Technical Report Documentation Page

1. Report No. FHWA/TX-11/0-6623-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Literature Review of Current Practices in Dealing with Fluctuations of Maintenance Budgets		5. Report Date September 2011 6. Performing Organization Code
7. Author(s) Epigmenio Gonzalez, Wenxing Liu, Mike Murphy, James T. O'Connor, Chandra R. Bhat, Yetkin Yildirim		8. Performing Organization Report No. 0-6623-1
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 1616 Guadalupe, Suite 4.202 Austin, TX 78701		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 0-6623
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080		13. Type of Report and Period Covered Technical Report 9/1/2010-9/31/2011 14. Sponsoring Agency Code

15. Supplementary Notes
Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

16. Abstract
A literature review was conducted to investigate current budget cutting strategies used in routine roadway maintenance planning, including methods and techniques that are employed by other state and international transportation organizations (DOT's). Methods that quantify impact and increased risk factors from the reduction of routine maintenance activities were investigated. Methods developed based upon previous research were tabulated and evaluated by objective criteria such as cost savings, resource savings, and road user/stakeholder satisfaction. The researchers reviewed the data and identified the most effective risk analysis techniques, which served as the basis for the maintenance risk modeling under this project.

17. Key Words Transportation budget, roadway maintenance planning, routine roadway maintenance		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161; www.ntis.gov.	
19. Security Classif. (of report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 25	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Literature Review of Current Practices in Dealing with Fluctuations of Maintenance Budgets

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CTR Technical Report:	0-6623-1
Report Date:	September 2011
Project:	0-6623
Project Title:	Optimizing Resource Allocations for Routine Highway Maintenance
Sponsoring Agency:	Texas Department of Transportation
Performing Agency:	Center for Transportation Research at The University of Texas at Austin

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

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Acknowledgments

The authors would like to extend their sincere thanks to the Projector Director (PD), Tammy Sims, P.E., Special Project Engineer of the TxDOT Maintenance Division, who has been instrumental to the successful conduct of this project. Special thanks are also extended to the Project Monitoring Committee (PMC) and Expert Working Group (EWG) members for their advice and guidance:

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Table of Contents

List of Figures

Chapter 1. Introduction

Introduction

A literature review was conducted to investigate current budget cutting strategies used in routine roadway maintenance planning, including methods and techniques that are employed by other state and international transportation organizations (DOT's). Methods that quantify impact and increased risk factors from the reduction of routine maintenance activities were investigated. Methods developed based upon previous research were tabulated and evaluated by objective criteria such as cost savings, resource savings, and road user/stakeholder satisfaction. The researchers reviewed the data and identified the most effective risk analysis techniques, which served as the basis for the maintenance risk modeling under this project. Although considerable literature on this subject was reviewed during the preparation of this proposal, a further review of recent efforts will help the proposed research.

State of Practice

Information gathered by the researchers indicates that many state and international DOT's are experiencing the same budget shortfalls and fluctuations as the Texas Department of Transportation (TxDOT). Many of these agencies have adopted asset management systems that help evaluate and determine the optimum timing for key routine maintenance activities. But as needs continue to outpace resources, more agencies have resorted to increasing maintenance intervals. This can have a detrimental impact in the long-term performance of the infrastructure, ultimately resulting in reduced service life.

1.1 United States

1.1.1 Florida Department of Transportation (FDOT)

The Florida Department of Transportation (FDOT) uses a Maintenance Rating Program (MRP) to assess and evaluate the condition of maintenance features on the state highway system. This program is used to determine the quality and effectiveness of routine maintenance strategies. The results obtained from this program are ultimately used to schedule and prioritize routine maintenance activities and to develop both short- and long-term work plans. The main goals of the MRP include:

- Establish procedures and guidelines for maintaining safe, aesthetically pleasing and stable roadways.
- Establish uniformity of maintenance operations statewide.
- Promote safe, effective, and efficient use of state resources (i.e. equipment, personnel).

1.1.2 Washington State Department of Transportation (WSDOT)

The Washington State Department of Transportation (WSDOT) implements a similar system called Maintenance Accountability Process (MAP). This process is aligned with the department's strategic planning, budget, and maintenance service delivery. In essence, MAP provides the necessary tools to evaluate the effectiveness and accountability of the state's maintenance program. The program basically relies upon random evaluations of selected sample locations. After conducting field surveys, the results are compared against established benchmarks and a level of service is determined. This level of service is then plotted and a historic performance trend is obtained.

Perhaps, MAP's most important and significant tool is its Priority Matrix. This Priority Matrix ranks the maintenance activities according to their contribution towards the maintenance program objectives. These objectives include:

- Safety of traveling public and employees
- Operation of the highway system (keeping the road open)
- Meeting environmental responsibilities
- Maintaining the infrastructure
- Addressing legal mandates other than environmental (including torts)
- Contributing to comfort, aesthetics, and convenience

Each maintenance activity is then assigned a value between 0 and 9 (9 being the highest impact) in terms of each of the maintenance objectives identified above. A cumulative score is then obtained that essentially becomes the priority value or rank. The maintenance activities are then ranked in order of descending priority value. The MAP also serves as a communication tool between all the stakeholders. The Washington state government, transportation commission, and taxpaying public are kept informed on the impact of policy and budget decisions on the program service delivery.

1.1.3 New York State Department of Transportation (NYSDOT)

The New York State Department of Transportation (NYSDOT) adopted a Maintenance and Operations First Strategy (MOF). The first step of MOF is to obtain a yearly analysis and inventory on the existing infrastructure. This information is then compiled. Trend lines are plotted on the condition and performance of the infrastructure. This helps identify rapid deterioration levels, triggering maintenance and rehabilitation activities as well as prioritizing projects. Asset preservation is the top priority on all major trade and intercity corridors.

Another benefit obtained from the MOF strategy is the development of the maintenance activities guidelines. These guidelines allow the department to develop a timing interval for certain maintenance activities. This type of system may not result in the most efficient use of resources.

1.1.4 Ohio Department of Transportation (ODOT)

The Ohio Department of Transportation (ODOT) uses an Infrastructure Asset Management System to monitor and evaluate the performance of its transportation assets. This system combines performance-modeling capabilities that enhance the decision support system. Monitoring asset performance allows ODOT to:

- Evaluate the effectiveness of maintenance standards and strategies
- Assign priorities

- Forecast future condition and performance values
- Assess risk management

Prioritizing maintenance activities involves the following components:

- Benefit
- Cost
- Fund availability
- Facility type
- Type of maintenance
- Risk assessment
- Cost of failure
- Rate of deterioration

1.1.5 Vermont Agency of Transportation (VTrans)

The Vermont Agency of Transportation (VTrans) prioritizes projects to ensure the limited money available for highway maintenance activities is allocated in the most efficient and effective manner. Prioritizing projects allows VTrans to:

- Explain to transportation stakeholders/public why one project is chosen over another
- Ensure good stewardship of the state’s resources
- Prioritize important projects to the top of the list
- Essential part of VTrans asset management approach (Asset preservation means doing the right fix at the right time on the right projects.)

In addition to the prioritization approach used by VTrans, in 2005 and 2006 the state legislature passed statutes requiring the agency to develop a project prioritization approach that assigns a numeric score. This new priority rating process focuses on the following factors:

- Safety
- Traffic volume
- Availability of alternate routes
- Future maintenance and reconstruction costs
- Priorities assigned by the Regional Planning Commission (RPC)

1.2 Great Britain

1.2.1 Highway Agency (HA)

The Highway Agency (HA) in the UK is currently conducting research on several key projects that would provide the information necessary to allow the agency to make strategic decisions in the operation, maintenance, and improvement to the Strategic Road Network (SRN). It is important to mention that these two topics are currently in the research stage and no additional information is available at this time.

The first research project is titled "Developing a Prototype Safety Risk Model and Safety Risk Profile Bulletin." The objective of this research project is to develop a Safety Risk Model, whose purpose is to identify and capture the safety risks to road users, road workers, and third parties associated with the operation, maintenance, and improvement to the SRN. The output of this research project will be a prototype Safety Risk Model and outline Safety Risk Profile Bulletin. This model will be used to demonstrate the potential uses and benefits of this approach to understanding the safety risks on the network.

The next research topic is titled "Risk Approach to Prioritizing Maintenance." The Value Management (VM) process currently used by the HA does not perform well in terms of comparing the relative benefits obtained on work done on different types of infrastructure assets. Therefore, there is a need for transparency and better understanding of risk when prioritizing maintenance strategies. This new process will provide the managers or decision makers with an overall understanding of the consequences of funding or not funding maintenance activities. Essentially, it ties a value to the proposed work and the benefits that would be provided. Most importantly, it allows the comparison or assessment across different types or classes of assets. The long-term objective is to develop a monetization approach to evaluate the costs and benefits of undertaking work. This process will eventually be integrated with the Multi Criteria Decision Tools (MCDT) used for prioritizing maintenance.

1.3 Australia

1.3.1 VICROADS

VICROADS is the highway agency for the State of Victoria in Australia. It adopted a "Stitch in Time" strategy towards road maintenance. This approach was first adopted in 1993 and been in place ever since. In order for this strategy to work, it requires the periodic measuring, monitoring and managing of infrastructure conditions. These conditions include roughness, cracking, rutting, and skid resistance. Closely monitoring the change in these conditions over time identifies the timing of preventive maintenance activities. A computerized Pavement Management System (PMS) is used to estimate the road conditions based on different funding levels as well as performing maintenance treatments. The Stitch in Time Strategy is based on the following goals:

- Ensure road conditions meet user safety needs
- Reduce Vehicle Operating Costs (VOC), especially in high traffic roadways, where the VOC's are higher than the cost of the maintenance treatments
- Minimize long-term maintenance costs by focusing on timely prevention rather than the cure

VICROADS also has a separate Roadside Management Strategy to address some of the stakeholders' expectations as well as legal and statutory obligations. These State and Federal obligations include:

- Road safety
- Protection of native flora and fauna
- Protection of biodiversity
- Weed control
- Management of cultural heritage sites, sites of aboriginal or archeological significance

- Water quality
- Environmentally sustainable development

1.3.2 Queensland Department of Main Roads

The Queensland Department of Main Roads is the highway agency for the State of Queensland, Australia. This agency uses the Road Asset Maintenance Policy and Strategy (RAMPS), which shifted the focus towards a stronger management of the performance and condition of the state controlled network. Some of the specific objectives that resulted from this policy and strategy include:

- Ensure sound maintenance decisions are made
- Ensure road assets perform effectively, throughout their service lives
- Enable a method for determining necessary maintenance funding requirements
- Ensure that the necessary maintenance funds are allocated

Research Field

1.4 Overview of Risk Assessment Process

In this research, in order to prioritize the projects, a valid approach to evaluate the impact of not selecting an individual project is needed. Although there are many different risk assessment methods available, the fundamentals of the risk assessment process are common:

- Identify hazards
- Assess risk
- Reduce risk
- Document the results

In most companies and industries the most used risk assessment process follows seven steps:

1. Set the limits/scope of the analysis
2. Identify tasks and hazards
3. Assess risk– Initial: Risk Scoring Systems
4. Reduce risk
5. Assess risk– Residual
6. Decision making process
7. Output results/documents

Figure 1 is the flowchart of risk assessment process, and it reflects how risk assessment is conducted in industrial practice.

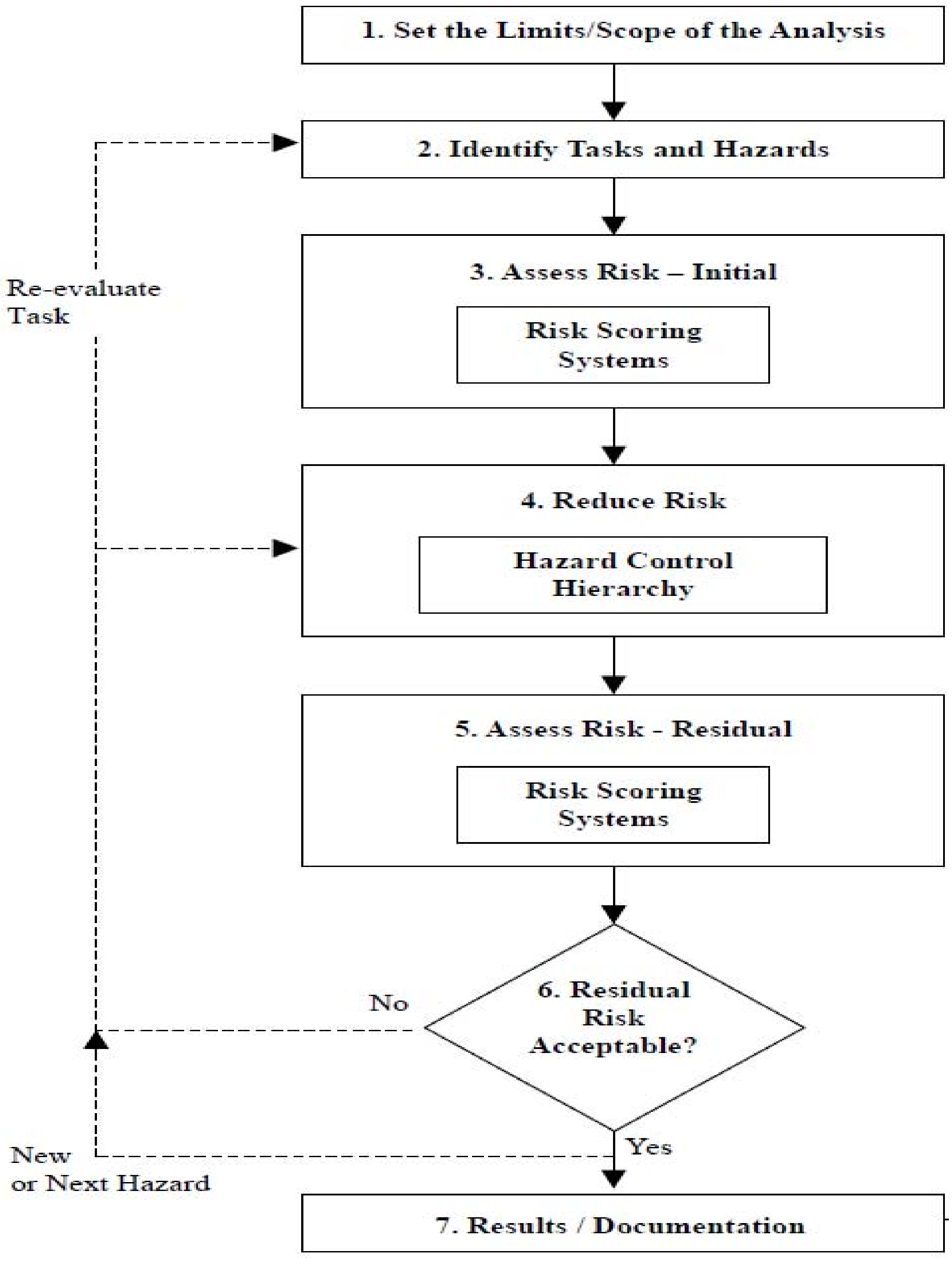

Figure 1. The Risk Assessment Process

(Source: Bruce W. Main, PE, CSP, Risk Assessment: Basics and Benchmarks, 2004)

1.5 Developed methodologies

1.5.1 Four-Stage Process Risk Assessment

Syadaruddin Syachrani et al. (2009) proposed a four-stage Process Risk Assessment in their work, “A Risk Management Approach to Safety Assessment of Trenchless Technologies for Culvert Rehabilitation”, which is a project-level experts’ opinion based risk analysis approach which was used to evaluate and select trenchless technologies for the Oklahoma State Highway drainage system.

A generic risk assessment framework based on a four-stage process is employed, which includes (1) risk identification; (2) estimation of frequency of occurrence and severity of hazard; (3) risk categorization; and (4) risk treatment. The findings of Syachrani’s work could be useful for planners who make decisions about the most appropriate trenchless technique for future culvert rehabilitation projects.

In this research, each trenchless technology is divided into separate activities. On the activity level, risk assessment is conducted concerning the exposure risk of workers on site, and the risk to system damage. The expert panel assigned a likelihood grade to each individual step considering the severity and probability of occurrence. Then, the total risk exposure associated to each technique is obtained by summing up the risk for each step. The prioritization of trenchless techniques is obtained by ranking the risk scores.

1.5.2 Risk Priority Numbers (RPNs)

Zaifang Zhang et al. (2010) used RPNs to determine risk prioritization of failure modes in Failure Mode and Effects analysis (FMEA) for a drilling machine.

The risk is assessed from three aspects:

1. Severity, which rates the severity of the potential effect of the failure
2. Occurrence, which rates the likelihood that the failure will occur
3. Detection, which rates the likelihood that the problem will be detected before it reaches the end

The total risk is obtained by using following formula:

RPN= Severity × Occurrence × Detection

The disadvantage of this approach is that decisions based solely on the RPN (considered in isolation) may result in inefficiency and/or increased risk.

Fuzzy logic can also be integrated into RPNs method.

1.5.3 Transportation Risk Analysis

Genserik L.L. Reniers et al. (2010) proposed a Transportation Risk Analysis tool for hazardous substances (TRANS) to assess the relative risk levels in moving hazardous materials by various transport modes. This approach is based on multi-criteria analysis and likelihood scores of accidents in which dangerous cargoes are involved, possibly causing fatalities.

TRANS is a phased approach. First, transportation routes are divided into a number of 'route segments' using a purpose built methodology. Second, for each route segment the likelihood and the possible outcome of transportation risks are determined. The likelihood and the consequences of a potential transport accident are both assessed by the TRANS user in a user-friendly way.

Risk is assessed from two aspects: likelihood grade (LG) and consequence grade (CG). Each route segment is plotted on a diagram that uses LG as the vertical axis and CG as the horizontal axis. Finally, the segment scores are aggregated as a transportation route risk score.

1.5.4 Probabilistic Quantitative Risk Assessment (QRA) Model

Risk can also be assessed based on reliability computation. Qiang Meng et al. (2010) proposed probabilistic QRA model consists of the estimation of work zone crash frequency, an event tree and consequence estimation models. There are seven intermediate events – age (A), crash unit (CU), vehicle type (VT), alcohol (AL), light condition (LC), crash type (CT), and severity (S) – in the event tree.

Since the estimated value of probability for some intermediate event may have large uncertainty, the uncertainty can thus be characterized by a random variable. The consequence estimation model takes into account the combination effects of speed and emergency medical service response time (ERT) on the consequence of work zone crash. Finally, a numerical example based on the Southeast Michigan work zone crash data is carried out. The numerical results show that there will be a 62% decrease of individual fatality risk and 44% reduction of individual injury risk if the mean travel speed is slowed down by 20%. In addition, there will be a 5% reduction of individual fatality risk and 0.05% reduction of individual injury risk if ERT is reduced by 20%. In other words, slowing down speed is more effective than reducing ERT in the casualty risk mitigation.

1.5.5 Adaptive Risk Management

In most cases, risk is a qualitative term. But in some specific cases, risk can be assessed using quantitative standards, such as exposure and risk assessment of zinc in Japanese surface waters (Wataru et al. 2010).

Evaluation of the effect of stormwater runoff to zinc concentrations in a river showed that zinc concentrations in river water increased significantly from roadway drainage flowing into the river. The cost-effectiveness analysis demonstrated that although enforcement of the zinc national effluent standard may be effective at a certain level for public water areas in Japan, the degree of the effectiveness is highly dependent on the characteristics (e.g., sources and background) of the watersheds. An emissions and exposure assessment, along with cost-effectiveness analysis, is crucial for developing realistic and appropriate ecological risk management of zinc.

1.5.6 Analytic Hierarchy Process

AHP has been successfully used in a number of different fields and disciplines. Its ability to handle both qualitative as well as quantitative data makes AHP an ideal methodology for our particular application. There has been extensive research on prioritizing using AHP method, which further validates its use. Even within AHP framework, there are different variations of

AHP. The fundamental approach of AHP is to break a large complex task into smaller more manageable subtasks. In essence, different levels or hierarchies are created, depending on the complexity of the problem. Furthermore, the individual projects are prioritized, based on the pair wise comparisons. This is accomplished by comparing two attributes at a time and assigning a relative value. Finally, a priority vector is developed from the synthesis of the pair wise priorities.

A similar application used AHP to prioritize pavement projects. After extensive research and comparison, they discovered that Absolute AHP resulted in a higher coefficient of correlation with a 95% confidence level when compared to the direct assessment method. In addition, the Absolute AHP resulted in the least number of comparisons required to prioritize the individual projects. For example, the Direct Assessment Method required almost 30,000 comparisons and the Relative AHP required almost 9,500 comparisons, while Absolute AHP only required 39. This clearly demonstrates that Absolute AHP will provide the greatest utility while requiring the least amount of effort.

1.6 Applications of AHP

1.6.1 Petroleum Pipeline Route Selection

Dey, P. K., Tabucanon M.T. & Ogunlana S.O. (1996) propose a conceptual framework. In their work, they indicate the overall objective in selecting a petroleum pipeline route is the connection of the crude/natural gas source to the refinery or utility company. Obviously, choosing the shortest, most direct route is always a goal for capital expenditure reasons, but many important goals exist simultaneously in the route selection project and at times these goals may conflict. Geophysical, environmental, political, social, economic, and regulatory factors interact to define the route possibilities. Sam Nataraj (2005) uses AHP as a tool used in petroleum pipe industry to help in decision making.

1.6.2 Electric Power Systems

In electric power systems research, there are many different alternatives of demand response (DR) programs for improving load profile characteristics and achieving customer satisfaction. Tehran (2009) used economic models, MAMD techniques, including entropy, TOPSIS, and AHP to help power market regulator to set rules for selecting and prioritizing DR programs in power market. Tehran’s study shows MAMD techniques can be used as a toolbox to overcome the market operation problems such as price spikes, insufficient spinning reserve margin, system security, and reliability.

1.6.3 Dental Service Evaluation

Tsuen-Ho Hsu et al. (2009) report in their study the development of a comprehensive model that measures dental service quality in a hierarchical method. AHP is used to examine the quality structure of dental services. Since the pair wise values could be viewed as random variables, Monte Carlo simulation is also added to the model. Results from this model provide stronger confidence for the management of dental clinics than traditional AHP, and have significant cost-saving and revenue-increasing contributions. The proposed model extends the applications of both AHP and the Monte Carlo simulation in service industry management, and proves its ability in clearly prioritizing critical attributes, in that it greatly sharpens the effectiveness of the decision-making process

1.6.4 Prioritization of Pavement Data Collection

Zhanmin Zhang et al. (2004) used Analytic Hierarchy Process (AHP) in pavement data collection prioritization. AHP was selected because it is relatively simple in comparison to other decision-making aids. Also, the consistency-checking capability inherent in the AHP mechanism ensures that the judgments elicited are consistent and not random.

Data collection prioritization is based on the pavement management user needs. Various types of data collection activities are grouped into different categories. The activity groups are:

- General administrative activities
- Design specifications and optimization-related activities
- Engineering and economic analysis
- Pre-construction site condition evaluation
- Historical traffic patterns and expected usage assessment
- Construction and maintenance history
- General field and construction-related activities
- Environmental impact assessment
- Quality control-related activities
- Existing condition assessment

The prioritization is the selection of activity groups, not individual data collection activities. And the basic objectives for pavement management should be:

1. Aiding in policy decisions: it should aid in policy-related decisions such as cost minimization, environmental impact assessment, aesthetics, legislative, and political issues.
2. Structural adequacy enhancement: it should help in enhancing the structural adequacy for longer service life of the pavement network.
3. Serviceability enhancement: it should help in enhancing the serviceability through improved rideability of the pavement network.
4. Safety improvement: it should assist in improving the safety of the pavement network.

These four objectives serve as the criteria of prioritization using AHP. The averaged priority (ranking) is given by using AHP based on experts' opinions.

Conclusions

During the state-of-practice literature review, it became apparent that most state and international DOT's are facing the same budget and resource constraints as TxDOT. The approach used by many of these agencies has been to focus on asset management for pavement preservation. Most recognize the importance of roadside maintenance activities in the overall safety, preservation, operation, and aesthetics of the system. However, there is no organized methodology that incorporates all aspects of roadway maintenance used for prioritizing all maintenance activities. The outcome of this research project will allow maintenance activities to be prioritized based on the overall risk of each activity in terms of maintenance objectives.

Though there are many alternative methodologies in research field, we recommend using AHP for project prioritization. AHP is relatively simple compared to other methodologies and has a consistency-checking mechanism built in. From existing research and practice, it is apparent that using AHP to prioritize projects and allocate resources is feasible.

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