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NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT **273**

MANUAL FOR THE SELECTION OF OPTIMAL MAINTENANCE LEVELS OF SERVICE

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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MANUAL FOR THE SELECTION OF OPTIMAL MAINTENANCE LEVELS OF SERVICE

RAM B. KULKARNI and CECIL J. VAN TIL
Woodward-Clyde Consultants
San Francisco, California

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(HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and enginees. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation officials, or the Federal Highway Administration, U.S. Department of Transportation.

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FOREWORD

By Staff
Transportation Research Board

This manual will be of interest to chief administrative officers concerned with highway budgets and maintenance managers who must establish a myriad of maintenance levels of service within budget constraints. It is organized to be readily understandable and usable by maintenance managers responsible for maintenance management systems. The manual will also be of interest to researchers who are developing maintenance performance relationships inasmuch as such relationships can be incorporated into the manual.

A given road or system of roads provides varying levels of service to the road user. Maintenance levels of service have an influence on the magnitude of the maintenance effort (e.g., pavement patching, mowing, paint striping) and, therefore, on work scheduling requirements, work priorities, and resource allocations. The selection of maintenance levels of service is influenced by a number of considerations that include safety, rideability, economics, environmental impact, protection of investment, and aesthetics. To optimize the expenditure of maintenance resources, there was a need to develop a systematic and objective method to establish maintenance levels of service for all maintenance elements of the highway (such as pavement surface, shoulder, vegetation, signs, structures, drainage ditches). Such a method, based on decision analysis theory, was successfully developed and tested in Phase I of NCHRP Project 14-5. The method was demonstrated in two states for pavement edge drop-off and vegetation control and is reported in *NCHRP Report 223.*

Although the development of the method was completed in Phase I, it was recognized that a need existed for a tested, self-sufficient user's manual to instruct maintenance personnel on the implementation of the method. Such a user's manual, one that could be easily understood by users having a limited knowledge of mathematical or analytical procedures, was produced in Phase II.

The manual not only provides step-by-step instructions, but it also presents a simpler method compared to that reported in *NCHRP Report 223* without sacrifice of accuracy. It is of use to determine optimum maintenance levels of service, given resource constraints of labor, material, and equipment. It can accommodate mandated levels of service and will optimize those remaining levels of service. It is of particular value in answering "what if" type questions concerning increasing or decreasing budgets. Furthermore, the material provided in the manual enables the user to defend maintenance budgets under scrutiny of legislators and to involve such persons in the budget preparation process.

The manual has been successfully tested in three state highway maintenance departments having operational maintenance management systems. Implementation of the methodology is estimated by those departments to require 4 to 18 man-months, depending on staff familiarization with the methodology and the sophistication of the state's maintenance management system. The manual is not recommended to be used by states without a maintenance management system inasmuch as data from such a system will be required.

The three states that have tested the manual were able to implement the method with little or no assistance from the research agency. Two states commented on its usefulness as follows. Arizona commented, "The Manual is a logical next step in technology in development and enhancement of highway maintenance management 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 commented, "I feel that New Jersey should benefit from using ASOP [the method]. This is especially true when attempting to show the effect of budget cuts on level of service." These states and Virginia have successfully implemented the manual for a portion of their maintenance budget using existing personnel. It is believed that the simplified method presented in this report is ready for application.

CONTENTS

ACKNOWLEDGMENTS

The research reported herein was conducted under NCHRP Project 14-5(2) by Woodward-Clyde Consultants. Dr. Ram B. Kulkarni was the principal investigator. The other author of the report was Cecil J. Van Til. Mr. Fred Finn provided valuable inputs to the preparation of the manual. He and Travis Smith reviewed a draft version of the manual and made useful suggestions to improve its clarity. Mr. Ezio Alviti made significant improvements in the computer program. Mr. Jim Rafidi made computer runs for the illustrative example. The following state agency personnel were involved in testing the user manual: Messrs. George Way and Benjamine Ong (Arizona), David Mahone and Philip Harris (Virginia), and John Dunn and Richard Balgowan (New Jersey).

MANUAL FOR THE SELECTION OF OPTIMAL MAINTENANCE LEVELS OF SERVICE

SUMMARY

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, based on their experience. In the research conducted under 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. This report contains a user manual that was developed to provide detailed instructions for highway agency personnel in the application of the methodology to their specific highway system.

The manual is organized to be self-sufficient; i.e., no outside assistance from persons experienced in the formal methodology will be necessary. It is also intended that the manual be comprehensive; i.e., the instructions cover all of the steps necessary to implement the methodology within a highway agency. A series of 12 well-defined steps is presented in the manual. Each step consists of a description of how the step is to be completed, a statement of what is intended to be accomplished as a result of completion of the step, and completion of the step in the form of an illustrative example. Appropriate forms have been designed for recording the information obtained in each step. A complete set of blank forms is provided in an appendix. Forms completed for the illustrative example are included in each step.

A draft of the user manual was initially tested in Arizona and Virginia. The manual was revised to reflect the review comments received from the personnel from these States. The revised manual was then tested in New Jersey. The methodology was successfully implemented and the computer program was executed by the New Jersey Department of Transportation personnel without any outside assistance. Only minor editorial revisions were suggested by the agency personnel. The revised final user manual, contained in this report, appears to satisfy the criteria of being comprehensive and self-sufficient.

All three State agencies involved in the testing program (Arizona, Virginia, and New Jersey) have indicated that the agency should benefit by using the methodology, especially when attempting to show the effects of budget cuts on levels of service, and to provide an objective and defensible basis for making decisions of maintenance levels of service for different components of a highway system.

A major achievement of this study was the simplified and yet theoretically sound procedure for value assessments. The previous procedure required assessments of tradeoffs between different pairs of attributes. Experience showed that such assessments would be extremely complicated and could not be made by an agency without outside assistance. The simplified procedure has greatly facilitated the assessment of necessary

value judgments. The agencies involved in the testing program were able to implement this procedure without difficulty.

The value assessment procedure provides a formal mechanism for inviting the participation of different impacted groups (highway managers, engineers, legislators, and lay persons) in establishing the relative importance of various factors that affect the selection of maintenance levels of service. This process can be beneficial in improving the public acceptability of an agency's decisions on what levels of service should be maintained for different parts of a highway system.

Two major constraints on the use of the methodology are: (1) a working maintenance management system should be available, and (2) the total number of alternative levels of service for all maintenance conditions combined should not exceed 100. Neither of these constraints should pose any particular problem to most transportation agencies. Some form of a maintenance management system has been implemented by many state departments of transportation in the United States. Access to a maintenance management system is particularly important for estimating resource requirements for alternative levels of service. The constraint on the maximum number of levels of service should not be very restrictive. For most agencies, 25 to 30 different maintenance conditions should be adequate for representing 80 to 90 percent of the complete maintenance program. Assuming an average of three alternative levels of service for each maintenance condition, the total number of levels of service should fall well below the limit of 100.

CHAPTER ONE

INTRODUCTION

The selection of levels of service (maintenance level of service is defined for purposes of this manual as a "threshold deficiency level of maintenance condition that should trigger an appropriate maintenance activity, as for example, 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) for maintenance of the various elements of a highway (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, based on their experience. In the research conducted under NCHRP Report 223, a more formal methodology was developed to assist in decisions regarding optimum maintenance levels of service for those highway elements that are subject to the constraints of available money and manpower. To facilitate the use of this methodology, it was coded in the form of a computer program ASOP (*A*lgorithm for the *S*election of *O*ptimum *P*olicy).

The result of the analysis performed by the program is presented as the "selected policy" for the given resource restraints. The selected policy is in the form of a list of a specific level of service for each maintenance CONDITION. An option is available to enter two or more resource levels, in order to evaluate the sensitivity of levels of service to changes in level of available resources.

The objective of this manual is to provide detailed instructions for highway agency personnel in the application of the methodology to their specific highway system. The instructions are directed to experienced maintenance engineers. No previous experience in this methodology is needed; however, assistance from computer data processing personnel familiar with FORTRAN will be required.

It is intended that this manual be self-sufficient, i.e., that no outside assistance from persons experienced in the methodology will be necessary. It is also intended that this manual be comprehensive, i.e., that the instructions cover all of the steps necessary to implement the methodology within a highway agency.

ORGANIZATION OF THE MANUAL

This manual consists of a series of 12 well-defined steps (Ch. Two through Ch. Thirteen) with each step consisting of a description of how the step is to be completed, a statement of what is intended to be accomplished as a result of completion of the step, and completion of the step in the form of an illustrative example. Appropriate forms have been designed for recording the information obtained in each step. A complete set of blank forms is contained in Appendix C. Forms completed for the illustrative example are included in each step, where applicable.

For Steps 1 through 5, the example develops tabular information representative of the maintenance operations of an entire highway system. For subsequent steps, the example focuses on one maintenance ELEMENT only. This was done both for clarity in explanation and because of the great volume of fictitious data which would have to be developed if an entire highway system were used throughout.

Following the 12 steps are three appendixes that are intended for reference use by computer personnel. Appendix A is a description of program control options, Appendix B contains the detailed output for the example problem, and Appendix C contains blank forms for recording information obtained in each step. For ready reference, a pull-out page of definitions of key terms is provided as the last page of this manual.

USING THE MANUAL

The following general approach is suggested for use of this manual in implementing the methodology by a highway agency maintenance department:

1. Organize the effort as a special project and assign complete responsibility for implementation to a principal investigator who has had broad experience in the agency's maintenance activities, willingness to accept new and innovative concepts, and an interest in completing implementation of the system within the highway agency. Either a knowledge of computer data processing and familiarity with FORTRAN, or assistance from a person with such knowledge and familiarity, will be necessary.
2. After a thorough study of this manual, the principal investigator should prepare a work plan, including particularly the selection and assignment of appropriate personnel to participate in the necessary group assessments and in assembling of available data from files and records.
3. Once the assignments have been made and the personnel notified, it is suggested that a group meeting of assigned personnel be held to explain the overall system and its purpose, the role of the various assigned personnel, and a tentative time schedule. Consideration should be given to holding additional group meetings during the course of the work to discuss progress and problems.
4. The principal investigator then proceeds with the implementation in a step-by-step manner as presented in this manual. It is suggested that Steps 2 through 6 be completed one ELEMENT at a time. This will allow for iterating on these steps and finalizing the necessary information for each ELEMENT before moving to the next one. Steps 7 through 12 will require considering all ELEMENTS at the same time.
5. After the initial testing is completed, it is expected that the computer program will be run once every year for the resources available for the following year. Only Steps 10 through 12 will have to be repeated. However, it is suggested that the entire methodology be repeated periodically, for example, every 5 years or so in order to account for any changes in user preferences.

CHAPTER TWO

STEP ONE—PREPARE A LIST OF MAINTENANCE ELEMENTS

DESCRIPTION

In this first step, the entire highway system is divided into a limited number of physical categories referred to as maintenance ELEMENTS. As an example, the following 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.
8. Snow and Ice Control.

It is recommended that these eight ELEMENTS be used without modifications in all but a few exceptional cases. Although each of these ELEMENTS could readily be subdivided into two or more ELEMENTS (e.g. number 3 could be two separate ELEMENTS, "shoulders" and "approaches"), this is not recommended. The system does not require such additional detail, and introducing a greater number of ELEMENTS complicates the system by requiring more evaluation. Exceptional cases in which an ELEMENT might be deleted from this list might be, for example, delete number 2 if an agency had no portland cement concrete pavement in its system, or delete number 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.

RESULT

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 presented earlier in this chapter.

CHAPTER THREE

STEP TWO—PREPARE A LIST OF CONSIDERATIONS AND ASSIGN CONSIDERATIONS TO ELEMENTS

DESCRIPTION

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. Following are examples of CONSIDERATIONS that might be applicable:

1. Safety.
2. Riding Comfort.
2. Preservation of Investment.
4. Aesthetics.
5. User cost.
6. User Convenience.

CONSIDERATIONS are the factors that are used to evaluate the performance of a maintenance ELEMENT in terms of its ability to serve the highway user. 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," "drainage," "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." The six CONSIDERATIONS listed 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 rather than as user-related CONSIDERATIONS, and are accounted for in a subsequent optimization part of the model.

To complete this step, one or more of the CONSIDERATIONS are assigned to each maintenance ELEMENT which are to be used in evaluating it. For example, if the CONSIDERATIONS listed above 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 1a.

If the list of ELEMENTS in Step 1 and the CONSIDERATIONS listed above adequately represent, without change, the highway agency's system, the assignment shown in this table might also be adequate. Note that only those few CONSIDERATIONS which play a major part in its evaluation are assigned to an ELEMENT. For example, although "aesthetics" might have some part in evaluating other ELEMENTS, it is assigned only to the ELEMENT "roadside," where it plays a dominant role. Similarly, the CONSIDERATION "safety" has not been assigned to the ELEMENT "roadside" because its role is not considered to be a dominant one for this ELEMENT. Further, in exceptional cases a CONSIDERATION listed here may not be appropriate for a particular highway agency. For example, note that the CONSIDERATION "user convenience" is appropriate for the ELEMENT "roadside" only if rest areas are provided and maintained by the highway agency.

Following assignment of all CONSIDERATIONS to the appropriate ELEMENTS, they should be tabulated in a form similar to Columns 1 and 2 in Table 1a.

RESULT

The result of completion of Step 2 is the assignment of CONSIDERATIONS to ELEMENTS and completion of the first two columns of a table similar to the example in Table 1a.

Table 1a. 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				

CHAPTER FOUR

STEP THREE—SELECT AN ATTRIBUTE FOR EACH CONSIDERATION

DESCRIPTION

In this step, one and only one 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 "percent change in frequency of accidents." This example, and examples of ATTRIBUTES that might be selected for other CONSIDERATIONS are presented in Column 3 of Table 1b, opposite the examples of CONSIDERATIONS presented in Column 2 of this table.

An ATTRIBUTE is a numerical scale for measuring the effects of alternate levels of service on a given CONSIDERATION. There are two general types of ATTRIBUTES to consider—natural and constructed. A natural ATTRIBUTE is one whose levels are physically measurable. For example, for the CONSIDERATION "safety," a natural ATTRIBUTE may be "percent change in frequency of accidents" relative to the ELEMENTS "traveled way, flexible," and "traveled way, rigid"; or may be "percent of drivers who cannot recover after driving over edge of traveled way" relative to the ELEMENT "shoulders and approaches." These are considered to be natural ATTRIBUTES because they can be physically measured, even though, as likely in these examples, very little hard data may be available and estimates may have to be used. 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 various degrees of the effect 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 establishment of scales are presented in Step 7 (Ch. Eight).

Note that the selection of ATTRIBUTES should usually involve an iterative procedure. A preliminary list of ATTRIBUTES may be prepared from the examples presented in Table 1b, followed by meetings with appropriate specialists. For example, when selecting ATTRIBUTES related to the ELEMENT "roadside," agronomists or landscape specialists might be consulted. The objective of the meetings with specialists would be to assess:

- Whether the preliminary list of ATTRIBUTES includes all areas of concern.
- Whether the ATTRIBUTES on the preliminary list are practical, i.e., if the effects of alternate levels of service could be measured in terms of these ATTRIBUTES.
- Whether there are appropriate additions, deletions, or modifications to the preliminary list of ATTRIBUTES.

After all information resulting from the meetings of specialists has been received, the principal investigator should make the final assignment of ATTRIBUTES. Of course, after a sufficient period of trial use, the list may be modified if it appears that the operation of the program would be improved. The completed list should be tabulated in a form similar to Column 3 in Table 1b. Each ATTRIBUTE should be numbered sequentially, as shown.

Unlike the examples of ELEMENTS and CONSIDERATIONS presented in Columns 1 and 2, which should require little change, the ATTRIBUTES presented in Column 3 are presented as preliminary suggestions only.

RESULT

The result of completion of Step 3 is the selection of an ATTRIBUTE for each of the CONSIDERATIONS previously assigned to the ELEMENTS and tabulation of these ATTRIBUTES in the third column of a table similar to the example in Table 1b.

Table 1b. 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*			

STEP FOUR—SELECT CONDITIONS FOR EACH ATTRIBUTE

DESCRIPTION

In this step, at least one and no more than three maintenance CONDITIONS applicable to each of the ATTRIBUTES previously listed are 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 "percent change in 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. As a second example, for "percent of drivers who cannot recover" (which is an example ATTRIBUTE for the CONSIDERATION "safety" for the ELEMENT "shoulders and approaches"), two CONDITIONS might be "edge of traveled way drop off" and "surface deterioration of shoulders." These examples, 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 1c. Note that the same CONDITION may be appropriately used for more than one ATTRIBUTE.

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. Since 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. For example, the maintenance budget of the Ohio DOT for the fiscal year 1977 shows that the top 20 maintenance activities cover 86 percent of the total budget.

It is also important to note here that the number of maintenance CONDITIONS that are assigned to each ATTRIBUTE should be limited to three. Although the computer program can theoretically handle any number, estimating the effects of alternate levels of service (a later step) becomes extremely complicated and impractical if more than three CONDITIONS are assigned to an ATTRIBUTE.

There is a good deal of flexibility available in the selection of CONDITIONS, and those developed by one highway agency may differ considerably from those developed by another. These differences may result from many factors, such as: differences in the available maintenance data base; differences in perception by maintenance personnel of the applicability or relative importance of certain CONDITIONS; or effects of climate or environment on the relative importance of some CONDITIONS.

In selecting CONDITIONS, it is realized that there is considerable room for difference of opinion as to what items should be included. For example, "potholes" might be perceived as a CONDITION for the ATTRIBUTE "percent change in frequency of accidents" for the CONSIDERATION "safety" for the maintenance ELEMENT "traveled way, flexible." Since the number of CONDITIONS for an ATTRIBUTE is limited to three, selection of potholes would require that one of the three listed as examples in Column 4 would be deleted as having less importance than potholes. An approach that may be used to solve such a problem of priority is to establish a base item in the budget which would cover filling potholes as they appear regardless of the level of service established for the limited number of CONDITIONS selected. "Potholes" would then not appear as a CONDITION. This base budget item could also include contingency funds to provide for emergency items that must be taken care of as they occur—for example, to repair or replace a major sign or signal knocked down in an accident. Another approach that might be considered is that "potholes" are more closely related to the CONSIDERATION "riding comfort" than to "safety," in which case "potholes" might be a third CONDITION (together with the present examples of "rutting" and roughness") relative to the CONSIDERATION "riding comfort" for the ELEMENT "traveled way, flexible."

Upon 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 1c. CONDITIONS must be numbered sequentially, as shown, with a CONDITION for a given ELEMENT assigned the same number, regardless of the number of ATTRIBUTES to which it is assigned. However, if the same CONDITION appears for more than one ELEMENT, it is assigned a different number within each ELEMENT. For example, "cracking" in Table 1c is assigned number 5 for "traveled way, flexible," and number 9 for "traveled way, rigid." After thorough testing in use, assignment of a CONDITION may be changed if it is judged that a significant improvement in operation of the program would result.

RESULT

The result of completion of Step 4 is 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 1c; and numbering the CONDITIONS as shown for the examples in this table.

Table 1c. 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*		

CHAPTER SIX

STEP FIVE—ESTABLISH A PARAMETER FOR EACH CONDITION

DESCRIPTION

One and only one 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 percent of lane area affected." This example is the first item in Column 5 of Table 1d, 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 it applies. 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 it may have two items paired to make a combined definition (such as "depth of rut and percent of lane area affected" for the CONDITION "rutting"; or "width of cracks and percent 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 be considered as contributing to a better understanding of the description.

RESULT

The result of the completion of Step 5 is the establishment of a PARAMETER for defining alternate levels of service for each of the maintenance CONDITIONS previously selected and tabulation of these PARAMETERS in the appropriate position in the fifth column of a table similar to the example in Table 1d.

CHAPTER SEVEN

STEP SIX—SPECIFY ALTERNATE LEVELS OF SERVICE FOR EACH CONDITION

DESCRIPTION

In this step, numerical values of the PARAMETERS used to define alternate levels of service for the maintenance CONDITIONS are established. The number of alternative levels of service defined for each maintenance CONDITION should be between two and five. 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 @ 8″ height, full width," maintenance activity in mowing would be scheduled to be done when this condition is reached. Some general guidelines for generating appropriate alternate levels of service are:

- The description of each level of service should be definitive and nonambiguous; in other words, 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 field maintenance personnel because such measurements 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.

Table 1d. 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*	

• 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 is as follows.

First, department personnel with special knowledge regarding a given maintenance CONDITION are asked to assume that there are no constraints on resources (dollars, manpower) for this CONDITION. They are then asked the question: How would they 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 would have to be adopted. They are then asked the second question: How would they 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, since later analysis becomes increasingly more complicated as the number of alternate levels of service increases.

Methods that can be considered for specifying alternate levels of service include:

- Physical measurement.
- Appearance.
- Frequency of work.
- Quantity of work.

The physical measurement mode of specification involves a mechanized manner of measurement of a maintenance CONDITION. For example, the CONDITION "slippery surface" might be expressed in terms of the PARAMETER "skid number," and three or more levels of skid number might be used to express the alternate levels of service at which maintenance of the surface would be performed.

If appearance is used as a mode of specification of alternate levels of service, a description must be prepared to define how the component should appear at the time maintenance should be performed. For the CONDITION "blocked or damaged drainage structures," the PARAMETER might be "appearance when repair or clean-out should be done," and levels of service would consist of three or more descriptions of degree of blocking or damage to drainage structures. To supplement the descriptions, one or more illustrative photographs might be used.

In some cases, the most practical and effective manner of specification of alternate levels of service may be by statements of how frequently work is done in accordance with established procedures. For example, for the CONDITION "rest areas," the PARAMETER might be "frequency of cleaning of rest areas," and three or more levels of service would consist of three or more statements of the number of times per day or week cleaning is accomplished.

These may also be cases in which specification of levels of service may be most appropriately done in terms of quantity of work. Depending on whether the work is labor-intensive or material-intensive, either the annual number of person-hours, or the amount of material used annually may be used to specify the work quantity. As an example, consider a possible maintenance CONDITION of "undesirable growth of trees and shrubs." The PARAMETER might be "person-hours spent in cutting and removing," and three alternate levels of service might be "30 percent increase," "no change," and "30 percent decrease."

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 assumes 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.

RESULT

The result of completion of Step 6 is 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 tabulating these alternate levels of service in Column 6 of Table 1d.

To this point, it has been assumed that each level of service would apply to the entire mileage of the agency's system of highways, regardless of class. However, for some CONDITIONS, it may be desired to provide a different level of service for each of two or more classes of highways; for example, it may be desired to provide a higher level of service for Interstate highways than for other highways. This situation can be handled using one of the two approaches described as follows.

Approach 1. Using the procedures described above, three to five alternative levels of service are first established separately for each class of highway. The separate descriptions at each level of service are then combined into a single description for each level. For example, if for the CONDITIONS "grass growth" and PARAMETER "height of grass and width of mowing," the alternative level-of-service 1 (highest) selected for Interstate is "mow @ 4″ height, full width" and for all other highways is "mow @ 8″ height, full width," the designation for alternative level-of-service 1 could be "Interstate—mow @ 4″ height, full width; other highways—mow @ 8″ height, full width."

Approach 2. In the first approach, it is assumed that the current levels of service for different classes of highways are different and these levels of service are either to be improved or lowered for the entire highway system. If cross combinations such as improving the current level of service on one class of highways, but lowering it on another are to be considered, the second approach should be used. In this approach, a given CONDITION is considered to be a separate CONDITION for each class of highways, and different levels of service are established for the CONDITION as a function of the class of highways. For example, consider the CONDITION "slippery surface" and assume that skid number requirements are different for high hazard locations and all other locations. Assuming that all possible combinations of alternative levels of service for slippery surface at these two classes of locations are to be considered, two separate CONDITIONS would be established in Step 4, as follows: slippery surface at high hazard locations and slippery surface at other locations. Three to five alternate levels of service would then be established in this Step 6 separately for each CONDITION.

It should be noted that the second approach increases the number of maintenance CONDITIONS to be included in the program and hence should be used only if the first approach is considered to be inappropriate.

EXAMPLE

The ELEMENT selected as an example for completion in this and the following steps is "roadside". As shown in Table 1d, two CONSIDERATIONS were selected for this ELEMENT—"aesthetics" and "user convenience" (Col. 2). The ATTRIBUTE selected for "aesthetics" was "degree of pleasing appearance," and for "user convenience" it was "degree of cleanliness of rest areas" (Col. 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" (Col. 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 clean-up of litter and debris," and "frequency of clean-up of rest area," respectively (Col. 5).

In this 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 1e 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 1e 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."

If different alternate levels of service were selected for Interstate highways than for all other highways, four alternative levels of service for the CONDITION "grass growth," expressed in terms of its PARAMETER, "height of grass and width of mowing," might be:

1. Interstate—mow @ 4″ height, full width; other highways—mow @ 8″ height, full width.
2. Interstate—mow @ 8″ height, full width; other highways mow @ 12″ height, 30′ maximum width.
3. Interstate—mow @ 12″ height, 30′ maximum width; other highways—mow @ 18″ height, one machine pass width.
4. Interstate—mow @ 18″ height, one machine pass width; other highways—mow for safety reasons only.

Table 1e. 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

CHAPTER EIGHT

STEP SEVEN—DETERMINE EFFECTS OF ALTERNATE LEVELS OF SERVICE ON CONSIDERATIONS

DESCRIPTION

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 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 in 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 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 1e for each ELEMENT involved is used to assist in these descriptions. Review and discuss the summaries of information distributed prior to the meeting.
4. Select and complete the appropriate form, Figures C-1, C-2, or C-3 in Appendix C. (Completed forms are shown later in this step.) Figure C-1 is used if only one PARAMETER and one CONDITION are involved. Figure C-2 is used for the situation of two PARAMETERS and two CONDITIONS; and Figure C-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. Since sufficient objective data are seldom available, the specialists will have to use their judgments, 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.

RESULT

The result of the completion of Step 7 is a completed form Figures C-1, C-2, or C-3 for each CONSIDERATION under study.

The computer program has been designed so that the information from the completed form can be directly coded as input data without external calculations.

EXAMPLE

In Step 6, the ELEMENT "roadside" was selected as an example and alternate levels of service were developed for the CONDITIONS applicable to this ELEMENT and tabulated in Table 1e. To continue this example for Step 7, the effects on the CONSIDERATION "aesthetics" of the three sets of alternate levels of service applicable to the CONDITIONS "grass growth," "noxious weeds and brush," and "litter and debris," must be determined, as well as the effects on the CONSIDERATION "user convenience" of the single set of levels of service applicable to the one CONDITION "rest areas."

The first task is the development of a numerical scale for each of the ATTRIBUTES involved. Since neither of these ATTRIBUTES "degree of pleasing appearance" and "degree of cleanliness of rest areas" are natural ATTRIBUTES, i.e., one whose levels are physically measurable (as discussed in Step 3), a subjective scale or index must be constructed. Figure 2 is an example of a scale which might be constructed for the ATTRIBUTE "degree of pleasing appearance." It is assumed that the following approach was used in developing this scale:

1. A group of knowledgeable persons was assembled, and the scope and purpose of the scale explained to them.
2. The approach suggested was to first describe the most pleasing appearance which might reasonably be expected to result from maintenance of roadside by this highway agency. This resulted in the description shown for Level 1 in Figure 2.
3. It was then suggested that a description be prepared for the least pleasing appearance which might be tolerated. This resulted in a description for the lowest level of this ATTRIBUTE.
4. It was then suggested that descriptions be prepared for an appropriate number of intermediate levels of appearance between those developed for the most pleasing (Level 1) and the least pleasing. It was decided that two intermediate levels would

ELEMENT ______

CONSIDERATION ______

ATTRIBUTE ______

Level of ATTRIBUTE	Description of ATTRIBUTE Levels
1	
2	
3	
4	
5	

Figure 1. Format for describing levels of ATTRIBUTES to establish scale for CONSIDERATIONS.

ELEMENT *Roadside*

CONSIDERATION *Aesthetics*

ATTRIBUTE *Degree of Pleasing Appearance*

Level of ATTRIBUTE	Description of ATTRIBUTE Levels
1	*Neat, clean, well-kept, park-like*
2	*Less than neat, spotty areas of weed and brush growth and of tall grass, occasional bits of trash and debris*
3	*Not well-kept, significant areas of weed and brush growth and of tall grass, some accumulation of trash and debris*
4	*Unkempt, overgrown, rough, areas of significant accumulation of trash and debris*
5	

Figure 2. Example of a constructed scale for the ATTRIBUTE "Degree of Pleasing Appearance."

ELEMENT *Roadside*

CONSIDERATION *User Convenience*

ATTRIBUTE *Degree of Cleanliness of Rest Areas*

Level of ATTRIBUTE	Description of ATTRIBUTE Levels
1	*Neat, clean, well-kept, trash receptacles not full, all fixtures and drains operating properly*
2	*Floors and fixtures not always completely clean, trash receptacles sometimes full, some trash on floor, some towel dispensers may be empty*
3	*Trash receptacles sometimes overflowing and trash accumulating on floor, at times a fixture may be non-operative or a drain blocked, graffiti on walls or doors , no paper towels at times*
4	
5	

Figure 3. Example of a constructed scale for the ATTRIBUTE "Degree of Cleanliness of Rest Areas."

be appropriate. These were prepared as shown for Levels 2 and 3 in Figure 2, and the "least pleasing" description was designated as Level 4 as also shown in Figure 2.

In a similar manner, a scale was constructed for the ATTRIBUTE "degree of cleanliness of rest areas," as shown in Figure 3.

Once these ATTRIBUTE scales have been developed, the effect of the alternate levels of service on the applicable CONSIDERATIONS can proceed. In this example, the simplest case, that of only one CONDITION and its set of alternate levels of service, will be completed first. Figure C-1 presented the form applicable to this case. Figure 4 is this form completed for the

Assessors 1. ______ Date ______

2. ______ 4. ______

3. ______ 5. ______

ELEMENT *Roadside*

CONSIDERATION *User Convenience*

ATTRIBUTE *12. Degree of Cleanliness of Rest Areas*

CONDITION *16. Rest Areas*

PARAMETER *Frequency of Clean up of Rest Areas*

Level of Service (↑ Higher — Lower ↓)	Alternate Levels of Service of the CONDITION in terms of the PARAMETER: *Frequency of Clean up of Rest Areas*	Level of ATTRIBUTE: *12. Degree of Cleanliness of Rest Areas*
1	*Twice a day*	*1*
2	*Four times a week*	*2*
3	*Twice a week*	*3*
4		
5		

*Figure 4. Example of the estimate of effects of **CONDITION 14** on **ATTRIBUTE 12.***

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Assessors 1. ______ 4. ______ Date ______

2. ______ 5. ______

3. ______ ELEMENT *Roadside* CONSIDERATION *Aesthetics*

ATTRIBUTE No. *11* *Degree of Pleasing Appearance*

CONDITION No. *13* *Grass Growth*

No. *14* *Noxious Weeds and Brush*

No. *15* *Litter and Debris*

CONDITION No. 14	CONDITION No. 15	CONDITION No. 13: *1*	*2*	*3*	*4*	
1	*1*	*1*	*2.5*	*3*	*3.5*	
	2					
	3	*3*		*3.5*	*3.6*	
2	*1*	*1.5*				
	2		*2*	*3.6*		
	3				*3.7*	
3	*1*	*2*				
	2		*2.7*	*3.7*		
	3	*3*			*4*	

*Figure 5. Example of the estimate of the effects of **CONDITIONS 13, 14, and 15** on **ATTRIBUTE 11.***

example of the ATTRIBUTE "degree of cleanliness of rest areas." In this simple example, there are three alternate levels of service (Table 1e) and three levels of the ATTRIBUTE, with alternate level-of-service 1 resulting in Level 1 of the ATTRIBUTE, alternate 2 in Level 2, and alternate 3 in Level 3. This is a logical result since, with only one CONDITION involved, the number and descriptions of ATTRIBUTE levels developed would be strongly influenced by the number and descriptions of the alternate levels of service.

For the second case in this example, there are three CONDITIONS affecting the ATTRIBUTE "degree of pleasing appearance" and each CONDITION has three or four alternate levels of service (Table 1e). Figure C-3 presents the form applicable to this case. Figure 5 is this form completed for the example of the ATTRIBUTE "degree of pleasing appearance." The following outlines the approach which applies to this example case:

1. Number the column and row headings to represent the number of alternate levels of service for each of the three CONDITIONS as shown on Table 1e; i.e., (a) CONDITION 13 "Grass Growth," has four alternate levels of service, so the heads of four columns are numbered 1 through 4 (the fifth column is not used for this example); (b) CONDITION 14, "Noxious Weeds and Brush," has three alternate levels of service, so the first three major rows are numbered 1 through 3 (the lower 2 major rows are not used for this example); and (c) CONDITION 15, "Litter and Debris," also has three alternate levels of service, so each of the first three subrows of the three major rows are numbered 1 through 3, and the lower 2 subrows in these major rows are not used for this example.

2. There are now 36 blanks that represent possible combinations of levels of service ($4 \times 3 \times 3$). Each of these blanks can be filled with a number representing the level of the ATTRIBUTE which is judged to result from the combination of the three levels of service representing that blank. Fortunately, only a limited number of these blanks need be completed to make the system operative. (The theoretical minimum number is the total number of alternative levels of service for all CONDITIONS involved plus two less the number of CONDITIONS, in this case $4 + 3 + 3 + 2 - 3 = 9$. However, it is advisable as a check of consistency to have at least 2 or 3 additional, so the minimum here should be 11 or 12. In this case, 16 of the blanks were completed.) It is suggested that the process be started by completing the "corners" first, i.e., the blanks which represent combinations of high and low values of the alternate levels of service. In this example, the following sequence was used:

a. Consider the combination of alternate level-of-service 1 for all three CONDITIONS. This was judged to obviously result in the most pleasing appearance (i.e., Level 1 of the ATTRIBUTE) and the number 1 was entered in this blank.

b. Consider the combination of the lowest level of service for all three CONDITIONS; i.e., 4 for CONDITION No. 13, and 3 for CONDITIONS No. 14 and No. 15. Again, this was judged to be quite obvious in that this worst possible combination should result in the least pleasing appearance (i.e., Level 4 of the ATTRIBUTE) and the number, 4, was entered in this blank.

c. Consider the combination of the highest level of service for CONDITIONS No. 14 and 15, and the lowest for CONDITION No. 13. This was judged to be midway between ATTRIBUTE Levels 3 and 4, and 3.5 was entered here.

d. Consider the fourth "corner," which is the combination of the lowest level of service for CONDITIONS No. 14 and No. 15, and the highest for CONDITION No. 13. This was judged to result in an appearance represented by ATTRIBUTE Level 3, and 3 was entered in this blank.

e. A number of intermediate blanks are now considered. Judgments are based on the relative effects of each of the CONDITIONS on the "degree of pleasing appearance," and in the consistency of the judgments. To be consistent, the number entered must increase from top-to-bottom in each vertical column, and left-to-right in the horizontal rows, although the increase need not be in a linear manner.

CHAPTER NINE

STEP EIGHT—ESTIMATE RESOURCE NEEDS FOR EACH LEVEL OF SERVICE

DESCRIPTION

In this step, the resources required to maintain each maintenance CONDITION at each of its alternate levels of service is determined. The results of these estimates can be conveniently tabulated in the format shown in Figure C-4, Appendix C. Experienced persons in maintenance planning and operations should be involved in providing the necessary information in Figure C-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.

RESULT

The result of the completion of STEP 8 is the completion of a form such as illustrated in Figure C-4 (App. C) for each of the CONDITIONS and their levels of service developed in previous steps.

EXAMPLE

For the continuation of the example from previous steps, the annual resources required for each of the levels of service established for CONDITIONS No. 13, No. 14, No. 15 and No. 16 must be estimated. For this example, resources assumed to be available are of three types: labor, expressed as total hours; and materials and equipment, each expressed as total annual dollars. It is suggested that the estimating process be approached as follows:

1. Estimate the total annual resources (expressed in terms of the three types used in this example, or in another convenient manner) now being applied to each of the maintenance CONDITIONS used in the example. Figure 6 is a fictitious example of such an estimate. Enter these estimated apportioned resources on the form for the level of service considered to represent current practice for each CONDITION. A blank form for recording this information is provided in Figure C-5, Appendix C. The assumed estimates for current practice for the CONDITIONS used in this example (Nos. 13, 14, 15, and 16) are tabulated in Figures 7a, 7b, 7c and 7d, respectively, opposite Level 2. (For this example, it was assumed that the level of service representing current practice is Level 2 for all four of these CONDITIONS.)

2. Estimate the increased amount of resources that would be required to maintain each CONDITION at each level of service

Maintenance CONDITION	Current Level of Service	Estimated Current Annual Resource Expenditure		
		Type 1 (Labor–hours)	Type 2 (Materials–dollars)	Type 3 (Equipment–dollars)
No. 13, Grass Growth	*2*	*153,256*	*$362,242*	*$891,674*
No. 14, Noxious Weeds and Brush	*2*	*35,528*	*$355,276*	*$334,378*
No. 15, Litter and Debris	*2*	*67,664*	*$45,109*	*$180,436*
No. 16, Rest Areas	*2*	*151,875*	*$136,298*	*$292,067*
Total for ELEMENT, Roadside		*408,323*	*$898,925*	*$1,698,555*

Figure 6. Estimated current annual resource expenditure for CONDITIONS 13, 14, 15, and 16.

Maintenance CONDITION *No. 13 Grass Growth*

Alternate Levels of Service	Resources Required Annually		
	Type 1 (Labor–hours)	Type 2 (Materials–dollars)	Type 3 (Equipment–dollars)
Level 1 *Mow @ 8" height, full width*	*202,298*	*478,159*	*1,177,010*
Level 2 *Mow @ 12" height, 30' maximum width*	*153,256*	*362,242*	*891,674*
Level 3 *Mow @ 18" height, one machine pass*	*104,214*	*246,325*	*606,338*
Level 4 *Mow for safety reasons only*	*62,835*	*148,519*	*365,586*

Figure 7a. Estimates of resources required for alternate levels of service for the example maintenance CONDITION 13.

Maintenance CONDITION *No. 14 Noxious Weeds and Brush*

Alternate Levels of Service	Resources Required Annually		
	Type 1 (Labor–hours)	Type 2 (Materials–dollars)	Type 3 (Equipment–dollars)
Level 1 *Three time per year*	*54,358*	*543,572*	*511,598*
Level 2 *Once a year*	*35,528*	*355,276*	*334,378*
Level 3 *Do not apply herbicide*	*5,329*	*53,291*	*50,157*

Figure 7b. Estimates of resources required for alternate levels of service for the example maintenance CONDITION 14.

Maintenance CONDITION *No. 15 Litter and Debris*

Alternate Levels of Service	Resources Required Annually		
	Type 1 (Labor–hours)	Type 2 (Materials–dollars)	Type 3 (Equipment–dollars)
Level 1 *Once a month*	*98,789*	*65,859*	*263,437*
Level 2 *Once every three months*	*67,664*	*45,109*	*180,436*
Level 3 *Once a year*	*36,539*	*24,359*	*97,435*

Figure 7c. Estimates of resources required for alternate levels of service for the example maintenance CONDITION 15.

Maintenance CONDITION *No. 16 Rest Areas*

Alternate Levels of Service	Resources Required Annually		
	Type 1 (Labor–hours)	Type 2 (Materials–dollars)	Type 3 (Equipment–dollars)
Level 1 *Twice a dav*	*189,844*	*170,373*	*365,084*
Level 2 *Four times a week*	*151,875*	*136,298*	*292,067*
Level 3 *Twice a week*	*113,906*	*102,224*	*219,050*

Figure 7d. Estimates of resources required for alternate levels of service for the example of maintenance CONDITION 16.

higher than the current practice level, and the decrease in resources that would result from maintaining each CONDITION at the levels below the current practice level. These estimates will have to be based primarily on the judgment of persons with experience in relation to each of the maintenance CONDITIONS. To assist in making these judgments, it would be helpful for each person to have an idea as to the current percent of the available budget now being spent on all maintenance CONDITIONS. Figure 8 is a fictitious example as to how such information on budget expenditures could be tabulated for this purpose. A blank form for recording this information is provided in Figure C-6, Appendix C. A convenient approach to consider is, first to estimate the additional (or lesser) percent of person and equipment hours and of materials required for each of the other levels of service, and second, to convert these percents into total dollars or hours for each of the levels. In the example, this is done for additional Levels 1, 3, and 4 for CONDITION No. 13, and for additional Levels 1 and 3 for CONDITIONS No. 14, No. 15, and No. 16, as shown in Figures 7a, 7b, 7c, and 7d for these levels.

In preparation for the next step, it will be useful to calculate the percent of the available maintenance budget spent on each

Maintenance Condition	Approximate Percent of an "Available" Maintenance Budget Spent on The CONDITION*
Grass Growth	*4.9*
Noxious Weeds and Brush	*1.8*
Litter and Debris	*1.6*
Rest Areas	*3.4*

**Roughly based on data from Ohio DOT*

Figure 8. Example of approximate percent of an "available" maintenance budget which might be spent on each of the example CONDITIONS.

ATTRIBUTE (the term "available" is used to indicate that the budget figure used here is the total maintenance budget less such items as may be set aside as contingency for emergencies and other essential maintenance activities that are performed regardless of the levels of service selected). This is done by summing the percents of the budget spent on different CONDITIONS that affect each ATTRIBUTE. Figure 9 shows how this information is tabulated for the discussion example. A blank form for recording this information is provided in Figure C-7. For the entire system, Figure 8 would include all maintenance CONDITIONS, and Figure 9 would include all ATTRIBUTES.

ATTRIBUTE	Current Level	Maintenance CONDITIONS That Affect the ATTRIBUTE	Percent of Available Budget Spent on The CONDITION	Percent of Available Budget Spent on The ATTRIBUTE
Degree of Pleasing Appearance	*2*	*Grass Growth*	*4.9*	
		Noxious Weeds and Brush	*1.8*	
		Litter and Debris	*1.6*	
			8.3	*8.3*
Degree of Cleanliness of Rest Areas	*2*	*Rest Areas*	*3.4*	*3.4*

Figure 9. Percent of available maintenance budget which might be spent on the ATTRIBUTES in the example.

CHAPTER TEN

STEP NINE—ASSESS DESIRABILITY FOR EACH LEVEL OF EACH ATTRIBUTE

DESCRIPTION

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., 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.

Each task is described as follows.

A. *Preparation for Group Value Assessments.* In this task, the principal investigator selects a panel of individuals whose value judgments will be incorporated in the program, prepares assessment forms, and compiles background information to facilitate assessments.

In order to obtain value judgments that represent a broad spectrum of viewpoints, it will be desirable (although not necessary) to arrange for the participation of individuals with different perspectives (e.g., maintenance engineers, legislators, and highway users). Such a panel of individuals should be selected and provided with background information relative to objectives of the study, descriptions (including pictures/diagrams) of selected ATTRIBUTES and the different levels of each ATTRIBUTE. It will also be useful to provide information regarding the approximate percent of the available maintenance budget spent to maintain the current level of each ATTRIBUTE. Such information for the discussion example was shown in Figure 9, Step 8.

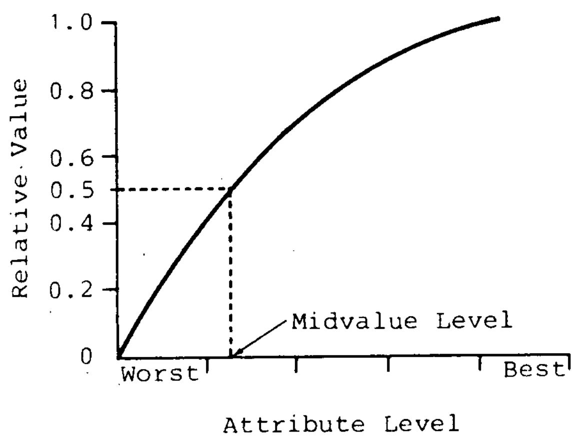
Figure C-8 shows a form that should be used to record each assessor's responses. Each assessor would be required to complete one such form for each ATTRIBUTE. The basic assessment question is: What maximum proportion of the total available maintenance budget would one be *willing* to spend in order to maintain a specified level of an attribute? The higher the proportion of the budget one would be willing to spend for a particular level of the attribute, the higher would be the relative value of that level. As indicated in Figure C-8, the assessment form should note the level of the attribute currently being maintained and the percent of the available maintenance budget spent to maintain that level.

B. *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, where appropriate, pictures/slides of actual highway conditions displaying different levels of the ATTRIBUTES should be shown. The format of the assessment forms should then be explained. It will be important to point out that the assessors should use "percent 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 as to what might be the *actual cost* of maintaining this level. "Willingness to pay" is an expression of the relative value of the results of maintaining at that level, not an estimate of the cost of doing so. Placing a very high value on a level is similar to saying, "I would be willing to pay a good deal more than the actual cost to achieve this level"; while placing a very low value would be similar to saying, "achieving this level is worth a good deal less than what the actual cost might be."

A couple of assessment forms should be completed during the group session to find out if the assessors understand the concept and to discuss any difficulties that may be faced by them. The remaining forms can be completed afterwards by each of the assessors and returned to the principal investigator within some specified time period.

C. *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. Arrange all responses regarding a given ATTRIBUTE in an ascending order on a form such as Figure C-9.
2. Find the median of all responses with regard to each level of the ATTRIBUTE. If the total number of responses, n is odd, the median is the middle value in the ordered list of responses. For example, if n is 7, the median is the 4th response. If n is even, the median is the average of the two middle values in the ordered list of responses. For example, if $n = 8$, the median is the average of the 4th and 5th responses. The median, rather than the mean, is used to represent group consensus, because the median is not much affected by extreme responses.
3. Calculate the relative value of each ATTRIBUTE level as shown in Figure C-9.
4. Plot ATTRIBUTE levels on the x-axis and the corresponding relative values as calculated in Figure C-6 on the y-axis. Pass a smooth curve through the plotted points. Find the ATTRIBUTE level corresponding to a relative value of 0.5. This is called the midvalue level of the ATTRIBUTE (see sketch below).



5. The computer program requires three levels of each ATTRIBUTE in the following order: best, midvalue, and worst. Tabulate the best, midvalue, and worst levels of each ATTRIBUTE in the format shown in Figure C-10.

The computer program also requires the relative weights of different ATTRIBUTES. The relative weight of each ATTRIBUTE is calculated as shown in Figure C-11. Basically, the relative weight of an ATTRIBUTE is proportional to the increase in the maximum proportion of the budget one would be willing to spend in order to improve the level of the ATTRIBUTE from the worst to the best. In the procedure shown in Figure C-11, the relative weights are normalized so that they sum to 1. The median values of the maximum proportion of budget identified in Figure C-9 for each ATTRIBUTE are used in Figure C-11 to obtain P_i, the increase in the maximum proportion of the budget to go from the worst to the best level for the ith ATTRIBUTE.

EXAMPLE

For the continuation of the example from previous steps, Step 9 requires first that the relative desirability of the different levels of the two ATTRIBUTES, No. 11, "degree of pleasing appearance," and No. 12, "degree of cleanliness of rest areas," be assessed. It was assumed that a group of four persons with experience in this area are asked to make the assessment. They are briefed on the system as described in this manual and on current maintenance practices within the highway agency. In addition, they are given the average percent of the available maintenance budget that has been spent on maintenance activities related to these two activities during the past 2 years. This information was recorded in Figure 9 in the previous step, as follows: for maintenance activities related to ATTRIBUTE No. 11, "degree of pleasing appearance"—8.3 percent; and to ATTRIBUTE No. 12, "degree of cleanliness of rest areas"—3.4 percent. (This is based on a hypothetical total annual available maintenance budget of $57.1 million and average annual expenditures related to grass growth, $2.78 million; to noxious weeds and brush, $1.04 million; to litter and debris, $0.90 million; and to rest areas, $1.92 million.) Each of the four persons was then asked, "What maximum percent of the total available annual maintenance budget would you be willing to spend in order to maintain each of the levels of the ATTRIBUTE?" It was pointed out that the percent of maintenance budget currently being spent on an ATTRIBUTE should be used only as background information and that this percent could be changed if the present budget allocation to the ATTRIBUTE was considered to be inappropriate. Each person was asked to record his replies on a form prepared for the purpose (Fig. C-8). The replies received from all four persons were then tabulated on a form such as Figure C-9.

The replies that are assumed to have been received regarding this example for ATTRIBUTE No. 11, "degree of pleasing appearance," are shown in Figures 10a, 10b, 10c and 10d, and summarized in Figure 10e; and regarding this example of ATTRIBUTE No. 12, "degree of cleanliness of rest areas," in Figures 11a, 11b, 11c, and 11d, and summarized in Figure 11e. Note that, for this example, it is assumed that all four assessors considered the present budget allocations to maintain the current

HIGHWAY AGENCY

Assessor 1 Date

ELEMENT Roadside

CONSIDERATION Aesthetics

ATTRIBUTE No. 11 Degree of Pleasing Appearance

Desirability	Level of Attribute	Maximum Percent of Total Available Maintenance Budget "Willing to Pay"
Least	4	3.7
	3	5.2
	2	8.3
	1	8.7
Most		

Figure 10a. Assessor 1's judgment as to the relative desirability of the levels of ***ATTRIBUTE 11.***

HIGHWAY AGENCY

Assessor 2 Date

ELEMENT Roadside

CONSIDERATION Aesthetics

ATTRIBUTE No. 11 Degree of Pleasing Appearance

Desirability	Level of Attribute	Maximum Percent of Total Available Maintenance Budget "Willing to Pay"
Least	4	4.1
	3	7.5
	2	8.3
	1	8.5
Most		

Figure 10b. Assessor 2's judgment as to the relative desirability of the levels of ***ATTRIBUTE 11.***

HIGHWAY AGENCY

Assessor 3 Date

ELEMENT Roadside

CONSIDERATION Aesthetics

ATTRIBUTE No. 11 Degree of Pleasing Appearance

Desirability	Level of Attribute	Maximum Percent of Total Available Maintenance Budget "Willing to Pay"
Least	4	5.8
	3	7.2
	2	8.3
	1	8.8
Most		

Figure 10c. Assessor 3's judgment as to the relative desirability of the levels of ***ATTRIBUTE 11.***

HIGHWAY AGENCY

Assessor 4 Date

ELEMENT Roadside

CONSIDERATION Aesthetics

ATTRIBUTE No. 11 Degree of Pleasing Appearance

Desirability	Level of Attribute	Maximum Percent of Total Available Maintenance Budget "Willing to Pay"
Least	4	3.3
	3	6.4
	2	8.3
	1	8.4
Most		

Figure 10d. Assessor 4's judgment as to the relative desirability of the levels of ***ATTRIBUTE 11.***

HIGHWAY AGENCY

Calculated by ______ Date ______
ELEMENT *Roadside*
CONSIDERATION *Aesthetics*
ATTRIBUTE (No. *11*) *Degree of Pleasing Appearance*

Desirability (Least ↑ … Most ↓)	ATTRIBUTE LEVEL *	Maximum Percent of Total Available Maintenance Budget "Willing to Pay"**						Calculated Relative Value of ATTRIBUTE Level
		Assessor 1	Assessor 2	Assessor 3	Assessor 4	Assessor 5	Median of all Assessors Responses***	
Least	Level *4*	*3.7*	*4.1*	*5.8*	*3.3*		(a) *3.9*	0
	Level *3*	*5.2*	*7.5*	*7.2*	*6.4*		(b) *6.8*	$\frac{b-a}{d-a}$ = *0.62*
	Level *2*	*8.3*	*8.3*	*8.3*	*8.3*		(c) *8.3*	$\frac{c-a}{d-a}$ = *0.94*
	Level *1*	*8.7*	*8.5*	*8.8*	*8.4*		(d) *8.6*	*1*
Most							(e)	

* As determined in Step Seven
** As recorded for each Assessor on form shown as Figure C-5
*** If n is an odd number, the median is the middle value; if n is an even number, the median is the average of the two middle values.

Figure 10e. Calculation of relative values of the different levels of ***ATTRIBUTE 11.***

HIGHWAY AGENCY

Assessor *1* Date ______

ELEMENT *Roadside*

CONSIDERATION *User Convenience*

ATTRIBUTE *No. 12 Degree of Cleanliness of Rest Areas*

Desirability (Least ↑ … Most ↓)	Level of Attribute	Maximum Percent of Total Available Maintenance Budget "Willing to Pay"
Least	*3*	*1.9*
	2	*3.4*
	1	*4.1*
Most		

Figure 11a. Assessor 1's judgment as to the relative desirability of the levels of ***ATTRIBUTE 12.***

HIGHWAY AGENCY

Assessor *2* Date ______

ELEMENT *Roadside*

CONSIDERATION *User Convenience*

ATTRIBUTE *No. 12 Degree of Cleanliness of Rest Areas*

Desirability (Least ↑ … Most ↓)	Level of Attribute	Maximum Percent of Total Available Maintenance Budget "Willing to Pay"
Least	*3*	*2.5*
	2	*3.4*
	1	*3.5*
Most		

Figure 11b. Assessor 2's judgment as to the relative desirability of the levels of ***ATTRIBUTE 12.***

HIGHWAY AGENCY

Assessor 3 Date

ELEMENT Roadside

CONSIDERATION User Convenience

ATTRIBUTE No. 12 Degree of Cleanliness of Rest Areas

Desirability (Least ↑ / Most ↓)	Level of Attribute	Maximum Percent of Total Available Maintenance Budget "Willing to Pay"
Least	3	1.0
	2	3.4
	1	6.1
Most		

*Figure 11c. Assessor 3's judgment as to the relative desirability of the levels of **ATTRIBUTE 12.***

HIGHWAY AGENCY

Assessor 4 Date

ELEMENT Roadside

CONSIDERATION User Convenience

ATTRIBUTE No. 12 Degree of Cleanliness of Rest Areas

Desirability (Least ↑ / Most ↓)	Level of Attribute	Maximum Percent of Total Available Maintenance Budget "Willing to Pay"
Least	3	2.1
	2	3.4
	1	3.7
Most		

*Figure 11d. Assessor 4's judgment as to the relative desirability of the levels of **ATTRIBUTE 12.***

HIGHWAY AGENCY

Calculated by Date

ELEMENT Roadside

CONSIDERATION User Convenience

ATTRIBUTE (No.12) Degree of Cleanliness of Rest Areas

Desirability	ATTRIBUTE LEVEL *	Maximum Percent of Total Available Maintenance Budget "Willing to Pay"**						Calculated Relative Value of ATTRIBUTE Level
		Assessor 1	Assessor 2	Assessor 3	Assessor 4	Assessor 5	Median of all Assessors Responses***	
Least	Level 3	1.9	2.5	1.0	2.1		(a) 2.0	0
	Level 2	3.4	3.4	3.4	3.4		(b) 3.4	$\frac{b-a}{c-a}$ = 0.74
	Level 1	4.1	3.5	6.1	3.7		(c) 3.9	1
							(d)	
Most							(e)	

* As determined in Step Seven

** As recorded for each Assessor on form shown as Figure C-5

*** If n is an odd number, the median is the middle value; if n is an even number, the median is the average of the two middle values.

*Figure 11e. Calculation of relative values of the different levels of **ATTRIBUTE 12.***

levels of the two ATTRIBUTES to be appropriate. However, for a real application, the present budget allocations could be changed by the assessors.

After summarizing the results of the group judgments (Figs. 10e and 11e), these same forms are used to arrive at a median value for each ATTRIBUTE level and to calculate the relative values of the levels. This is done as previously described in this step and as demonstrated in the last two columns of Figures 10e and 11e.

As previously described and illustrated, the midvalue level of each ATTRIBUTE must now be determined. Figure 12a illustrates how this is done for ATTRIBUTE No. 11 and Figure 12b for ATTRIBUTE No. 12. As indicated, the midvalue level of ATTRIBUTE No. 11 is 3.3, and of ATTRIBUTE No. 12 is 2.4. The computer program requires the best, midvalue, and worst levels of each of the ATTRIBUTES. As these are determined, it is convenient to tabulate them in the format illustrated by Figure C-10. Figure 13 illustrates how the results from ATTRIBUTE Nos. 11 and 12, used in this example, are tabulated.

To complete this step of the example, the relative weight of each of the ATTRIBUTES for the entire highway maintenance system must be determined. The form for tabulating and calculating these relative weights was shown in Figure C-11. The entry in Column 2 of this table is obtained by reference to previous calculations of relative values of the different levels of the ATTRIBUTE. For instance, for ATTRIBUTE No. 11, this value is obtained from the next to the last column of Figure 10e by subtracting the median value for the worst level (3.9) from the median value for the best level (8.6) to equal 4.7. This number is tabulated in Column 2 of Figure 14 as P_{11}. In the same manner from Figure 11e, the value for P_{12} is 3.9 − 2.0 = 1.9. The remainder of the values in Column 2 of Figure 14 are purely fictitious numbers entered for purposes of completing this example calculation. They should not be used in any way as indicators of reasonable values for these ATTRIBUTES in a real situation.

The relative weights of each of the ATTRIBUTES for this example are calculated in Column 3 of Figure 14, as shown. Each of the P values in Column 2 is divided by the sum of all the P values to obtain the values shown in Column 3. As a numerical check of these calculations, the values of all the items in Column 3 are added. This sum should be equal to one.

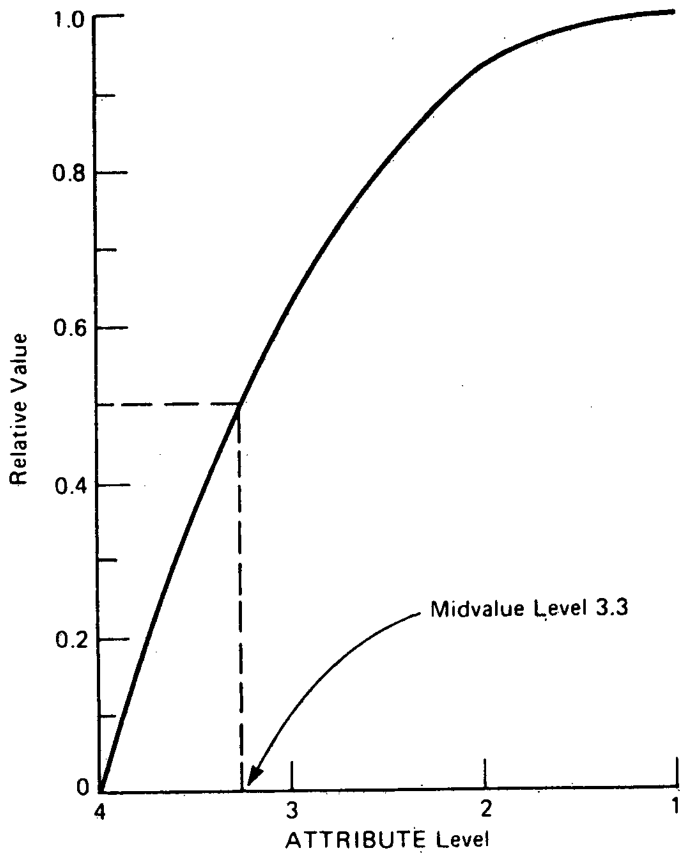


Figure 12a. Determination of midvalue level for ATTRIBUTE 11.

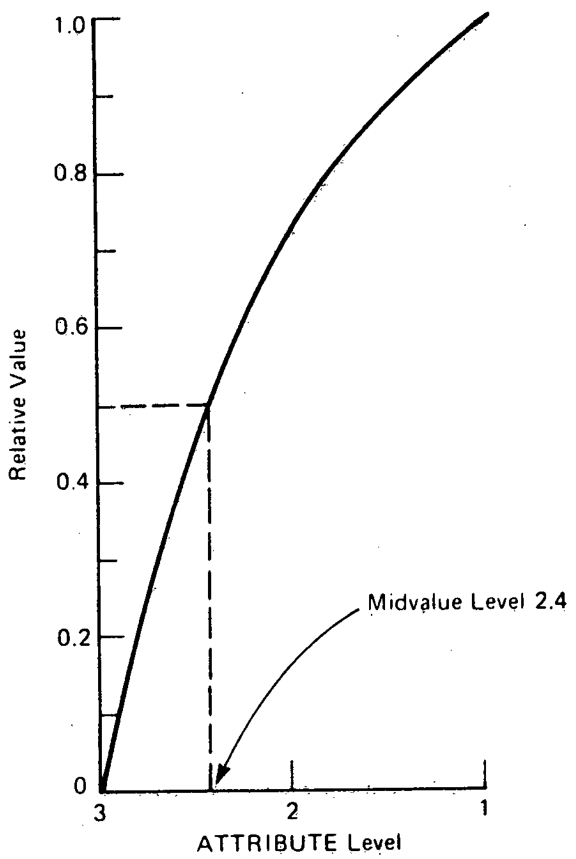


Figure 12b. Determination of midvalue level for ATTRIBUTE 12.

ATTRIBUTE	No.	ATTRIBUTE Levels		
		Best	Midvalue	Worst
......				
......				
Degree of Pleasing Appearance	*11*	*1*	*3.3*	*4*
Degree of Cleanliness of Rest Area	*12*	*1*	*2.4*	*3*
......				

Figure 13. Tabulation of best, midvalue, and worst levels of ALL ATTRIBUTES.

HIGHWAY AGENCY

Calculated by ________________ Date ________

ATTRIBUTE Number	Increase in the Maximum Percent of Total Available Budget to go from the Least to the Most Desirable Level	Relative Weight of the ATTRIBUTE
1	P_1 = *2.60*	P_1/P = *0.0504*
2	P_2 = *1.10*	P_2/P = *0.0213*
3	P_3 = *1.33*	P_3/P = *0.0258*
4	P_4 = *0.91*	P_4/P = *0.0176*
5	P_5 = *2.17*	P_5/P = *0.0421*
6	P_6 = *0.91*	P_6/P = *0.0176*
7	P_7 = *1.10*	P_7/P = *0.0213*
8	P_8 = *0.76*	P_8/P = *0.0147*
9	P_9 = *4.19*	P_9/P = *0.0812*
10	P_{10} = *1.95*	P_{10}/P = *0.0378*
11	P_{11} = *4.70*	P_{11}/P = *0.0911*
12	P_{12} = *1.90*	P_{12}/P = *0.0368*
13	P_{13} = *0.94*	P_{13}/P = *0.0182*
14	P_{14} = *2.12*	P_{14}/P = *0.0411*
15	P_{15} = *5.42*	P_{15}/P = *0.1050*
16	P_{16} = *3.97*	P_{16}/P = *0.0769*
17	P_{17} = *1.84*	P_{17}/P = *0.0357*
18	P_{18} = *7.02*	P_{18}/P = *0.1360*
19	P_{19} = *6.68*	P_{19}/P = *0.1294*
	$P = \Sigma P_i$ = *51.61*	$\Sigma P_i/P$ = 1.0

Figure 14. Calculation of relative values of all example ATTRIBUTES as listed in Table 1d.

CHAPTER ELEVEN

STEP TEN—ORGANIZE AND INPUT DATA FOR COMPUTER PROGRAM

DESCRIPTION

All of the basic data necessary to run the computer program ASOP are obtained in Steps 1 through 9. In this step, the procedure for placing these data on computer cards and running the Base Case and Sensitivity analyses are described. This step requires a reasonable familiarity with computer operations and a knowledge of FORTRAN.

The format of this step is a FORTRAN statement that specifies how the information will be input. The letters A, F, I, and X refer to alphanumeric, floating point (real), integer, and blank fields, respectively. The integer field should be right justified, i.e., the last digit should be rightmost in the field. Floating point fields are required to use a decimal point. An alphanumeric field can be any combination of characters and numbers.

A summary of all input data cards is shown in Figure 15. The input data cards for the illustrative example are shown in Figure 16. The program checks for common errors in organizing input data. A description of error diagnostics to identify possible sources of error is contained in Appendix A.

	DESCRIPTION OF DATA	NO. OF CARDS	ITEMS ON EACH CARD	FORMAT	CARD GROUP NUMBER
	Problem Identification	1	TITLE	20A4	1
	Problem Size Specification	1	NXEL, NRC	2I5	2
	Resource Availability	NRC	RSTR, BM	10A4, F40.0	3
Repeat NXEL times	Maintenance Element and Number of Maintenance Conditions	1	ESTR, NXCO	10A4, I5	4.1
Repeat NXCO times	Maintenance Conditions and Number of Alternative Levels-of-Service	1	MSTR, KIJ	10A4, I5	4.2
Repeat KIJ times	Description of Alternative Levels-of-Service	1	XSTR	20A4	4.3
	Resource Requirements of Alternative Levels-of-Service	1	RCOST(1), RCOST(2), ...	8F10.0	4.4
Repeat NXEL times	Number of Considerations for Each Maintenance Element	1	ESTR, NXCO	10A4, I5	5.1
	Description of Considerations and Attributes	NXCO	CSTR, TSTR	20A4	5.2
	Program Control Option	1	IOI	I10	6
	Best, Midvalue and Worst Levels of i^{th} Attribute	NMC	THET (I, J,), J = 1, 3	3F10.0	7
	Relative Weights of Attributes	1+	ALI(1), ALI(2), ...	8F10.3	8
Repeat NMC times	Description of an Attribute	1	DESC	20A4	9.1
	Maintenance Conditions Which Affect a Given Attribute	1	NCON, MCON(I), I = 1, NCON	I1, 4X, 9I5	9.2
	Number of Assessments of Effects on a Given Attribute	1	NAS	I3	9.3
	Specification of Assessments	NAS	ISUB(1), ISUB(2), ..., ASMNT	5(I1, 1X), F10.0	9.4
	Option Number for Parametric Analysis	1	IANAL	I10	10.1
	Inputs for Desired Options	← See detailed instructions →			10.2
	Last Card	1	IANAL (set to zero)	I10	11

Figure 15. A summary of input data cards.

```
NCHRP 14-5 (2)    EXAMPLE PROBLEM
```
Card 1: Problem Identification

```
     1      3
```
Card 2: Problem Size Specification

```
LABOR IN HOURS                                      408323.
MATERIALS IN DOLLARS                                898925.
EQUIPMENT IN DOLLARS                                1698535.
```
Card Group 3: Resource Availability

```
ROADSIDE                                                  4
GRASS GROWTH                                              4
MOW AT 8 IN. HEIGHT, FULL WIDTH
202298.    478159.    1177010.
MOW AT 12 IN. HEIGHT, 30 FT. MAX WIDTH
153256.    362242.    891674.
MOW AT 18 IN. HT, ONE MACHINE PASS WIDTH
104214.    246325.    606338.
MOW FOR SAFETY REASONS ONLY
62835.     148519.    365586.
NOXIOUS WEEDS AND BRUSH                                   3
THREE TIMES PER YEAR
54358.     543572.    511598.
ONCE A YEAR
35523.     355276.    334378.
DO NOT APPLY HERBICIDE
5329.      53291.     50157.
LITTER AND DEBRIS                                         3
ONCE A MONTH
98789.     65859.     263437.
ONCE EVERY THREE MONTHS
67664.     45109.     180436.
ONCE A YEAR
36539.     24359.     97435.
REST AREAS                                                3
TWICE A DAY
189844.    170373.    365084.
FOUR TIMES A WEEK
151875.    136298.    292067.
TWICE A WEEK
113906.    102224.    219050.
```
Card Group 4: Maintenance Elements, Maintenance Conditions, Alternative Levels-of-Service, and Resource Requirements

```
ROADSIDE                                                  2
AESTHETICS                                  DEGREE OF PLEASING APPEARANCE
USER CONVENIENCE                            DEGREE OF CLEANLINESS AT REST AREAS
```
Card Group 5: Considerations and Attributes

```
          10
           0
```
Card Group 6: Program Control Option

```
1.        3.3        4.
1.        2.4        3.
```
Card Group 7: Best, Mid-value, and Worst Levels of Each Attribute

```
.7143     .2857
```
Card Group 8: Relative Weights of Various Attributes

```
DEGREE OF PLEASING APPEARANCE
3         1     2     3
 16
1 1 1     1.
2 1 1     2.5
3 1 1     3.
4 1 1     3.5
1 1 3     3.
3 1 3     3.5
4 1 3     3.6
1 2 1     1.5
2 2 2     2.
3 2 2     3.6
4 2 3     3.7
1 3 1     2.
2 3 2     2.7
3 3 2     3.7
1 3 3     3.
4 3 3     4.
DEGREE OF CLEANLINESS AT REST AREAS
1         4
  3
1          1.
2          2.
3          3.
```
Card Group 9: Effects of Alternative Levels-of-Service on Attributes

```
 1
 3
 1 347075.
 2 764086.
 3 1443772.
 5
 2
 1 .6333
 2 .3667
10
 1
 3
 1 469571.
 2 1033764.
 3 1953338.
10
```
Card Group 10: Sensitivity Analysis Options

```
 0
```
Card Group 11: End of Input Data Card

Figure 16. Input data cards for the illustrative example.

PROCEDURE FOR PLACING DATA ON COMPUTER CARDS

Card 1: Problem Identification (FORMAT 20A4)

Cols. 1–80	TITLE	Title to identify the problem to be run.

Description. Any convenient title may be used for identification, provided it requires no more than 80 spaces. The title used in this example is "NCHRP 14-5(2) Example Problem."

Card 2: Problem Size Specification (FORMAT 2I5)

Cols. 1–5	NXEL	Number of maintenance ELEMENTS

Description. In a real situation, this number would be obtained from Column 1 of Table 1d and the number of ELEMENTS entered here would be 8. However, time constraints did not permit fabrication of fictitious data for all ELEMENTS and this example continues with the ELEMENT "roadside" only, so the number of ELEMENTS entered here is 1.

Cols. 6–10	NRC	Number of resource constraints

Description. This number is obtained from Figure 6. There are three types of resources considered here, so the number for this example is 3. This number would remain the same, regardless of the number of ELEMENTS.

Card Group 3: Resource Availability Data (FORMAT 10A4, F40.0)

Cols. 1–40	RSTR	Name of resource
Cols. 41–80	BM	Amount of resource available

Description. This group contains one card for each resource. Since there are three resources in this example (see note for Card 2), three cards are used. The names of the resources are obtained from Figure 6 and each of the three resource names are entered on its separate card in Cols. 1–40 (i.e., Labor—hours; Materials—dollars; and Equipment—dollars, respectively).

The amount of resource available for each named resource would be the total amount available for all ELEMENTS being considered. If the entire system as presented in Table 1d were to be used here, the total available resources for all 8 ELEMENTS would be used. Since this example can consider the ELEMENT Roadside only, the resource totals are found in Figure 6 and the number entered in the card for Labor—hours is 408323; for the card Materials—dollars, it is 898925; and for the card Equipment—dollars, it is 1698555.

Card Group 4: Maintenance Elements, Maintenance Conditions, Alternative Levels-of-Service and Resource Requirements

Description. This group of cards contains NXEL (number of maintenance ELEMENTS) subgroups. Each subgroup specifies data for a given maintenance ELEMENT in the order described below. All cards for the ELEMENT must be completed before moving on to the next ELEMENT.

Card 4.1: FORMAT (10A4,I5)

Cols. 1–40	ESTR	Description of a maintenance ELEMENT

The description of all maintenance ELEMENTS (i.e., their names) are obtained from Column 1 in Table 1d. For this example (or for any use of only part of the list of ELEMENTS), only those ELEMENTS to be used in the example are entered. Since this example permits the use of the one ELEMENT only, only one card is used, with the number 1 and the description "Roadside" entered in the indicated columns.

Cols. 41–45	NXCO	Number of maintenance CONDITIONS for this maintenance ELEMENT

Again, if all 8 ELEMENTS of the entire system were to be used, the number of CONDITIONS in Column 4 of Table 1d opposite each of these ELEMENTS would be entered here. CONDITIONS which appear more than once for an ELEMENT would be counted only once. For example, the number of CONDITIONS for the ELEMENT "Traveled Way, Flexible" would be 5 (not 10). Since this example permits the use of the ELEMENT Roadside only, the number of CONDITIONS to be entered on the card for this ELEMENT is 4 (i.e., Nos. 13, 14, 15, and 16).

Cards 4.2, 4.3, and 4.4 should be repeated for each maintenance CONDITION applicable for the given maintenance ELEMENT.

Card 4.2: FORMAT (10A4,I5)

Cols. 1–40	MSTR	Description of a maintenance CONDITION

The description (i.e, the name) of each maintenance CONDITION for the given maintenance ELEMENT from Column 4 of Table 1d would be entered on its separate card if the entire system represented by this table were to be used. Since this example is limited to the one ELEMENT Roadside, one card is completed for each of the four applicable CONDITIONS only. It should also be noted that the requirement for numbering the CONDITIONS in order, beginning with number 1 for the first in the table, also applies to use of part of the system. Thus, the four CONDITIONS (Nos. 13, 14, 15, and 16 in Table 1e) should be renumbered and entered for this example as Nos. 1, 2, 3, and 4.

Cols. 41–45	KIJ	Number of alternative levels of service for this maintenance CONDITION

For each of the CONDITION cards completed above, enter the number of alternate levels of service applicable to that CONDITION. For this example, we must go to Column 6 of Table

1e, which has been completed for the example ELEMENT "Roadside" only. For the four CONDITION cards completed above, the number of alternate levels of service entered would be 4,3,3 and 3, respectively.

Cards 4.3 and 4.4 should be repeated for each alternative level of service for the given maintenance CONDITION.

Card 4.3: FORMAT (20A4)

Cols. 1–40	XSTR	Description of an alternative level of service

For each of the alternate levels of service, one card must be prepared with its description. For a real situation, this would mean one card for each of the alternate levels of service for the given maintenance CONDITION entered in Column 6 of a completed Table 1d. For this example, alternate levels of service have been described only for those CONDITIONS related to the one ELEMENT Roadside.

Card 4.4: FORMAT (8F10.0)

Cols. 1–10	RCOST(1)	Amount of Type 1 resource required for this level of service
Cols. 11–20	RCOST(2)	Amount of Type 2 resource required for this level of service

•
•
•

For each of the level-of-service cards prepared above, one card is prepared to show the amount of each of the types of resources required for this level of service. For this example, the necessary information is obtained from Figures 7a, 7b, 7c, and 7d. The first card would represent Level 1 of CONDITION No. 13, "Grass Growth," and require three entries (202298, 478159, and 1177010) for the three types of resource involved. There would be a separate card for each of the other levels (2, 3, and 4) of this CONDITION and a card for each of the levels of CONDITION Nos. 14, 15, and 16.

Card Group 5: Considerations and Attributes

Description. This group of cards contains NXEL (number of maintenance ELEMENTS) subgroups. Each subgroup specifies descriptions of CONSIDERATIONS and ATTRIBUTES for a given maintenance ELEMENT in the order shown below.

Card 5.1: FORMAT (10A4,I5)

Cols. 1–40	ESTR	Description of a maintenance ELEMENT

One card would be prepared for each ELEMENT in the system. As described for Card 4.1, for this example there is only one ELEMENT, Roadside, (renumbered as 1 for this example as noted for Card 4.1) and a card is prepared with this entry in the location designated.

Cols. 41–45	NXCO	Number of CONSIDERATIONS for this maintenance ELEMENT

On each of the ELEMENT cards prepared, the number of CONSIDERATIONS associated with it is entered. For this example, the number of CONSIDERATIONS associated with the ELEMENT Roadside is 2 (Aesthetics and User Convenience) and this number is entered on the card for the ELEMENT Roadside. Note that if information on the entire system in Table 1d were able to be entered, there would be 4 CONSIDERATIONS each for the ELEMENTS Traveled Way, Flexible and Traveled Way, Rigid; 2 for the ELEMENT Shoulders and Approaches, etc.

Card 5.2: FORMAT (20A4)

Cols. 1–40	CSTR	Description of a CONSIDERATION

One card is prepared for each of the CONSIDERATIONS. For this example, there are two CONSIDERATIONS and one card is prepared with the entry Aesthetics and one with User Convenience.

Cols. 41–80	TSTR	Description of an ATTRIBUTE for this CONSIDERATION

Each of the CONSIDERATIONS has one ATTRIBUTE, as shown in Column 3 of Table 1d. On each of the CONSIDERATION cards prepared, its ATTRIBUTE is entered in the location indicated. For this example, the ATTRIBUTE Degree of Pleasing Appearance is entered on the card for the CONSIDERATIONS Aesthetics and Degree of Cleanliness at Rest Areas for the CONSIDERATION User Convenience. (Although these two ATTRIBUTES are numbered as 11 and 12 in Table 1e, they should be renumbered as 1 and 2 for this example, since they are the only two ATTRIBUTES used in this example.)

Card 5.3, 5.4, . . ., repeat Card 5.2 for each CONSIDERATION for this maintenance ELEMENT.

Card 6: Program Control Options (FORMAT I10)

Description. This group of data specifies certain program control options pertinent to the optimization algorithm. All options have been assigned default values so that in typical runs information does not need to be specified. The variable IOI in the following data card should be set equal to zero to signal the use of default values.

Cols. 1–10	IOI	Program control option parameter (should be set to zero for typical runs)

Only if an operations research expert has familiarized himself with the optimization algorithm, should the default values be changed. Information necessary to use the control options and the formats of inputs required are given in Appendix A.

For this example, the entry 0 is made on this card.

Card Group 7: Best, Mid-Value and Worst Levels of Each Attribute (FORMAT 3F10.0)

Description. This group contains NMC (total number of ATTRIBUTES) cards. Each card specifies the best, midvalue and worst levels of a given ATTRIBUTE. The program internally fits a quadratic equation to the three specified points.

Cols. 1–10	THET(i,1)	Best level of ith ATTRIBUTE
Cols. 11–20	THET(i,2)	Midvalue level of ith ATTRIBUTE
Cols. 21–30	THET(i,3)	Worst level of ith ATTRIBUTE

One card is prepared for each ATTRIBUTE. For this example, we are able to use only the two associated with the ELEMENT Roadside. The best, midvalue and worst level of these two ATTRIBUTES are obtained from Figure 13. The entries 1, 3.3, and 4 are made on the card for the ATTRIBUTE Degree of Pleasing Appearance; and 1, 2.4, and 3 for the ATTRIBUTE Degree of Cleanliness at Rest Areas.

Card 8: Relative Weights of Various Attributes (FORMAT 8F10.3)

Description. This card specifies the relative weights of the different ATTRIBUTES.

Cols. 1–10	ALI(1)	Relative weight of the first ATTRIBUTE
Cols. 11–20	ALI(2)	Relative weight of the second ATTRIBUTE

•
•
•

As many as 8 ATTRIBUTES can be handled on one card. If more than 8 ATTRIBUTES are involved, use more cards as necessary until relative weights of all attributes are specified. If the entire system as illustrated by Table 1d were able to be used, three cards would be required for the 19 ATTRIBUTES shown in Column 3 (8, 8, and 3). For this example, the relative weights of the two ATTRIBUTES Nos. 11 and 12 (renumbered as 1 and 2 for this example) are required. If all ATTRIBUTES in Table 1d were to be used, the values would be obtained from the third column in Figure 14, and the values 0.0911 and 0.0368 would be entered for ATTRIBUTES 11 and 12. However, the requirement for these values is that the sum of all values is 1. This requirement must be satisfied for the ATTRIBUTES entered, so for this example, the value 0.7143 is used for the renumbered ATTRIBUTE No. 1 and 0.2857 for the renumbered ATTRIBUTE No. 2, totaling 1 and retaining their approximate values relative to each other.

Card Group 9: Effects of Alternative Levels-of-Service on Attributes

Description. The information assessed in Step 7 for each ATTRIBUTE is entered on cards as follows. Each of the Cards 9.1, 9.2, and 9.3 described below is repeated for each ATTRIBUTE.

Card 9.1: FORMAT (20A4)

Cols. 1–80	DESC	Description of the ATTRIBUTE

The description of each ATTRIBUTE is entered on a separate card in the location indicated. For this example, there are two ATTRIBUTES involved—Degree of Pleasing Appearance is entered on the first card and Degree of Cleanliness at Rest Areas on a second card (see Table 1e). (Note that these have been renumbered as 1 and 2, as explained for Card 8.)

Card 9.2: FORMAT (I1,4X,9I5)

Col. 1	NCON	Number of maintenance CONDITIONS that affects this ATTRIBUTE

A separate card is prepared for each ATTRIBUTE and the number of maintenance CONDITIONS that affect each is entered on the card. Two cards would be prepared for this example, with the number 3 for the CONDITIONS that affect ATTRIBUTE No. 11 (now No. 1) and the number 1 for the one CONDITION that affects ATTRIBUTE No. 12 (now No. 2).

Cols. 6–10	MCON(1)	Index of the first maintenance CONDITION that affects this ATTRIBUTE
Cols. 11–15	MCON(2)	Index of the second maintenance CONDITION that affects this ATTRIBUTE
•		
•		
•	MCON (NCON)	Index of the NCONth maintenance CONDITION that affects this ATTRIBUTE

On each of the ATTRIBUTE cards in which the number of maintenance CONDITIONS was entered, the index of each of these CONDITIONS is entered in the location indicated. The index would be the number assigned to the CONDITION in Column 4 of Table 1d, if the entire system were entered. For this example, the three CONDITIONS 13, 14, and 15 would be renumbered and 1, 2, and 3 would be entered on the card for the ATTRIBUTE, Degree of Pleasing Appearance, and the single CONDITION 16 would be renumbered and 4 would be entered on the card for the ATTRIBUTE Degree of Cleanliness at Rest Areas (see Table 1e, Columns 3 and 4).

Card 9.3: FORMAT (I3)

Cols. 1–3	NAS	Number of assessments completed for this ATTRIBUTE

This refers to the assessments made of the effects of each of the alternate levels of service of a CONDITION on the related ATTRIBUTE. The results of these assessments for this example are shown in Figure 4 for the effect of the three levels of service of the CONDITION Rest Areas on ATTRIBUTE No. 12, Degree of Cleanliness of Rest Areas (Table 1e); and in Figure 5 for the effect of the four levels of service of the CONDITION Grass Growth, the three levels of the CONDITION Noxious Weeds and Brush, and the three levels of the CONDITION Litter and Debris on ATTRIBUTE No. 11, Degree of Pleasing Appearance. The number of assessments is the number of the individual cells completed in Figure 4 for ATTRIBUTE No. 12 and in Figure 5 for ATTRIBUTE No. 11. Thus, for ATTRIBUTE No. 12, the number to enter is 3, i.e., there are assessment numbers entered in all three cells; and for ATTRIBUTE No. 12, the number to enter is 16, i.e., there are assessment numbers entered in 16 of the possible 36 cells in Figure 5.

Card 9.4: FORMAT (5(I1,1X),F10.0)

This card is for entry of the first assessment made for this ATTRIBUTE. The assessment is in the form of the ATTRIBUTE level as a function of a level of service of each maintenance CONDITION that affects the ATTRIBUTE. The data are entered as follows:

Col. 1	ISUB(1)	Index of the alternative level of service of the first maintenance CONDITION that affects this ATTRIBUTE
Col. 3	ISUB(3)	Index of the alternative level of service of the second maintenance CONDITION that affects this ATTRIBUTE
•		
•		
•	ISUB (NCON)	Index of the alternative level of service of the NCONth maintenance CONDITION that affects this ATTRIBUTE
Cols. 11–20	ASMNT	Assessed level of the ATTRIBUTE

Card 9.5: FORMAT (5(I1,1X), F10.0)

This card specifies the information for the second assessment made for this ATTRIBUTE using the same format as in *Card 9.4.*

•

•

•

Repeat the format of *Card 9.4* for all the assessments made for this attribute. Thus, there will be NAS (actual number of assessments) cards with the format of Card 9.4 for each ATTRIBUTE.

The term "first CONDITION" would be CONDITION No. 1 in Table 1d, if it was possible to use the entire system illustrated by this table as an example. Since this example includes only the CONDITIONS related to the ELEMENT Roadside, the "first CONDITION" is the first to be listed relative to the ELEMENT, i.e., No. 13 (renumbered No. 1 for this example), Grass Growth. The second, third, and fourth CONDITIONS for this example are those listed as 14, 15, and 16, respectively, in this table, renumbered as 2, 3, and 4 for this example.

In this series of cards, there is a separate card for each of the assessments for each of the ATTRIBUTES, i.e., a separate card for each of the completed cells in Figures 4 and 5. For example, taking the simplest case represented by Figure 4 first, there is only one CONDITION involved, so the card for the first assessment would have 1 entered for the index of the alternate level of service of the first maintenance CONDITION, and 1 for the assessed level of the ATTRIBUTE, i.e., the number entered in the first cell in Figure 4. To complete the entries related to this CONDITION, a second card (for the second assessment) would have 2 entered for the second alternate level of service and 2 for the related assessed level of the ATTRIBUTE (from the second cell), and a third card (for the third assessment) would have 3 entered for the third alternate level of service and 3 for the related assessed level of the ATTRIBUTE (from the third cell). This completes the input for this CONDITION.

The CONDITIONS represented by Figure 5 require 16 cards, because there are 16 separate assessments each represented by a completed cell in this figure. There are three CONDITIONS represented here, so each card will have three entries of index of alternative levels of service (one for each CONDITION), plus an entry for the assessed level of the ATTRIBUTE, i.e., the value entered in the cell in Figure 5 for this combination. Thus, the first card representing the upper left cell in Figure 5 would have these entries: 1 for the index of the first CONDITION (No. 13, renumbered as 1 for this example), 1 for the index of the second CONDITION (No. 14, renumbered as 2), 1 for the index of the third CONDITION (No. 15, renumbered as 3), and 1 for the assessed level of the ATTRIBUTE (the number in the cell). Continuing in an orderly manner to the next completed cell to the right, a second card would have these entries: 2 for the index of the first CONDITION, 1 for the index of the second CONDITION, 1 for the index of the third CONDITION, and 2.5 for the assessed level of the ATTRIBUTE. If cards are continued to be completed for cells in this order (left to right and top to bottom), the last (16th) card would have these entries: 4 for the index of the first CONDITION, 3 for the index of the second CONDITION, 3 for the index of the third CONDITION and 4 for the assessed level of the ATTRIBUTE.

Card Group 10: Sensitivity Analysis Options

Description. Completion of this group of cards supplies the input necessary to perform various sensitivity analyses. The user is able to vary the amount of resources available, change relative weights of ATTRIBUTES, eliminate certain levels of service from selection, produce the second best solution, or choose certain levels of service irrespective of the cost. Moreover, the user can select any number of options in the same run and

Table 2. Parametric analysis options.

Option No. (IANAL)	Description of Option
1	Change in amount of available resources
2	Specify mandatory levels-of-service for certain maintenance conditions
3	Exclude specified combination of levels-of-service from solution
4	Exclude solution last chosen - next best solution
5	Change relative weights of attributes
10	End of current group of parametric analysis

perform as many sensitivity analyses as permitted by computer time.

The first card in this group (Card 10.1 shown below) specifies a number associated with the particular option of sensitivity analysis selected by the user. Various options available for sensitivity analyses are given in Table 2. The organization of additional cards depends on the option selected and is described following Card 10.1. If multiple options are used in the same run, an additional Card 10.1 should be used to specify each option, followed by the additional cards required for that option.

Card 10.1: FORMAT (I10)

Cols. 1–10	IANAL	Option number of sensitivity analysis

Select the option desired from the list in Table 2 and enter the number of that option on this card.

Additional Cards for Option 1—Change in Amounts of Available Resources

Some or all of the available resources can be changed and the effect on the optimal solution can be determined with this option. If it is desired to use this option, complete a Card 10.1 with the entry 1. For this example, it was desired to use this option and such a card is prepared.

Card 10.2: FORMAT (I10)

Cols. 1–10	LML	Number of resources whose available amounts would be changed

The number of resources used for the basic example was three and the total amount of each type of resource available for this example is the total for the example ELEMENT Roadside as shown in Figure 6. For this sensitivity analysis example, it is assumed that changes would be made in all three resources, so the number 3 is entered on this card.

Card 10.3: FORMAT (I10, F10.0)

Cols. 1–10	I	Index of the resource whose available amount is to be changed
Cols. 11–20	V	New available amount of this resource

Repeat Card 10.3 for each of the resources whose available amounts are to be changed. Thus, there will be LML cards of this type.

For this example, it is assumed that the effect of reduction of the total of each of the types of resource available (Figure 6) by 15 percent is desired to be investigated. Thus, three cards would be prepared, one for each of the resource types and its new amount. Entries for the first card would be 1 for the index of the Type 1 resource and 347075 for the new available amount of this resource, a reduction of 15 percent in the current total available labor hours of 408,323. Entries for the second card would be 2 for the index of the Type 2 resource, and 764086 for the new available amount of this resource, a reduction of 15 percent in the current $898,925. Entries for the third card would be 3 for the index of Type 3 resource and 1443772 for the new available amount of this resource, a reduction of 15 percent in the current $1,698,555.

Additional Cards for Option 2—Specify Mandatory Levels of Service for Certain Maintenance CONDITIONS

This option is used to require that for certain maintenance

CONDITIONS, the levels of service specified by the user should be forced in the optimal solution. Note that if this option is used, a Card 10.1 should be completed with the entry 2. For this example, it was not desired to use this option and no such card was prepared.

Card 10.2: FORMAT (I10)

Cols. 1–10	LML	Number of maintenance CONDITIONS for which mandatory levels of service are specified

Card 10.3: FORMAT (2I5)

Cols. 1–5	J	Index of maintenance CONDITION
Cols. 6–10	K	Index of the alternative level of service for this maintenance CONDITION which is to be considered mandatory

Repeat Card 10.3 for each of the maintenance CONDITIONS for which mandatory levels of service are specified. Thus, there will be LML cards of this type.

Additional Cards for Option 3—Exclude a Specified Level of Service from the Solution

This option is used to exclude a specified level of service for a given maintenance CONDITION from the optimal solution. For example, because of a policy change, a particular level of service may be considered to be unacceptable and hence would be excluded from the set of recommended levels of service. If levels of service for more than one maintenance CONDITION are specified for exclusion, the program would not include all the levels of service in the final solution, although a subset of the levels of service may be included in the solution.

Note that if this option is used, a Card 10.1 should be completed with the entry 3. For this example, it was not desired to use this option and no such card was prepared.

Card 10.2: FORMAT (I10)

Cols. 1–10	LML	Number of maintenance CONDITIONS for which specified levels of service are to be excluded

Card 10.3: FORMAT (2I5)

Cols. 1–5	J	Index of maintenance CONDITION
Cols. 6–10	K	Index of the alternative levels of service for this maintenance CONDITION which is to be excluded

Repeat Card 10.3 for each of the maintenance CONDITIONS for which mandatory levels of service are specified. Thus, there will be LML cards of this type.

Additional Cards for Option 4—Exclude Solution Last Chosen

This option allows the user to find the second best solution to a problem. No additional cards (besides Card 10.1) are required for this option. Note that if this option is used, a Card 10.1 should be completed with the entry 4. For this example, it was not desired to use this option and no such card was prepared.

Additional Cards for Option 5—Change Relative Weights of ATTRIBUTES

The relative weights of different ATTRIBUTES can be changed with this option and the effect on the recommended levels of service can be determined. Note that the sum of all relative weights should always equal one. This option can be useful in analyzing differences of opinions regarding the maximum proportion of budget that should be spent on improving different ATTRIBUTES.

Card 10.2: FORMAT (I10)

Cols. 1–10	LML	Number of ATTRIBUTES whose relative weights are to be changed

Card 10.3: FORMAT (I10,F10.0)

Cols. 1–10	I	Index of the ATTRIBUTE whose relative weight is to be changed
Cols. 11–20	V	New relative weight of this ATTRIBUTE

Repeat Card 10.3 for each of the ATTRIBUTES whose relative weights are to be changed. Thus, there will be LML cards of this type.

Note that if this option is used, a Card 10.1 should be completed with the entry 5. For this example, it was desired to use this option and such a card was prepared. Because only two ATTRIBUTES are included in this example and the total of all relative weights must equal one, relative weights of both must be changed—one increased and the other decreased. Thus, the entry for the first card is 2. The initial relative weights are given in Figure 14 for ATTRIBUTE Nos. 11 and 12. For this example, it is assumed that the relative weight of No. 11 would be reduced to 0.0810 and of No. 12 increased to 0.0469. Because only two ATTRIBUTES are involved in this example, these are renumbered as 1 and 2, and the weights are normalized to 0.633 and 0.367 so that they sum to 1. Thus, a first Card 10.3 would be prepared with the entry 1 for the index of the ATTRIBUTE whose relative weight is to be changed and 0.633 for the new relative weight of this ATTRIBUTE. The second Card 10.3 would have the entry 2 for the index of the other ATTRIBUTE whose relative weight is to be changed and 0.367 for the new relative weight of this ATTRIBUTE.

Additional Cards for Option 10—End of Current Group of Sensitivity Analyses

Any number of sensitivity analyses can be performed simultaneously. The resources available and the relative weights can be changed and any level of service can be excluded or included at the same time. This is done by choosing the desired options from Table 2 and providing a Card 10.1 and additional cards as required for each option. After data for all desired options are specified, the user should provide a card with IANAL = 10 with a FORMAT (I10):

Cols. 1–10	IANAL	Option number that should be set to 10 to indicate the end of current group of sensitivity analyses. For this example, such a card with entry 10 is prepared here following the cards for the selected option 5.

The user can specify multiple groups of sensitivity analyses in the same run by using IANAL = 10 between each group of sensitivity analysis input data. Note that for any group of sensitivity analysis, changes are to be made from the values used in the preceding group of sensitivity analyses.

For this example, it was desired to run option 1 a second time with increases of 15 percent in the total amount of each type of resource available (Figure 6) rather than the 15 percent decrease used previously. This is done by completing another Card 10.1 with the entry 1, followed by a new set of three cards, one for each of the three resource types (see discussion regarding input for the additional cards for option 1 above). Entries for the first card would be 1 for the index of the Type 1 resource and 469571 for the new available amount of this resource, an increase of 15 percent in the current total available labor hours of 408,323. Entries for the second card would be 2 for the index of the Type 2 resource and 1033764 for the new available amount of this resource, an increase of 15 percent in the current $898,925. Entries for the third card would be 3 for the index of the Type 3 resource and 1953338 for the new available amount of this resource, an increase of 15 percent in the current $1,698,555.

It is decided that no further sensitivity analysis options are desired, so the end of the series of analyses is indicated by completing a card with IANAL = 10 with a FORMAT(I10).

Card 11: End of Input Data Card (FORMAT I10)

This should always be the last card in a data check.

Cols. 1–10	IANAL	This should be set equal to 0 to indicate the end of input data. This completes the example input and this last card is prepared with the input of 0.

CHAPTER TWELVE

STEP ELEVEN—RUN COMPUTER PROGRAM AND PRINT OUT RESULTS OF ANALYSIS

Step 10 described the procedure for placing the data developed for the program on computer cards and running the Base Case and Sensitivity analyses. Also in Step 10, specific data were developed for an example problem related to one of the example ELEMENTS, "roadside." In Step 11, the computer program is run with the example problem data and the output of the computer run is described in terms of the output from this example problem. Two printout options are available:

1. The brief output, consisting of a summary of the most important input data and the results of the base case analyses and of any sensitivity analysis options which were selected.
2. The detailed output, consisting of the brief output plus additional analytical details which may be useful to operations research personnel.

The brief output option is printed unless the detailed output is specifically selected. For Step 11, the following presents the brief output for the example problem, together with explanatory comments. The detailed output option for the example problem is presented in Appendix B. References to input are made by CARD or CARD GROUP number as given in Step 10.

```
***** ***** ***** ***** ***** ***** ***** ***** ***** *****
NCHRP 14-5 (2) EXAMPLE PROBLEM
***** ***** ***** ***** ***** ***** ***** ***** ***** *****
```

This is a printout of the title of the problem which was input on Card 1.

RESOURCES AVAILABLE FOR ALLOCATION

NAME OF RESOURCE	AMOUNT AVAILABLE
RESOURCE NUMBER 1 LABOR IN HOURS	408323.000
RESOURCE NUMBER 2 MATERIALS IN DOLLARS	898925.000
RESOURCE NUMBER 3 EQUIPMENT IN DOLLARS	1698555.000

This is a printout of the types of resources and the amount available for each which were input on CARD GROUP 3.

ALTERNATIVE LEVELS-OF-SERVICE AND THEIR COSTS FOR MAINTENANCE CONDITIONS OF GIVEN MAINTENANCE ELEMENTS

1 MAINTENANCE ELEMENT—ROADSIDE

1 MAINTENANCE CONDITION—GRASS GROWTH

ALTERNATIVE LEVEL NUMBER 1

MOW AT 8 IN. HEIGHT, FULL WIDTH	
LABOR IN HOURS	202298.000
MATERIALS IN DOLLARS	478159.000
EQUIPMENT IN DOLLARS	1177010.000

ALTERNATIVE LEVEL NUMBER 2

MOW AT 12 IN. HEIGHT, 30 FT. MAX WIDTH	
LABOR IN HOURS	153256.000
MATERIALS IN DOLLARS	362242.000
EQUIPMENT IN DOLLARS	891674.000

ALTERNATIVE LEVEL NUMBER 3

MOW AT 18 IN. HEIGHT, ONE MACHINE PASS WIDTH	
LABOR IN HOURS	104214.000
MATERIALS IN DOLLARS	246325.000
EQUIPMENT IN DOLLARS	606338.000

ALTERNATIVE LEVEL NUMBER 4

MOW FOR SAFETY REASONS ONLY	
LABOR IN HOURS	62835.000
MATERIALS IN DOLLARS	148519.000
EQUIPMENT IN DOLLARS	365586.000

2 MAINTENANCE CONDITION—NOXIOUS WEEDS AND BRUSH

ALTERNATIVE LEVEL NUMBER 1

THREE TIMES PER YEAR	
LABOR IN HOURS	54358.000
MATERIALS IN DOLLARS	543572.000
EQUIPMENT IN DOLLARS	511598.000

ALTERNATIVE LEVEL NUMBER 2

ONCE A YEAR	
LABOR IN HOURS	35528.000
MATERIALS IN DOLLARS	355276.000
EQUIPMENT IN DOLLARS	334378.000

ALTERNATIVE LEVEL NUMBER 3

DO NOT APPLY HERBICIDE	
LABOR IN HOURS	5329.000
MATERIALS IN DOLLARS	53291.000
EQUIPMENT IN DOLLARS	50157.000

3 MAINTENANCE CONDITION—LITTER AND DEBRIS

ALTERNATIVE LEVEL NUMBER 1

ONCE A MONTH	
LABOR IN HOURS	98789.000
MATERIALS IN DOLLARS	65859.000
EQUIPMENT IN DOLLARS	263437.000

ALTERNATIVE LEVEL NUMBER 2

ONCE EVERY THREE MONTHS	
LABOR IN HOURS	67664.000
MATERIALS IN DOLLARS	45109.000
EQUIPMENT IN DOLLARS	180436.000

ALTERNATIVE LEVEL NUMBER 3

ONCE A YEAR	
LABOR IN HOURS	36539.000
MATERIALS IN DOLLARS	24359.000
EQUIPMENT IN DOLLARS	97435.000

4 MAINTENANCE CONDITION—REST AREAS

ALTERNATIVE LEVEL NUMBER 1

TWICE A DAY	
LABOR IN HOURS	189844.000
MATERIALS IN DOLLARS	170373.000
EQUIPMENT IN DOLLARS	365084.000

ALTERNATIVE LEVEL NUMBER 2

FOUR TIMES A WEEK	
LABOR IN HOURS	151875.000
MATERIALS IN DOLLARS	136298.000
EQUIPMENT IN DOLLARS	292067.000

ALTERNATIVE LEVEL NUMBER 3

TWICE A WEEK	
LABOR IN HOURS	113906.000
MATERIALS IN DOLLARS	102224.000
EQUIPMENT IN DOLLARS	219050.000

The name and number of each maintenance ELEMENT and CONDITION is printed as a heading for all alternate levels of service associated with that ELEMENT and CONDITION. Included with each alternate level of service is its number, its name, and the amount of each resource required to implement it. This is a summary of information input in Card Group 4. Note that for this example, the printout includes the one ELEMENT Roadside; the four CONDITIONS, Grass Growth, Noxious Weeds and Brush, Litter and Debris, and Rest Areas; and 4, 3, 3, and 3 levels of service for the four CONDITIONS, respectively.

THE ATTRIBUTES

1 MAINTENANCE ELEMENT—ROADSIDE

CONSIDERATIONS	ATTRIBUTES
AESTHETICS	1 DEGREE OF PLEASING APPEARANCE
USER CONVENIENCE	2 DEGREE OF CLEANLINESS OF REST AREAS

The number and name of each ATTRIBUTE is printed opposite the CONSIDERATION to which it is assigned. This is the information which was input on CARD 5.2.

ATTRIBUTE RANGE, VALUE FUNCTION COEFFICIENTS AND RELATIVE WEIGHTS

NO.	BEST	MIDPT	WORST	COEF A	COEF B	LAMBDA WTS
1	1.000	3.300	4.000	1.07291	2.68884	0.7143
2	1.000	2.400	3.000	1.19778	1.80107	0.2857

The number of each of the ATTRIBUTES which was input is printed on the first column on the left, with six columns of numbers for the ATTRIBUTES. The first three columns are printouts of the best, midpoint, and worst levels of each ATTRIBUTE (input on Card Group 7). An exponential value function of the form shown below is developed from these three points, and the next two columns contain the computed values of the coefficient "A" and the coefficient "B" in this function:

$$V(\theta_i) = A\,(1 - e^{B\theta}\,i)$$

in which $V(\theta_i)$ = value of attribute θ_i. The last column is a printout of the relative weights assigned to each ATTRIBUTE (input on Card 8).

DEGREE OF PLEASING APPEARANCE

DEGREE OF PLEASING APPEARANCE
ATTRIBUTE 1

THE 3 MAINTENANCE CONDITIONS WHICH AFFECT THIS ATTRIBUTE ARE—

1. GRASS GROWTH
2. NOXIOUS WEEDS AND BRUSH
3. LITTER AND DEBRIS

THERE ARE 16 ASSESSMENTS

CONDITION 1 LEVEL NO	CONDITION 2 LEVEL NO	CONDITION 3 LEVEL NO	ASSESSMENT
1	1	1	1.000
2	1	1	2.500
3	1	1	3.000
4	1	1	3.500
1	1	3	3.000
3	1	3	3.500
4	1	3	3.600
1	2	1	1.500
2	2	2	2.000
3	2	2	3.600
4	2	3	3.700
1	3	1	2.000
2	3	2	2.700
3	3	2	3.700
1	3	3	3.000
4	3	3	4.000

COMPARISON TABLE

ACTUAL VALUE	PREDICTED VALUE	DEVIATION
1.0000	1.6960	−0.6960
2.5000	2.1247	0.3753
3.0000	3.0495	−0.0495
3.5000	3.0778	0.4222
3.0000	2.4722	0.5278
3.5000	3.8258	−0.3258
3.6000	3.8540	−0.2540
1.5000	1.5485	−0.0485
2.0000	2.3101	−0.3101
3.6000	3.2348	0.3652
3.7000	3.7066	−0.0066
2.0000	2.0035	−0.0035
2.7000	2.7652	−0.0652
3.7000	3.6899	0.0101
3.0000	2.7798	0.2202
4.0000	4.1616	−0.1616

STD. ERROR OF ESTIMATE— 0.44243

ESTIMATES OF EFFECT COEFFICIENTS ARE—

BZERO(1) =	−0.054
B(1, 1,1) =	0.461
B(1, 1,2) =	0.318
B(1, 1,3) =	0.009
B(1, 2,1) =	0.103
B(1, 2,2) =	0.152
B(1, 3,1) =	0.259
B(1, 3,2) =	0.148

DEGREE OF CLEANLINESS OF REST AREAS

DEGREE OF CLEANLINESS AT REST AREAS
ATTRIBUTE 2

THE ONE MAINTENANCE CONDITION WHICH AFFECTS THIS ATTRIBUTE IS—

4. REST AREAS

THERE ARE 3 ASSESSMENTS

CONDITION 4 LEVEL NO	ASSESSMENT
1	1.000
2	2.000
3	3.000

ESTIMATES OF EFFECT COEFFICIENTS ARE-

B(2, 4,1) =	1.000
B(2, 4,2) =	0.500
B(2, 4,3) =	0.000

This section of the printout contains information relative to the assessment made of the effects of CONDITIONS on the ATTRIBUTES. Printed first is data that was input on Card Group 9, as follows:

a. The name of the ATTRIBUTE and the number assigned to it. In this example, the first part of this section is headed by "Degree of Pleasing Appearance, ATTRIBUTE 1" and the second part by "Degree of Cleanliness of Rest Areas, ATTRIBUTE 2."

b. The number of maintenance CONDITIONS which affect the ATTRIBUTE and a list of these CONDITIONS. For ATTRIBUTE 1 there are three CONDITIONS and the list of these three includes: 1. Grass Growth, 2. Noxious Weeds and Brush, and 3. Litter and Debris; and for ATTRIBUTE 2, there is one CONDITION listed as 4. Rest Areas.

c. The number of assessments that were made and a list of these assessments. The assessments listed should correspond to the input on Card Group 9. This example output lists 16 assessments relative to ATTRIBUTE 1 and its three CONDITIONS, and three assessments relative to ATTRIBUTE 2 and its one CONDITION.

d. A comparison table listing actual values of the assessments made in the first column, values predicted for this value by the model developed in the second column, and the deviation of the predicted value from the actual value in the third column. For ATTRIBUTE 1 this table contains 16 items corresponding to the 16 assessments made relative to this ATTRIBUTE; for ATTRIBUTE 2 this table is omitted because the assessments were simple, and there was no deviation between actual and predicted value.

e. Estimates of effect coefficients. A column of terms is listed followed by a column of corresponding nonzero coefficients *B(i,j,k)*. Index *i* refers to the maintenance ELEMENT, index *j* to the maintenance CONDITION, and index *k* to the alternate level-of-service. Thus, B(1,1,1) = 0.461 indicates that the estimate of the effects coefficient relative to ELEMENT No. 1, CONDITION No. 1, and level-of-service No. 1 is 0.461; and B(1,3,2) = 0.148 (the last item in the table) is relative to ELEMENT No. 1, CONDITION No. 3 and level-of-service No. 2. These effect coefficients are used to calculate the level of an ATTRIBUTE for given levels of service for the maintenance CONDITIONS which affect the ATTRIBUTE. The following equation is used:

ATTRIBUTE LEVEL = (worst level) + (best level − worst level) × [BZERO + Effect Coefficients for Given Levels of Service]

BASE CASE ANALYSIS

```
***** ***** ***** ***** ***** ***** ***** ***** ***** *****
NCHRP 14-5 (2) EXAMPLE PROBLEM
***** ***** ***** ***** ***** ***** ***** ***** ***** *****
```

COMPLETE ENUMERATION

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

EVALUATION OF THE ATTRIBUTES

DEGREE OF PLEASING APPEARANCE IN-
DIVIDUAL VALUE— 0.662 WEIGHTED VALUE— 0.473

DEGREE OF CLEANLINESS OF REST AREAS
INDIVIDUAL VALUE— 1.000 WEIGHTED VALUE— 0.286

THE VALUE OF THIS POLICY IS 0.7583

This section of the printout headed by "Base Case Analysis" gives the optimum policy for maintenance of those CONDITIONS included in the program. This policy is optimum in the sense that it will result in a "value" equal to or greater than any other policy, within the constraints of the available resources. The printout for a base case analysis includes the following:

a. The two words "complete enumeration" indicate that all possible policies have been checked and that the policy printed is at least as good as any other. This would always be stated here, unless one has selected one of the special options that are satisfied with a "good" policy but does not require the optimum policy.

b. The alternate levels of service selected for each of the maintenance CONDITIONS for each ELEMENT are tabulated. These are the levels at which these CONDITIONS should be maintained for optimum use of the available resources.

c. The cost of the selected policy is printed in the form of a table with the names of each type of resource in the first column, the amount of each of these types of resources that are available in the second column, and the amount of each of these types of resources that are used by the selected policy in the third column. By definition, the amount of each type of resource used must be equal to or less than the amount available.

d. The value of the selected policy is given in terms of an individual and weighted value for each ATTRIBUTE, and the value of the policy, i.e., the total of the individual weighted values. The individual values are the values from the equations developed from the information from the last column in Figures 10e and 11e for the level of the ATTRIBUTE obtained from Figures 4 and 5. The weighted values are the individual values multiplied by the appropriate relative weights of the ATTRIBUTES input in Card 8. In this example, the individual value of 0.662 would be multiplied by 0.7143 (the relative value for the ATTRIBUTE, Degree of Pleasing Appearance) to get the weighted value of 0.473; and the individual value of 1.000 would be multiplied by 0.2857 (the relative value for the ATTRIBUTE, Degree of Cleanliness of Rest Areas) to get the weighted value of 0.286. The sum of these weighted values is the value of the policy—0.758. Values are calculated on a linear scale of 0 to 1. Thus, for example, a policy with a value of 0.8 would be considered to be twice as "good" as another policy with a value of 0.4.

SENSITIVITY ANALYSIS

CASE 1

CHANGE IN AMOUNT OF RESOURCES AVAILABLE FOR ALLOCATION

LABOR IN HOURS	
PREVIOUSLY AVAILABLE—	408323.00
PRESENTLY AVAILABLE—	347075.00
MATERIALS IN DOLLARS	
PREVIOUSLY AVAILABLE—	898925.00
PRESENTLY AVAILABLE—	764086.00
EQUIPMENT IN DOLLARS	
PREVIOUSLY AVAILABLE—	1698555.00
PRESENTLY AVAILABLE—	1443772.00

CHANGES IN RELATIVE WEIGHTS

DEGREE OF PLEASING APPEARANCE
OLD WEIGHT— 0.714 NEW WEIGHT— 0.633

DEGREE OF CLEANLINESS OF REST AREAS
OLD WEIGHT— 0.286 NEW WEIGHT— 0.367

***** ***** ***** ***** ***** ***** ***** ***** ***** *****
NCHRP 14-5 (2) EXAMPLE PROBLEM
***** ***** ***** ***** ***** ***** ***** ***** ***** *****

COMPLETE ENUMERATION

THE SELECTED POLICY IS

MAINTENANCE ELEMENT—ROADSIDE

MAINTENANCE CONDITION	ALTERNATIVE SELECTED
GRASS GROWTH	= MOW AT 12 IN. HEIGHT, 30 FT. MAX WIDTH
NOXIOUS WEEDS AND BRUSH	= DO NOT APPLY HERBICIDE
LITTER AND DEBRIS	= ONCE A YEAR
REST AREAS	= FOUR TIMES A WEEK

THE COSTS OF THE SELECTED POLICY

RESOURCE	BUDGET	USED
LABOR IN HOURS	347075.00	346999.00
MATERIALS IN DOLLARS	764086.00	576190.00
EQUIPMENT IN DOLLARS	1443772.00	1331333.00

EVALUATION OF THE ATTRIBUTES

DEGREE OF PLEASING APPEARANCE
INDIVIDUAL VALUE— 0.545 WEIGHTED VALUE— 0.345

DEGREE OF CLEANLINESS OF REST AREAS
INDIVIDUAL VALUE— 0.711 WEIGHTED VALUE— 0.261

THE VALUE OF THIS POLICY IS 0.6059

For the Sensitivity Analyses, the output is similar to that for the Base Case. For Case 1, two of the inputs were changed—each of the types of available resources was reduced by 15 percent (see example input for Option 1—Change in Amounts of Available Resources—Card Group 10), and the relative weights of the ATTRIBUTES was changed (see example input for Option 5—Change in Relative Weights of ATTRIBUTES). The first section of the output is a printout of the previously available amount of resources and of the presently available amount of resources, i.e., the amount specified for this Case 1 of the Sensitivity Analysis; and a printout of the previous relative weights of the ATTRIBUTES (old weights) and of the relative weights specified for this Case 1 of the Sensitivity Analysis (new weights). The remainder of the printout is in the same form as the Base Case. Note that this Case 1 policy, with reduced available resources, has a lesser value of 0.6059 compared to 0.7583 for the Base Case.

SENSITIVITY ANALYSIS

CASE 2

CHANGE IN AMOUNT OF RESOURCES AVAILABLE FOR ALLOCATION

LABOR IN HOURS	
PREVIOUSLY AVAILABLE—	347075.00
PRESENTLY AVAILABLE—	469571.00
MATERIALS IN DOLLARS	
PREVIOUSLY AVAILABLE—	764086.00
PRESENTLY AVAILABLE—	1033764.00
EQUIPMENT IN DOLLARS	
PREVIOUSLY AVAILABLE—	1443772.00
PRESENTLY AVAILABLE—	1953338.00

***** ***** ***** ***** ***** ***** ***** ***** ***** *****

NCHRP 14-5 (2) EXAMPLE PROBLEM

***** ***** ***** ***** ***** ***** ***** ***** ***** *****

COMPLETE ENUMERATION

THE SELECTED POLICY IS

MAINTENANCE ELEMENT—ROADSIDE

MAINTENANCE CONDITION	ALTERNATIVE SELECTED
GRASS GROWTH	= MOW AT 12 IN. HEIGHT, 30 FT. MAX WIDTH
NOXIOUS WEEDS AND BRUSH	= ONCE A YEAR
LITTER AND DEBRIS	= ONCE EVERY THREE MONTHS
REST AREAS	= TWICE A DAY

THE COSTS OF THE SELECTED POLICY

RESOURCE	BUDGET	USED
LABOR IN HOURS	469571.00	446292.00
MATERIALS IN DOLLARS	1033764.00	933000.00
EQUIPMENT IN DOLLARS	1953338.00	1771572.00

EVALUATION OF THE ATTRIBUTES

DEGREE OF PLEASING APPEARANCE
INDIVIDUAL VALUE— 0.837 WEIGHTED VALUE— 0.530

DEGREE OF CLEANLINESS OF REST AREAS
INDIVIDUAL VALUE— 1.000 WEIGHTED VALUE— 0.367

THE VALUE OF THIS POLICY IS 0.8968

For Sensitivity Analysis Case 2, the input was the same as for Case 1, except that each of the three types of available resources was increased by 15 percent over that available for the Base Case. Note that the printout in the first section of this output lists the previously available resources as those in Case 1, not in the Base Case. In the same manner, no listing is made of the relative weights of ATTRIBUTES for this Case 2, because no change was made from the relative weights for Case 1. The remainder of the printout is in the same form as the Base Case and Case 1. Note that in this Case 2 policy, with greater amounts of resources available, the value of the policy is 0.8968, higher than both the Base Case and Case 1 of the Sensitivity Analysis. Because no other Sensitivity Analysis options were selected, this ends the printout.

CHAPTER THIRTEEN

STEP TWELVE—FORMULATE RECOMMENDATIONS

Step 11 described the results of the computer analysis in terms of a printout for the example problem. In Step 12, guidelines are presented for the assessment of these results and formulation of recommendations for their implementation. These guidelines are presented in terms of the three major applications of the program, as follows:

1. The most direct use of the program is in the selection of optimum levels of service for the given amounts of available resourses. The user provides the necessary input data and the program selects the levels of service for all maintenance CONDITIONS included in the system. The selected levels of service are tabulated in the printout following the heading, "The Selected Policy is." The levels of service are optimum in the sense that they maximize user benefits as measured by the releative values assigned to the ATTRIBUTES within the restraints of the available resources. The printout of the Base Case Analysis illustrates that for the data entered for the example problem, the selected policy is:

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

Before making recommendations regarding implemention of this selected policy, it is suggested that the costs of this policy in terms of resources used be compared to the resources available. Note that for the example problem, the resources available and used are printed out immediately following the selected policy under the heading "The Costs of the Selected Policy." In this example, there are three types of resources and the program does not permit any of these types of resources to exceed that listed as available. Thus, it is possible that the amount of resources available may be unbalanced as to type compared to those used by the selected policy. For example, in the Base Case Analysis printout, the labor hours type of resource appears to govern the selection because the available hours are closer to being used than are the dollars for both materials and equipment. (There are 21,327 unused labor hours, and unused dollars are $158,898 for materials and $370,070 for equipment, a total of $528,968.) If it were practical to convert some of the materials and equipment funds to additional labor hours, the program could be rerun with this change in the proportion of resource type to determine whether the selected policy would be affected. After this check for balance of types of resources has been made, the recommendations formulated could reflect the alternatives of implementing the selected policy on available resources, or of changing the proportion of resources and implementing the new selected policy.

2. A second application of the program, closely related to the first, is the assessment of the effects of changes in the maintenance budget on the levels of service. With the sensitivity analysis option described in previous steps, the user can determine the optimum levels of service for different sets of available resources in one run of the program. Of particular interest are those situations (such as appreciable reductions in the maintenance budget) which would result in significantly lower levels of service. This is useful information to communicate to those responsible for approving maintenance budgets, since any adverse effects of budget cuts can be identified explicitly. This can be illustrated by comparison of the selected policies for the example sensitivity analysis Case 1 and Case 2. The selected policies were as follows:

	Alternative Selected	
Maintenance CONDITION	Case 1	Case 2
Grass Growth	12 in. ht, 30′ max width	12 in. ht, 30′ max width
Noxious Weeds & Brush	Do not apply herbicide	Once a year
Litter and Debris	Once a year	Once every 3 mos
Rest Areas	Four times a week	Twice a day

As discussed in Step 11, the inputs for these two cases are identical except that the available resource for Case 2 is appreciably greater than for Case 1. This application of the problem can give the necessary background for formulation of recommendations regarding the level of maintenance budget required to maintain the desired levels of service.

3. The program may also be used to evaluate the significance of differences of opinion of the evaluators regarding the relative weights assigned to the ATTRIBUTES. The relative weights assigned to the ATTRIBUTES are an important input to the program. Since they are established by the pooling of opinions of the assessors assigned, there may be differences of opinion. It is important to discover how significant these differences are in terms of their effect on the selection of optimum policy. Their significance can be evaluated by running the program with different sets of relative weights of ATTRIBUTES, and comparing the resulting selected policies. If little change in the optimum levels of service results from the changes in relative weights, the differences in opinion may be ignored as of little conse-

quence. However, a significant change in the optimum levels of service would indicate that additional effort should be expended in the resolution of the differences of opinion. With the sensitivity analysis option previously described, the effects of changing relative weights of ATTRIBUTES may be assessed in one run of the computer. In the example problem, this option was selected to change the relative weights of the ATTRIBUTE Degree of Pleasing Appearance from 0.714 in the Base Case to 0.633 for Case 1 and 2; and the relative weight of the ATTRIBUTE Degree of Cleanliness of Rest Areas from 0.286 in the Base Case to 0.367 for Case 1 and 2. As a result of the use of this option, recommendations may be formulated for establishment of a set of relative weights of ATTRIBUTE which is considered to be most appropriate for use.

APPENDIX A

DESCRIPTION OF PROGRAM CONTROL OPTIONS AND CAPABILITIES

A number of program control options are provided in the computer program ASOP. The primary objective of these options is to enable the user to increase the efficiency of the program and thus reduce the computation time. All the options have been assigned default values so that for routine runs of the program, it would not be necessary for a maintenance engineer to specify values for any of the options. Proper use of most of the options would require some knowledge of the optimization algorithm.

The various options with the variable name, index, and default value of each option are shown in Table A-1. The format required to specify any particular option is as shown below.

FORMAT (2I10,F10.0)

Cols. 1-10	IOI	The number associated with the desired program control option
Cols. 11-20	IOV	Integer option parameter field; this field is used to set an integer-valued parameter to a value other than its default value

Cols. 21-30	ROV	Real option parameter field; this field is used to set a real-valued parameter to a value other than its default value

This format should be used for each option parameter that is to be set to a value other than its default value. The appropriate field -- real or integer -- should contain the optional value of the parameter.

Some of the options require additional data input cards. These are explained in the description of the program control options which follows. The last card in the group of program control options cards must always be the one shown below.

FORMAT (I10)

Cols. 1-10	IOI	This should be set equal to zero.

Option 1: Initial Value

Program control option 1 sets the real variable RNIT to ROV. The optimization algorithm considers RNIT to be a lower bound to the solution of the maximization problem. If no solution better than RNIT can be found, the program reports that no feasible solution better than RNIT could be found. The purpose of this option is to save run time by allowing the branch-and-bound algorithm to not search branches which would not yield a solution better than RNIT. Note that RNIT should be low enough so that solutions to the base case and to all the sensitivity analysis cases can be found if they exist.

Option 2: K in Test 2

Program control option 6 sets RKAY to ROV. Test 2 is the bounding procedure of the optimization algorithm. The bound of a partial solution is the maximum possible value any completion of this partial solution could have without regard to feasibility. Let VALUE be the value of the current best solution. Test 2 compares the bound of a partial solution with VALUE x RMUL + RKAY. If the bound is less than this computed value, then the branch is cut, meaning that no solutions along this branch are examined. The variable RMUL is set by control option 3. The hope was that by setting RKAY and RMUL to some appropriate values, the efficiency of the algorithm would be improved. This does not appear to be the case, so that the user should simply use the default values.

Option 3: Multiplier in Test 2

Program control option 3 sets the real variable RMUL to ROV. Refer to control option 2 for a discussion of this option.

Option 4: CPU Time Limit

Control option 4 sets the real variable STOPT to ROV. The user can limit the CPU time available to program ASOP to STOPT. This option is available on systems which allow a Fortran program to access the CPU time via a subroutine call. At the time of this printing, this feature has been implemented on CDC and PRIME computers. The user need only "uncomment" a few lines in subroutine MMONE between line 143 and line 175. Instructions are present in the code. A user can examine this code and modify the two references to the CPU time routine available on his computer system. The program is shipped with this option disabled, since it cannot be implemented on all systems. The effect of this option differs from using a CPU time limit at the system level. When the value of STOPT is exceeded, a report is generated identifying the best solution found thus far by the program. (Using a system CPU time limit would cut off the program, but no report would be generated.) The value of STOPT applies to the toal time required by the Base Case and any sensitivity analysis cases. The CPU time limit specified at the system level must exceed STOPT by a few seconds, so that a report can be generated. An alternative manner of limiting the effort expended by program ASOP is to use control option 6.

Option 5: Feasibility Tolerance

Program control option 5 sets the real variable FTOL to ROV. The program uses single precision variables throughout its computation. To avoid having a solution considered infeasible when it should be exactly feasible, the internal optimization algorithm multiplies the resource limits by 1 + FTOL. Certain critical values are recomputed from scratch every 500 iterations to help control error propagation.

Option 6: Maximum Iterations

Control option 6 sets the integer variable MAXIT to IOV. The user can limit the number of major iterations between intermediate solutions to MAXIT iterations. See the description of control option 7 for an explanation of intermediate solution. With most problems, the number of iterations between successive intermediate solutions increases sharply as you approach the optimal solutions. The program reports the best solution it has located before exceeding MAXIT. Note that program ASOP will proceed to the next sensitivity analysis case if one exists.

Option 7: Starting Solution

Program control option 7 sets the logical variable KBS to TRUE if IOV > 0. The optimization algorithm scans the solution

space using implicit enumeration. The variables are first ranked using the criteria prescribed by control options 8 and 9. This ranking determines the order in which a variable is added to the solution. The highest ranked available variable is added to the solution until a variable has been selected for each maintenance CONDITION. This is called a complete solution. A solution where a variable has not been selected for each maintenance CONDITION is called a partial solution. If control option 10 has been set to long print, then each successively better complete solution found by the algorithm is printed out as a vector of values identifying the variable selected for each maintenance CONDITION. This is labeled as an intermediate solution, since it may not be the optimal solution. The value and resource usage are also shown. The algorithm successively removes and adds variables to this status vector to keep track of its implicit enumeration of the solution space. Therefore, knowledge of the ranking of the variables and of this status vector is sufficient for determining which solutions have already been scanned in the solution space. If the run time limit had been inadequate in a previous run, the user can direct the program to start at the last intermediate solution, rather than the beginning. This would save considerable computation time. The variable IOV on the option specification card should be set to the total number of elements of the status vector IPS which were printed. The text editor may then be used to copy the intermediate solution from the output file to follow the option specification card.

The format used for reading these records is the same as the format used for writing them.

FORMAT (15 I5)

Cols. 1-5	IPPS (1)	First element of starting solution
Cols. 6-10	IPPS (2)	Second element of starting solution
.		
.		
.		

When this option is used, the user must be certain that the exact same problem is being continued. This is most easily done by adding this option to the old version of the input file and re-submitting the run. If a sensitivity analysis case is being continued, the solutions to the base case and to any previous sensitivity analysis cases in this run should be discarded since the starting solution option affects every case being run. The sensitivity analysis cases which follow the case being continued should be removed from this run. The starting solution option cannot be used to continue a sensitivity analysis case which uses sensitivity analysis option 4. If the user does not wish to use the long print option as a standard practice, the original run can be repeated with a larger time limit.

Option 8: Ranking Option

Program control option 8 sets the logical variable IROPT to FALSE if IOV > 0. If IROPT is TRUE, then control option 9 is used to determine the ranking of the variables. If IROPT is FALSE, then the user specifies the ranking to be used by the program. The number of variables in the problem, NV, is the total number of variables across all maintenance CONDITIONS supplied by the user in the input file. The user then specifies the NV ranks on as many cards as necessary using the following format.

FORMAT (20 I4)

Cols. 1-4	INRANK (1)	Rank of first alternative of maintenance CONDITION 1
Cols. 5-8	INRANK (2)	Rank of second alternative of maintenance CONDITION 1
.		
.		
.		
Cols. ___	INRANK (NV)	Rank of last alternative of last maintenance CONDITION

The user is referered to control option 7 for a discussion of the role of ranking in the optimization algorithm.

Option 9: Method of Ranking

Control option 9 sets the integer variable MROPT to IOV. If IROPT is TRUE as determined by control option 8, then the variables are ranked by the program using one of several methods. If MROPT = 1, then the variables are ranked by benefit/cost. If MROPT = 2, then the variables are ranked by benefit. Rankings 3 through 6 perform poorly and should not be used. If the user should set MROPT to any other value, the program will produce the same results, but it will require a much longer run time since an essentially random ranking would result. See control option 7 for a discussion on how the ranking is used by the optimization algorithm.

Option 10: Print Option

Program control option 10 sets the logical variable IPRT to TRUE if IOV > 0. When IPRT is TRUE, the program wites the ranking results, starting solutions, and the intermediate solutions to the output file. The nubmer of intermediate solutions may be large for some runs. See control option 7 for the definition of an intermediate solution.

ASSESSMENT OF PROGRAM CAPABILITIES AND LIMITATIONS

The ASOP (Algorithm for the Selection of Optimal Policy) program is a portable FORTRAN implementation of a constrained multi-attribute decision analysis algorithm designed to understand resource allocation problems. To make ASOP more useful, its capabilities and limitations are discussed below.

ASOP is capable of running on different computer systems provided the system is able to compile FORTRAN IV.

ASOP is capable of solving in a reasonable time (usually less than a few minutes) problems with twenty to twenty-five maintenance conditions and three or four alternative levels-of-service per maintenance condition. ASOP is limited to problems that have less than 200 alternatives for all maintenance conditions. The number of maintenance conditions is limited to 100. The number of elements is limited to 10.

ASOP is capable of handling decision analysis problems with as many as thirty-five attributes. In the options with internal computation for the estimates of effect coefficients, the program is limited in that each attribute may not depend on more than five maintenance conditions. With external computation, ASOP does not place a limit on the number of conditions allowed to affect a maintenance attribute.

ASOP is capable of handling constrained decision analysis problems with as many as twenty different resources, each of which may be named. The number of resources plus the number of times that sensitivity analysis options 3 and 4 are used in any sensitivity analysis case must be forty or less.

The program is written so that it is possible to spend less time computing at the risk of producing a good but suboptimal solution. The program control options should be carefully studied to understand how changing the default values for options 2, 3, 4, and 6 makes this possible.

Parametric analyses are within the capabilities of the ASOP. One can change the amount of available resources, look for the next best solution, change value trade-offs, or force certain alternatives to be selected. Not only is it possible to perform more than one parametric analysis in a single computer run, but it is also possible to combine different parametric changes in each parametric run.

ERROR DIAGNOSTICS

Error checks are built into the program so that costly runs with incorrect data can be stopped. It is never possible to detect all errors although the most common errors should be detected. The error detection code is not exhaustive and the user is responsible for providing the input data in a correct

form. The diagnostic messages will often aid in detecting mistakes although missing and/or out of order data may cause diagnostic messages that seem inappropriate. A description of the error checks follows.

"ATTRIBUTE RANGE SPECIFICATIONS ARE INCORRECTLY DEFINED"

- In Card Group 7 of the input data, the program will stop if BEST > MIDVALUE > WORST or BEST < MIDVALUE < WORST is not true for all attributes. If the MIDVALUE is not in the range defined by the WORST and BEST values, something is wrong. Another common error in this group of input data occurs when the worst value is entered first instead of last. It is not possible to detect this error directly. If a lambda weight is negative, this is a likely source of the problem.

The following errors are detected in Card Group 9 of the input data. Recall that the assessment of effects on attributes are input in this group.

"_____ IS AN INVALID VALUE FOR THE NUMBER OF MAINTENANCE CONDITIONS"

- The number of conditions that affect a given attribute must be 1, 2, 3, 4 or 5.

"DUPLICATE MAINTENANCE CONDITIONS WERE SPECIFIED"

- For each attribute, MCON is a vector which denotes the different conditions which affect that attribute. It is an error if the same condition is specified twice to affect the same attribute.

"THESE MAINTENANCE CONDITIONS ARE INVALID"

- Each of the different maintenance conditions that can affect an attribute must be a possible maintenance condition.

"INSUFFICIENT NUMBER OF ASSESSMENTS. _____ ARE REQUIRED"

- An error condition exists if the number of assessments, NAS, is less than the minimum number of assessments, MINAS. The value of MINAS is determined by the number of points necessary to perform a regression while allowing two degrees of freedom. One needs to assess a point for all alternative levels of all maintenance conditions that affect an attribute plus two less the number of maintenance conditions that affect the attribute.

"AN INVALID LEVEL OR ASSESSMENT HAS BEEN SPECIFIED"

- If $(0 < \text{level identification} \leq \text{NLEV})$ is not true, then an error condition exists. One must enter an assessed value preceded by a number of different level identifications on the same record. The level identifications should refer to maintenance conditions in the same order as one specified the maintenance conditions affecting the attribute being assessed. Each identification should express an alternative level possible for the given maintenance condition. An error in the order of these level identifications is easy to make and should be carefully avoided.

"AN INVALID LEVEL OR ASSESSMENT HAS BEEN SPECIFIED"

- ASMNT must be in the range of [Θmin, Θmax] for the appropriate attribute. The assessed value should not be better than the best possible value for the attribute being assessed nor should the assessed value be worse than the worst possible value.

"LEVELS WERE NOT ASSESSED FOR THE MAINTENANCE CONDITIONS SPECIFIED"

- Each level of each maintenance condition must be represented in at least one of the NOS assessments. If this is not true, the regression routines will run incorrectly, if at all.

"THE LAST _____ ASSESSMENTS WERE DISCARDED WITHOUT SCANNING"

- Only the first 100 assessed points for each attribute are considered. If more than 100 points are input, then the points ignored may cause some of the above mentioned errors.

"THE SIMPLE CORRELATIONS MATRIX IS SINGULAR"

- A singular matrix is an error. This indicates that it was not possible to do the regression analysis. One should go over the data. It may be necessary to change the set of assessments.

TABLE A-1

PROGRAM CONTROL OPTIONS

OPTION	VARIABLE	NUMBER	DEFAULT VALUE
Initial Value	RNIT	1	-9999.0
K in Test 2	RKAY	2	0.0
Multiplier in Test 2	RMUL	3	1.0
CPU Time Limit	STOPT	4	1000000
Feasibility Tolerance	FTOL	5	5×10^{-6}
Maximum Iteration	MAXIT	6	$2^{31} - 1$
Starting Solution*	KBS	7	FALSE
Ranking*	IROPT	8	TRUE
Ranking Method	MROPT	9	2
Print	IPRT	10	FALSE

*Additional input data cards are required for these options as specified in the descriptions of the options.

APPENDIX B

DETAILED OUTPUT FOR THE EXAMPLE PROBLEM

```
   A        SSSS      OOO       PPP
  A A      S         O   O      P   P
 A   A     S         O   O      P   P
 AAAAA      SSS      O   O      PPPP
 A   A         S     O   O      P
 A   A         S     O   O      P
 A   A     SSSS       OOO       P
```

AN ALGORITHM FOR THE SELECTION OF OPTIMAL POLICY

SELECTION OF HIGHWAY MAINTENANCE LEVELS-OF-SERVICE
A COMPUTER PROGRAM
DEVELOPED UNDER CONTRACT
TO THE
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

BY

WOODWARD-CLYDE CONSULTANTS

```
****** ****** ****** ****** ****** ****** ****** ****** ****** *****
NCHRP 14-5 (2)  EXAMPLE PROBLEM
****** ****** ****** ****** ****** ****** ****** ****** ****** *****
```

RESOURCES AVAILABLE FOR ALLOCATION

NAME OF RESOURCE		AMOUNT AVAILABLE
RESOURCE NUMBER 1 LABOR IN HOURS	<=	408323.000
RESOURCE NUMBER 2 MATERIALS IN DOLLARS	<=	898925.000
RESOURCE NUMBER 3 EQUIPMENT IN DOLLARS	<=	1698566.000

ALTERNATIVE LEVELS-OF-SERVICE

AND

THEIR COSTS

FOR

MAINTENANCE CONDITIONS OF GIVEN MAINTENANCE ELEMENTS

1 MAINTENANCE ELEMENT -- ROADSIDE

1 MAINTENANCE CONDITION -- GRASS GROWTH

ALTERNATIVE LEVEL NUMBER 1

MOW AT 8 IN. HEIGHT, FULL WIDTH

LABOR IN HOURS	202298.000
MATERIALS IN DOLLARS	478159.000
EQUIPMENT IN DOLLARS	1177010.000

ALTERNATIVE LEVEL NUMBER 2

MOW AT 12 IN. HEIGHT, 30 FT. MAX WIDTH

LABOR IN HOURS	153256.000
MATERIALS IN DOLLARS	362242.000
EQUIPMENT IN DOLLARS	891674.000

ALTERNATIVE LEVEL NUMBER 3

MOW AT 18 IN. HEIGHT, ONE MACHINE PASS WIDTH

LABOR IN HOURS	104214.000
MATERIALS IN DOLLARS	246325.000
EQUIPMENT IN DOLLARS	606338.000

ALTERNATIVE LEVEL NUMBER 4

MOW FOR SAFETY REASONS ONLY

LABOR IN HOURS	62835.000
MATERIALS IN DOLLARS	148519.000
EQUIPMENT IN DOLLARS	365586.000

2 MAINTENANCE CONDITION -- NOXIOUS WEEDS AND BRUSH

ALTERNATIVE LEVEL NUMBER 1

THREE TIMES PER YEAR

LABOR IN HOURS	54356.000
MATERIALS IN DOLLARS	543572.000
EQUIPMENT IN DOLLARS	511598.000

ALTERNATIVE LEVEL NUMBER 2

ONCE A YEAR

LABOR IN HOURS	35528.000
MATERIALS IN DOLLARS	355276.000
EQUIPMENT IN DOLLARS	334378.000

ALTERNATIVE LEVEL NUMBER 3

DO NOT APPLY HERBICIDE

LABOR IN HOURS	5329.000
MATERIALS IN DOLLARS	53291.000
EQUIPMENT IN DOLLARS	50157.000

3 MAINTENANCE CONDITION -- LITTER AND DEBRIS

ALTERNATIVE LEVEL NUMBER 1

ONCE A MONTH

LABOR IN HOURS	98789.000
MATERIALS IN DOLLARS	65859.000
EQUIPMENT IN DOLLARS	263437.000

ALTERNATIVE LEVEL NUMBER 2

ONCE EVERY THREE MONTHS

LABOR IN HOURS	67664.000
MATERIALS IN DOLLARS	45109.000
EQUIPMENT IN DOLLARS	180436.000

ALTERNATIVE LEVEL NUMBER 3

ONCE A YEAR

LABOR IN HOURS	36539.000
MATERIALS IN DOLLARS	24359.000
EQUIPMENT IN DOLLARS	97435.000

4 MAINTENANCE CONDITION -- REST AREAS

ALTERNATIVE LEVEL NUMBER 1

TWICE A DAY

LABOR IN HOURS	189844.000
MATERIALS IN DOLLARS	170373.000
EQUIPMENT IN DOLLARS	365084.000

ALTERNATIVE LEVEL NUMBER 2

FOUR TIMES A WEEK

LABOR IN HOURS	151875.000
MATERIALS IN DOLLARS	136258.000
EQUIPMENT IN DOLLARS	292067.000

ALTERNATIVE LEVEL NUMBER 3

TWICE A WEEK

LABOR IN HOURS	113906.000
MATERIALS IN DOLLARS	102224.000
EQUIPMENT IN DOLLARS	219050.000

T H E   A T T R I B U T E S

1 MAINTENANCE ELEMENT -- ROADSIDE

CONSIDERATIONS	ATTRIBUTES
AESTHETICS	1 DEGREE OF PLEASING APPEARANCE
USER CONVENIENCE	2 DEGREE OF CLEANLINESS OF REST AREAS

OPTIONS USED

INITIAL VALUE SET AT-	-9999.000
K IN TEST2 IS-	0.000
MULTIPLIER IN TEST2 IS-	1.000
MAXIMUM RUN TIME-	1000000.
FEASIBILITY TOLERANCE-	0.000005
MAXIMUM ITERATIONS -	2147483647
STARTING SOLUTION OPTION-	F
RANKING OPTION-	T
METHOD OF RANKING OPTION-	2
PRINT OPTION-	T
INTERNAL COMPUTATION OPTION-	2
ARBITRARY CONSTRAINT OPTION-	0
NO SUBSTITUTION OPTION-	F

THE CONSTRAINT MATRIX

```
B (   1) =   0.40832300E+06
A (   1) =
0.202E+06 0.153E+06 0.104E+06 0.628E+05 0.544E+05 0.355E+05 0.533E+04 0.988E+05
0.677E+05 0.365E+05 0.190E+06 0.152E+06 0.114E+06

B (   2) =   0.89892500E+06
A (   2) =
0.478E+06 0.362E+06 0.246E+06 0.149E+06 0.544E+06 0.355E+06 0.533E+05 0.659E+05
0.451E+05 0.244E+05 0.170E+06 0.136E+06 0.102E+06

B (   3) =   0.16965350E+07
A (   3) =
0.118E+07 0.892E+06 0.606E+06 0.366E+06 0.512E+06 0.334E+06 0.502E+05 0.263E+06
0.180E+06 0.974E+05 0.365E+06 0.292E+06 0.219E+06
```

ATTRIBUTE RANGE, VALUE FUNCTION COEFFICIENTS AND RELATIVE WEIGHTS

NO.	BEST	MIDPT	WORST	COEF A	COEF B	LAMBDA WTS
1	1.000	3.300	4.000	1.07291	2.68864	0.7143
2	1.000	2.400	3.000	1.19778	1.80107	0.2857

DEGREE OF PLEASING APPEARANCE

DEGREE OF PLEASING APPEARANCE
ATTRIBUTE 1

THE 3 MAINTENANCE CONDITIONS WHICH AFFECT THIS ATTRIBUTE ARE -

1. GRASS GROWTH
2. NOXIOUS WEEDS AND BRUSH
3. LITTER AND DEBRIS

THERE ARE 16 ASSESSMENTS

CONDITION 1 LEVEL NO	CONDITION 2 LEVEL NO	CONDITION 3 LEVEL NO	ASSESSMENT
1	1	1	1.000
2	1	1	2.500
3	1	1	3.000
4	1	1	3.500
1	1	3	3.000
3	1	3	3.500
4	1	3	3.600
1	2	1	1.500
2	2	2	2.000
3	2	2	3.600
4	2	3	3.700
1	3	1	2.000
2	3	2	2.700
3	3	2	3.700
1	3	3	3.000
4	3	3	4.000

XY-MATRIX

1	2	3	4	5	6	7	8
1.00	0.00	0.00	1.00	0.00	1.00	0.00	1.00
0.00	1.00	0.00	1.00	0.00	1.00	0.00	0.50
0.00	0.00	1.00	1.00	0.00	1.00	0.00	0.33
0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.17
1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.33
0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.17
0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.13
1.00	0.00	0.00	0.00	1.00	1.00	0.00	0.83
0.00	1.00	0.00	0.00	1.00	0.00	1.00	0.67
0.00	0.00	1.00	0.00	1.00	0.00	1.00	0.13
0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.10
1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.67
0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.43
0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.10
1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

VARIABLE	MEAN	STANDARD DEVIATION	CORRELATION X VS. Y	REGRESSION COEF.	STD. ERROR OF REG. COEF.	COMPUTED T VALUE
1	0.3125E+00	0.4787E+00	0.6282E+00	0.4606E+00	0.1059E+00	0.4351E+01
2	0.1875E+00	0.4031E+00	0.2785E+00	0.3177E+00	0.1519E+00	0.2092E+01
3	0.2500E+00	0.4472E+00	-.3770E+00	0.9427E-02	0.1317E+00	0.7155E-01
4	0.4375E+00	0.5123E+00	0.2311E-01	0.1025E+00	0.1089E+00	0.9413E+00
5	0.2500E+00	0.4472E+00	0.1313E+00	0.1517E+00	0.1005E+00	0.1509E+01
6	0.3750E+00	0.5000E+00	0.5854E+00	0.2568E+00	0.9374E-01	0.2760E+01
7	0.2500E+00	0.4472E+00	-.7202E-01	0.1478E+00	0.1610E+00	0.9180E+00
DEPENDENT						
8	0.3667E+00	0.2932E+00				

INTERCEPT ----------------.5387E-01

MULTIPLE CORRELATION ---0.9301E+00

COMPARISON TABLE

ACTUAL VALUE	PREDICTED VALUE	DEVIATION
1.0000	1.6960	-0.6960
2.5000	2.1247	0.3753
3.0000	3.0495	-0.0495
3.5000	3.0778	0.4222
3.0000	2.4722	0.5278
3.5000	3.8258	-0.3258
3.6000	3.8540	-0.2540
1.5000	1.5485	-0.0485
2.0000	2.3101	-0.3101
3.6000	3.2348	0.3652
3.7000	3.7066	-0.0066
2.0000	2.0035	-0.0035
2.7000	2.7652	-0.0652
3.7000	3.6899	0.0101
3.0000	2.7798	0.2202
4.0000	4.1616	-0.1616

STD. ERROR OF ESTIMATE ---- 0.44243

ANALYSIS OF VARIANCE FOR THE REGRESSION

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F-VALUE
ATTRIBUTABLE TO REGRESSION	7	0.1116E+01	0.1594E+00	0.7330E+01
DEVIATION FROM REGRESSION	8	0.1740E+00	0.2175E-01	
TOTAL	15	0.1290E+01		

ESTIMATES OF EFFECT COEFFICIENTS ARE -

```
BZERO( 1)     =   -0.054
B( 1, 1,1)    =    0.461
B( 1, 1,2)    =    0.318
B( 1, 1,3)    =    0.009
B( 1, 2,1)    =    0.103
B( 1, 2,2)    =    0.152
B( 1, 3,1)    =    0.259
B( 1, 3,2)    =    0.148
```

DEGREE OF CLEANLINESS OF REST AREAS

DEGREE OF CLEANLINESS AT REST AREAS
ATTRIBUTE 2

THE ONE MAINTENANCE CONDITION WHICH AFFECTS THIS ATTRIBUTE IS -

4. REST AREAS

THERE ARE 3 ASSESSMENTS

CONDITION 4

LEVEL NO	ASSESSMENT
1	1.000
2	2.000
3	3.000

ESTIMATES OF EFFECT COEFFICIENTS ARE -

```
B( 2, 4,1) =   1.000
B( 2, 4,2) =   0.500
B( 2, 4,3) =   0.000
```

BASE CASE ANALYSIS

```
****** ****** ****** ****** ****** ****** ****** ****** ****** *****
NCHRP 14-5 (2)  EXAMPLE PROBLEM
****** ****** ****** ****** ****** ****** ****** ****** ****** *****
```

THE ADJUSTED CONSTRAINT MATRIX

```
B (   1) =   0.18971400E+06
A (   1) =
0.139E+06 0.904E+05 0.414E+05 0.000E+00 0.490E+05 0.302E+05 0.000E+00 0.622E+
0.311E+05 0.000E+00 0.759E+05 0.380E+05 0.000E+00

B (   2) =   0.57053200E+06
A (   2) =
0.330E+06 0.214E+06 0.978E+05 0.000E+00 0.490E+06 0.302E+06 0.000E+00 0.415E+
0.207E+05 0.000E+00 0.681E+05 0.341E+05 0.000E+00

B (   3) =   0.96630700E+06
A (   3) =
0.811E+06 0.526E+06 0.241E+06 0.000E+00 0.461E+06 0.284E+06 0.000E+00 0.166E+
0.830E+05 0.000E+00 0.146E+06 0.730E+05 0.000E+00
```

ADJUSTED BENEFIT COEFFICIENTS

```
BZERO( 1) =       -0.054            BENEFIT COEFFICIENTS -
  0.461   0.318   0.009   0.000   0.103   0.152   0.000   0.259   0.148   0.000
  0.000   0.000   0.000

BZERO( 2) =        0.000            BENEFIT COEFFICIENTS -
  0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
  1.000   0.500   0.000
```

THE RANKING PROCEDURE

INDEX	GROUP	RANK	VALUE	CP	COST TOTAL
1	1	5	0.5096	0.5096	1857567.0000
2	1	6	0.3893	0.3893	1407272.0000
3	1	13	-0.0973	-0.0973	956977.0000
4	1	1	-0.1195	-0.1195	577040.0000
5	2	11	0.0940	0.0940	1109628.0000
6	2	8	0.1772	0.1772	725282.0000
7	2	2	-0.1195	-0.1195	108877.0000
8	3	7	0.3246	0.3246	428185.0000
9	3	9	0.1711	0.1711	293309.0000
10	3	3	-0.1195	-0.1195	158433.0000
11	4	10	0.1662	0.1662	725401.0000
12	4	12	0.0837	0.0837	580340.0000
13	4	4	-0.1195	-0.1195	435280.0000

STARTING SOLUTION

-4 -7 -10 -13

IFREL =
F F F T F F T F F T F F T

JFIRST = 5

RESOURCE	BUDGET		USED
LABOR IN HOURS	408323.00	>	218609.00
MATERIALS IN DOLLARS	898925.00	>	328393.00
EQUIPMENT IN DOLLARS	1698535.00	>	732228.00

INTERMEDIATE SOLUTION

-4 -7 -10 -13 1 -2 -3 -8 -11 -6 -5 9 -12

RESOURCE	BUDGET		USED
LABOR IN HOURS	408323.00	>	389197.00
MATERIALS IN DOLLARS	898925.00	>	678783.00
EQUIPMENT IN DOLLARS	1698535.00	>	1626053.00

VALUE OF OBJECTIVE = 0.59385

RUN STATISTICS

INFEASIBLE	PURSUE BRANCH?	CUT BRANCH	FORCE IN VARS
0.	8.	0.	3.

BACKSTEP	MAIN CYCLES	EVALUATE LEAF	ADD VARIABLE
0.	2.	1.	7.

INTERMEDIATE SOLUTION

-4 -7 -10 -13 1 -2 -3 -8 -11 -6 -5 -9 12

RESOURCE	BUDGET		USED
LABOR IN HOURS	408323.00	>	356941.00
MATERIALS IN DOLLARS	898925.00	>	692107.00
EQUIPMENT IN DOLLARS	1698535.00	>	1616669.00

VALUE OF OBJECTIVE = 0.71256

RUN STATISTICS

INFEASIBLE	PURSUE BRANCH?	CUT BRANCH	FORCE IN VARS
0.	5.	0.	4.

BACKSTEP	MAIN CYCLES	EVALUATE LEAF	ADD VARIABLE
1.	3.	2.	8.

INTERMEDIATE SOLUTION

-4 -7 -10 -13 -1 2 -3 -5 -8 6 -11 -9 12

RESOURCE	BUDGET		USED
LABOR IN HOURS	408323.00	>	377198.00
MATERIALS IN DOLLARS	898925.00	>	678175.00
EQUIPMENT IN DOLLARS	1698555.00	>	1615554.00

VALUE OF OBJECTIVE = 0.71677

RUN STATISTICS

INFEASIBLE	PURSUE BRANCH?	CUT BRANCH	FORCE IN VARS
0.	16.	2.	11.

BACKSTEP	MAIN CYCLES	EVALUATE LEAF	ADD VARIABLE
5.	8.	4.	18.

INTERMEDIATE SOLUTION

-4 -7 -10 -13 -1 -2 8 -9 6 -5 11 -12 -3

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

VALUE OF OBJECTIVE = 0.75827

RUN STATISTICS

INFEASIBLE	PURSUE BRANCH?	CUT BRANCH	FORCE IN VARS
0.	26.	5.	18.

BACKSTEP	MAIN CYCLES	EVALUATE LEAF	ADD VARIABLE
9.	13.	6.	25.

COMPLETE ENUMERATION

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	>	386596.00
MATERIALS IN DOLLARS	898925.00	>	740027.00
EQUIPMENT IN DOLLARS	1698555.00	>	1328485.00

EVALUATION OF THE ATTRIBUTES

```
DEGREE OF PLEASING APPEARANCE
 INDIVIDUAL VALUE-     0.662              WEIGHTED VALUE-     0.47
DEGREE OF CLEANLINESS OF REST AREAS
 INDIVIDUAL VALUE-     1.000              WEIGHTED VALUE-     0.26
```

THE VALUE OF THIS POLICY IS   0.7583

THE SOLUTION IS

```
X(  1) =   4                    ORDER(  4) =  1
X(  2) =   6                    ORDER(  6) =  6
X(  3) =   8                    ORDER(  8) =  7
X(  4) =  11                    ORDER( 11) = 10
```

RUN STATISTICS

INFEASIBLE	PURSUE BRANCH?	CUT BRANCH	FORCE IN VARS
0.	32.	11.	21.
BACKSTEP	**MAIN CYCLES**	**EVALUATE LEAF**	**ADD VARIABLE**
13.	16.	6.	28.

OPTIONS USED

```
INITIAL VALUE SET AT-                     -9959.000
K IN TEST2 IS-                                0.000
MULTIPLIER IN TEST2 IS-                       1.000
MAXIMUM RUN TIME-                      1000000.
FEASIBILITY TOLERANCE-                    0.000005
MAXIMUM ITERATIONS     -             2147483647
STARTING SOLUTION OPTION-                     F
RANKING OPTION-                               T
METHOD OF RANKING OPTION-                     2
PRINT OPTION-                                 T
INTERNAL COMPUTATION OPTION-                  2
NO SUBSTITUTION OPTION-                       F
ARBITRARY CONSTRAINT OPTION-                  0
```

SENSITIVITY ANALYSIS

CASE 1

CHANGE IN AMOUNT OF RESOURCES AVAILABLE FOR ALLOCATION

```
LABOR IN HOURS
     PREVIOUSLY AVAILABLE--    408323.00
     PRESENTLY  AVAILABLE--    347075.00

MATERIALS IN DOLLARS
     PREVIOUSLY AVAILABLE--    898925.00
     PRESENTLY  AVAILABLE--    764086.00

EQUIPMENT IN DOLLARS
     PREVIOUSLY AVAILABLE--   1698555.00
     PRESENTLY  AVAILABLE--   1443772.00
```

CHANGES IN RELATIVE WEIGHTS

```
DEGREE OF PLEASING APPEARANCE
      OLD WEIGHT--      0.714    NEW WEIGHT--      0.633

DEGREE OF CLEANLINESS OF REST AREAS
      OLD WEIGHT--      0.286    NEW WEIGHT--      0.367
```

```
****** ****** ****** ****** ****** ****** ****** ****** ****** ***
NCHRP 14-5 (2)  EXAMPLE PROBLEM
****** ****** ****** ****** ****** ****** ****** ****** ****** ***
```

THE ADJUSTED CONSTRAINT MATRIX

```
B (  1) =  0.12846600E+06
A (  1) =
0.139E+06 0.904E+05 0.414E+05 0.000E+00 0.490E+05 0.302E+05 0.000E+00 0.622E+
0.311E+05 0.000E+00 0.759E+05 0.360E+05 0.000E+00

B (  2) =  0.43569300E+06
A (  2) =
0.330E+06 0.214E+06 0.978E+05 0.000E+00 0.490E+06 0.302E+06 0.000E+00 0.415E+
0.207E+05 0.000E+00 0.681E+05 0.341E+05 0.000E+00

B (  3) =  0.71154400E+06
A (  3) =
0.811E+06 0.526E+06 0.241E+06 0.000E+00 0.461E+06 0.284E+06 0.000E+00 0.166E+
0.830E+05 0.000E+00 0.146E+06 0.730E+05 0.000E+00
```

ADJUSTED BENEFIT COEFFICIENTS

```
BZERO( 1) =      -0.054          BENEFIT COEFFICIENTS -
  0.461  0.318  0.009  0.000  0.103  0.152  0.000  0.259  0.148  0.000
  0.000  0.000  0.000

BZERO( 2) =       0.000          BENEFIT COEFFICIENTS -
  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000
  1.000  0.500  0.000
```

THE RANKING PROCEDURE

INDEX	GROUP	RANK	VALUE	CP	COST TOTAL
1	1	5	0.4519	0.4519	1280627.0000
2	1	6	0.3452	0.3452	830332.0000
3	1	13	-0.0863	-0.0863	380037.0000
4	1	1	-0.1059	-0.1059	100.0000
5	2	12	0.0833	0.0833	1000851.0000
6	2	9	0.1571	0.1571	616505.0000
7	2	2	-0.1059	-0.1059	100.0000
8	3	7	0.2878	0.2878	269852.0000
9	3	11	0.1517	0.1517	134976.0000
10	3	3	-0.1059	-0.1059	100.0000
11	4	8	0.2608	0.2608	290221.0000
12	4	10	0.1548	0.1548	145160.0000
13	4	4	-0.1059	-0.1059	100.0000

STARTING SOLUTION

-4 -7 -10 -13

IFRE =
F F F T F   F T F F T   F F T

JFIRST = 5

RESOURCE	BUDGET		USED
LABOR IN HOURS	347075.00	>	218609.00
MATERIALS IN DOLLARS	764086.00	>	328393.00
EQUIPMENT IN DOLLARS	1443772.00	>	732228.00

INTERMEDIATE SOLUTION

-4 -7 -10 -13 -1 -5 2 -3 -8 -11 -6 12 -9

RESOURCE	BUDGET		USED
LABOR IN HOURS	347075.00	>	346999.00
MATERIALS IN DOLLARS	764086.00	>	576190.00
EQUIPMENT IN DOLLARS	1443772.00	>	1331333.00

VALUE OF OBJECTIVE = 0.60594

RUN STATISTICS

INFEASIBLE	PURSUE BRANCH?	CUT BRANCH	FORCE IN VARS
0.	8.	0.	3.

BACKSTEP	MAIN CYCLES	EVALUATE LEAF	ADD VARIABLE
0.	2.	1.	8.

COMPLETE ENUMERATION

THE SELECTED POLICY IS

MAINTENANCE ELEMENT - ROADSIDE

MAINTENANCE CONDITION	ALTERNATIVE SELECTED
GRASS GROWTH	= MOW AT 12 IN. HEIGHT, 30 FT. MAX WID
NOXIOUS WEEDS AND BRUSH	= DO NOT APPLY HERBICIDE
LITTER AND DEBRIS	= ONCE A YEAR
REST AREAS	= FOUR TIMES A WEEK

THE COSTS OF THE SELECTED POLICY

RESOURCE	BUDGET		USED
LABOR IN HOURS	347075.00	>	346999.00
MATERIALS IN DOLLARS	764086.00	>	576190.00
EQUIPMENT IN DOLLARS	1443772.00	>	1331333.00

EVALUATION OF THE ATTRIBUTES

DEGREE OF PLEASING APPEARANCE
INDIVIDUAL VALUE- 0.545 WEIGHTED VALUE- 0.345

DEGREE OF CLEANLINESS OF REST AREAS
INDIVIDUAL VALUE- 0.711 WEIGHTED VALUE- 0.261

THE VALUE OF THIS POLICY IS 0.6059

THE SOLUTION IS

X(1) = 2	ORDER(2) = 5
X(2) = 7	ORDER(7) = 2
X(3) = 10	ORDER(10) = 3
X(4) = 12	ORDER(12) = 10

RUN STATISTICS

INFEASIBLE	PURSUE BRANCH?	CUT BRANCH	FORCE IN VARS
0.	23.	10.	13.
BACKSTEP	MAIN CYCLES	EVALUATE LEAF	ADD VARIABLE
7.	10.	1.	19.

OPTIONS USED

INITIAL VALUE SET AT-	-9999.000
K IN TEST2 IS-	0.000
MULTIPLIER IN TEST2 IS-	1.000
MAXIMUM RUN TIME-	1000000.
FEASIBILITY TOLERANCE-	0.000005
MAXIMUM ITERATIONS -	2147483647
STARTING SOLUTION OPTION-	F
RANKING OPTION-	T
METHOD OF RANKING OPTION-	2
PRINT OPTION-	T
INTERNAL COMPUTATION OPTION-	2
NO SUBSTITUTION OPTION-	F
ARBITRARY CONSTRAINT OPTION-	F

```
                    SENSITIVITY ANALYSIS

                          CASE   2


    CHANGE IN AMOUNT OF RESOURCES AVAILABLE FOR ALLOCATION


    LABOR IN HOURS
         PREVIOUSLY AVAILABLE--     347075.00
         PRESENTLY  AVAILABLE--     469571.00

    MATERIALS IN DOLLARS
         PREVIOUSLY AVAILABLE--     764086.00
         PRESENTLY  AVAILABLE--    1033764.00

    EQUIPMENT IN DOLLARS
         PREVIOUSLY AVAILABLE--    1443772.00
         PRESENTLY  AVAILABLE--    1953338.00

****** ****** ****** ****** ****** ****** ****** ****** ****** *****
NCHRP 14-5 (2)  EXAMPLE PROBLEM
****** ****** ****** ****** ****** ****** ****** ****** ****** *****



                THE ADJUSTED CONSTRAINT MATRIX


B (   1) =   0.25096200E+06
A (   1) =
0.139E+06 0.904E+05 0.414E+05 0.000E+00 0.490E+05 0.302E+05 0.000E+00 0.622E+0
0.311E+05 0.000E+00 0.759E+05 0.380E+05 0.000E+00

B (   2) =   0.70537100E+06
A (   2) =
0.330E+06 0.214E+06 0.978E+05 0.000E+00 0.490E+06 0.302E+06 0.000E+00 0.415E+0
0.207E+05 0.000E+00 0.681E+05 0.341E+05 0.000E+00

B (   3) =   0.12211100E+07
A (   3) =
0.811E+06 0.526E+06 0.241E+06 0.000E+00 0.461E+06 0.284E+06 0.000E+00 0.166E+0
0.830E+05 0.000E+00 0.146E+06 0.730E+05 0.000E+00


                ADJUSTED BENEFIT COEFFICIENTS

BZERO( 1) =      -0.054          BENEFIT COEFFICIENTS -
  0.461  0.318  0.009  0.000  0.103  0.152  0.000  0.259  0.148  0.000
  0.000  0.000  0.000


BZERO( 2) =       0.000          BENEFIT COEFFICIENTS -
  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000
  1.000  0.500  0.000
```

THE RANKING PROCEDURE

INDEX	GROUP	RANK	VALUE	CP	COST TOTAL
1	1	5	0.4519	0.4519	1280627.0000
2	1	6	0.3452	0.3452	830332.0000
3	1	13	-0.0863	-0.0863	380037.0000
4	1	1	-0.1059	-0.1059	100.0000
5	2	12	0.0833	0.0833	1000851.0000
6	2	9	0.1571	0.1571	616505.0000
7	2	2	-0.1059	-0.1059	100.0000
8	3	7	0.2878	0.2878	269852.0000
9	3	11	0.1517	0.1517	134976.0000
10	3	3	-0.1059	-0.1059	100.0000
11	4	8	0.2608	0.2608	290221.0000
12	4	10	0.1548	0.1548	145160.0000
13	4	4	-0.1059	-0.1059	100.0000

STARTING SOLUTION

-4 -7 -10 -13

IFRE =
F F F T F F T F F T F F T

JFIRST = 5

RESOURCE	BUDGET		USED
LABOR IN HOURS	469571.00	>	218609.00
MATERIALS IN DOLLARS	1033764.00	>	328393.00
EQUIPMENT IN DOLLARS	1953338.00	>	732228.00

INTERMEDIATE SOLUTION

-4 -7 -10 -13 1 -2 -3 -5 8 -9 -11 -6 12

RESOURCE	BUDGET		USED
LABOR IN HOURS	469571.00	>	458291.00
MATERIALS IN DOLLARS	1033764.00	>	733607.00
EQUIPMENT IN DOLLARS	1953338.00	>	1782671.00

VALUE OF OBJECTIVE = 0.82671

RUN STATISTICS

INFEASIBLE	PURSUE BRANCH?	CUT BRANCH	FORCE IN VARS
0.	6.	0.	3.

BACKSTEP	MAIN CYCLES	EVALUATE LEAF	ADD VARIABLE
0.	3.	1.	6.

INTERMEDIATE SOLUTION

-4 -7 -10 -13 1 -2 -3 -5 -8 11 -12 -6 9

RESOURCE	BUDGET		USED
LABOR IN HOURS	469571.00	>	465135.00
MATERIALS IN DOLLARS	1033764.00	>	746532.00
EQUIPMENT IN DOLLARS	1953338.00	>	1772687.00

```
VALUE OF OBJECTIVE =          0.89321

                         RUN STATISTICS

  INFEASIBLE   PURSUE BRANCH?    CUT BRANCH      FORCE IN VARS
      0.              9.              0.               5.

     BACKSTEP     MAIN CYCLES   EVALUATE LEAF    ADD VARIABLE
         2.            5.             3.              9.

                      INTERMEDIATE SOLUTION

 -4   -7  -10  -13   -1    2   -3   -8   11  -12   -5    6    9

    RESOURCE                                  BUDGET          USED
LABOR IN HOURS                             469571.00  >    446292.00
MATERIALS IN DOLLARS                      1033764.00  >    933000.00
EQUIPMENT IN DOLLARS                      1953338.00  >   1771572.00

  VALUE OF OBJECTIVE =          0.89677

                         RUN STATISTICS

  INFEASIBLE   PURSUE BRANCH?    CUT BRANCH      FORCE IN VARS
      0.             20.              5.              14.

     BACKSTEP     MAIN CYCLES   EVALUATE LEAF    ADD VARIABLE
         7.           13.             5.             20.


COMPLETE ENUMERATION


        THE SELECTED POLICY IS


        MAINTENANCE ELEMENT - ROADSIDE

        MAINTENANCE CONDITION                  ALTERNATIVE SELECTED

GRASS GROWTH                          = MOW AT 12 IN. HEIGHT, 30 FT. MAX WIDTH
NOXIOUS WEEDS AND BRUSH               = ONCE A YEAR
LITTER AND DEBRIS                     = ONCE EVERY THREE MONTHS
REST AREAS                            = TWICE A DAY


                  THE COSTS OF THE SELECTED POLICY


    RESOURCE                                  BUDGET          USED
LABOR IN HOURS                             469571.00  >    446292.00
MATERIALS IN DOLLARS                      1033764.00  >    933000.00
EQUIPMENT IN DOLLARS                      1953338.00  >   1771572.00
```

EVALUATION OF THE ATTRIBUTES

DEGREE OF PLEASING APPEARANCE
INDIVIDUAL VALUE- 0.837 WEIGHTED VALUE- 0.530

DEGREE OF CLEANLINESS OF REST AREAS
INDIVIDUAL VALUE- 1.000 WEIGHTED VALUE- 0.367

THE VALUE OF THIS POLICY IS 0.8968

THE SOLUTION IS

X(1) =	2	ORDER(2) =	6
X(2) =	6	ORDER(6) =	9
X(3) =	9	ORDER(9) =	11
X(4) =	11	ORDER(11) =	8

RUN STATISTICS

INFEASIBLE	PURSUE BRANCH?	CUT BRANCH	FORCE IN VARS
0.	26.	11.	17.
BACKSTEP	MAIN CYCLES	EVALUATE LEAF	ADD VARIABLE
12.	16.	6.	23.

OPTIONS USED

INITIAL VALUE SET AT-	-9999.000
K IN TEST2 IS-	0.000
MULTIPLIER IN TEST2 IS-	1.000
MAXIMUM RUN TIME-	1000000.
FEASIBILITY TOLERANCE-	0.000005
MAXIMUM ITERATIONS -	2147483647
STARTING SOLUTION OPTION-	F
RANKING OPTION-	T
METHOD OF RANKING OPTION-	2
PRINT OPTION-	T
INTERNAL COMPUTATION OPTION-	2
NO SUBSTITUTION OPTION-	F
ARBITRARY CONSTRAINT OPTION-	0

SENSITIVITY ANALYSIS

CASE 3

END OF SENSITIVITY ANALYSIS

APPENDIX C — BLANK FORMS FOR RECORDING ASSESSED INFORMATION

Assessors 1. ______________________ Date ______________________

2. ______________________ 4. ______________________

3. ______________________ 5. ______________________

ELEMENT ______________________

CONSIDERATION ______________________

ATTRIBUTE ______________________

CONDITION ______________________

PARAMETER ______________________

Level of Service (Higher ↑ / Lower ↓)	Alternate Levels of Service of the CONDITION in terms of the PARAMETER: ______________	Level of ATTRIBUTE: ______________
Higher	1	
	2	
	3	
	4	
Lower	5	

Figure C-1 — Form for Recording Estimates of Effects of a Single Maintenance CONDITION on a Consideration in terms of its ATTRIBUTE

HIGHWAY AGENCY

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

ELEMENT ______________
CONSIDERATION ______________
ATTRIBUTE ______________
CONDITION 1 ______________
CONDITION 2 ______________

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

Figure C-2 – Form for Recording Estimates of Effects of Two Maintenance CONDITIONS on a CONSIDERATION in Terms of its ATTRIBUTE

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					
	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 C-3 – Form for Recording Estimate 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 C-4 — Form for Tabulating Estimates of Resources Required for Alternate Levels of Service

Maintenance CONDITION	Current Level of Service	Estimated Current Annual Resource Expenditure		
		Type 1 (Labor–hours)	Type 2 (Materials–dollars)	Type 3 (Equipment–dollars)
Total for ELEMENT				

Figure C-5—Form for Recording Current Annual Resource Expenditures for Maintenance CONDITIONS of a Given Maintenance ELEMENT

Maintenance CONDITION	Approximate Percent of an "Available" Maintenance Budget Spent on the CONDITION

Figure C-6—Form for Recording Approximate Percent of an "Available" Maintenance Budget Currently Spent on Each Maintenance CONDITION

ATTRIBUTE	Current Level	Maintenance CONDITIONS That Affect the ATTRIBUTE	Percent of Available Budget Spent on the CONDITION	Percent of Available Budget Spent on the ATTRIBUTE

Figure C-7—Form for Recording Percent of Available Maintenance Budget Currently Spent on Each ATTRIBUTE

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 C-1, C-2, or C-3.

Figure C-5 – Form for Use in Recording Each Assessor's Judgement as to the Relative Desirability of the Levels of an ATTRIBUTE

HIGHWAY AGENCY

Calculated by ______________________ Date ______________

ELEMENT ______________________

CONSIDERATION ______________________

ATTRIBUTE (No.) ______________________

	ATTRIBUTE LEVEL *	Maximum Percent of Total Available Maintenance Budget "Willing to Pay"**						Calculated Relative Value of ATTRIBUTE Level
		Assessor 1	Assessor 2	Assessor 3	Assessor 4	Assessor 5	Median of all Assessors Responses***	
Least ↑							(a)	0
Desirability							(b)	$\frac{b-a}{e-a} =$
							(c)	$\frac{c-a}{e-a} =$
							(d)	$\frac{d-a}{e-a} =$
Most ↓							(e)	1

* As determined in Step Seven

** As recorded for each Assessor on form shown as Figure C-5

*** If n is an odd number, the median is the middle value; if n is an even number, the median is the average of the two middle values.

Figure C-6 – Form for Calculating Relative Values of Different ATTRIBUTE Levels

ATTRIBUTE	No.	ATTRIBUTE Levels		
		Best	Midvalue	Worst

Figure C-7 – Form for Tabulation of Best, Midvalue, and Worst Levels of All ATTRIBUTES

HIGHWAY AGENCY

Calculated by ______________________ Date ____________

ATTRIBUTE Number	Increase in the Maximum Percent of Total Available Budget to go from the Least to the Most Desirable Level	Relative Weight of the ATTRIBUTE
1	P_1 =	P_1/P =
2	P_2 =	P_2/P =
3	P_3 =	P_3/P =
4	P_4 =	P_4/P =
5	P_5 =	P_5/P =
6	P_6 =	P_6/P =
.....	..... =	..... =
.....	..... =	..... =
n	P_n =	P_n/P =
	$P = \sum P_i$ =	$\sum P_i/P$ = 1.0

Figure C-8 – Form for Calculating Relative Values (Weights) of All ATTRIBUTES

DEFINITIONS OF SPECIAL 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 ½ 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.*

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