Decisions in Selection of Maintenance Levels of Service

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ABSTRACT

The selection of levels of service for maintenance of the various elements of a highway (e.g., traveled way, drainage, or roadside) is influenced by such multiple, often conflicting, considerations as safety, riding comfort, and aesthetics. Decisions regarding maintenance levels of service are now usually made by maintenance personnel in a generally informal, intuitive manner, on the basis of their experience. In research for NCHRP Project 14-5, a more formal methodology was developed to assist in decisions regarding optimal maintenance levels of service for those highway elements that are subject to the constraints of available money, manpower, and equipment. In Phase II of this study, a user manual was developed to provide detailed instructions for highway agency personnel in the application of the methodology to their specific highway system. The main steps of the user manual are described in this paper. The manual is designed to be self-explanatory: no outside assistance from persons experienced in the formal methodology will be necessary. It is also intended that the manual be comprehensive: the instructions cover all of the steps necessary to implement the methodology within a highway agency. These desirable features of the manual were tested in Arizona, New Jersey, and Virginia. Results of testing indicate that it is practical to develop the necessary inputs for the implementation of the methodology and that a highway agency should benefit by using the methodology, especially when attempting to document the impact of budget cuts on levels of service and to provide an objective and defensible basis for the selection of levels of service.

A primary objective of this paper is to describe a methodology for the selection of levels of service for highway maintenance. A level of service for maintenance of a given highway element defines the threshold deficiency level of the element that should trigger an appropriate maintenance activity (e.g., grass should be mowed when it is 12 in. high or a drainage ditch should be cleaned when 50 percent of its area is blocked). The levels of service affect decisions about where, when, and how much maintenance is required. Thus management responsibilities for work scheduling, work priorities, budget estimation, and resource allocation are significantly influenced by the selection of levels of service.

Decisions about levels of service are now usually made by maintenance personnel in a generally informal, intuitive manner, on the basis of their experience. In research for NCHRP Project 14-5, a more formal methodology was developed to determine the levels of service that maximize highway user benefits subject to the constraints of available resources (money, manpower, equipment, and materials).

In Phase II of this project, a user manual was developed to provide detailed instructions for highway agency personnel in the application of the methodology to their specific highway system. The manual was designed to be self-explanatory: no outside assistance from persons experienced in the formal methodology would be necessary. It was also intended that the manual be comprehensive: the instructions cover all of the steps necessary to implement the methodology within a highway agency. The manual was tested in Arizona, New Jersey, and Virginia. The purpose of this testing was to check whether the instructions in the manual were sufficiently clear and complete to enable a highway agency to implement the methodology within its currently available resources (staff and computer facilities).

The manual is organized in 12 well-defined and distinct steps. The following sections of this paper describe how each step is to be completed and what is intended to be accomplished as a result of completion of the step. Results of testing the manual in the three state agencies are also discussed.

STEP 1: PREPARE A LIST OF MAINTENANCE ELEMENTS

In this first step, the entire highway system is divided into a limited number of physical categories referred to as maintenance elements. For example, these eight might be selected to represent an entire typical highway system:

1. Traveled way, flexible,
2. Traveled way, rigid,
3. Shoulders and approaches,
4. Roadside,
5. Drainage,
6. Structures,
7. Traffic control and service facilities, and
8. Snow and ice control.

Results of initial testing indicate that these eight elements can be used without modifications in all but a few exceptional cases. Exceptional cases in which an element might be deleted from this list might be, for example, delete 2 if an agency had no portland cement concrete pavement in its system, or delete 8 if climate were such that snow and ice control were unnecessary. An example of an exceptional case in which an element would be added is if a ferry system were operated and maintained by the highway agency.

The result of completion of Step 1 is a list of elements selected to represent the entire highway system under study, such as the example.

STEP 2: PREPARE A LIST OF CONSIDERATIONS AND ASSIGN CONSIDERATIONS TO ELEMENTS

In this step, a list of considerations that can be used to evaluate the performance of the maintenance elements previously listed is first prepared. Appropriate considerations from this list are then assigned to each element.

Considerations are the factors that are used to evaluate how well each maintenance element serves its intended function. For example, "safety" is an important consideration by means of which the performance of most of the listed elements may be evaluated, including "traveled way" (both flexible and rigid), "shoulders and approaches," "traffic control and service facilities," and "snow and ice control." However, "safety" would not likely be chosen as an important consideration for the element "roadside."

Following are examples of considerations that might be applicable:

1. Safety,
2. Riding comfort,
3. Preservation of investment,
4. Aesthetics,
5. User cost, and
6. User convenience.

These six considerations should be adequate for use by most highway agencies, and adding to or deleting from this list should be done only in exceptional cases. It should be noted that although "maintenance cost" is an important consideration in the usual sense, it is not included in this list. In this system, maintenance costs are viewed as constraints on the system not as user-related considerations and are accounted for in a subsequent optimization part of the methodology.

To complete Step 2, one or more considerations are assigned to each maintenance element to be used in evaluating it. For example, if the considerations listed were to be used in the evaluation of the maintenance elements listed in Step 1, they might be assigned as presented in Columns 1 and 2 in Table 1. Note that only those few considerations that play a major part in its evaluation are assigned to an element. For example, although "aethestics" might have some part in evaluating other elements, it is assigned only to the element "roadside," where it plays a dominant role.

The assignment of considerations shown in Table 1 should be reasonable for most highway agencies. However, revisions in this table may be made if considered to be essential by the agency.

The result of completion of Step 2 is the assignment of considerations to elements in the form of a table such as Table 1.

STEP 3: SELECT AN ATTRIBUTE FOR EACH CONSIDERATION

In this step, an attribute is selected to express the level of each consideration on a numerical scale. For example, for the consideration "safety," which has been assigned to the maintenance element "traveled way, flexible," the attribute selected might be "percentage change in frequency of accidents."

An attribute provides a numerical scale for measuring the effects of alternative levels of service on a given consideration. There are two general types of attributes to consider--natural and constructed. A natural attribute is one the levels of which are physically measurable. For example, for the consideration "safety," a natural attribute may be "percentage change in frequency of accidents" relative to the elements "traveled way, flexible" and "traveled way, rigid," or it may be "percentage of drivers who cannot recover after driving over edge of traveled way" relative to the element "shoulders and approaches."

A constructed attribute is one for which a physical measurement is not possible. In such cases, a subjective scale or index must be constructed to define the levels of this attribute. For example, the consideration "aesthetics" cannot be measured objectively, so a constructed attribute "degree of pleasing appearance" with a subjective scale of 1 to 4 might be used to define it. Each number on the subjective scale should be described in sufficient detail so that the associated level of impact of each is communicated clearly and unambiguously. Pictures may be used to provide additional communication of a visual nature.

Examples of attributes that might be selected for various considerations are shown in Column 3 of Table 2. Each attribute should be numbered sequentially, as shown. One and only one attribute is assigned to each consideration. Unlike the examples of elements and considerations presented in Columns 1 and 2, which should require little change, the attributes shown in Column 3 are presented as preliminary suggestions only and may be revised or replaced by the user agency.

The result of completion of Step 3 is the selection of an attribute for each of the considerations previously assigned to the elements.

STEP 4: SELECT CONDITIONS FOR EACH ATTRIBUTE

In this step, at least one, but no more than three, maintenance conditions applicable to each of the attributes previously listed is selected. The conditions should be such that, at some level of deficiency of the condition, repair or correction will be required and that a change in the level of the condition would be expected to have an influence on the associated attribute. For example, for the attribute "percentage change in the frequency of accidents" previously selected as an example applicable to the consideration "safety" for the maintenance element "traveled way, flexible," the three conditions "rutting," "slippery surface," and "roughness" might be selected. This example, as well as examples of maintenance conditions that might be selected as applicable to all other examples of attributes presented in Step 3, are presented in Column 4 of Table 3. Note that the same condition may be appropriately used for more than one attribute for a given maintenance element.

Each selected maintenance condition should be such that alternative levels of service could be considered for it. If only one level of service is applicable for a particular condition, it should not be included in this methodology. Thus, for example, nonfunctioning major signals may not be included as a maintenance condition if the policy is to repair these as they are reported.

The examples of conditions in Column 4, like the examples of attributes in Column 3, are presented as preliminary suggestions only. Because all of them have not as yet been tested in trial applications with highway agencies, this list should be used by a highway agency as a guide for preparing its own preliminary list only. Meetings should be held with appropriate specialists to generate lists of conditions that are appropriate for the specific highway agency. To keep the analysis tractable, it is desirable to include in the set of maintenance conditions only those that are of major concern. Usually, it should be possible to define a total of 20 to 25 maintenance conditions for which 70 to 80 percent of the annual maintenance budget is expended.

TABLE 1 Suggested Format for Recording Maintenance System Data, Columns 1 and 2: Assignment of Considerations to Elements

Column 1 Maintenance ELEMENTS	Column 2 Maintenance Element CONSIDERATIONS	Column 3 ATTRIBUTES of the Considerations	Column 4 Maintenance CONDITION Affecting Attributes	Column 5 PARAMETERS for Defining Maintenance Conditions	Column 6 Alternate Maintenance Levels of Service, in Terms of Parameters
Traveled Way, Flexible	*Safety*				
	Riding Comfort				
	User Cost				
	Preservation of Investment				
Traveled Way, Rigid	*Safety*				
	Riding Comfort				
	User Cost				
	Preservation of Investment				
Shoulders and Approaches	*Safety*				
	Preservation of Investment				
Roadside	*Aesthetics*				
	User Convenience				
Drainage	*Safety*				
	Preservation of Investment				
Structures	*Preservation of Investment*				
Traffic Control and Service Facilities	*Safety*				
	User Convenience				
Snow and Ice Control	*Safety*				
	User Convenience				

TABLE 2 Suggested Format for Recording Maintenance System Data, Column 3: Selection of an Attribute for Each Consideration

Column 1 Maintenance ELEMENTS	Column 2 Maintenance Element CONSIDERATIONS	Column 3 ATTRIBUTES of the Considerations	Column 4 Maintenance CONDITION Affecting Attributes	Column 5 PARAMETERS for Defining Maintenance Conditions	Column 6 Alternate Maintenance Levels of Service, in Terms of Parameters
Traveled Way, Flexible	*Safety*	*1. Percent change in frequency of accidents*			
	Riding Comfort	*2. Present Serviceability Index (PSI)*			
	User Cost	*3. Percent increase in excess user costs*			
	Preservation of Investment	*4. Frequency of rehabilitation of pavement*			
Traveled Way, Rigid	*Safety*	*5. Percent change in frequency of accidents*			
	Riding Comfort	*6. Present Serviceability Index (PSI)*			
	User Cost	*7. Percent increase in excess user costs*			
	Preservation of Investment	*8. Frequency of rehabilitation of pavement*			
Shoulders and Approaches	*Safety*	*9. Percent of drivers who cannot recover after driving over edge of traveled way*			
	Preservation of Investment	*10. Percent increase in pavement rehabilitation cost*			
Roadside	*Aesthetics*	*11. Degree of Pleasing Appearance*			
	User Convenience	*12. Degree of cleanliness at rest areas*			
Drainage	*Safety*	*13. Percent of time water accumulates on pavement*			
	Preservation of Investment	*14. Percent of time water accumulates on pavement*			
Structures	*Preservation of Investment*	*15. Percent change in useful life of structures*			
Traffic Control and Service Facilities	*Safety*	*16. Maximum percent of traffic signals which would be ineffective at a given time*			
	User Convenience	*17. Maximum percent of signs, markings, and lights which would be ineffective at a given time*			
Snow and Ice Control	*Safety*	*18. Number of hours road is open under adverse driving conditions*			
	User Convenience	*19. Percent of road mileage closed following storm*			

TABLE 3 Suggested Format for Recording Maintenance System Data, Column 4: Selection of Conditions for Each Attribute

Column 1 Maintenance ELEMENTS	Column 2 Maintenance Element CONSIDERATIONS	Column 3 ATTRIBUTES of the Considerations	Column 4 Maintenance CONDITION Affecting Attributes	Column 5 PARAMETERS for Defining Maintenance Conditions	Column 6 Alternate Maintenance Levels of Service, in Terms of Parameters
Traveled Way, Flexible	*Safety*	1. *Percent change in frequency of accidents*	1. *Rutting*		
			2. *Slippery Surface*		
			3. *Roughness*		
	Riding Comfort	2. *Present Serviceability Index (PSI)*	1. *Rutting*		
			3. *Roughness*		
	User Cost	3. *Percent increase in excess user costs*	1. *Rutting*		
			3. *Roughness*		
	Preservation of Investment	4. *Frequency of rehabilitation of pavement*	4. *Ravelling*		
			5. *Cracking*		
			3. *Roughness*		
Traveled Way, Rigid	*Safety*	5. *Percent change in frequency of accidents*	6. *Slippery Surface*		
			7. *Settlement, heave, or distortion*		
	Riding Comfort	6. *Present Serviceability Index (PSI)*	8. *Faulting*		
			7. *Settlement, heave, or distortion*		
	User Cost	7. *Percent increase in excess user costs*	9. *Cracking*		
			8. *Faulting*		
			7. *Settlement, heave, or distortion*		
	Preservation of Investment	8. *Frequency of rehabilitation of pavement*	9. *Cracking*		
			10. *Spalling*		
			8. *Faulting*		
Shoulders and Approaches	*Safety*	9. *Percent of drivers who cannot recover after driving over edge of traveled way*	11. *Edge of traveled way drop-off*		
			12. *Surface deterioration of shoulders*		
	Preservation of Investment	10. *Percent increase in pavement rehabilitation cost*	11. *Edge of traveled way drop-off*		
Roadside	*Aesthetics*	11. *Degree of Pleasing Appearance*	13. *Grass Growth*		
			14. *Noxious weeds and brush*		
			15. *Litter and debris*		
	User Convenience	12. *Degree of cleanliness at rest areas*	16. *Rest Areas*		
Drainage	*Safety*	13. *Percent of time water accumulates on pavement*	17. *Blocked or damaged drainage structures*		
	Preservation of Investment	14. *Percent of time water accumulates on pavement*	17. *Blocked or damaged drainage structures*		
Structures	*Preservation of Investment*	15. *Percent change in useful life of structures*	18. *Structural deficiencies*		
			19. *Structure cleaning and painting*		
Traffic Control and Service Facilities	*Safety*	16. *Maximum percent of traffic signals which would be ineffective at a given time*	20. *Traffic signals*		
	User Convenience	17. *Maximum percent of signs, markings, and lights which would be ineffective at a given time*	21. *Signs and markings*		
			22. *Lighting*		
Snow and Ice Control	*Safety*	18. *Number of hours road is open under adverse driving conditions*	23. *Snow and ice buildup*		
	User Convenience	19. *Percent of road mileage closed following storm*	23. *Snow and ice buildup*		

On completion of the selection, the conditions should be tabulated opposite the attributes to which they are assigned in a form similar to Column 4 in Table 3. Conditions for a given maintenance element must be numbered sequentially, as shown, with a condition assigned the same number, regardless of the number of attributes to which it is assigned.

The results of completion of Step 4 are the selection of one to three maintenance conditions applicable to each of the attributes previously selected, tabulation of these conditions in the appropriate position in the fourth column of a table similar to Table 3, and numbering the conditions as shown for the examples in this table.

STEP 5: ESTABLISH A PARAMETER FOR EACH CONDITION

A parameter to define alternate levels of service for each maintenance condition is established in this step. For example, for the maintenance condition "rutting," an example of a parameter that might be selected to define it is "depth of rut and percentage of lane area affected." This example is the first item in Column 5 of Table 4 and is presented opposite the maintenance condition "rutting" in Column 4. Column 5 also presents examples of parameters that might be used for defining each of the other examples of maintenance conditions listed in Column 4.

Parameters should be capable of being expressed numerically or by simple, easily understood descriptions. The numerical or descriptive definitions should be able to differentiate clearly between different levels of the condition to which the parameter applies. There should be one, and only one, parameter assigned to each condition. A parameter may consist of a single definitive item (such as "skid resistance in terms of skid number at 40 mph" for the condition "slippery surface") or may have two items paired to make a combined definition (such as "depth of rut and percentage of lane area affected" for the condition "rutting" or "width of cracks and percentage of lane area affected" for the condition "cracking").

Where development of a numerical parameter does not appear to be feasible, a descriptive parameter may have to be used. For example, if the parameter selected for the condition "structural deficiencies" relative to the maintenance element "structures" is "appearance when repair should be done," the description of appearance should be as unequivocal as possible. Photographs may be used to supplement the descriptions if they would contribute to a better understanding of the description.

The results of the completion of Step 5 are the establishment of a parameter for defining alternate levels of service for each of the maintenance conditions previously selected and the tabulation of these parameters in the appropriate position in the fifth column of a table similar to the example in Table 4.

STEP 6: SPECIFY ALTERNATE LEVELS OF SERVICE FOR EACH CONDITION

In this step, numerical values of the parameters used to define alternate levels of service for the maintenance conditions are established. A maintenance level of service specifies a threshold value of a parameter that triggers the scheduling of an appropriate maintenance activity. For example, if one alternate maintenance level of service for the parameter "height of grass and width of mowing" is "mow at 8 in. height, full width," maintenance activity in mowing would be scheduled to be done when this condition was reached. Some general guidelines for generating appropriate alternate levels of service are

- The description of each level of service should be definitive and nonambiguous (i.e., it should communicate clearly to maintenance personnel when they are expected to work on a maintenance condition).
- The description of a level of service should not involve complicated measurements on the part of the field maintenance personnel--they would be difficult to make in the field and likely to be ignored. Ideally, only visual inspections and simple measurements, quickly made, should be involved.
- Each of the alternate levels of service should be feasible. For example, if the analysis results in selection of the lowest level of service for a maintenance condition, the agency should be willing to adopt that level of service.
- The resource requirements (dollars, manpower) of the levels of service should be significantly different from each other so that truly different options are represented by each. If two levels of service differ only slightly with respect to their maintenance costs, they might better be combined to represent a single level of service.

At the conclusion of this step, a range of alternate levels of service from the highest (ideal) to the lowest (barely tolerable) will have been generated. A general procedure for developing alternate levels of service follows.

First, department personnel with special knowledge of a given maintenance condition are asked to assume that there are no constraints on resources (dollars, manpower) for alleviating this condition. They are then asked the question: How would you improve the current level of service for this condition? Discussion of this question would normally lead to suggesting a level of service somewhat higher than the current practice within the agency--"ideal" but physically attainable. Next, they are told to assume that a severe cut in budget for this condition has been made and that a reduced level of service will have to be adopted. They are then asked the second question: How would you reduce the current level of service for this condition for this reduced budget? This would normally result in suggesting a level of service considerably lower than the current practice, possibly barely tolerable. With these two levels of service as the upper and lower bounds, and the current level of service between them, three alternate levels of service have now been described. Three levels of service are usually adequate for a condition. However, if the range between them is great, the possibility of one or two additional intermediate levels of service should be considered. Five levels of service should be considered a maximum for all but the most unusual of cases because analysis becomes increasingly more complicated as the number of alternate levels of service increases.

Physical measurement and appearance provide direct measures of levels of service to be maintained in the field and these are the preferred modes. Frequency or quantity of work performed assume that certain levels of service are automatically maintained if the amount of effort or material is expended according to established procedures, without direct measurement of results in the field. Although generally less desirable, frequency or quantity of work may provide reasonable specification of levels of service if direct measurement would be impractical and description of the desired appearance would be too cumbersome.

TABLE 4 Suggested Format for Recording Maintenance System Data, Column 5: Establishment of a Parameter for Each Condition

Column 1 Maintenance ELEMENTS	Column 2 Maintenance Element CONSIDERATIONS	Column 3 ATTRIBUTES of the Considerations	Column 4 Maintenance CONDITION Affecting Attributes	Column 5 PARAMETERS for Defining Maintenance Conditions	Column 6 Alternate Maintenance Levels of Service, in Terms of Parameters
Traveled Way, Flexible	Safety	1. Percent change in frequency of accidents	1. Rutting	Depth of rut and percent of lane area affected	
			2. Slippery Surface	Skid resistance (SN_{40})	
			3. Roughness	Mays Ride Meter Index	
	Riding Comfort	2. Present Serviceability Index (PSI)	1. Rutting	Depth of rut and percent of lane area affected	
			3. Roughness	Mays Ride Meter Index	
	User Cost	3. Percent increase in excess user costs	1. Rutting	Depth of rut and percent of lane area affected	
			3. Roughness	Mays Ride Meter Index	
	Preservation of Investment	4. Frequency of rehabilitation of pavement	4. Ravelling	Severity and percent of lane area affected	
			5. Cracking	Width of cracks, and percent of lane area affected	
			3. Roughness	Mays Ride Meter Index	
Traveled Way, Rigid	Safety	5. Percent change in frequency of accidents	6. Slippery Surface	Skid resistance (SN_{40})	
			7. Settlement, heave, or distortion	Height, and percent of lane area affected	
	Riding Comfort	6. Present Serviceability Index (PSI)	8. Faulting	Height, and percent of joints affected	
			7. Settlement, heave, or distortion	Height, and percent of lane area affected	
	User Cost	7. Percent increase in excess user costs	9. Cracking	Width of cracks, and percent of lane area affected	
			8. Faulting	Height, and percent of joints affected	
			7. Settlement, heave, or distortion	Height, and percent of lane area affected	
	Preservation of Investment	8. Frequency of rehabilitation of pavement	9. Cracking	Width of cracks, and percent of lane area affected	
			10. Spalling	Width of spalls, and percent of joints affected	
			8. Faulting	Height, and percent of joints affected	
Shoulders and Approaches	Safety	9. Percent of drivers who cannot recover after driving over edge of traveled way	11. Edge of traveled way drop-off	Average height of drop-off	
			12. Surface deterioration of shoulders	Severity of localized depressions	
	Preservation of Investment	10. Percent increase in pavement rehabilitation cost	11. Edge of traveled way drop-off	Average height of drop-off	
Roadside	Aesthetics	11. Degree of Pleasing Appearance	13. Grass Growth	Height of grass and width of mowing	
			14. Noxious weeds and brush	Number of applications of herbicide per year	
			15. Litter and debris	Frequency of clean up of litter and debris	
	User Convenience	12. Degree of cleanliness at rest areas	16. Rest Areas	Frequency of clean up of rest areas	
Drainage	Safety	13. Percent of time water accumulates on pavement	17. Blocked or damaged drainage structures	Appearance when repair or clean out should be done	
	Preservation of Investment	14. Percent of time water accumulates on pavement	17. Blocked or damaged drainage structures	Appearance when repair or clean out should be done	
Structures	Preservation of Investment	15. Percent change in useful life of structures	18. Structural deficiencies	Appearance when repair should be done	
			19. Structure cleaning and painting	Frequency of cleaning and painting	
Traffic Control and Service Facilities	Safety	16. Maximum percent of traffic signals which would be ineffective at a given time	20. Traffic signals	Frequency of inspection and priority of corrective measures	
	User Convenience	17. Maximum percent of signs, markings, and lights which would be ineffective at a given time	21. Signs and markings	Frequency of inspection and priority of corrective measures	
			22. Lighting	Frequency of inspection and priority of corrective measures	
Snow and Ice Control	Safety	18. Number of hours road is open under adverse driving conditions	23. Snow and ice buildup	Frequency of inspection and priority of corrective measures	
	User Convenience	19. Percent of road mileage closed following storm	23. Snow and ice buildup	Frequency of inspection and priority of corrective measures	

The results of completion of Step 6 are the establishment of three to five alternative levels of service (in terms of the established parameters) for each of the maintenance conditions previously selected and tabulation of these alternate levels of service in Column 6 of Table 4.

For example, the element selected as an example for completion in this and the following steps is "roadside." As shown in Table 4, two considerations were selected for this element--"aesthetics" and "user convenience" (Column 2). The attribute selected for "aesthetics" was "degree of pleasing appearance," and for "user convenience" it was "degree of cleanliness of rest areas" (Column 3). Three conditions were selected as affecting the attribute "degree of pleasing appearance"--"grass growth," "noxious weeds and brush," and "litter and debris." One condition "rest areas" was selected as affecting the attribute "degree of cleanliness of rest areas" (Column 4). The parameters selected to define these four conditions were "height of grass and width of mowing," "number of applications of herbicides per year," "frequency of cleanup of litter and debris," and "frequency of cleanup of rest area," respectively (Column 5).

In Step 6, four alternate levels of service were selected for the condition "grass growth." These were expressed in terms of its parameter "height of grass and width of mowing." Column 6 of Table 5 shows these four alternate levels of service, as well as three alternate levels of service for each of the three other conditions selected for this example. Note that Table 5 is a portion of the table developed in previous steps for this example, showing only those considerations, attributes, conditions, parameters, and levels of service applicable to the one example element "roadside."

STEP 7: 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., "percentage 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 study in which this system was developed indicated that available data would not be adequate for directly estimating the effects of alternative levels of service. The procedure developed for estimating these effects involves structured interviews with specialists to supplement such data as may be available. This proposed procedure involves the following tasks:

1. Prepare summaries of pertinent information and data available from agency records or the literature.
2. Select two to five specialists to participate in structured interviews. Local experience as well as general background and knowledge of the specialty area and interest in participating in the program are major criteria for selection of these specialists. Distribute the summaries of available information to the specialists in advance of the interviews, with instructions to read and become familiar with the information.
3. Organize a meeting with the specialists. Establish a scale for each attribute and tabulate each scale in a form similar to that shown in Figure 1. Explain the scale of each attribute being evaluated and the consideration and element to which each applies. Also describe the alternate levels of service in terms of the parameter used to define the maintenance condition that affects the attribute. A completed Table 5 for each element involved is used to assist in these descriptions. Review and discuss the summaries of information that were distributed before the meeting.
4. Select and complete the appropriate form, Figure 1, 2, or 3. Figure 1 is used if only one parameter and one condition are involved. Figure 2

TABLE 5 Suggested Format for Recording Maintenance System Data, Column 6: Specification of Example Alternate Levels of Service 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

Assessors 1. _____ Date _____
2. _____ 4. _____
3. _____ 5. _____

ELEMENT _____
CONSIDERATION _____
ATTRIBUTE _____
CONDITION _____
PARAMETER _____

Alternate Levels of Service of the CONDITION in terms of the PARAMETER: _____	Level of ATTRIBUTE: _____
1	
2	
3	
4	
5	

Lower — Level of Service — Higher

FIGURE 1 Form for recording estimates of the effects of a single maintenance condition on a consideration in terms of its attribute.

HIGHWAY AGENCY

Assessors 1. _____ Date _____
2. _____ 4. _____
3. _____

ELEMENT _____
CONSIDERATION _____
ATTRIBUTE _____
CONDITION 1 _____
CONDITION 2 _____

CONDITION 2	Alternate Levels of Service	CONDITION 1: 1	2	3	4	5
	1					
	2					
	3					
	4					
	5					

FIGURE 2 Form for recording estimates of the effects of two maintenance conditions on a consideration in terms of its attribute.

is used for two parameters and two conditions and Figure 3 for three parameters and three conditions. The objective of the interview meeting is to obtain a consensus of the specialists regarding the estimates to be entered on the form. Because sufficient objective data are seldom available, the specialists will have to use their judgment, based on experience and logic, to extrapolate from the available data to arrive at the estimates. If significant differences of opinion occur, they should, if possible, be resolved through discussion during the meeting. If these differences cannot be resolved, they should be noted and further investigated during the sensitivity analysis described in a later step.

The result of the completion of Step 7 is a completed form (Figure 1, 2, or 3) for each consideration under study.

A computer program has been designed so that the information from the completed form (Figure 1, 2, or 3) can be directly coded as input data without external calculations.

STEP 8: 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 are determined. The results of these estimates can be conveniently tabulated in the format shown in Figure 4. 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. With time, more information should become available, and more precise estimates of resource requirements can be made.

The result of the completion of Step 8 is the completion of a form such as the one shown in Figure 4 for each of the conditions and their levels of service developed in previous steps.

STEP 9: ASSESS DESIRABILITY OF EACH LEVEL OF EACH ATTRIBUTE

In this step the relative desirability (value) of the different levels of each attribute selected in Step 7 is assessed. For example, how much better or worse is one level of an attribute (e.g., percentage of drivers who cannot recover = 5) relative to another level of this attribute (e.g., percentage of drivers who cannot recover = 10)? The relative desirability is determined by assessing how much it would be worthwhile to spend to maintain an improved level of the attribute.

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

1. Preparation for group value assessments,
2. Conducting group assessment meetings, and
3. Analysis of assessment data.

A description of each task follows.

HIGHWAY AGENCY

Assessors 1. _____ 4. _____ Date _____

2. _____ 5. _____

3. _____ ELEMENT _____ CONSIDERATION _____

ATTRIBUTE No. _____

CONDITION No. 1 _____

No. 2 _____

No. 3 _____

CONDITION No. 3	CONDITION No. 2	CONDITION No. 1	1	2	3	4	5
1	1	1					
		2					
		3					
		4					
		5					
	2	1					
		2					
		3					
		4					
		5					
	3	1					
		2					
		3					
		4					
		5					
	4	1					
		2					
		3					
		4					
		5					
	5	1					
		2					
		3					
		4					
		5					

FIGURE 3 Form for recording estimates of the effects of three maintenance conditions on a consideration in terms of its attribute.

Maintenance CONDITION _____

Alternate Levels of Service	Resources Required Annually		
	Type 1 (e.g. Labor—hours or days)	Type 2 (e.g. Materials—dollars)	Type 3 (e.g. Equipment—hours, days, or dollars)
Level 1			
Level 2			
Level 3			
Level 4			
Level 5			

FIGURE 4 Form for tabulating estimates of resources required for alternate levels of service.

Preparation for Group Value Assessments

This task involves the selection of a panel of individuals whose value judgments will be incorporated in the methodology, preparation of assessment forms, and compilation of background information to facilitate assessments.

To obtain value judgments that represents a broad spectrum of viewpoints, it will be desirable (although not necessary) to arrange for the participation of individuals with differing background and experience (e.g., maintenance engineers, legislators, and highways users). Such a panel of individuals should be selected and provided with background information about project objectives, descriptions of selected attributes, and the different levels of each attribute. It will also be useful to compile information about the approximate percentage of the available maintenance budget spent to maintain the current level of each attribute. This can be done by estimating the percentage of the budget spent on different maintenance conditions that affect each attribute.

The final part of this task is to design the assessment forms. One form will be required for each attribute. The basic assessment question is: What maximum proportion of the total available maintenance budget would you be willing to spend in order to maintain a specified level of an attribute? The higher the proportion of the budget people are willing to spend for a particular level of the attribute, the higher the relative value of that level. A typical assessment form is shown in Figure 5.

Conducting Group Assessment Meetings

A group meeting of all the assessors should be held to explain the purpose of the study and the important role of the assessors in the determination of relative weights of different attributes. The selected attributes should be described and, when appropriate, pictures of actual highway conditions displaying different attribute levels should be shown. The format of the assessment forms that each assessor will be asked to complete should be discussed. It will be important to point out that the assessors should use "percentage of the total available maintenance budget" as an indication of the value they placed on maintaining the attribute at each of the levels described, not what might be the actual cost of maintaining it at this level.

Sufficient assessment forms should be completed during the group session to make certain that the assessors understand the concept and to resolve any difficulties that might be faced. The remaining forms may be completed afterwards by each of the assessors and returned to the principal investigator within some specific time period.

HIGHWAY AGENCY

Assessor _____ Date _____

ELEMENT _____

CONSIDERATION _____

ATTRIBUTE _____

Level* of Attribute:	Maximum Percent of Total Available Maintenance Budget "Willing to Pay"
Least ↑ Desirability ↓ Most	

* Values assessed in Step Seven and recorded on form shown as Figure 1,2 or 3.

FIGURE 5 Form for use in recording each assessor's judgment about the relative desirability of the levels of an attribute.

Analysis of Assessment Data

After receiving the completed assessment forms, the principal investigator proceeds with the analysis of the data. Forms for each attribute are analyzed sequentially. For each given attribute, the following procedure is followed:

1. Responses for each attribute level are arranged in an ascending order.
2. The median of all responses is determined. The median, rather than the mean, is used to represent group consensus because median is not affected much by extreme responses.
3. The relative value of each attribute level is calculated from the following equation:

$$\text{Relative value} = (PB_i - PB_L)/(PB_M - PB_L) \quad (1)$$

where

PB_i = maximum percentage of budget the group is willing to pay to maintain the attribute at the ith level,
PB_L = maximum percentage of budget the group is willing to pay to maintain the attribute at the least desirable level, and
PB_M = maximum percentage of budget the group is willing to pay to maintain the attribute at the most desirable level.

4. Plot attribute levels on X-axis and the corresponding relative values on Y-axis. Pass a smooth curve through the plotted points. Find the attribute level that corresponds to a relative value of 0.5. This is called the midvalue level of the attribute.

After the analysis for all of the attributes is completed, the relative weight of each attribute is calculated from the following equation:

$$W_i = [(PB_M - PB_L) \text{ for ith attribute}] \div [\Sigma\ (PB_M - PB_L) \text{ for all attributes}] \quad (2)$$

The result of completion of Step 9 is the calculation of the midvalue level and the relative weight of each attribute.

STEP 10: ORGANIZE AND INPUT DATA FOR COMPUTER PROGRAM

All the data necessary to run the computer program are obtained in Steps 1-9. In Step 10, these data are organized in a format required for the program. Detailed instructions are provided in the User Manual.

STEP 11: RUN COMPUTER PROGRAM AND PRINT OUT RESULTS OF ANALYSIS

In this step the computer program is executed with the input data prepared in the previous step. The program output displays the input data so that their accuracy can be checked and describes the optimum maintenance policy in terms of the preferred level of service for each maintenance condition. Additional parts of the output include the available and used amounts of resources, the contributions of individual attributes to the overall value of the policy, and the overall value itself on a scale of 0 to 1. In addition, results of sensitivity analyses that may have been specified by the user are also printed. The types of sensitivity analyses that could be conducted include change available resources, change relative weights of attributes, include or exclude specified level of service, and find the second-best solution. For each specification of sensitivity analysis, the program finds and displays the optimum maintenance policy.

STEP 12: FORMULATE RECOMMENDATIONS

The program identifies the optimum maintenance policy for given amounts of resources. Before recommendations for implementation of this policy are made, the costs of the policy in terms of resources used should be compared to the resources available. This would help in identifying any imbalance among the different types of resources. For example, the dollar amount of budget may not be fully used, but the number of manhours may be used to the limit. If it were practical to convert some of the dollar amount to additional labor hours (for example, by contracting out some of the work), the program could be rerun with this change to determine whether the selected policy would be affected. If a policy with a higher value is found, this should be taken into account in recommending the selection of a maintenance policy.

It will also be desirable to examine results of sensitivity analysis before making final recommendations. For example, the program might be run to assess the impact of changes in the current maintenance budget on the levels of service. Of particular interest are those situations (such as appreciable reductions in the budget) that could result in significantly lower levels of service. This is useful information to communicate to those responsible for approving maintenance budgets because any adverse effects of budget cuts can be identified explicitly.

RESULTS OF TESTING OF THE USER MANUAL

A draft of the User Manual was initially tested in Arizona and Virginia. Results of this testing indicated that some organizational and editorial changes in the manual would increase the clarity of the instructions. Appropriate revisions to the manual were made to reflect the recommendations of these two agencies. It was encouraging, however, that testing in neither agency required any change in the basic methodology or the computer program.

The revised manual was then tested in New Jersey. No particular difficulty was experienced by New Jersey Department of Transportation personnel in developing the required input data, organizing and entering the data in the computer, executing the computer program, and interpreting program output to establish maintenance levels of service. Although trips were made to Arizona and Virginia to get the testing program started, no such trip was required to New Jersey, nor were any telephone consultations necessary.

Given the different conditions and maintenance practices in the three states involved in the testing program, it appears that the methodology for establishing optimal maintenance levels of service should be applicable to most highway agencies and that the User Manual should enable any agency to implement the methodology without any outside assistance.

CONCLUSIONS

The User Manual developed and tested in this study provides a comprehensive and self-explanatory document that can be used by any transportation agency, without outside assistance, to establish the most appropriate maintenance levels of service for different components of a highway system. The levels of service determined from the methodology described in the manual will maximize user benefits subject to the constraints of available agency resources (dollars, manpower, equipment, and materials). The only major constraint on the use of the methodology is that the agency should have a working maintenance management system in place.

The use of the methodology can be extended beyond highway maintenance levels of service to include levels of service for the maintenance of other modes of transportation and to address the allocation of an overall maintenance budget among all competing modes of transportation.

The computer program documented in the User Manual provides an efficient zero-one integer programming algorithm that can be used, with some modifications, on problems beyond the highway maintenance problem. For example, the question of which highway construction projects should be funded in each year of a multiyear construction program can be analyzed using the algorithm with appropriate modifications.

The potential benefits of implementing the methodology include the following:

- Defensible and well-documented process for establishing maintenance level of service;
- Improved communication among all levels of management and field personnel within the agency regarding maintenance needs and priorities;
- Potential for constructive participation by maintenance engineers, legislators, and citizens in the assessment of the relative importance of evaluation criteria (attributes); and
- Selection of maintenance policies that make optimal use of limited resources.

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