decision node (square) represents a choice among possible maintenance options, and a chance node (circle) represents the probability of the asset entering into certain states. A vector of the short-term cost and the long-term cost will characterize each path through the decision tree. Figure 5 illustrates an MODT.
All alternatives of the decision tree are collapsed backward to determine if any options are dominated at any given decision node. Dominated solutions are those that are inferior with respect to all the objectives tracked by the tree. Inferior solutions are eliminated, forming a set of Pareto optimal alternatives. These alternatives can be displayed with respect to all three primary objectives, as in Figure 6 below. Each circle represents an optimal alternative, and its placement along the x- or y-axis denotes the alternative’s long- and short-term costs, respectively. The radius of the circle represents the overall condition of the assets achieved by choosing that alternative.

Risk Fingerprinting

The risk fingerprinting approach utilizes several secondary objectives to filter and prioritize remaining maintenance options. The project team agreed upon certain secondary objectives and performance metrics with which to measure each strategy. Filtering out low-priority options keeps the number of alternative actions at a reasonable level. With each possible maintenance action, VDOT should attempt to satisfy the following criteria using the corresponding performance metrics:

- Maximize performance (ride quality, capacity sufficiency)
- Maximize safety (expected change with action of accident rate)
- Maximize reliability (probability of meeting design requirements)
- Maximize customer satisfaction (ride quality, traffic disruption, local acceptance, public opinion)
- Maximize accessibility (detour length, relative importance to area)
- Maximize economic benefit (average daily traffic, relative importance to area, importance to network)
- Maximize positive appearance (appearance improvement)
- Maximize future condition (expected condition score over set horizon)

All of the secondary metrics for each maintenance action will be available in individual bar graph format, creating unique risk fingerprints. An example of a risk fingerprint for a maintenance action illustrating Average Daily Traffic (ADT), Detour Length, Network Importance, and Local Importance is shown in Figure 7.

For the purposes of filtration, each risk fingerprint will categorize the priority of the maintenance option as either high priority, medium priority, or low priority. To carry out this process, we utilize threshold filters. For each fingerprint, the values for the secondary metrics are compared against pre-specified threshold values. Any metric that falls below the threshold causes the option to be filtered out. We have the option...
to create certain filtering rules that will allow us to specify the number of threshold values that a risk fingerprint must fall below before it is filtered out. For the purposes of this project, we have adapted the risk fingerprinting method to identify the value of the priority level of the maintenance option by using a pair of filters: a high filter and a low filter. If a maintenance option fingerprint exceeds both filters, the process will classify that option as a high priority. If it exceeds only the low filter, the process will classify the option as medium priority. And if it falls below both filters, the process will classify the option as a low priority. Again, filtering rules will specify how these categories are strictly defined.

For example, the maintenance option in Figure 7 fell below all threshold values for the high priority filter (Figure 8), but the Local Importance metric of this option exceeded the threshold value for the low priority filter (Figure 9). Thus, it would be categorized as a medium priority maintenance option under the assumption that only one metric value must overcome its low priority threshold in order for it to be categorized as medium priority.

APPLICATIONS

The proposed needs-based approach utilizes information from current records and databases to identify all the maintenance options available to VDOT. Then, these options are evaluated with respect to specific primary objectives, using Multiobjective Decision Tree Analysis while eliminating inferior maintenance policies. Remaining maintenance options are ranked and filtered according to secondary objectives using Risk Fingerprinting. Maintenance options are then aggregated and presented to managers at the District level and the MPLG level in order to aid them in the process of allocating maintenance funds. Figure 10 illustrates the proposed process (Center for Risk Management 2002).

RECOMMENDATIONS

Before the results of this project are realized, more work will need to be done to resolve specific details for process components such as the decision tree and risk fingerprinting. This should include determining the chance node probabilities for the MODT analysis and refining them over time to confirm their accuracy. Also, VDOT should use expertise to determine which maintenance options are reasonable given certain asset conditions and incorporate them into the MODT.

The completion of a full modeling simulation would greatly benefit VDOT. The complete study would analyze and prioritize maintenance strategies for a specific set of real world assets and result in a realistic statewide maintenance action prioritization scheme. Such a simulation would impartially test the model and demonstrate the potential benefits of this methodology. VDOT should also make efforts to computerize the modeling applications at all levels of the decisionmaking hierarchy. The analysis necessary for constructing more complex examples will require the
aid of automated computation. Therefore, both the final modeling tool and the preceding analysis simulations should be computer-based.

Obtaining feedback from the client is a crucial element of this project. The project’s steering committee has been invaluable in accomplishing the team’s goals of understanding the problem, knowing what resources VDOT had available, and developing a model that would provide a solution. The feedback process should continue throughout the duration of the project. VDOT employees could offer suggestions for more realistic decision trees, for they are more aware of what the possible maintenance actions are given previous years’ maintenance policies. To further improve communication regarding the project, an archival website should be created. The website will outline the design process and implementation for use by VDOT and those whose interests pertain to maintenance prioritization methods.

Once the final framework has been completed, it will then be implemented at all levels within VDOT and take effect with budget allocations statewide. Software tools and training should be provided to VDOT maintenance decisionmakers, and a system for monitoring future support needs should be established.

REFERENCES


BIOGRAPHIES

John Robinson is a fourth-year Systems Engineering major from Tallahassee, FL. He has a minor in Biomedical Engineering and his concentration is in Biomedical Systems. His main contribution to this project was his research into pavement maintenance modeling techniques. John plans to attend graduate school in the near future, seeking a degree in Biomedical Engineering.

Justin Rousseau is a fourth-year Systems Engineering major from Oklahoma City, OK. His concentration is in Management Systems. Justin’s principal contribution to the project was his specialization in HHM design and in the analysis of pavement preservation management.

Alex Uhl is a fourth-year Systems Engineering major from Richmond, VA. His concentration is in Environmental and Water-Resource Systems, and he has also obtained a minor in Environmental Science. Alex’s principal contribution to the project was his analysis of bridge maintenance prioritization.

Chad Warner is a fourth-year Systems Engineering major from Milltown, NJ. His concentration is in Management and Electrical Systems. He also has a minor in technology, management, and policy. Chad has plans of attending law school in September 2002.