USING HIGHWAY MAINTENANCE MANAGEMENT SYSTEM INFORMATION TO SELECT OPTIMUM LEVELS OF SERVICE

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INTRODUCTION

State highway agencies in the United States are responsible for maintaining highways so that users are provided with a safe and comfortable product, and the investment in the facility is protected. To assist field supervisors in maintaining desired conditions, guidelines that describe recommended levels of service for various highway elements (such as pavement, shoulder, vegetation, and drainage structure) are prepared by maintenance engineers. Selection of levels of service is influenced by a number of considerations that include safety, riding comfort, economics, environmental impact, protection of investment, and aesthetics.

Constraints on available resources (money, personnel, equipment, and materials) may preclude maintenance of every highway element in its most desired condition. Consequently, it may be necessary to make tradeoffs between different maintenance elements. For example, if both activities cannot be accomplished with the available funds, should money be spent on either improving a deficiency of the traveled way or reshaping obstructed drainage ditches? Which elements should be maintained at a desired level of service and which should be allowed to regress to lower than desired levels? In most cases, these decisions are made informally by maintenance personnel (e.g. field supervisors). However, because the issues involved are complex, inconsistent decisions may be made that result in less than optimum levels of service.

A systematic and formal method could be used when making policy decisions of optimum levels of service for highway maintenance elements for given amounts of resources. The method would consider each component of quality and weigh those components to reflect different user evaluations. It would also allow different levels of service to be established for various maintenance elements, road classifications, and local values.

State highway agencies selected the development of such a method for research projects 14-5 and 14-5(2) in the National Cooperative Highway Research Program (NCHRP). The NCHRP is supported on a continuing basis by funds from the member states in the American Association of State Highway and Transportation Officials and receives the full cooperation and support of the Federal Highway Administraton, United States Department of Transportation. It is administered by the Transportation Research Board of the National Research Council serving the National Academy of Sciences. The research was conducted by Woodward-Clyde Consultants.

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RESEARCH OBJECTIVES

The objectives of Project 14-5 were:

1. To document existing practices used to establish levels of service.
2. To formulate a method to establish levels of service that consider user values and tradeoffs among safety, riding comfort, economics, environmental impact, protection of investment, and aesthetics.
3. To develop a manual containing step-by-step procedures for highway maintenance organizations to implement the method when establishing levels of service.
4. To demonstrate and document how the method would be used to develop the levels of service for two diverse maintenance problems - traveled way drop-off and control of roadside vegetation growth.

The objectives of Project 14-5(2) were to (1) improve upon the manual and, where possible, simplify it and (2) test the manual sequentially in three agencies to produce a self-sufficient manual that could be used without consultant assistance. The improved manual has been published as NCHRP Report 273[1], and the research going into the method development has been published as NCHRP Report 223[2].

RESULTS

The results of the research are organized in the categories that reflect the accomplishment of the research objectives.

A. Documentation of Existing Experience

Interviews with participants from various state DOT's, as well as a literature review, confirmed that a combination of factors is considered in establishing levels of service. These factors are:

1. Safety
2. Preservation of public investment in the highway system
3. Comfort and convenience of user
4. Aesthetics
5. Legal implications
6. Traffic volume and route classification
7. Political and social considerations

In the method described in the following pages, all but legal implications are considered explicitly. Political considerations can be handled by the method through participation of elected officials in a structured process to establish values for various benefits achieved from doing maintenance.

B. The Theoretical Basis of the Method

Decision analysis techniques were used to develop a rational and consistent basis for choosing among alternatives, and a nonlinear integer program was developed to determine an optimum set of levels of service. Decision analysis approach has proven effective with problems involving multiple considerations and uncertain consequences. (The works of Raiffa [3], Schlaifer [4], Keeney and Raiffa [5], and Fishburn [6] discuss the theoretical basis of the decision analysis approach and its applications to practical problems.) Complex problems in many diverse disciplines have been analyzed using this approach. The problems include nuclear power-plant siting in Keeney and Nair [7], environmental impact assessment in Nair et al. [8], seeding of hurricanes in Howard et al. [9], and development of a pavement management system in Kulkarni et al. [10]. The nonlinear zero-one algorithm was developed by Woodward-Clyde Consultants (WCC) and is an effective tool for maximizing nonlinear functions when one of several alternative levels of service is to be chosen.

C. Description of the Method

Before going further, it is important for understanding to define the following terms:

Maintenance Element - A part of the physical highway system that must be maintained (e.g., traveled way, roadside, or drainage).

Maintenance Conditions - A condition of a maintenance element that at some level of deficiency will require repair or correction (e.g., cracking for traveled way or grass growth for roadside).

Maintenance Activity - The work required to repair or convert a maintenance condition to restore it from a deficient level of service to an acceptable level (e.g., crack filling for cracking or mowing for grass growth).

Level of Service - The level at which a maintenance condition is considered to be deficient and which triggers maintenance activity (e.g., cracks are to be filled when 1/2 in. wide over 35 percent of length for cracking or grass is to be mowed for 30-ft maximum width when it is 12 in. high for grass growth.

Consideration - A factor that is used to evaluate the performance of a maintenance element and to establish a level of service (e.g., safety and riding comfort for traveled way or aesthetics and user convenience for roadside).

Attribute - A descriptor that is capable of expressing the level of a consideration on a numerical scale (e.g., percent change in frequency of accidents for safety or degree of pleasing appearance for roadside).

Parameter - A measure for defining, in numerical or descriptive terms, the alternate levels of service of a maintenance condition.

Levels of Service on one hand trigger maintenance activities and consequently set the costs of maintaining a highway system and, on the other hand, set the benefits obtained from maintenance as described by considerations and their attributes.

In this method, combinations of alternative levels of service for different maintenance conditions are examined, and those combinations that satisfy constraints of available resources are identified. For each combination that satisfies such constraints, the effects on relevant considerations are quantified. Next, relative weights for various considerations are determined based on assessed "willingness to pay" for a higher level of an attribute and, conversely, the desired savings for a lower level of an attribute. The final stage of the analysis identifies the combination of alternative levels of service with maximum overall value. This is the optimum combination of levels of service in the sense that it maximizes overall value subject to the constraints of available resources. The following discussion describes the data inputs and program outputs so that the method and its usefulness can be better understood.

D. Data Inputs

Table 1 provides a suggested format for recording maintenance system data. As an example, data are provided for the maintenance element roadside. Maintenance conditions affecting considerations are grass growth, noxious weeds and brush, litter and debris, and rest areas. By varying the levels of service associated with these conditions, the attributes vary for the chosen considerations, e.g., aesthetics and user convenience. The steps to complete all the columns in Table 1 are described in the manual.

Table 1. Suggested format for recording maintenance system data related to the element "Roadside".

ELEMENTS	CONSIDERATIONS	ATTRIBUTES	CONDITIONS	PARAMETERS	Alternate Levels of Service
Roadside	*Aesthetics*	*11. Degree of Pleasing Appearance*	*13. Grass Growth*	*Height of grass and width of mowing*	*1. Mow @ 8" height, full width*
					2. Mow @ 12" height, 30' maximum width
					3. Mow @ 18" height, one machine pass width
					4. Mow for safety reasons only
			14. Noxious Weeds and Brush	*Number of applications of herbicide per year*	*1. Three time per year*
					2. Once a year
					3. Do not apply herbicide
			15. Litter and Debris	*Frequency of clean up of litter and debris*	*1. Once a month*
					2. Once every three months
					3. Once a year
	User Convenience	*12. Degree of Cleanliness of Rest Areas*	*16. Rest Areas*	*Frequency of clean up of rest areas*	*1. Twice a day*
					2. Four time a week
					3. Twice a week

Three of four remaining steps in preparing input data rely heavily on data contained in maintenance management systems. They are as follows:

(1) Determine Effects of Alternate Levels of Service on Considerations.

For each of the numerical values of alternate levels of service established for a condition, its effect on the consideration to which it is applicable is determined in this step. The effect on a consideration (e.g., safety) is estimated in terms of the attribute of that consideration (e.g., percent of drivers who cannot recover). Ideally, the procedure for estimating the effects should be based on objective data (i.e., on field measurements). However, the results of the research indicated that available data were often not adequate for directly estimating the effects of alternate levels of service. The procedure developed for estimating those effects involves structured interviews with specialists to supplement such data as may be available.

(2) Estimate Resource Needs for Each Level of Service

In this step, the resources required to maintain each maintenance condition at each of its alternate levels of service is detemined. Experienced persons in maintenance planning and operations should be involved in providing the necessary information. If a maintenance management system is being used by the highway agency, a significant amount of information needed for this tabulation may be readily available because some of the alternative levels of service may have already been used or considered for use. For alternative levels of service not previously used or considered for use, hard data for estimation of resource requirements will be lacking and judgmental estimates will be required. Best estimates must be made from data available now, and from the experience of those making the estimates. Resource requirements need to be specified in terms of labor, materials, and equipment.

(3) Assess Desirability for Each Level of Each Attribute

In this step, the relative desirability (value) of the different levels of each attribute is assessed. For example, how much better or worse is one level of an attribute (e.g., percent of drivers who cannot recover = 5) relative to another level of this attribute (e.g., percent of drivers who cannot recover = 10)? The relative desirability is determined by assessing how much the agency should be willing to spend in order to maintain each level of an attribute.

This step requires the completion of the following three sequential tasks:

A. Preparation for group value assessments.
B. Conducting group assessment meetings.
C. Analysis of assessment data.

Assessors should use "percent of the total available maintenance budget" as an indication of the value they place on maintaining the attribute at each of the levels described, not as to what might be the actual cost of maintaining the levels. "Willingness to pay" is an expression of the relative value of the results of maintaining at a level, not an estimate of the cost of doing so. In this manner, assessments of benefits are made in a structured way.

(4) Organize and Input Data for Computer Program

This step is covered in detail in the manual and is not important to understanding the method and its usefulness.

F. Program Outputs

The last step in the manual is "Run Computer Program and Print Results of Analysis". The results of the example problem, considering only the Roadside element, is given in Table 2. The optimal Level of Service for each maintenance condition and the resources consumed are clearly stated. Comparing the Levels of Service chosen with those considered (Table 2) suggests that minimal attention should be given to grass growth and more attention to litter and debris and rest areas. For this problem, the existing budget was used as the resource constraint. Alternately, budgets greater and less than the existing budget can be used to answer "what if" type questions. For budget cuts, the program outputs show clearly what maintenance conditions should receive less attention if expenditures are to be optimized. Such information is extremely useful to highway administrators who brief legislators on the impacts of proposed changes to highway maintenance budgets. Furthermore, existing budgets under scrutiny of legislators can be better defended.

Table 2. Program Output

THE SELECTED POLICY IS

MAINTENANCE ELEMENT—ROADSIDE

MAINTENANCE CONDITION	ALTERNATIVE SELECTED
GRASS GROWTH	= MOW FOR SAFETY REASONS ONLY
NOXIOUS WEEDS AND BRUSH	= ONCE A YEAR
LITTER AND DEBRIS	= ONCE A MONTH
REST AREAS	= TWICE A DAY

THE COSTS OF THE SELECTED POLICY

RESOURCE	BUDGET	USED
LABOR IN HOURS	408323.00	386996.00
MATERIALS IN DOLLARS	898925.00	740027.00
EQUIPMENT IN DOLLARS	1698555.00	1328485.00

G. Limitations to the Method

Experience in state highway departments indicates that the program software will handle up to 8 maintenance elements, 25 maintenance conditions, and 100 levels of service. It is the 100 levels of service that puts a cap on the size of the problem. To keep to 100 levels of service the analyst may have to decrease the number of maintenance elements considered or restrict the application to one functional class of road. Otherwise, the program can be run for an entire highway system, or portions of it such as by district or by highway corridor.

EXPERIENCE WITH THE METHOD

States that had early experience with the method during the course of its development were Pennsylvania and Louisiana. These states volunteered to be "Guinea Pigs" for trials by the research agency. Two maintenance conditions, pavement edge drop-off and vegetation control, were tested. Software was debugged and data gathering procedures were refined. Results were reasonable and in most instances confirmed current practice.
In the development of the manual, the methodology was tested by three states with little or no assistance from the research agency.

Arizona testing included 6 maintenance elements, 15 maintenance conditions and 46 alternative maintenance levels of service. Arizona commented, "The manual is a logical next step in technology for development and enhancement of highway maintenance systems". Furthermore, Arizona said, "I found the manual quite clear and easily understandable. Most users with a well-organized maintenance management system should have very little difficulty in following the manual."

New Jersey testing included 4 maintenance elements, 11 maintenance conditions and 33 alternative levels of service. The research agency report on New Jersey said, "No particular difficulty was experienced by New Jersey personnel in generating the required input data, organizing and entering the data into the computer, executing the computer program, and interpreting the program output to establish maintenance levels of service." No trip was made by the consultant to New Jersey to assist the agency in starting the testing activities, nor were any telephone consultations necessary. New Jersey commented, "I feel that New Jersey should benefit from using ASOP (the methodology). This is especially true when attempting to show the effect of budget cuts on level of service."

Virginia testing included 8 maintenance elements, 57 maintenance conditions and about 180 alternative maintenance levels of service. This exceeded the capacity of the methodology software and caused major difficulties in executing the program. Virginia continues to work with the methodology and has been successful by first separately considering secondary roads (normally gravel surfaced), primary, and interstate and second by reducing the number of maintenance conditions considered for each element.

Cost to implement the method, estimated by highway departments that have successfully tested the methodology, range from 4 to 5 man-months in Arizona to 1.0 to 1.5 man-years in New Jersey. Arizona's estimate is shorter because it assumes that all persons involved in implementation are familiar with the maintenance management system inventory, the method terminology, and the method data requirements, whereas the New Jersey estimate includes substantial "learning time".

Specific problems encountered with implementing the method are discussed under general categories in the material that follows. Further work on ameliorating these problems is being planned in the National Cooperative Highway Research Program.

A. Data Input Needs

Although much of the cost data required for input may be obtained from a maintenance management system (MMS), it is not always easy. Costs are sometimes aggregated in the MMS consequently requiring the analyst to make educated guesses. A case in point was costs related to permanent patching. Permanent patching is undertaken to eliminate rutting and to reduce roughness. The costs of permanent patching had to be broken out to amounts for rutting and amounts for roughness to satisfy the needs of the method. It does take an experienced maintenance manager to make such estimates. The needed estimates became very clear in the guidance provided by the manual and were obtained in all instances without difficulty.

A more difficult estimating problem related to cost data is the estimating required for levels of service where no historical data or experience exists. Again judgements from an experienced maintenance manager are needed.

B. Problem With the Program Size

The 100 levels of service limitation to the program precludes adding rehabilitation/construction to the method. Some maintenance managers feel that the usefulness of the program would be considerably enhanced if the method would suggest an optimal allocation of resources between maintenance and construction. Furthermore, it has been found that legislators reviewing maintenance budgets like to consider both maintenance and construction at the same time.

C. Problem with Long Forecasting Periods

Application of the method for resources needed 3 to 4 years in the future is difficult because of lack of confidence in the base data for such a long projection. In this respect, the method is no different than most other forecasting methods that are empirically based.

D. Problems with Personnel Changes

The program must be run by a person familiar with it. As it is unlikely that any highway department would adjust levels of service each year, there could be long periods of time between applications. In such cases, new computer personnel would have to be trained.

E. Problem with Senior Management Concerns

The method is a tool to assist decision-makers, but, at first impression, the method appears to make the decisions. Consequently, unless decisions of senior management are being challenged, senior management will not see any reason to move to a level-of-service approach for resource allocation

There needs to be a desire to move to a level-of-service approach. Where many levels of service are provided by fiat, an optimization program is of little use.

F. Problem with Involving Legislators

The structural process called for in the step "Assess Desirability for Each Level of Each Attribute" involves a group of persons from which assessments are obtained. This group can be made up of any persons who are users of highways. Involvement of legislators in the group is appropriate and desirable. Their responses to the "willingness-to-pay" questions provide the required assessment of maintenance benefits. Although the opportunity exists for legislators to participate, to this time it has not been attempted. In all states, such participation is recognized as being of potential benefit. Nevertheless, experience there with top-level management has shown a degree of impatience and lack of understanding. It has been hard for analyst to explain the process satisfactorily. It has been difficult to show how their judgements influence the output, as such decision-makers want to assess in advance the consequences of their decisions. Planning for further work on the method implementation will consider the development of a guide on how to engage the participation of legislators in a productive, meaningful process for all concerned.

CONCLUSION

The method, particularly its conceptual foundation is highly valued by all those who have worked with it, not withstanding the problems described related to implementation. It is important to realize that no one state has experienced all the problems noted. Work is continuing to ameliorate the problems. The important conclusion is that the manual has been implemented successfully by state agencies with maintenance management systems, using existing personnel. It is ready for use and worthy of consideration by all highway maintenance organizations having maintenance management systems.

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