ARIZONA DEPARTMENT OF TRANSPORTATION

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DEVELOPMENT OF FRAMEWORK FOR PAVEMENT MANAGEMENT SYSTEM FOR ARIZONA

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HIGHWAYS DIVISION · RESEARCH SECTION ·

Final Report - Phase I

DEVELOPMENT OF FRAMEWORK FOR PAVEMENT MANAGEMENT SYSTEM FOR ARIZONA

by

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Submitted to

The Arizona Department of Transportation
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Phoenix, Arizona 85007

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16. Abstract

The investigation was designed to develop an implementable pavement management system incorporating multiple attributes of cost and performance factors.

The pavement management system compares alternate initial designs with selected maintenance procedures to determine the most appropriate combinations of design and maintenance strategies. The system also works with in-service pavements.

Unique features of the system include the use of utility theory to combine multiple attributes into a single summary value, the consideration of "tradeoffs" between attributes and the inclusion of uncertainty in the prediction models.

Computer programs have been prepared and the system is considered ready for trial implementation on selected projects within the state.

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PREFACE

Systems engineering in its broad sense is a codified procedure for attacking complex problems in a coordinated fashion to permit realistic decisions that can be justified on the basis of selected decision criteria.

Highway departments have shown an increasing interest in the development of pavement management systems starting with the publication of the National Cooperative Research Program's (NCHRP) Reports 139 and 140 which described such a system related primarily to selection of initial pavement design. An implementation project followed in which the initial development was modified to meet the needs of selected states. The results of this effort are described in NCHRP Report 160. The major pavement attribute considered in these systems was the pavement serviceability history.

In 1974, the Washington Department of Highways undertook the development of a pavement management system using different combinations of pavement attributes as compared with the NCHRP investigations, with emphasis on maintenance strategies for in-service roadways.

Arizona has initiated an extensive data acquisition program which provides the basis for a pavement management system for this state. The investigation described herein is an effort to extend the results from the NCHRP and Washington studies into an implementable system for Arizona.

As planned, the investigation involved extensive participation by the staff of the Arizona Department of Transportation in all phases of the work. The number of people who provided assistance is too large to enumerate at this time; however, particular recognition is made to Messers. Rowan Peters, George Way, John Burns, John Eisenberg, Benjamin Ong and to the Engineer of Research, Gene Morris. The cooperation of Deputy State Highway Engineer Oscar Lyons was particularly encouraging in that interest at this level indicated a commitment to the development of a pavement management system essential to its successful implementation.

1.0

BACKGROUND

A major responsibility of any transportation agency is to develop and maintain a highway network which will provide a facility meeting performance objectives at the most reasonable cost possible. A typical decision would be the selection of a specific type of pavement construction or the maintenance alternatives and sequences (strategies) which will provide an optimum application of resources. One generalized procedure for achieving such goals is the development and implementation of a pavement management system.

A pavement management system can be defined as the systematic development of information and procedures necessary in optimizing the design and maintenance of pavements. In a practical application the pavement management system will help choose the best design or maintenance strategy from among those alternatives considered appropriate for Arizona by members of the Department of Transportation staff. Maintenance procedures need not be limited to those previously used in Arizona; however, it is necessary to estimate the expected performance based on research, demonstration projects or the experience of other agencies involved in the design and construction of pavements.

Thus, a pavement management system is designed to assist the decision maker in the what, where, and when of pavement design and maintenance; what type of design and maintenance to select, where and when maintenance should be performed. It should be clear that the pavement management system cannot make a decision; only the person assigned the responsibility for the decision can do that. However, the pavement management system can provide a significant tool as an aid in making such decisions.

It is important to realize that a pavement management system (PMS) does not, of itself, develop maintenance alternatives, that is, procedures for the correction of pavement deficiencies. However, the PMS provides the framework by which alternate procedures can be compared. The system may temporarily suffer from a lack of background information for newly developed construction or maintenance concepts; for example, engineers know very little about the performance of pavements constructed with recycled materials. Hence, the pavement management system tends to lose reliability for this particular alternative. To a significant degree the ability to predict future performance depends on observations of past performance.

In order for the PMS to provide decision-making information, it is necessary to determine the appropriate dependent variable, that is, what factor or factors should be used as the major determinants for an engineering decision. The first such variable that would come to mind is cost. However, the decision need not be exclusively based on minimizing cost. It could be that for some reasonable (acceptable) increase in cost a desirable improvement in riding quality could be achieved. Hence, some tradeoff may be possible between cost and improved long-term performance.

The PMS should reflect the preferences of those who have the responsibility for the selection of design and maintenance policy with regard to both general guidelines and specific project-by-project determinations. It is not the purpose of the PMS to produce decision recommendations which would be significantly at variance with those individuals who make such decisions at the present time. The system should generally produce information which reflects the experience, preference and priorities of responsible members of the Arizona DOT staff.

In the following sections of this report an effort is made to summarize the initial phase in the development of a pavement management system for the Arizona DOT; the Appendices are provided for those interested in further explanations and discussions regarding the details of the investigation.

2.0

OBJECTIVE

The principal objective of this investigation was to develop a framework or model for a pavement management system which would provide a rationale for the decision maker in selecting (1) the optimum initial structural design and maintenance strategy for new pavements and (2) the optimum maintenance strategy for in-place (existing) pavements.

In order to achieve this objective it was necessary to undertake the following tasks:

1. Identify pavement attributes
2. Identify pavement maintenance alternatives
3. Develop models for predicting pavement attributes
4. Develop models for predicting costs
5. Develop appropriate "tradeoffs" or utility functions for the pavement attributes to be included for optimization by the pavement management system.

For purposes of this investigation an attribute is defined as some pavement characteristic which is considered to significantly influence the overall acceptability of the pavement to the user. For example, riding comfort is probably the most significant attribute that a pavement may possess; however, riding comfort is not the only attribute desired or required for a pavement.

An additional objective for the development of the PMS is to recognize uncertainties in the models with regard to the ability to predict attributes. The inclusion of uncertainty allows the decision maker to assign levels of reliability as a requirement for optimization by the pavement management system. For example, on the Interstate System a high reliability requirement of 90 or 95 percent could be used and on the Secondary System a requirement of 60 to 75 percent would not be unreasonable.

In order to develop a management system it is necessary to identify maintenance alternatives; hence, one requirement was to enumerate those procedures currently considered appropriate for Arizona. It can be expected that additional procedures will be incorporated in the future; however, in order to develop a complete working system at this time it was the Consultant's recommendation to proceed with those alternatives for which the DOT has or is accumulating the most experience.

3.0

APPROACH

In order to obtain the necessary information and to develop a data base for performance and cost, a considerable amount of interaction was necessary with the Arizona DOT staff. The overall approach used in achieving the objectives is described in the following sections of this report.

3.1 IDENTIFICATION OF PAVEMENT ATTRIBUTES

The identification of pavement attributes was accomplished in a meeting with Headquarters personnel and the Pavement Management Steering Committee on September 23 and 24, 1975. At that meeting the Consultant presented a tentative list of objective functions and pavement attributes as shown in Figure 1. The attributes were generally identified with: (1) safety, (2) riding comfort, and (3) physical distress. The specific measurements for the attributes were: (1) skid number, (2) rut depth, (3) roughness, and (4) dollar cost.

Pavement cracking did not appear in the original recommendation for the following reasons:

1. There are no reliable procedures for predicting cracking as to when or how much will occur;
2. There is no information to estimate the cost required to maintain a pavement as a function of the amount of cracking;
3. There is no information for relating cracking to pavement serviceability (riding quality); and

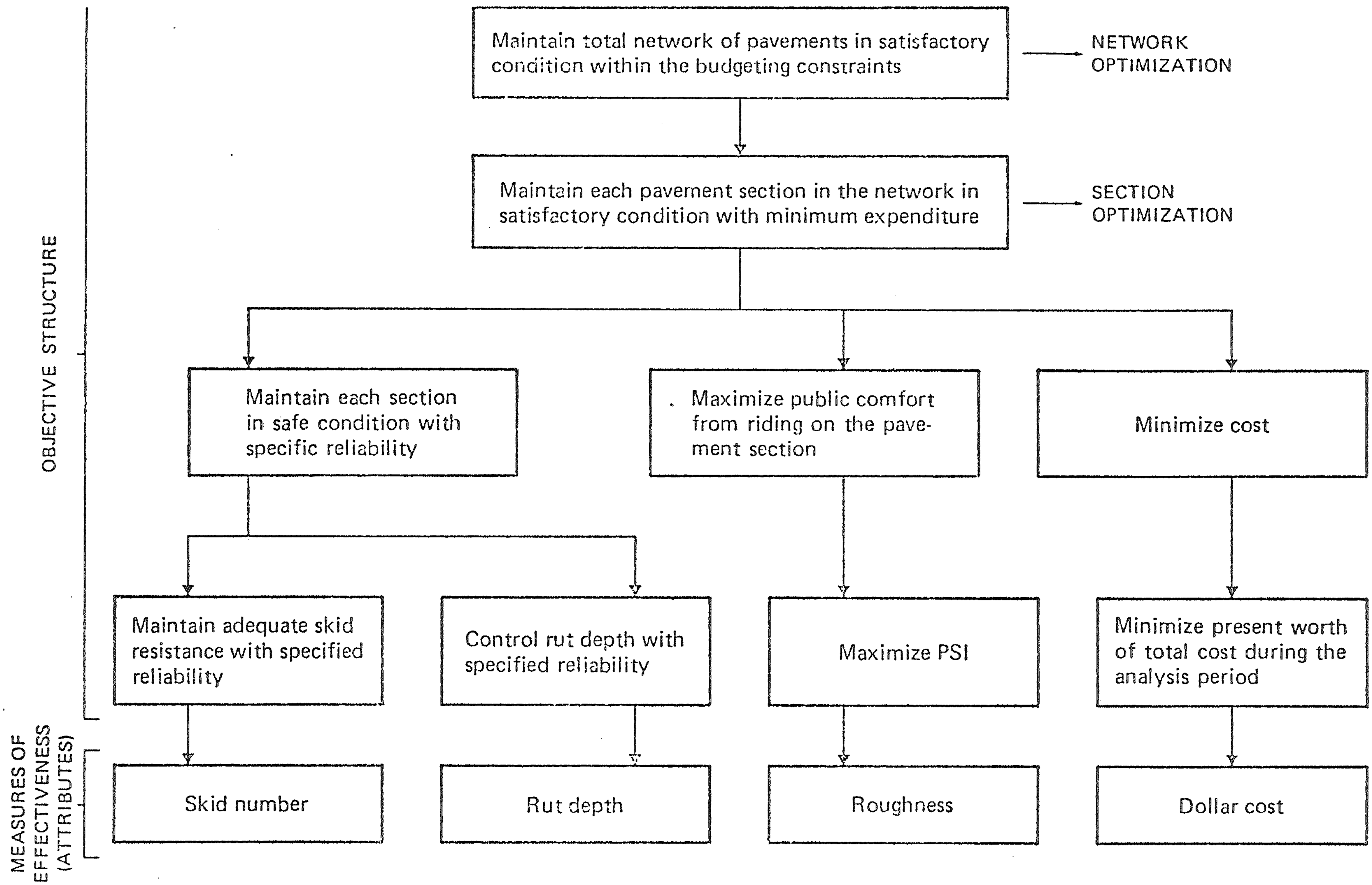

Figure 1. OBJECTIVE STRUCTURE AND MEASURES OF EFFECTIVENESS (Attributes)

4. there is no information as regards the limiting value of cracking.

It is conceded that cracking is an important pavement attribute; however, for the above reasons it was deferred from the present model until such time as one or two of the above problems can be resolved.

In lieu of predicting cracking, the Consultant proposed to substitute pavement deflection, that is, deflection to serve as a proxy for both structural strength and pavement condition. It is postulated that the average or distributed deflection, for example, 80 percentile or average plus two standard deviations, for a given pavement will reflect the amount of cracking — increasing deflection with increasing amounts and severity of cracking. This assumption is predicated on a random selection of locations for which deflection measurements are to be obtained.

Rut depth was also deleted since this type of physical distress is not presently a problem in Arizona and would not be necessary for the management system.

The Consultant recognized the need for assigning some value for excess user costs related to any inconvenience incurred by the travelling public due either to the condition of the pavement or delays related to maintenance (construction).

The ability to identify excess user costs, due to the condition of the pavement, requiring the user to slow down has not been sufficiently developed to justify its inclusion in the system. Kher (1976) reported that passenger car speed reductions do occur as the pavement becomes very rough; however, there is no evidence that commercial vehicles reduce speed. Since there is poor agreement on the value of passenger car time it was not considered; and since trucks seem not to be affected, the factor becomes moot.

It is recognized that vehicle operating costs are an important consideration to the user of a highway. The excess operating costs as a function of the condition of the pavement are not known; hence, this factor was not considered directly in the development of the System.

Though the excess user costs associated with pavement condition were not directly included in the cost attribute, it should be pointed out that the decision maker's perception of the benefit (or penalty) of better (or worse) pavement condition was captured in the PMS by considering tradeoffs between cost and roughness index, and between cost and skid number.

The final factor related to user inconvenience was the consideration of delays due to construction for major maintenance. Provision has been made for this factor in the model by including the attributed time delays associated with major maintenance.

In summary, after discussion with the Arizona DOT, the pavement attributes required for the PMS were determined to be: (1) skid number, as measured by the Mu meter; (2) longitudinal roughness as measured by the Mays meter; (3) dollar costs for routine and major maintenance; and (4) time delays associated with major maintenance.

Based on discussions with staff engineers and review of state reports,* tentative limits for skid number and roughness index were as follows:

Skid number —	43 minimum for all classes of roads
Roughness index —	40 maximum for Interstate and major primary, 50 maximum for primary, secondary and other classifications.

*Cornell (1973); Allen, Cornell, Burns, and Eisenberg (1974); Burns (1973); and Arizona Highway Department Reports Nos. 3 and 10.

3.2 MAINTENANCE ALTERNATIVES

Our understanding is that major maintenance recommendations originate in the field at the district level and are reviewed and sometimes revised by headquarters staff. Thus, the criteria for deciding when and what type of maintenance tends to be somewhat subjective at the present time. Guidelines for the selection of appropriate maintenance have been prepared by headquarters staff and are shown in Figure 2. It is pertinent to note that one of the objectives of the pavement management system is to systematize and document those decisions, but not necessarily to radically change the type of recommendation which is made in the field on the basis of experience and judgment. As a matter of fact, in the initial stages one of the tests for the system will be the reasonableness of the decision as evaluated by experienced engineers.

It is necessary to divide maintenance into two categories: (1) routine and (2) major. In our discussions it became evident that it would be necessary to differentiate between these two types of maintenance.

For purposes of the comparisons to be included in the pavement management system, the Consultant recommends the following:

1. Routine maintenance is that maintenance which would be accomplished on a systematic basis according to Department policy. This would include, as a minimum, items 101 through 109 and 119 of the PECOS maintenance management program. Routine maintenance would also include the uses of flush seals to be scheduled by the District Engineer.
2. Major maintenance would include all procedures not specifically included under routine maintenance, and which generally involve treatment of the total paved area and such modifications to the shoulder area as are required for safety and comfort. The most common type of major maintenance to be considered by the pavement management system will be an asphalt concrete overlay including seal coats on the secondary routes only.

ASPHALTIC CONCRETE REHABILITATION
(FORMAT PATTERNED AFTER NCHRP PROJECT I-10(17))

DISTRESS MODE	DISTRESS MANIFESTATION	DISTRESS MECHANISM	POTENTIAL MEASUREMENT TECHNIQUE	POSSIBLE SOLUTIONS
Fracture	Cracking	Inadequate Structure	Deflection (Dynaflect)	(1) Overlay (Mean Deflection >1.1 mils (Other) .8 mils (Interstate), All Cracking <10%) (2) Membrane & Overlay (mean Defl >1.1 mils (Other) .8 mils (Interstate), Random and Alligator Cracking >50%) (3) Membrane & ACFC (Mean Defl <1.1 mils (Other) .8 mils (Interstate), Random and Alligator Cracking >50% (4) H-S & ACFC (Mean Defl <1.1 mils (Other) .8 mils (Interstate), Block and Transverse Cracking >50%) (5) H-S & Overlay (Mean Defl >1.1 mils (Other .8 mils (Interstate), Block and Transverse Cracking >50%)
		Repeated Loading (i.e. fatigue	Cracking Index (Random & Alligator)	
		Thermal Changes (i.e. Shrinkage)	Cracking Index (Block & Transverse)	
Distoration	Permanent Deformation	Inadequate Structure	Deflection (Dynaflect) - Mays	(1) Overlay (Deflection >1.1 mils (Other) .8 mils (Interstate)
		Creep	Visual Assessment - Mays	(1) Overlay (2) H-S & Overlay (3) Reconstruction
		Densification	Rut Depth	(1) Overlay
		Consolidation	Rut Depth & Longitudinal Cracks	(1) Overlay (2) Membrane and Overlay
		Swelling	Swell Tests	(1) Membrane and Overlay (Swell >5%)
Surface Failure	Stripping & Raveling	Adhesion (i.e. Loss of Bond)	Cohesiometer — (Mr) — Visual	(1) Recycling (If Curable by Additive) (2) Reconstruct
		Abrasion by Traffic	Visual Assessment	(1) Chip Seal (ADT <1000) (2) ACFC (ADT >1000)
		Durability of Binder	Viscosity	(1) Flush (Rejuvenator) (Viscosity High) (2) Flush (Asphalt) (Viscosity Moderate)
Surface Friction		Polishing Bleeding	Skid Number (Mu-Meter)	(1) Chip Seal (No Bleeding, ADT <1000, Sn <43) (2) ACFC (Low Bleeding Sn <43) (3) H-S & ACFC (Heavy Bleeding, Sn <43) (4) Slurry Seal*

NOTE: Deflection Values are Nominal Values for "Average" Roadway with the Need for Overlay Based on Remaining Life of 5 years or Less.

NOTE: H-S Refers to Heater-Scarification. Mr Refers to Modulus of Resiliency.

*Alternate in lieu of 1 to 3 (Temporary Expedient)

Figure 2. CURRENT GUIDELINES FOR SELECTION OF MAINTENANCE TYPE

As the pavement management system is perfected and the data bank accumulates more information it should be possible to extend major maintenance to include such factors as the flush seal or improved subsurface drainage for the asphalt pavements and grinding or subsealing of Portland Cement Concrete (PCC) pavements. Also, reclamation of existing pavements can be included when information becomes available.

Major maintenance to be considered at this time is as follows:

a. For Portland cement concrete pavements —

   Asphalt concrete friction course (ACFC) with and without asphalt rubber membrane;

b. For asphalt type pavements on Interstate or major primary routes —

   -ACFC with and without rubber membrane;

   -ACFC with and without heater-remix (scarifier);

   -ACFC with increasing thicknesses of asphalt concrete overlays, up to 4 inches, with and without rubber membrane and with or without heater-remix (Note: the limiting value of 4 inches is considered tentative and based on a paper by G. Morris to the Rubber Reclaimers Association entitled, "Asphalt-Rubber Membranes: Development, Use, Potential."); and

   -ACFC with increasing thicknesses of asphalt concrete overlays greater than 4 inches, without rubber membrane or heater-remix.

c. For asphalt type pavements on secondary and other routes —

   -All of those considered under Item b; and

   -Chip seals on existing pavements.

3. A third maintenance consideration will subdivide major maintenance (or betterment) into either preventive or corrective categories. Preventive maintenance considers some type of betterment before the pavement condition falls below limiting values. Corrective maintenance assumes the pavement is at or below a limiting value indicating the need for improvement.

3.3 DEVELOPMENT OF PREDICTION MODELS

As previously discussed, a requirement of the pavement management system is to predict the values of specific attributes with time. One procedure to develop such prediction capability is by means of regression analysis using data obtained from measurements. For this investigation there was a minimum of objective data (measurements). It was therefore necessary to develop subjective data from experience. It is pertinent to note that the appropriate measurements are now being made; however, the data base up to the present time is insufficient for the development of the prediction models. Future updating based on field measurements should improve the reliability of the model and strengthen the objectivity of the models.

In order to generate the data base of information required for the prediction of road roughness, it was jointly agreed with DOT staff that the following factors should be included in the regression model:

1. Traffic — expressed in terms of equivalent 18 kip (8200 Kg) single-axle loads.
2. Deflection — as obtained with a Dynaflect and converted into equivalent Bankelman beam values for a 9 kip (4100 Kg) dual tire loading (asphalt pavements only). Deflections for pavements which are being considered for initial design (prior to construction) can be estimated by using layered system computer programs such as CHEV5L or PSAD, either of which are currently in the Arizona DOT program library. Alternatively, past experience with similar construction can be used as a first trial. For the present development, estimates of deflection were obtained from the subjective judgments of engineers currently involved in making such measurements.
3. Environment — the state was divided into three zones for this initial effort as follows: (1) 0 to 5000 feet, (2) greater than 5000 feet and (3) greater than 5000 feet with swelling clay foundation.
4. Age — the age in years since initial construction or the latest betterment (major maintenance).

5. Thickness — the thickness of the PCC slab (Portland cement concrete pavements only) or thickness of overlay (asphalt pavements only).

The prediction model for skid number included the following types of information:

- Aggregate Types — the dominant aggregates used in the state are limestone, granite and basalt; each aggregate type was coded for the regression
- Environment, Age, and Traffic — the same as used for the roughness prediction model.

Some question has been raised regarding the use of the 5000 foot elevation to identify a difference in environment which could significantly influence the annual change in road roughness. Possibly this value should be set at 3000 feet. For the development of the PMS framework it is sufficient to recognize the potential influence of elevation; future updating can more accurately define the most appropriate limits.

Traffic input for skid number could also be considered in terms of annual daily traffic (ADT); however, again, as a first iteration it is considered that equivalent 18 kip (8200 Kg) loads will reflect the total traffic volume.

As previously indicated, the limited amount of field data dictated an alternate approach for generating the type of information required for predicting roughness index and skid number for pavements. The alternative approach was to quantify the experience of engineers within the DOT in such a way as to obtain sufficient information for a first iteration of a prediction model. A general description of the type of information obtained and the procedure used for generating subjective data is given in Appendix A.

It is pertinent to discuss the use of deflection as a determinant of future roughness since a great deal of reliance is being given to the role of this particular measurement. A number of field studies have shown that deflection can effectively be used as a determinant of performance; three of the most notable would be represented by results of the AASHO Road Test (1962), studies by the Ontario (Canada) Ministry of Transportation and Communication (1965) and developments of the Asphalt Institute (1969). For over 20 years the California Transportation Laboratories have used deflection as a design parameter. Their latest procedures are described in "Structural Overlays for Pavement Rehabilitation."* With this background of results, and others, the Consultant considered deflection a reasonable proxy for pavement in-situ strength and condition (cracking).

The results of the analysis obtained from the subjective data base are illustrated in Figures 3 and 4 for the change in roughness index (CRI) and Figure 5 for change in skid number (CSN). The equations used to predict these changes are as follows:

For new or in-service construction

$$\ln CRI = 0.8815 \ln RGN + 0.6965 \ln DEFL + 0.1901 \ln TRAF + 0.4217 \ln AGE + 1.6638 \quad (1)$$

where

CRI = annual change in roughness index

RGN = environmental region as previously defined

DEFL = equivalent Benkelman beam deflection obtained from correlations with Dynaflect measurements

TRAF = average annual equivalent 18 kip (8200 Kg) single-axle loads estimated for the specific roadway

AGE = age of the pavement in years

For the example parameters shown in Figure 3 the expected change in roughness index (CRI) in the eighth year is 5.80; thus, from the eighth to ninth year the roughness index would be expected to increase by 5.80 units.

*Bushey, Baumeister, and Mathews (1975).

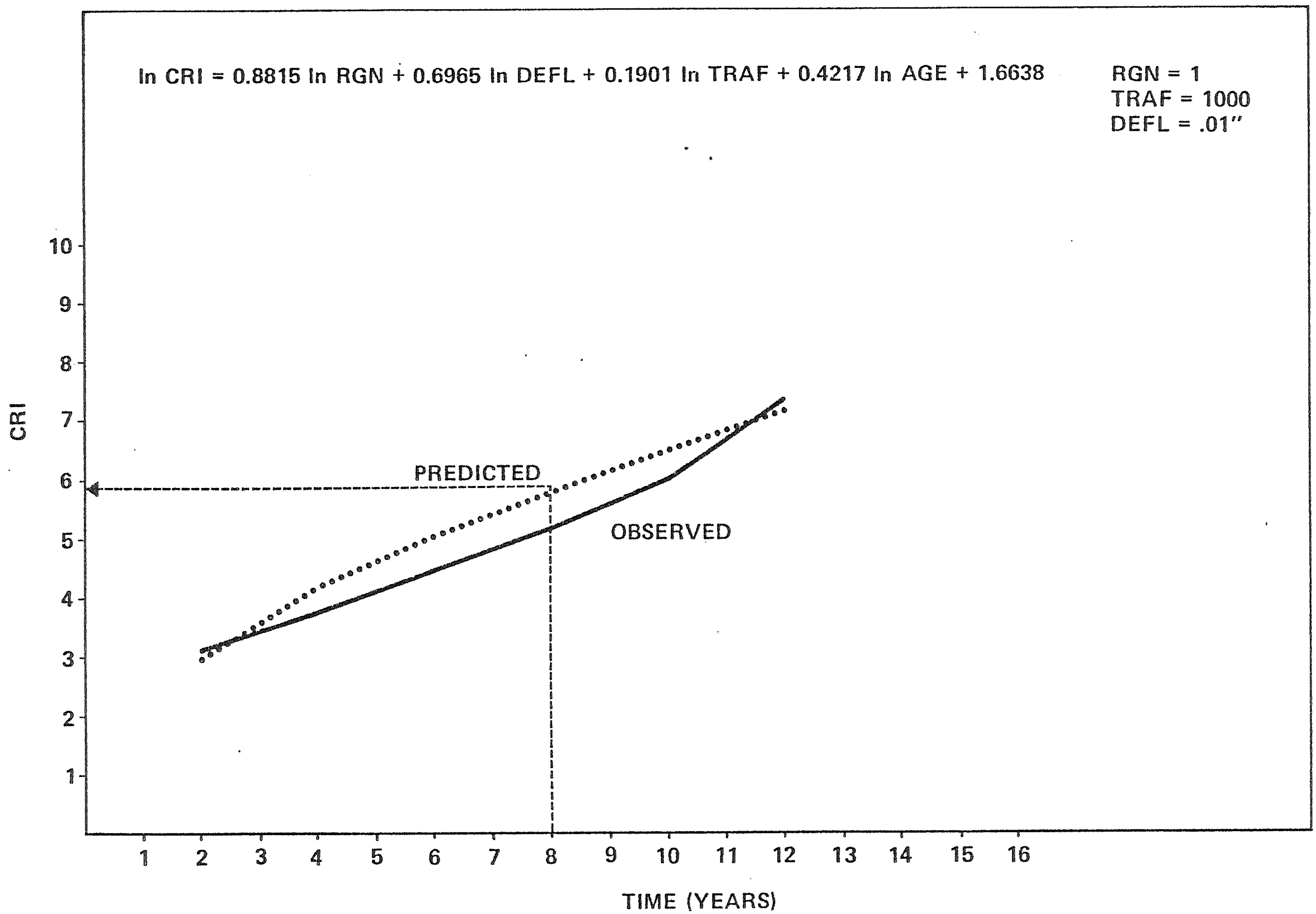

Figure 3. CHANGE IN RI FOR AC PAVEMENTS (New or in-service construction)

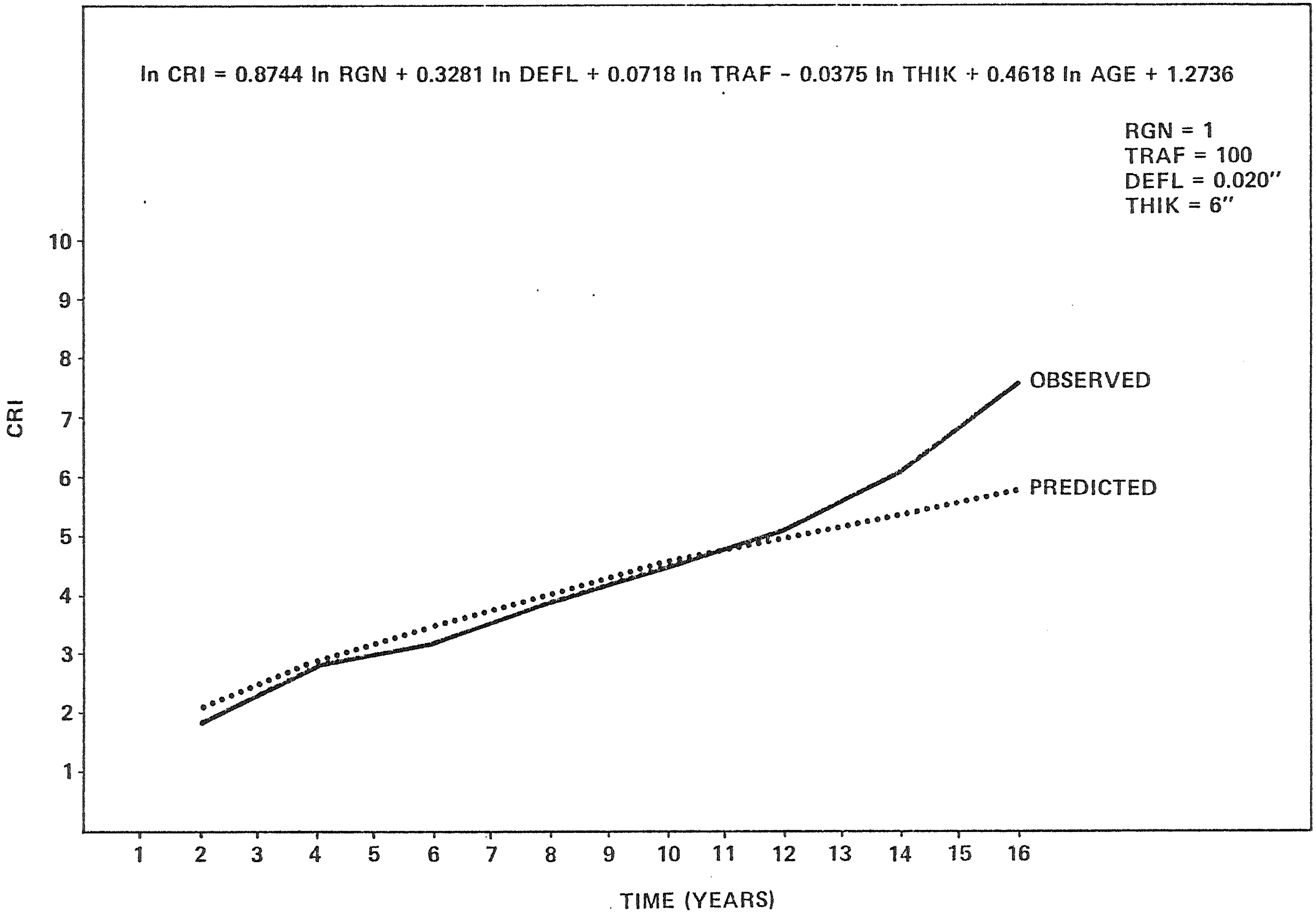

Figure 4. CHANGE IN RI FOR AC PAVEMENT (Major maintenance): 6" OVERLAY + ACFC, NO RUBBER, NO H.S.

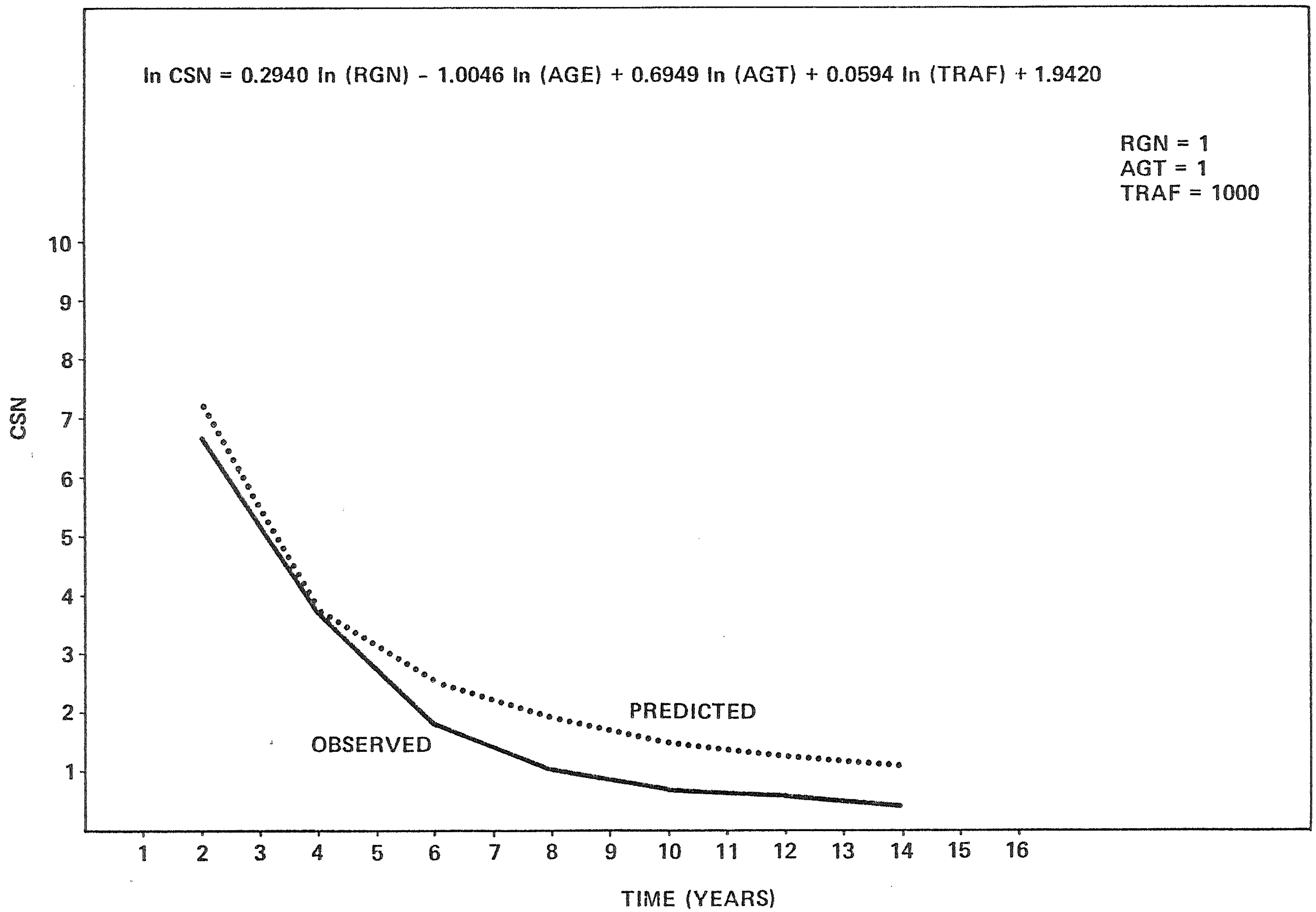

Figure 5. CHANGE IN SN FOR ACFC

For an overlay plus an asphalt concrete friction course without an asphalt-rubber inner-layer or heater-scarification

$$\ln CRI = 0.8744 \ln RGN + 0.3281 \ln DEFL + 0.0718 \ln TRAF - 0.0375 \ln THIK + 0.4618 \ln AGE + 1.2736 \qquad (2)$$

where

CRI, RGN, DEFL, TRAF, and AGE are the same as used in equation (1) and

THIK = thickness of the overlay

For new construction or overlays

$$\ln CSN = 0.2940 \ln RGN - 1.0046 AGE + 0.6949 \ln AGT + 0.0594 \ln TRAF + 1.9420 \qquad (3)$$

where

CSN = annual change in skid number

RGN, AGE, and TRAF are the same as used in equation (1) and

AGT = type of aggregate; 1 for basalt, 2 for gravel, and 3 for limestone.

A complete listing of all prediction equations is given in Appendix A.

Because of the uncertainties in environment, traffic, material properties, etc., exact predictions of future pavement performance are generally not possible. The decision making process must explicitly take into account these uncertainties. To illustrate this problem, consider an example in which, for the sake of simplicity, only the roughness index was a consideration and suppose it is desired to formulate the best maintenance strategy for an in-service pavement with a maximum allowable roughness index of 40. Figure 6 can be used to illustrate the example. Assume the current measurements on the section indicate a roughness index of 25 which is considered a single value and does not include any prediction errors. The best estimate of roughness index values at 2, 4, and 6 years in the future is indicated by the

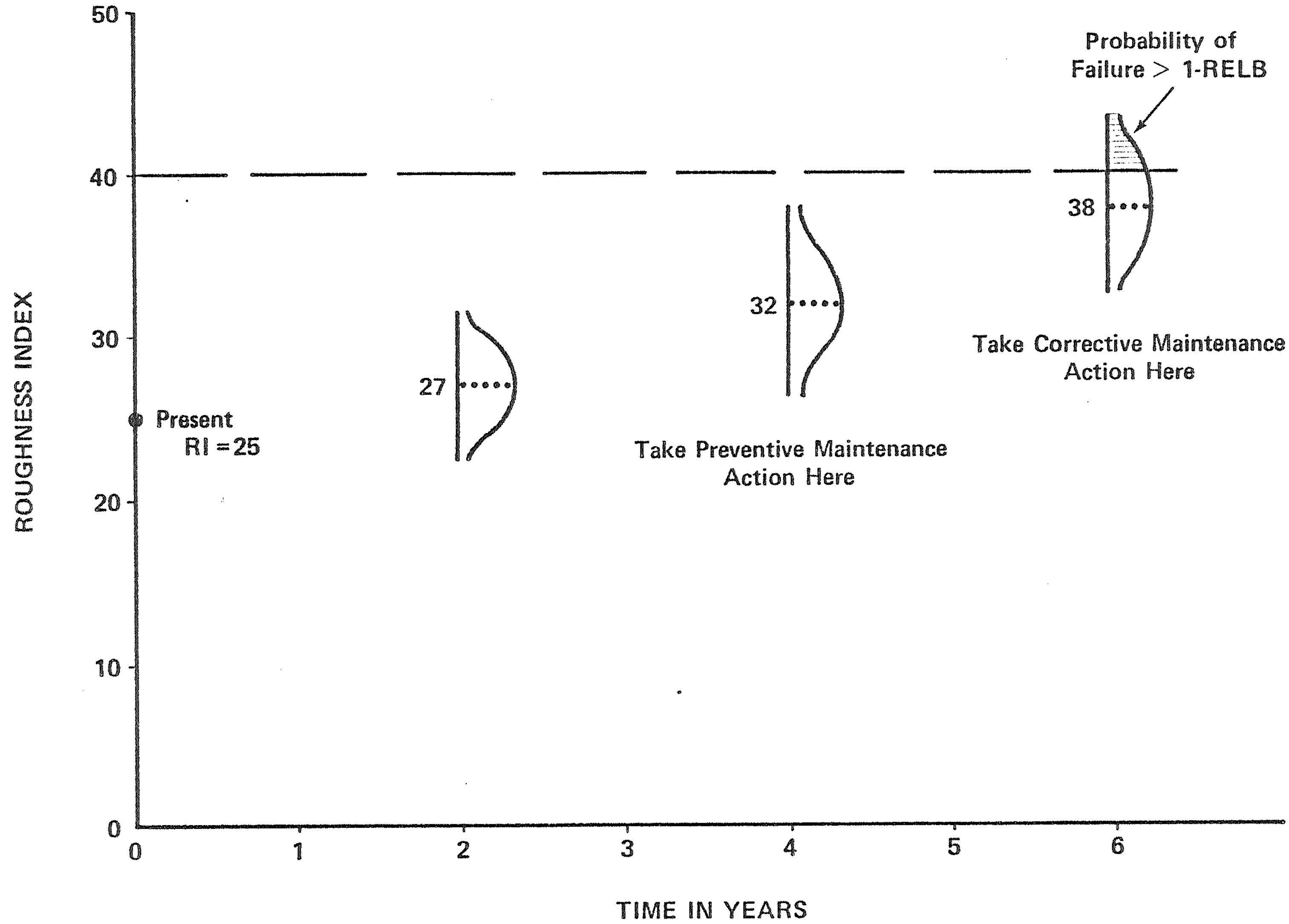

Figure 6. CONSIDERATION OF RELIABILITY IN SELECTING FEASIBLE MAINTENANCE STRATEGIES

central values of 27, 32, and 38 respectively. However, there is a chance that the value could be higher or lower than the expected value as indicated by the normal distribution curves at each time period. Thus, in 6 years there is, for example in Figure 6, a 30 percent chance that the roughness index would exceed 40. If a 70 percent reliability were specified, corrective maintenance would be required during the sixth year and preventive maintenance should be investigated at the fourth year for possible implementation in the fourth or fifth year. Thus, the level of reliability required would influence the final decision recommendation.

3.4 COST INFORMATION

Cost factors included in the pavement management system are:

1. Cost of new construction will be obtained from the SAMP 6 program developed under the National Cooperative Research Program which outputs construction costs for alternate pavement designs on a square yard basis which can be converted to a lane mile basis for input to the Arizona pavement management system.

   The SAMP 6 program provides a series of alternate designs based on the results of the AASHO Road Test. The pavement management system will project the selected optimum designs to Arizona conditions.

   The SAMP 6 program is currently operational on Arizona DOT computers with Arizona cost information.

2. Routine maintenance or those costs which are routinely scheduled in order to control the rate of deterioration and to keep the general level of serviceability above minimum levels. The amount of money required to maintain the roadway through routine maintenance will determine to a large degree when major maintenance will be required.

   The data base of information for routine maintenance could be the maintenance management system identified as PECOS. Discussion with the managers of this system indicate that additional controls and data processing will be required before the appropriate information can be obtained directly from PECOS.

As an interim procedure the Arizona DOT staff has developed an equation for estimating routine maintenance costs based on age and condition.

$$RM = -200 + 10 \times (\text{Roughness Index}) + 35 \times (\text{Age}) \qquad (4)$$

3. Costs of major maintenance are those costs related to overlays or such other betterments as are deemed appropriate to a major improvement in the condition of the pavement. Lane mile costs for various maintenance alternatives were provided by the Arizona DOT staff.

4. Salvage value was determined as a function of the remaining life at the end of the designated design or comparison period, usually 20 years although not limited to this period.

$$\text{Salvage values} = \frac{\text{Remaining life of last overlay}}{\text{Expected life of last overlay}} \times \begin{array}{l}\text{Cost of}\\ \text{last overlay}\end{array} \qquad (5)$$

Cost can be summarized in terms of their discounted present worth value or in terms of equivalent annual cost per lane mile. The latter value, which is simply an alternate way of expressing present worth, was used since the amounts are more easily perceived by the pavement manager. Thus, costs are calculated as follows:

$$\begin{aligned}\text{Present Worth Cost} = {} & \sum_i RM(i) \times DF(i) + \sum_j (\text{Cost of major maintenance at time } j) \times DF(j) \\ & - (\text{Salvage value at end of analysis period}) \times DF(n)\end{aligned}$$

$$\text{Equivalent Annual Cost} = (\text{Present Worth Cost}) \times (\text{Factor for Annual Cost})$$

where

$RM(i)$ = routine maintenance costs per lane mile during the i^{th} year

$DF(i)$ = discount factor for calculating present worth of money spent at i^{th} year.

3.5 DEVELOPMENT OF UTILITY FUNCTIONS

Most pavement management systems developed in the United States to date deal with a maximum of two attributes and are concerned only with actions based on limiting values of one of those attributes. Uncertainty has not been incorporated in any definitive way although the pavement management system developed for the Washington Highway Commission (1974) recognizes the existence of uncertainty. A typical system would be based on the attributes of cost and riding quality. The objective would be to determine the maintenance strategy which would keep the riding quality at or above the specified limiting value at the minimum cost. No consideration would be given to the level or trend of riding quality during the period prior to the time it reaches the limiting value or the uncertainty of predicting riding quality.

For the Arizona Pavement Management System it is necessary to simultaneously consider four attributes (multiple attributes) and to include uncertainty. In order to do this the Consultant has employed concepts developed in decision analysis theory (Raiffa, 1970) incorporating multiattribute utility functions.

Appendix B provides a detailed discussion of utility theory as applied to this investigation. Briefly, the procedure provides for the determination of a preference function or utility function which allows the history and uncertainty of a particular attribute to be summarized in a single utility value. Additionally, the procedure provides for combining the individual utilities for each attribute into a combined utility function using weighting coefficients determined by the techniques described in Appendix B.

Also, for a decision making problem involving multiple and sometimes conflicting attributes, for example, preference for better riding quality at some acceptable increase in cost, it is possible to establish how much the decision maker is willing to sacrifice in one attribute in order to achieve on some other attribute. These are termed as "trade-offs" between conflicting attributes and are also considered as part of the utility function.

The technique for obtaining utility functions was through an interview process with members of the Arizona DOT. The procedure and example questions used to obtain utility function are given in Appendix B.

Thus, the optimization for design and maintenance strategies is based on obtaining the maximum expected utility between alternate design and maintenance strategies.

3.6 DISCUSSION OF RESULTS

The pavement management system is represented by a computer program incorporating all of the concepts previously described. The computer program in this case is described by the acronym SOMSAC (Selection of Optimum Maintenance Strategies for Asphalt Concrete Pavements).

The user's manual for SOMSAC is provided in Appendix C which includes an example problem with all of the input and ouput information.

A parametric study of SOMSAC was conducted to find the sensitivity of the best maintenance strategy and its associated cost to the changes in the input parameters. A summary of this study for in-service pavements and for new designs is shown in Tables 1 and 2 respectively. The parameters changed in the case of in-service pavements were region, utility function, deflection, presence or absence of cracking, and limiting roughness index. For the new designs, region, utility function, and limiting roughness index were changed. The changes regarding region, deflection, cracking, and limiting roughness index are self-explanatory. A brief discussion of the two utility functions used in the parametric study is given below.

Table 1. SENSITIVITY OF THE BEST MAINTENANCE STRATEGY FOR IN-SERVICE PAVEMENTS

		REGION 1				REGION 3			
		Utility Function 1		Utility Function 2		Utility Function 1		Utility Function 2	
		Deflection		Deflection		Deflection		Deflection	
Limiting RI	Cracking	0.015 in.	0.03 in.	0.015 in.	0.03 in.	0.015 in.	0.03 in.	0.015 in.	0.03 in.
40	YES	11 Year Maint. Alt. 2 ACFC W-RC, WO-HS EAC = $711	12 Year Maint. Alt. 0 ACFC W-RC, WO-HS EAC = $880	13 Year Maint. Alt. 2 ACFC WO-RC, WO-HS 10 ACFC WO-RC, W-HS EAC = $678	14 Year Maint. Alt. 2 ACFC WO-RC, WO-HS 10 ACFC WO-RC, W-HS EAC = $718	15 Year Maint. Alt. 0 ACFC WO-RC, W-HS 8 ACFC W-RC, WO-HS 18 ACFC WO-RC, WO-HS EAC = $1238	16 Year Maint. Alt. 0 ACFC WO-RC, W-HS 8 ACFC WO-RC, W-HS 14 ACFC WO-RC, W-HS EAC = $1271	17 Year Maint. Alt. 0 ACFC WO-RC, W-HS 8 ACFC WO-RC, W-HS 16 ACFC WO-RC, WO-HS EAC = $1151	18 Year Maint. Alt. 0 ACFC WO-RC, W-HS 8 ACFC WO-RC, W-HS 14 ACFC WO-RC, W-HS EAC = $1271
	NO	21 Year Maint. Alt. 2 ACFC W-RC, WO-HS EAC = $711	22 Year Maint. Alt. 0 ACFC W-RC, WO-HS EAC = $880	23 Year Maint. Alt. 2 ACFC WO-RC, WO-HS 10 ACFC WO-RC, W-HS EAC = $678	24 Year Maint. Alt. 0 ACFC WO-RC, WO-HS 8 ACFC WO-RC, WO-HS 16 ACFC WO-RC, WO-HS EAC = $829	25 Year Maint. Alt. 0 ACFC WO-RC, W-HS 8 ACFC W-RC, WO-HS 18 ACFC WO-PC, WO-HS EAC = $1238	26 Year Maint. Alt. 0 ACFC WO-RC, W-HS 8 ACFC WO-RC, W-HS 14 ACFC WO-RC, W-HS EAC = $1271	27 Year Maint. Alt. 0 ACFC WO-RC, WO-HS 4 ACFC WO-RS, W-HS 14 ACFC WO-RC, W-HS EAC = $1094	28 Year Maint. Alt. 0 ACFC WO-RC, W-HS 8 ACFC WO-RC, W-HS 14 ACFC WO-RC, W-HS EAC = $1271
50	YES	31 Year Maint. Alt. 4 ACFC WO-RC, W-HS EAC = $626	32 Year Maint. Alt. 2 ACFC WO-RC, W-HS EAC = $737	33 Year Maint. Alt. 4 ACFC WO-RC, W-HS EAC = $626	34 Year Maint. Alt. 2 ACFC WO-RC, WO-HS 10 ACFC WO-RC, W-HS EAC = $670	35 Year Maint. Alt. 0 ACFC WO-RC, W-HS 10 ACFC WO-RC, W-HS EAC = $968	36 Year Maint. Alt. 0 ACFC WO-RC, W-HS 8 ACFC WO-RC, WO-HS 12 ACFC WO-RC, W-HS EAC = $1178	37 Year Maint. Alt. 0 ACFC WO-RC, W-HS 12 ACFC WO-RC, W-HS EAC = $910	38 Year Maint. Alt. 0 ACFC WO-RC, W-HS 10 ACFC W-RC, WO-HS EAC = $1040
	NO	41 Year Maint. Alt. 4 ACFC WO-RC, W-HS EAC = $626	42 Year Maint. Alt. 2 ACFC WO-RC, W-HS EAC = $737	43 Year Maint. Alt. 4 ACFC WO-RC, W-HS EAC = $626	44 Year Maint. Alt. 2 ACFC WO-RC, WO-HS 12 ACFC WO-RC, W-HS EAC = $670	45 Year Maint. Alt. 0 ACFC WO-RC, W-HS 10 ACFC WO-RC, W-HS EAC = $968	46 Year Maint. Alt. 0 ACFC WO-RC, W-HS 8 ACFC WO-RC, WO-HS 12 ACIC WO-RC, W-HS EAC = $1178	47 Year Maint. Alt. 0 ACFC WO-RC, W-HS 12 ACFC WO-RC, W-HS EAC = $910	48 Year Maint. Alt. 0 ACFC WO-RC, W-HS 10 ACFC W-RC, WO-HS EAC = $1040

Table 2. SENSITIVITY OF THE BEST INITIAL DESIGN AND MAINTENANCE STRATEGY FOR NEW CONSTRUCTION

<table>
<tr><th rowspan="2">Limiting RI</th><th colspan="2">Region 1</th><th colspan="2">Region 3</th></tr>
<tr><th>Utility Function 1</th><th>Utility Function 2</th><th>Utility Function 1</th><th>Utility Function 2</th></tr>
<tr><td>40</td>
<td>11

<u>Year</u> <u>Maint. Alt.</u>
0 Initial design - full depth
8 ACFC WO-RC, W-HS

EAC = $4383</td>
<td>12

<u>Year</u> <u>Maint. Alt.</u>
0 Initial design - full depth
6 ACFC WO-RC, WO-HS
14 ACFC WO-RC, WO-HS

EAC = $4494</td>
<td>13

<u>Year</u> <u>Maint. Alt.</u>
0 Initial design - full depth
4 ACFC W-RC, WO-HS
14 ACFC WO-RC, W-HS

EAC = $4936</td>
<td>14

<u>Year</u> <u>Maint. Alt.</u>
0 Initial design - full depth
4 ACFC WO-RC, W-HS
14 ACFC WO-RC, W-HS

EAC = $4787</td></tr>
<tr><td>50</td>
<td>21

<u>Year</u> <u>Maint. Alt.</u>
0 Initial design - full depth
8 ACFC WO-RC, W-HS

EAC = $4330</td>
<td>22

<u>Year</u> <u>Maint. Alt.</u>
0 Initial design - full depth
8 ACFC WO-RC, W-HS

EAC = $4330</td>
<td>23

<u>Year</u> <u>Maint. Alt.</u>
0 Initial design - full depth
4 ACFC WO-RC, W-HS
12 ACFC WO-RC, W-HS

EAC = $4800</td>
<td>24

<u>Year</u> <u>Maint. Alt.</u>
0 Initial design - full depth
4 ACFC WO-RC, W-HS
12 ACFC WO-RC, W-HS

EAC = $4800</td></tr>
</table>

From the interviews with the district engineers and headquarters personnel, two significantly different sets of preferences were obtained. One preference set represented by utility function 1 indicated that the order of decreasing relative importance of the four attributes included in the system was: skid number, roughness index (or present serviceability index PSI), cost, and traffic delay. The district engineer with this preference structure would be willing to pay $9700 per year per lane-mile in order to improve the skid number from 25 to 45 and the same amount of money to improve the PSI from 2 to 3.8.

The second preference set represented by utility function 2 indicated that the order of decreasing relative importance of the attributes was: cost, skid number, roughness index, and traffic delay. In this case the district engineer would be willing to pay $9500 per year per lane-mile only if the skid number improved from 25 to 100 and he would pay up to $3000 per year per lane-mile to improve the PSI from 2 to 4.

The mathematical equations for these two utility functions are given in Appendix B. It is clear that the two functions represent significantly different views. The question whether these functions should be modified and which function should be used under what conditions must be resolved at the management level during implementation phase. The objective of the parametric study was to find how sensitive the best maintenance strategy would be to the choice of the utility function.

The notation used in Tables 1 and 2 is the following. Each box in the table represents a particular combination of the input parameters. A number in the left hand top corner in each box identifies the row and column of the box; for example, the box "ij" is in the "i^{th}" row and in the "j^{th}" column. In each box the best maintenance strategy is described and the equivalent annual cost (EAC) in dollars per lane-mile is indicated. A maintenance strategy consists of up to 3 maintenance alternatives adopted at different years from the start of the analysis. The time and type of each maintenance alternative are written in describing the best maintenance strategy. The maintenance alternative ACFC can be applied with or without rubber coat (RC) and with or without heat scarifier (HS); for example, the description "ACFC W-RC, WO-HS" indicates ACFC with rubber coat, but without heat scarifier. With regard to cracking, if cracking is observed at the present time the program would eliminate any maintenance alternative which did not have some provision for correcting the cracking condition. For this analysis, ACFC without rubber coat and without heat scarifier would not be scheduled at time zero if signficant cracking was observed.

The input parameters other than region, utility function, deflection, cracking, and limiting roughness index were fixed for the examples of the parametric study. A part of the computer output describing all the input data is shown in Figure 7.

The discussion of the results of the parametric study is divided into two parts, the first regarding in-service pavements (Table 1) and the second regarding new construction (Table 2). The following comments are pertinent with respect to the results shown in Table 1:

1. Region has a significant influence on the best maintenance strategy. Generally speaking, pavement condition deteriorates faster in Region 3 (elevation greater than 5000 ft and swelling clay) than in Region 1 (elevation less than 5000 ft). This necessitates more frequent major maintenance activities in Region 3 resulting in higher costs. As an example, compare results in boxes 21 and 25. Both have the same limiting roughness index (RI), cracking condition, deflection, and the same utility function. However, for box 21 associated with Region 1 the best maintenance strategy consists of only one action, namely ACFC with rubber coat and with heat scarifier at year 2 since the start of the analysis; the equivalent annual cost of this strategy is $711 per lane-mile. On the other hand, for box 25 associated with Region 3 the best maintenance strategy consists of 3 actions: ACFC without rubber coat, with

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PROBLEM NO. 1 - STATE OF ARIZONA - DEPARTMENT OF TRANSPORTATION - EXAMPLE NO. 1                    PAGE 1

CONTROL PARAMETERS

          NUMBER OF PERIODS IN THE ANALYSIS -----------------------------------   10
          NUMBER OF FEASIBLE INITIAL DESIGNS ----------------------------------    0
          NUMBER OF MAINTENANCE ALTERNATIVES ----------------------------------   10
          OPTION OF PRINTING INPUT DATA ONLY ----------------------------------    1
                    (0= PRINT INPUT DATA ONLY)
                    (1= EXECUTE THE PROGRAM)
          LIMITING VALUE OF RI ------------------------------------------------ 40.0
          LIMITING VALUE OF SN ------------------------------------------------ 43.0
          RELIABILITY FACTOR FOR NOT EXCEEDING THE LIMITING RI VALUE ----------  .842
          RELIABILITY FACTOR FOR NOT EXCEEDING THE LIMITING SN VALUE ---------- 1.282
          INDICATOR FOR NEW DESIGN --------------------------------------------    1
                    (0= NEW DESIGN OF PAVEMENT)
                    (1= IN-SERVICE PAVEMENT)
          NUMBER OF ALTERNATIVES TO BE ELIMINATED -----------------------------    0

DESCRIPTION OF MAINTENANCE ALTERNATIVES

          ALTERNATIVE NO. 1 : ROUTINE MAINTENANCE
          ALTERNATIVE NO. 2 : ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER
          ALTERNATIVE NO. 3 : ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
          ALTERNATIVE NO. 4 : ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
          ALTERNATIVE NO. 5 : 1 IN OVLAY + ACFC WITHOUT RUBBER COAT,WITHOUT HEAT SCARIFIER
          ALTERNATIVE NO. 6 : 1 IN OVLAY + ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
          ALTERNATIVE NO. 7 : 1 IN OVLAY + ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
          ALTERNATIVE NO. 8 : 3 IN OVLAY + ACFC WITHOUT RUBBER COAT,WITHOUT HEAT SCARIFIER
          ALTERNATIVE NO. 9 : 3 IN OVLAY + ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
          ALTERNATIVE NO.10 : 3 IN OVLAY + ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
```

Figure 7. INPUT DATA

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PROBLEM NO. 1 - STATE OF ARIZONA - DEPARTMENT OF TRANSPORTATION - EXAMPLE NO. 1                    PAGE 2

INFORMATION PERTINENT TO GIVEN PAVEMENT SECTION
          INDICATOR FOR PRESENCE OR ABSENCE OF ACFC ----------------------------    1
                        (0= WITH ACFC)
                        (1= WITHOUT ACFC)
          INDICATOR FOR CRACKING ----------------------------------------------    0
                        (0= NO CRACKING)
                        (1= CRACKING)
          INDICATOR FOR USING CHIP SEAL ---------------------------------------    0
                        (0= CHIP SEAL NOT TO BE USED)
                        (1= CHIP SEAL TO BE USED)
          AGGREGATE TYPE IN PRESENT CONDITION ---------------------------------  1.0
                        (1= BASALT OR CINDERS)
                        (2= GRAVEL)
                        (3= LIMESTONE)
          AGGREGATE TYPE TO BE USED IN FUTURE ACFC ----------------------------  1.0
                        (CODE SAME AS PRESENT--ABOVE)
          PAVEMENT AGE IN YEARS AT PRESENT TIME -------------------------------  8.0
          ENVIRONMENTAL REGION OF GIVEN PAVEMENT SECTION ----------------------  1.0
                        (1= LOW ALTITUDE, LOW RAINFALL)
                        (2= HIGH ALTITUDE, HIGH RAINFALL, NO SWELLING CLAY)
                        (3= HIGH ALTITUDE, HIGH RAINFALL, SWELLING CLAY)
          PRESENT DEFLECTION (IN INCHES) OF THE PAVEMENT SECTION --------------  .0150
          PRESENT RI(ROUGHNESS INDEX) OF THE PAVEMENT SECTION -----------------  27.0
          PRESENT SN(SKID NO.) OF THE PAVEMENT SECTION ------------------------  55.0

OVERLAY THICKNESS
          MAINT. ALT.   THICKNESS(INCHES)
               2              .750
               3              .750
               4              .750
               5             1.000
               6             1.000
               7             1.000
               8             3.000
               9             3.000
              10             3.000
```

Figure 7. (Cont.)

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PROBLEM NO.  1 - STATE OF ARIZONA - DEPARTMENT OF TRANSPORTATION - EXAMPLE NO. 1                                PAGE   3

PREDICTION MODELS

   1) CHANGE IN RI FOR NEW OR IN-SERVICE PAVEMENTS-
       LN(CRI) = C11 + C12 * LN(TRAFFIC) + C13 * LN(REGION) + C14 * LN(DEFLECTION) + C15 * LN(AGE)
       REGRESSION COEFFICIENTS  C11=  1.6600 C12=   .1900 C13=   .8820 C14=   .6960 C15=   .4220
       STANDARD ERROR=   .2120

   2) CHANGE IN RI FOLLOWING AN OVERLAY-
       LN(CRI) = CRH + C21 + C22 * LN(TRAFFIC) + C23 * LN(REGION) + C24 * LN(DEFLECTION) + C25 * LN(THICKNESS) + C26 * LN(AGE)
       REGRESSION COEFFICIENTS(EXCLUDING CRH)  C21=  1.2740 C22=   .0718 C23=   .8744 C24=   .3281 C25=   .0375 C26=   .4618
       STANDARD ERROR=   .2206
       CRH ARE CORRECTION FACTORS INDICATING EFFECT OF RUBBER COAT OR HEAT SCARIFIER ON PAVEMENT PERFORMANCE
       CORRECTION FACTORS (CRH) FOR GIVEN OVERLAYS
       MAINT. ALT.          CRH
             2              1.00
             3               .40
             4               .25
             5              1.00
             6               .50
             7               .33
             8              1.00
             9               .50
            10               .33

   3) CHANGE IN SN FOR NEW OR IN-SERVICE PAVEMENT-
       LN(CSN) = B11 + B12 * LN(TRAFFIC) + B13 * LN(REGION) + B14 * LN(AGG. TYPE) + B15 * LN(AGE)
       REGRESSION COEFFICIENTS  B11=  1.9720 B12=   .1007 B13=   .1147 B14=   .9393 B15= -1.4590
       STANDARD ERROR=   .2198

   4) CHANGE IN SN FOLLOWING ACFC-
       LN(CSN) = B21 + B22 * LN(TRAFFIC) + B23 * LN(REGION) + B24 * LN(AGG. TYPE) + B25 * LN(AGE)
       REGRESSION COEFFICIENTS  B21=  1.9420 B22=   .0594 B23=   .0294 B24=   .0649 B25= -1.0050
       STANDARD ERROR=   .3040

   5) RI IMMEDIATELY AFTER AN OVERLAY-
       LN(RIA) = XC0 + XC1 * LN(RIB) + XC2 * LN(T)
       REGRESSION COEFFICIENTS  XC0=  1.6280 XC1=   .3090 XC2=  -.2370
       STANDARD ERROR=   .0990
```

Figure 7. (Cont.)

PREDICTION MODELS - CONTINUED

6) SN IMMEDIATELY AFTER ACFC-
AVERAGE SN IMMEDIATELY AFTER ACFC= 80.0
STANDARD DEVIATION OF SN IMMEDIATELY AFTER ACFC= 3.333

7) REDUCTION IN DEFLECTION FOLLOWING MAJOR MAINTENANCE-

MAINT. ALT.	PERCENTAGE REDUCTION IN DEFLECTION
2	0
3	0
4	0
5	10.0
6	10.0
7	10.0
8	20.0
9	20.0
10	20.0

8) TRAFFIC DELAY DURING MAJOR MAINTENANCE OPERATIONS-

MAINT. ALT.	AVERAGE TRAFFIC DELAY IN MINUTES
2	7.0
3	7.0
4	7.0
5	7.0
6	7.0
7	7.0
8	7.0
9	7.0
10	7.0

COEFFICIENT OF VARIATION OF TRAFFIC DELAY= .1000

Figure 7. (Cont.)

PROBLEM NO. 1 - STATE OF ARIZONA - DEPARTMENT OF TRANSPORTATION - EXAMPLE NO. 1 PAGE 5

ROUTINE MAINTENANCE COSTS-

COSTS FOR ROUTINE MAINTENANCE ARE DERIVED FROM THE FOLLOWING FUNCTION-

RMCOST = -200.0 + 10.0 * RI + 35.0 * AGE

MAJOR MAINTENANCE COST

MAINT. ALT.	MAINT. COST
2	5632.00
3	8448.00
4	11733.00
5	12766.00
6	15582.00
7	18867.00
8	27034.00
9	29850.00
10	33135.00

COEFFICIENT OF VARIATION OF COST= .1000

EFFECTIVE INTEREST RATE= 0

TRAFFIC INFORMATION

AVERAGE ANNUAL TRAFFIC DURING FIRST YEAR OF ANALYSIS= 182500.00

ANNUAL TRAFFIC GROWTH RATE(IN PERCENT)= 5.00

Figure 7. (Cont.)

heat scarifier at year 0; ACFC with rubber coat, without heat scarifier at year 8; and ACFC without rubber coat, without heat scarifier at year 18. The cost of this strategy is $1238 per lane-mile, an increase of 74% over the cost of the first strategy.

2. The deflection of a pavement has a significant effect on its performance and hence on the selection of the best maintenance strategy. A higher deflection implies a weaker pavement and a higher rate of deterioration. This would necessitate more expensive maintenance and/or more frequent maintenance. Compare boxes 23 and 24 for illustrating this point. Both boxes have the same inputs except for deflection. The best strategy for box 23 with a deflection of 0.015 in. consists of two actions: ACFC without rubber coat, without heat scarifier at year 2 and ACFC without rubber coat, with heat scarifier at year 10. The cost of this strategy is $678 per lane-mile. On the other hand, the best strategy for box 24 with a deflection of 0.03 in. consists of three actions: ACFC without rubber coat, without heat scarifier at year 0; ACFC without rubber coat, without heat scarifier at year 8; and ACFC without rubber coat and without heat scarifier at year 16. The cost of this strategy is $829 per lane-mile which is 22% higher than that of the previous strategy.

3. The choice of the utility function seems to have some influence on the best maintenance strategy. As discussed earlier, utility function 1 implies relatively higher weights on skid number and roughness index than on cost. With the assumption of this utility function one would be willing to pay relatively large amounts of money to improve skid number or roughness index from the least desirable value to some acceptable but probably not most desirable value. Utility function 2 on the other hand assigns relatively higher weight to cost than to skid number or roughness index; this utility function would require improving pavement condition from least desirable to most desirable for relatively smaller amounts of money. To illustrate the effect of choice of the utility function on the best maintenance strategy, consider boxes 21 and 23 which have the same inputs except for the utility function. For box 21 with utility function 1 the best maintenance strategy is ACFC with rubber coat but without heat scarifier and the cost of this strategy is $711 per lane-mile. With

utility function 2, one would prefer a strategy with significant reduction in cost even though this would make pavement condition somewhat worse. Because of this consideration the best maintenance strategy for box 23 with utility function 2 indicates ACFC without rubber coat and without heat scarifier at year 2 and ACFC without rubber coat, with heat scarifier at year 10; the cost of this strategy is $678 per lane-mile which is 5% lower than the previous one.

4. The limiting value of roughness index has a significant effect on the selection of the best maintenance strategy. This effect is due to the fact that if somewhat higher values of roughness index are permissible, several strategies with somewhat lower costs would become feasible, which in the case of higher maintenance standards would not have been generated by the program. To illustrate this point, consider boxes 11 and 31 which have the same inputs except for the limiting roughness index. The best maintenance strategy in box 11 requires more expensive maintenance, namely ACFC with rubber coat at year 2. On the other hand the best maintenance strategy in box 31 with higher limiting roughness index allows less expensive maintenance, namely ACFC without rubber coat but with heat scarifier at a later time (year 4). The cost reduction because of allowing higher roughness on the road is about 12%. The cost reduction is even more prominent in Region 3. For example, there is a 22% cost reduction from the best maintenance strategy in box 15 to that in box 35.

5. Whether or not cracking is present does not seem to have any significant effect on the selection of the best maintenance strategy. The reason is that irrespective of presence or absence of cracking, an ACFC with either rubber coat or heat scarifier appears to be favored at year 0 over an ACFC without either of these features. Since a rubber coat or a heat scarifier would have some corrective action with regard to cracking, a maintenance action with either of these features would be permissible even in case of cracking.

6. An observation of some significance from Table 1 is that if a higher maintenance standard is desired (limiting RI = 40) and if a higher weight is put on roughness index than on cost (utility function 1), a rubber coat is favored over a heat scarifier, while the opposite is true under other conditions. For example, an

ACFC with rubber coat is selected in boxes 11, 12, 21, and 22; an ACFC with heat scarifier is selected in boxes 31, 32, 41, and 42.

The following observations can be made from the results of the parametric study shown in Table 2:

1. The full depth initial design is consistently selected as a part of the best strategy. The comparison between the full depth design and the conventional design as used in the illustrative example shows that the full depth design is weaker (deflection of 0.024 in. as against 0.015 in. for the conventional design), but cheaper (cost of $78,220 as against $93,166 for the conventional design). Thus, even though the conventional design performs better, the full depth design with one or two relatively inexpensive ACFC's can provide similar performance with less cost.
2. In Region 3 where the rate of pavement deterioration is much higher, an early major maintenance is required following the full depth construction. The best early major maintenance would be an ACFC with a rubber membrane (see box 13) if a high standard is to be maintained (limiting RI = 40) and if the relative weight on pavement condition is higher than that on cost (utility function 1). Under other conditions, an ACFC with heat scarifier is favored.

4.0 IMPLEMENTATION

The practical application of the pavement management system is the development of a systematic procedure for arriving at design and maintenance procedures which will meet specific objectives of the Arizona Department of Transportation management level personnel.

The findings of this investigation indicate the applicability of certain principals of decision theory which have not as yet been used in management systems and which provide for the inclusion of multiple attributes used to optimize the decision recommendations.

The computer programs developed under the investigation provide a framework for incorporating current data acquisition procedures being implemented by the state and can provide guidelines as to when and where measurements should be made.

The benefits to be achieved by implementing the system should be reflected in the optimum use of available funds for the design and maintenance of individual projects and will provide the basis for a network system designed to allocate funds according to the greatest need.

Appendix D provides a recommended program for implementation to field applications and includes a description of a series of tasks necessary for the second stage investigation.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the progress made in this phase of the investigation it is concluded that a pavement management system can be developed for the Arizona Department of Transportation which will incorporate the desired attributes and operating preferences of the decision makers within the organization.

It is too soon to indicate what problems might occur in the implementation phase; however, it is considered that some adjustments may be required in the prediction models and in the evaluation of the impact of user inconvenience to the decision recommendations; that is, how to evaluate the interference to traffic flow due to maintenance operations.

The pavement management system, as proposed, deals with project-by-project decisions; that is, assuming funds are available, what is the optimum sequence of decisions appropriate to the design and maintenance of a pavement? The project does not deal with network optimization which would address the problem of allocation of limited funds to those projects requiring some type of major maintenance or betterment.

It is recommended that a second and third phase program be initiated. The second phase would be to test the implementability of the system described under this investigation. Only a limited amount of progress and evaluation can be achieved without field application. The third phase is the development of a framework for network optimization. If at all possible these programs should overlap somewhat in order to assure compatability of each system.

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APPENDIX A

DEVELOPMENT OF PREDICTION MODELS FOR PAVEMENT CONDITION

INTRODUCTION

In order to evaluate alternative maintenance strategies it is necessary to predict the effect of each strategy on pavement condition measured in terms of skid number and roughness index. Typically, prediction models are developed by assuming some analytical model and estimating the parameters of such a model from observed field data. Alternative models are attempted and one giving the best fit to the data is generally adopted. Such an approach could not be utilized for this project because very little "objective" data in terms of field observations was available.

The difficulty with the current data bank is the relatively limited period over which information has been collected and not the type of information being collected. It can be expected that, with time, the data bank will provide all of the information needed by the pavement management system.

As an alternative to the present situation, it was decided to develop "subjective" data from the experience and judgment of the pavement engineers from Arizona DOT. Use of subjective information in statistical analysis is quite valid. This is generally termed as the Bayesian statistical approach. Because of the time constraints, it was necessary to use a procedure which would be easily understood by the engineers and could be implemented in a relatively short amount of time. Because of these reasons, it was decided to assess subjective information in the form of pavement performance curves since engineers would be most familiar with how pavements would perform under different conditions. From the performance curves subjective data points can be generated by using some simulation procedure. The details regarding assessment of subjective information in the form of performance curves, generation of subjective data through simulation, and use of subjective data in multiple regression analyses are given in the following sections.

ASSESSMENT OF SUBJECTIVE INFORMATION

The procedure used for assessing subjective information regarding skid number and roughness index is described below.

As a first step, the factors which would affect the changes in skid number and roughness index of a pavement were determined in consultation with the Arizona DOT staff. These factors for new construction and major maintenance for asphalt concrete (AC) pavements are shown below.

Dependent Variable	Independent Variables
Change in RI following new construction	Traffic, environmental region, deflection, age
Change in RI following major maintenance	Traffic, environmental region, deflection, overlay thickness, age
RI immediately after major maintenance	RI prior to major maintenance, overlay thickness
Change in SN following new construction or major maintenance	Traffic, environmental region, aggregate type, age
SN immediately after ACFC	Aggregate type

In the above list, region was taken to represent environmental variables (rainfall, climate, swelling of clay, etc.) and deflection was assumed as a proxy variable for pavement strength. Three regions were selected:

Region 1, low altitude ($\leq$ 5000 ft); Region 2, high altitude (> 5000 ft), no swelling clay; and Region 3, high altitude (> 5000 ft), swelling clay.

Subjective information was assessed in the form of performance curves for different combinations of the independent variables for the following maintenance alternatives: new construction, chip seal, ACFC, 1 in. overlay + ACFC, 3 in. overlay + ACFC, and 6 in. overlay + ACFC. The ACFC was considered without rubber coat and heat scarifier. Information regarding benefits of a rubber coat and a heat scarifier was asked separately which is described later in this section. Twelve different combinations of region, traffic, and deflection were selected for each maintenance alternative (see Figure A-1). For each combination, the assessor (the pavement engineer) was asked to sketch the curve of how the roughness index of a pavement with the given independent variables and a given initial condition would vary with time. The engineer was also asked to specify the limiting RI value and the time in years when the pavement would reach the limiting value. Because of the uncertainties in material properties, traffic, and environmental conditions, exact prediction of how a pavement would perform is generally not possible. This uncertainty in pavement performance must be recognized in assessing subjective information. In view of the uncertainty, the assessors were asked to given their pessimistic, optimistic, and most expected estimates of pavement life. With the assumption of normal distribution, this range corresponds to (mean $\pm$ 3 standard deviations). Since the assessors were quite familiar with the concepts of mean m and standard deviation σ in a normal distribution, they were able to specify the range ($m \pm 3\sigma$) in accordance with their perception of the uncertainties involved. With regard to skid number, combinations of traffic, region, and aggregate type were considered. Three types of aggregate were included: aggregate 1, basalt or cinders; aggregate 2, gravel; and aggregate 3, limestone. A typical form for specifying performance curves is shown in Figure A-2.

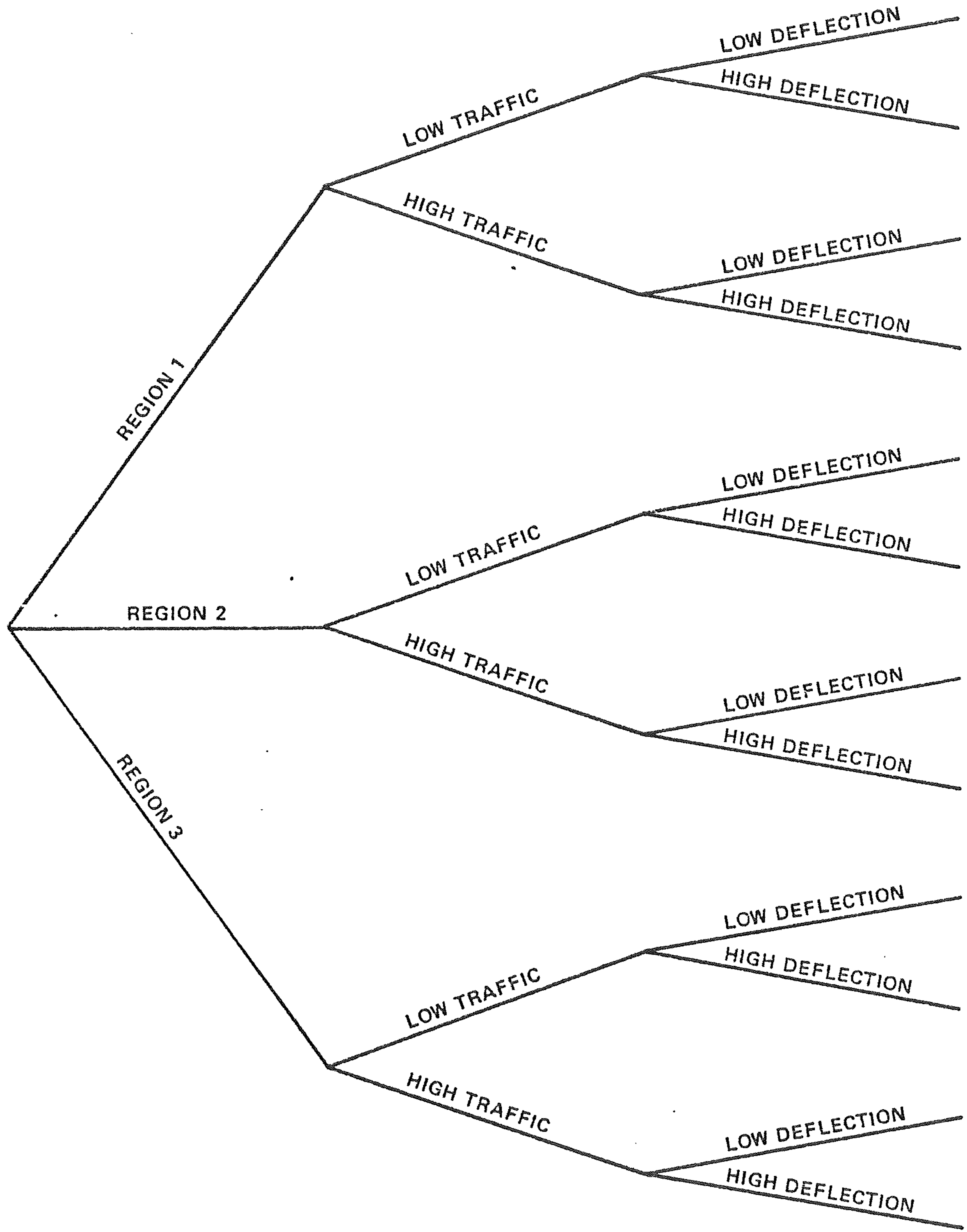


Figure A-1. PARAMETERS SPECIFIED IN ASSESSING PAVEMENT PERFORMANCE

Region = Traffic = Current Deflection =

Age = Current RI =

On the following graph

- indicate which curve most appropriately describes the performance trend
- indicate the year when the limiting value would be reached

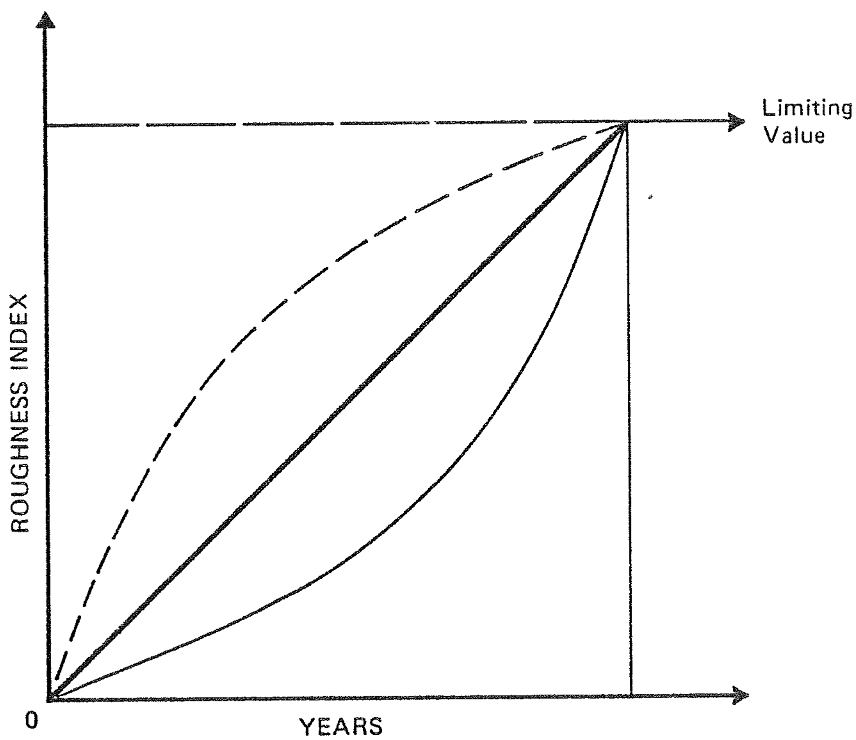


Figure A-2. A TYPICAL FORM FOR THE SPECIFICATION OF PERFORMANCE CURVE

In addition to the performance curves, information regarding pavement condition immediately following major maintenance was also obtained. For roughness index and skid number the information required is indicated in Figure A-3. For different major maintenance alternatives and for different prior conditions under each alternative, responses regarding posterior roughness index were obtained (see Figure A-4). Similarly, mean and standard deviation of skid numbers immediately following ACFC or seal coat with different aggregate types were also obtained from the assessors.

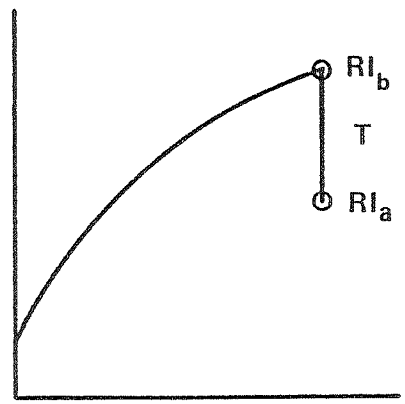
Use of all this information obtained from the Arizona DOT staff in generating subjective data points is described in the next section.

GENERATION OF SUBJECTIVE DATA THROUGH SIMULATION

In the previous step, performance curves were obtained for different combinations of appropriate independent variables. Next, six hypothetical pavements were selected with the given values of the independent variables. Performance of each pavement was determined from the assessed subjective information and performance data was then generated for that pavement. Because of the uncertainties indicated by the range of pavement life, all the six pavements with the same properties might not perform in an identical manner. A simple Monte Carlo simulation procedure was used to determine which performance path a given pavement would follow (see Figure A-5). A random number from a normal distribution with mean zero and standard deviation 1 was generated for each pavement. If this number was between -1 and -3, the pavement was assumed to have a life of $(m - 2\sigma)$; if the random number was between -1 and 1, the mean (expected) pavement life was assumed; and if the number was between 1 and 3, a pavement life of $(m + 2\sigma)$ was assumed.

After the appropriate performance curve was determined, the curve was drawn on graph paper showing the relationship between the dependent

(I) Roughness Index Immediately Following Major Maintenance



$RI_a = f\,(RI_b, T)$

RI_b = roughness index prior to major maintenance

RI_a = roughness index immediately following major maintenance

T = thickness of given major maintenance

Figure A-3. SUBJECTIVE INFORMATION ON PAVEMENT CONDITION IMMEDIATELY FOLLOWING MAJOR MAINTENANCE

(II) Skid Number Immediately Following ACFC or Seal Coat

SNA = average skid number immediately following ACFC or seal coat

SNSD = standard deviation of skid number immediately following ACFC or seal coat

(SNA, SNSD) = f (aggregate type)

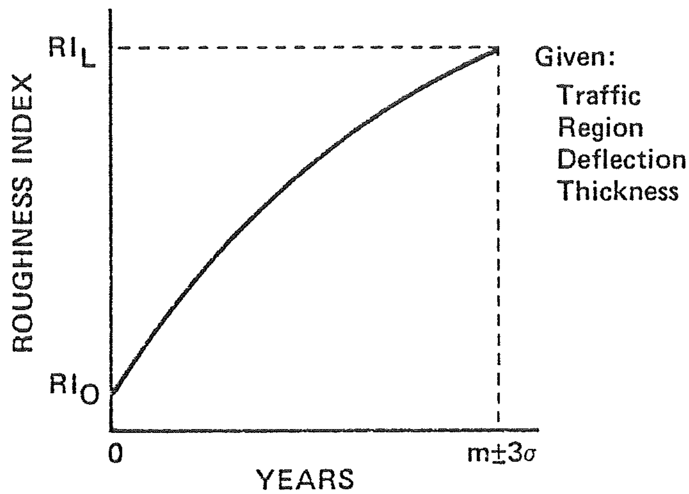
Figure A-3. SUBJECTIVE INFORMATION ON PAVEMENT CONDITION IMMEDIATELY FOLLOWING MAJOR MAINTENANCE (Continued)

AC PAVEMENTS (Major Maintenance on Existing Pavements)

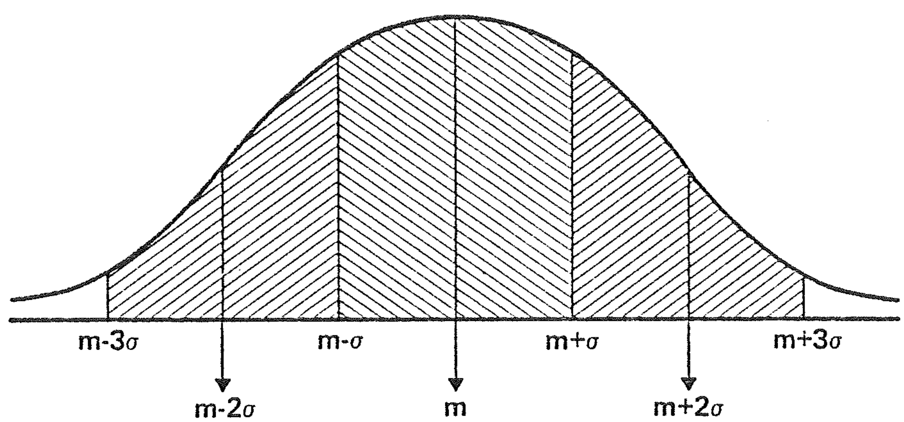
Indicate the effect of a given type of major maintenance on roughness index in the following table

Type of Major Maintenance	RI Prior to Major Maintenance	RI immediately after Major Maintenance
1. ACFC without rubber coat, without heat scarifier	0 – 10	
	10 – 20	
	20 – 30	
	30 – 40	
	40 – 50	
2. 1" overlay, plus ACFC without rubber coat, without heat scarifier	0 – 10	
	10 – 20	
	20 – 30	
	30 – 40	
	40 – 50	
3. 3" overlay, plus ACFC without rubber coat, without heat scarifier	0 – 10	
	10 – 20	
	20 – 30	
	30 – 40	
	40 – 50	
4. 6" overlay, plus ACFC without rubber coat, without heat scarifier	0 – 10	
	10 – 20	
	20 – 30	
	30 – 40	
	40 – 50	

Figure A-4. A TYPICAL FORM FOR SPECIFYING SUBJECTIVE INFORMATION REGARDING PAVEMENT CONDITION IMMEDIATELY AFTER MAJOR MAINTENANCE



RESPONSE FROM ARIZONA DOT STAFF



MONTE CARLO SIMULATION FOR HANDLING UNCERTAINTY

Figure A-5. USE OF SUBJECTIVE INFORMATION IN THE SIMULATION SCHEME variable (roughness index or skid number) and time in years. Points were then selected from this curve for the change in roughness index or skid number every two years (see Figure A-6). The change in the variable rather than the absolute value was selected as the dependent variable so as to reduce autocorrelations between successive values of the dependent variable. The selection of a unit time period of two years (instead of, say, one year) was predicated on the assumption that changes in roughness index or skid number (SN) in two years would be significant and show a reliable trend.

The above procedure was used for all the six hypothetical pavements for a given combination of independent variables. This was then repeated for every combination of independent variables for which performance curves were assessed. After all the subjective data points were generated, these were tabulated in a format suitable for multiple regression analysis. Discussion regarding results of regression analysis is given in the next section.

USE OF PERFORMANCE DATA IN MULTIPLE REGRESSION ANALYSES

Using the procedure outlined in the previous section, data points were generated for the following cases:

Dependent Variable	Independent Variables	Number of Data Points
Change in RI for new or in-service pavement	Region, deflection, traffic, age	283
Change in RI following major maintenance	Region, deflection, traffic, overlay thickness, age	1037
Change in SN for in-service pavement without ACFC	Region, age, traffic, aggregate type	352
Change in SN following ACFC or chip seal	Region, age, traffic, aggregate type	519

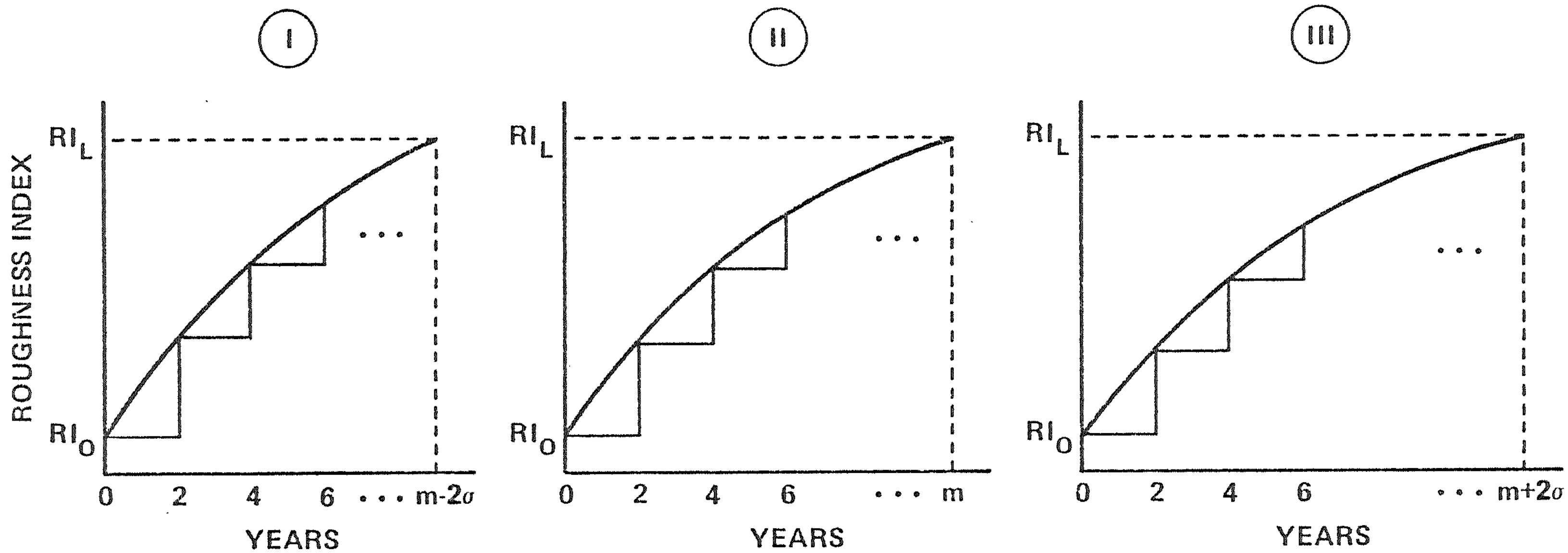


Figure A-6. GENERATION OF DATA ON CHANGE IN ROUGHNESS INDEX

It should be noted that only one equation was developed for change in SN following ACFC or chip seal. The reason for this was that the assessed performance curves for skid number following the two maintenance alternatives, namely ACFC and chip seal, were quite similar. With regard to traffic, average traffic at the middle year during any given time period of two years was used.

Different forms of regression equations were tried until sufficient predictive accuracy as indicated by multiple correlation coefficient and standard error was obtained. After a particular form was selected, outliers were examined and some of them were eliminated. The final regression equations developed for the four dependent variables shown earlier are as follows:

(1) change in RI (CRI) for new or in-service pavement

$$\ln(CRI) = 1.66 + 0.882 \ln(RGN) + 0.696 \ln(DEFL) + 0.19 \ln(TRAF) + 0.422 \ln(AGE)$$

$R^2 = 0.838$ Standard Error = 0.212

(2) change in RI following major maintenance

$$\ln(CRI) = 1.274 + \ln(CRH) + 0.874 \ln(RGN) + 0.328 \ln(DEFL) + 0.0718 \ln(TRAF) - 0.0375 \ln(THIK) + 0.4618 \ln(AGE)$$

$R^2 = 0.76$ Standard Error = 0.221

The significance of the variable CRH is explained later.

(3) Change in SN for in-service pavement without ACFC

$$\ln(CSN) = 1.972 + 0.1147 \ln(RGN) - 1.459 \ln(AGE) + 0.101 \ln(TRAF) + 0.9393 \ln(AGT)$$

$R^2 = 0.91$ Standard Error = 0.2198

(4) Change in SN following ACFC or chip seal

$$\ln(CSN) = 1.942 + 0.294 \ln(RGN) - 1.005 \ln(AGE) + 0.0594 \ln(TRAF) + 0.6949 \ln(AGT)$$

$R^2 = 0.788$ Standard Error = 0.304

where

RGN = environmental region
DEFL = deflection
TRAF = average annual traffic
AGE = age of the pavement in years
THIK = overlay thickness in inches
CRH = correction factor for rubber coat or heat scarifier

The variable CRH in the second equation above specifies a correction factor for taking into account the benefit of rubber coat or heat scarifier. The performance information was obtained for major maintenance alternatives with ACFC but without rubber coat or heat scarifier. The change in roughness index would be smaller if either rubber coat or heat scarifier was used. The factor CRH indicates how much smaller the change would be. For example, a CRH of 0.7 would imply that the change in RI is 0.7 times the change calculated assuming neither rubber coat nor heat scarifier. To specify CRH for a maintenance alternative with either rubber coat or heat scarifier, one could consider the increase in the pavement life of such a treatment. Let us say that the increase in pavement life for a particular alternative is x%. Then CRH for this alternative may be specified as (100/(100 + x)).

In addition to the regression equations predicting change in RI or SN following a particular maintenance alternative, it was also necessary to predict pavement condition (RI or SN) immediately following a given major maintenance alternative. The type of information which was obtained is shown in Figure A-3. A regression equation, with roughness index (RI_a) immediately after given major maintenance as a dependent variable and with roughness index (RI_b) prior to major maintenance and overlay thickness as independent variables, was developed. This equation is shown below.

$$\ln(RI_a) = 1.628 + 0.309 \ln(RI_b) - 0.237 \ln(THIK)$$

$R^2 = 0.921$ Standard Error = 0.099

As regards skid number immediately following ACFC or seal coat, two parameters, namely mean SNA and standard deviation SNSD can be specified for the aggregate type to be used in ACFC or seal coat.

DECISION ANALYSIS APPROACH TO THE DEVELOPMENT OF A PAVEMENT MANAGEMENT SYSTEM

The primary objective of a Pavement Management System (PMS) is to provide decision making information regarding the best maintenance strategy for a given pavement section. The best maintenance strategy would be determined, with regard to its consequences (or impacts), in terms of the following attributes:

- Skid number (SN)
- Present serviceability index (PSI) (or roughness index (RI))
- Traffic delay (TD) due to maintenance
- Equivalent annual dollar cost (EAC)

The decision analysis approach for selecting the best maintenance strategy can be divided into the following steps:

(a) Generation of feasible maintenance strategies

(b) Determination of consequences of each strategy

(c) Calculation of relative desirability or attractiveness of each strategy

(d) Determination of preferential ranking of the feasible maintenance strategies

These steps are described in the following sections. Throughout the discussion the basic concepts are illustrated in the context of a simple example. The discussion is practical and informal; for a more rigorous and formal description of the decision analysis, the book by Keeney and Raiffa may be consulted.*

*Keeney, R.L. and H. Raiffa, "Decision Analysis with Multiple Conflicting Objectives," John Wiley and Sons, New York, 1976.

Generation of Feasible Maintenance Strategies

A maintenance strategy in the context of a PMS is defined as the specification of timing and type of major maintenance to be performed during a designated analysis period. A maintenance strategy is considered to be feasible if it maintains pavement condition above the minimum acceptable standards as specified by the engineer. Because of the uncertainties in the prediction of pavement condition, one can guarantee maintaining the minimum standards only with a specified reliability; for example, a reliability of 90% implies that the chance that the pavement condition would be worse than the minimum required is at the most 1 in 10. In generating feasible strategies, both corrective and preventive maintenance modes must be considered. Corrective maintenance implies maintenance at or after the time the pavement condition becomes unacceptable; preventive maintenance, on the other hand, implies maintenance prior to reaching unacceptable condition.

The generation of feasible maintenance strategies can best be explained by means of a simple example where, for the sake of simplicity, only two attributes — present serviceability index (PSI) and cost — are considered. Let us suppose that we would like to formulate the best maintenance strategy for an in-service pavement with a present PSI of 3.0. Based on past experience and field measurements, we can predict the future PSI of this pavement. Because of the uncertainties in our ability to predict the PSI, we would obtain a distribution on the predicted PSI rather than a single value. Figure B-1 shows these distributions at different times during the analysis period. It must be pointed out that the prediction of PSI at any time period i is dependent on the on the PSI at time period (i-1) which is not known with certainty. The probability distribution of PSI at i^{th} time period is, therefore, obtained by combining the probability of a particular PSI value at period (i-1) and the conditional probability of the PSI at i given the PSI at (i-1) and integrating over all possible PSI values at (i-1).

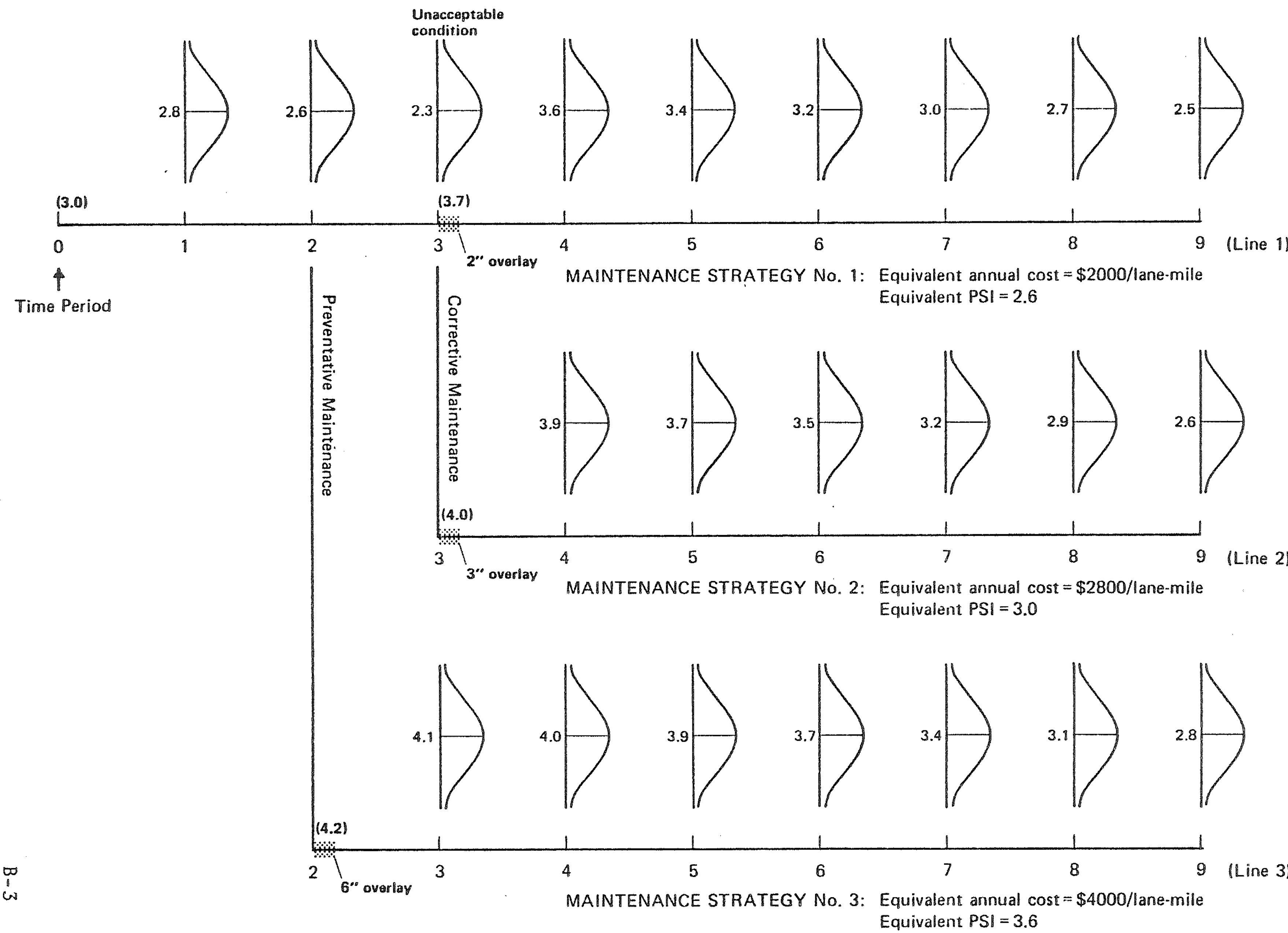


Figure B-1. CONSIDERATION OF UNCERTAINTIES IN PAVEMENT PERFORMANCE

In the implementation of this approach, various PSI values were generated using a Monte Carlo simulation procedure. This procedure is described in Appendix A.

The engineer may specify that the expected PSI of the section should remain above a limiting value of, say, 2.5 (this would correspond to a reliability of 50%). Following the performance history of the original pavement shown in Figure B-1 (line 1), it is seen that the expected PSI is 2.3 at the end of the third time period. Since this is an unacceptable condition, a corrective action must be taken at this time. Supppose a 2-in. overlay is applied to the pavement which brings the PSI to 3.2. Following the overlay the expected PSI remains above 2.5 through period 9 (Figure B-1, line 1); hence, no other action except routine maintenance is necessary for the remainder of the analysis period.

Instead of applying a 2-in. overlay, one could also consider other maintenance altermatives. For purposes of discussion let us suppose that the engineer schedules a 3-in. overlay at the end of the third time period (Figure B-1, line 2). The expected PSI is maintained above 2.5 following the overlay; hence, no further action is necessary.

Both of the strategies considered so far adopt corrective maintenance, that is, maintenance after unacceptable conditon is reached. However, the option of preventive maintenance, that is, maintenance prior to reaching unacceptable condition, must also be considered. Again for simplicity we will consider only one preventive action, namely a 6-in. overlay at the end of the second time period (Figure B-1, line 3). No further action is necessary following this overlay, since expected PSI remains above 2.5 during the remainder of the analysis period.

Thus, for the illustrative example, three feasible maintenance strategies are generated as shown in Figure B-1. Of course, by considering other maintenance alternatives such as ACFC with or without rubber coat and with or without heat scarifier along with different overlay thicknesses, many additional feasible strategies can be generated. The objective of the example was only to illustrate the logic used in generating feasible maintenance strategies.

Determination of Consequences of Each Feasible Strategy

The process of generating feasible maintenance strategies also provides the predictions of skid number and PSI at each time period during the designated analysis period. Using certain time delay models (for example, SAMP6 models), traffic delay due to maintenance activities to be scheduled under each strategy can be calculated. Also the equivalent annual cost of each strategy can be calculated using the cost models described in the main body of the report. Thus, the consequences (with their associated uncertainties) of each feasible strategy in terms of the four attributes — skid number, PSI, traffic delay and cost — can be determined. Because of the conflict between the performance attributes and the cost attribute, one particular strategy would not be the best with respect to all the attributes. Generally speaking, better pavement performance can be achieved through additional expenditure. To determine the best strategy, therefore, the decision maker's perception of incremental user benefits of better performance must be balanced against the incremental cost of achieving better performance. A formal preference structure of the decision maker is established for this purpose. This part of the analysis is discussed in the next section.

Calculation of Relative Desirability or Attractiveness of Alternative Maintenance Strategies

Through the previous steps, the alternative maintenance strategies are selected and consequences of each strategy in terms of probability distributions of the attributes over time are determined. The process of evaluating the alternative strategies in terms of overall desirability involves the following steps:

- o Establishing scalar utility functions incorporating the decision maker's attitudes towards risk
- o Incorporating time effects
- o Assessing tradeoffs between conflicting attributes
- o Calculating expected utility of each alternative strategy.

These steps are described below. The example shown in Figure B-1 is used for illustrating the basic concepts.

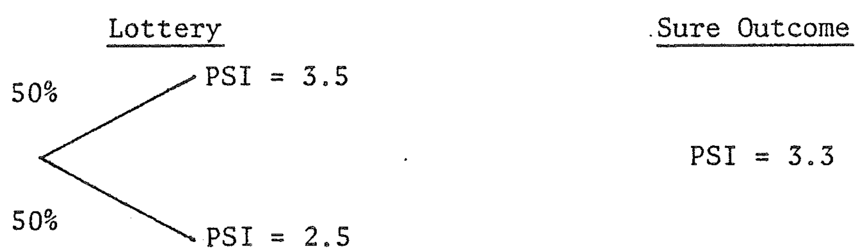
Establishing scalar utility functions. A scalar utility function is a mathematical expression for the decision maker's preferences for different levels of an attribute. The preferences are assessed under specified conditions of uncertainty. To illustrate the procedure involved in assessing a scalar utility function, let us consider the situation where there is a probability p that the PSI at a particular time period is x_1 and a probability (1-p) that the PSI is x_2. This is termed as a lottery situation because of the uncertainty involved. For example, on a particular section of road the following predictions are made based on uncertainties associated with past experience:

(a) there is a 50% chance that the PSI will be 3.5 at the end of ten years

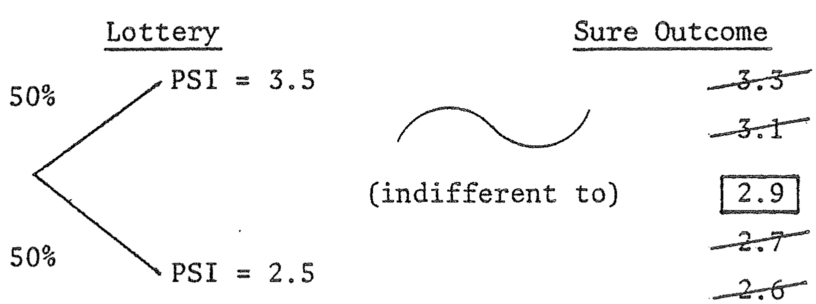
(b) there is a 50% chance that the PSI will be 2.5 at the end of ten years .

The two possible outcomes represent what will be referred to as a lottery situation. We would like to replace the lottery by a single number to facilitate analysis; yet, at the same time, we do not want to change the relative preference (utility, worth) of the strategy involving the lottery. This would be possible only if the single number replacing a lottery is just as desirable as the lottery. Thus, in comparision with the lottery situation, it is necessary to determine that guaranteed level of PSI at which the decison maker would either be satisfied or would be just willing to try the lottery; that is, he would be indifferent whether to accept the guaranteed, sure outcome or to play the lottery. This guaranteed or sure outcome is referred to in decison theory as the "certainty equivalent (CE)" of the specified lottery.

The implication of the certainty equivalent is that if a sure outcome slightly less desirable than the CE is offered, the decision maker would rather take his or her chances on the associated lottery; on the other hand, if the sure outcome is slightly more desirable than the CE, he or she would accept the sure outcome in lieu of the lottery. To illustrate this point, consider a lottery with a 50% chance of getting a PSI of 3.5 and a 50% chance of getting a PSI of 2.5. If the sure outcome of 3.3 is offered, which would you choose — the lottery or the sure outcome? Pictorially this situation is represented as follows:



Most engineers would choose the sure outcome of 3.3 in the above situation. If the sure outcome is 2.6 instead of 3.3, one might prefer the lottery with the reasoning that 2.6 is not much better than 2.5, the worst outcome in the lottery; hence, he might as well take his chances at getting a PSI of 3.5 by playing the lottery. As we can see, the decision maker's certainty equivalent for the lottery lies in between 3.3 and 2.6. By discussing various intermediate levels with the decision maker, his certainty equivalent can be assessed. Let us label this CE_1. Thus, the above procedure can be represented as follows:



The crossed out numbers indicate those sure outcomes which were considered but were ruled out as not being the certainty equivalent of the lottery. Finally, at 2.9 for a sure outcome, indifference was found implying $CE_1 = 2.9$. This response is boxed in the above diagram.

By assessing a few representative certainty equivalents it is generally possible to establish a preference function (also referred to as a utility function) over the range of interest of the attribute under consideration. This preference function (utility function) can then be used to compute certainty equivalents of all the uncertain situations which may have to be studied in determining the best maintenance strategy.

Incorporating time effects. In evaluating alternative maintenance strategies, consquences of each one in terms of the selected attributes must be compared over an analysis period of, say, 15 to 20 years. Because of uncertainties, the consequences are specified by probability distributions at each time period. The scheme for converting a string of probability distributions into an equivalent number is shown in Figure B-2. First, each probability distribution is replaced by its certainty equivalent calculated by using the scalar utility function. Next, the average of the utilities of all the certainty equivalents is calculated and finally, the equivalent level of the attribute corresponding to the average utility is obtained. This procedure assumes additive preferences over time. The implications of this assumption are that the scalar utility function remains unchanged over time and that a given level of an attribute at any time during the analysis period is equally desirable.

Continuing with the illustrative example shown in Figure B-1, let us suppose that the assumption of additive preference over time is reasonable. Using the above procedure, the attributes of PSI and annual cost in dollars per lane for the three alternative maintenance strategies can be summarized as shown in Table B-1.

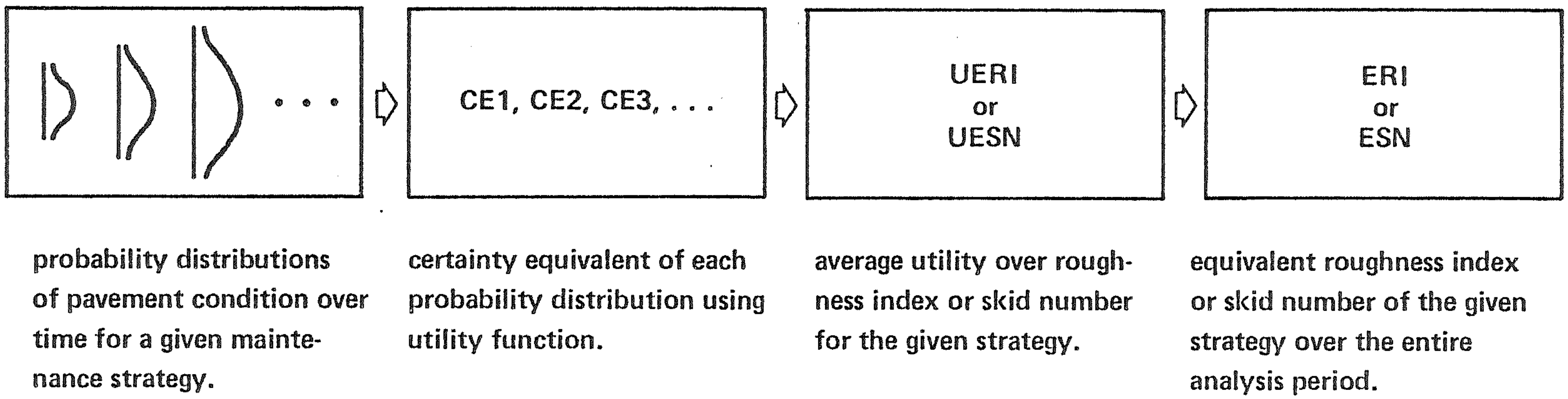


Figure B-2. CONVERSION OF A STRING OF PROBABILITY DISTRIBUTIONS INTO AN EQUIVALENT NUMBER

Table B-1.

Maint. Strategy #	Equivalent PSI	Equivalent Annual Cost
1	2.6	$2,000
2	3.0	$2,800
3	3.6	$4,000

Assessing tradeoffs between conflicting attributes. If only one attribute was of concern, the decision of best strategy would be relatively simple. For example, from the consideration of cost alone, maintenance strategy #1 in the above table is best while from the consideration of PSI alone, maintenance strategy #3 is best. When both cost and PSI are to be considered, the best strategy is intuitively not so obvious. It appears that maintenance strategy #2 requires an incremental cost of $800 per lane-mile per year to maintain the PSI at 3.0 instead of at 2.6. Similarly maintenance strategy #3 requires an additional cost of $2000 per lane-mile per year to maintain the PSI at 3.6 instead of at 2.6. To decide the best strategy, one must determine whether the specified increase in the PSI is worth the corresponding increase in the cost. Issues of this type must be resolved on the basis of the decision maker's perception of incremental benefits of higher PSI in relation to the incremental cost of maintaining the higher PSI.

Thus, for a decision making problem involving multiple and often conflicting attributes, it becomes necessary to establish how much the decision maker is willing to sacrifice on one attribute in order to achieve on some other attribute. These are termed the preference tradeoffs between the conflicting attributes. To illustrate the procedure for assessing tradeoffs, consider maintenance strategies #1 and #3 for the illustrative example shown in Figure 1 and summarized in Table B-1. Which of the two strategies would you prefer? This would depend upon whether one is willing to spend an additional amount of $2000 per lane-mile per year in order to maintain the PSI at 3.6 instead of at 2.6.

Let us suppose that strategy #3 is preferred; that is, benefits of higher PSI are perceived to be greater than the corresponding increase in cost. Suppose that the PSI of strategy #3 is maintained at 2.8 instead of at 3.6. Now strategy #1 might very well be preferred with the argument that increasing PSI from 2.6 to 2.8 is not worth the additional cost of $2000 per lane-mile per year. Obviously between the PSI of 3.6 and 2.8 there is a level of PSI at which the decision maker might feel indifferent between the two strategies, that is, at that level both the strategies might appear to be equally attractive. The objective of the tradeoff analysis would be to establish the indifference point between various levels of confliciting attributes. It is not necessary to establish tradeoffs between all possible combinations of the concerned attributes. By assessing a few typical tradeoffs, it is generally possible to establish an overall utility function which would be applicable to all practical situations one may have to face in making decisions.

Calculating expected utility of each alternative strategy. The individual utility functions assessed for each of the attributes represent the preferences for various levels of the attribute. The multiattribute utility function can be expressed as a simple function of the individual attribute utility functions under certain conditions. These conditons are referred to as preferential independence and utility independence.

A pair of attributes (X_i, X_j) is said to be preferentially independent of other attributes if preferences among (X_i, X_j) pairs do not depend on the level at which the others are fixed, given that the others are held fixed at some level. Preferential independence implies that the tradeoffs between attributes X_i and X_j do not depend on the values of the other attributes.

The attribute X_i is said to be utility independent of the other attributes if preferences among lotteries over X_i (that is, lotteries with uncertainty about the level of X_i only), given that the other attributes are held fixed, do not depend on the level at which these other attributes are fixed.

If the number of attributes is three or more, and if for some X_i, (X_i, X_j) is preferentially independent of the other attributes for all $j \neq i$, and X_i is utility independent of all the other attributes, then either

$$u(\underline{x}) = \sum_{i=1}^{n} k_i u_i(x_i) \qquad \text{if } \Sigma k_i = 1 \qquad \text{(B-1)}$$

or

$$u(\underline{x}) = (\{\prod_{i=1}^{n} [1 + kk_i u_i(x_i)]\} - 1)/k \qquad \text{if } \Sigma k_i \neq 1 \qquad \text{(B-2)}$$

where:

u = multiattribute utility function scaled between 0 and 1

x_i = level of i^{th} attribute

$u_i(x_i)$ = individual utility function for X_i scaled between 0 and 1

k = constant with value -1 or greater

k_i = scaling constants with values between 0 and 1.

The k_i are scaling constants which express the tradeoffs that exist among the attributes. The constant k can be determined from the k_i's. Thus, the multiattribute utility function can be completely defined when the individual attribute utility functions and the scaling constants, k_i, are known.

The expected utility of each alternative maintenance strategy can be calculated from the multiattribute utility function and the equivalent levels of all the attributes for the strategy. Let $\hat{x}_i^j$ denote the equivalent level of i^{th} attribute for the j^{th} strategy. The expected utility $E(u_j)$ of the j^{th} strategy assuming a multiplicative form for the overall utility function is given by:

$$E(u_j) = \frac{1}{k}\left\{\prod_i [1 + kk_i u_i(\hat{x}_i^j)] - 1\right\} \quad \text{(B-3)}$$

<u>Determination of Preferential Ranking of the Feasible Maintenance Strategy</u>

In decision problems involving uncertainty, the expected utility is the appropriate criterion for determining preferential ranking of alternative actions. This property follows from certain behavioral assumptions postulated by Von Neumann and Morgenstern.* The alternative with the highest expected utility is the most preferred.

The direct interpretation of the differences in the expected utility of alternative strategies to identify the magnitude of differences in the relative desirability of the strategies is difficult. One useful exercise in this respect is to calculate the 'net benefit' in dollars of the best strategy over all other strategies. The net benefit of the best strategy over another strategy can be defined as the increment in the cost of the best strategy which would make its expected utility equal to that of the other strategy. The difference in the expected utilities of the two strategies can be interpreted as being equivalent to the net benefit in dollars.

<u>Implementation of the Decision Analysis Approach for Developing a Pavement Management System</u>

Development of the prediction models for determining consequences of a given maintenance strategy is described in the main report and in Appendix A. In this section the assessment of the multiattribute utility function is described.

A number of people were assessed for their preferences regarding individual attributes and tradeoffs between attributes. The procedure

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*Von Neumann, J. and O. Morgenstern, "Theory of Games and Economic Behavior," 2nd Edition, Princeton University Press, 1947.

used was one-on-one interviews. The assumptions of preferential and utility independence, and additive preferences over time were checked with each assessor and were found to be reasonable. After studying the results of all the assessments, two distinct preference structures were identified. Each preference structure was quantified by averaging over the responses of the persons who were close to that preference structure. Preference structure 1 was identified as that for District 1 and preference structure 2 was identified as that for District 7. The multiplicative form of the utility function was applicable for both the Districts. The two functions are given below.

Scalar Utility Functions

Attribute	Worst Level	Best Level	Scalar Utility Function
X_i=skid number	25	100	$u_1(x_1) = 1.081\{1-\exp[-0.0345(x_1-25)]\}$ for both Districts
X_2=PSI	2	4	$u_2(x_2) = (x_2-2)/2$ for District 1 $u_2(x_2) = 1.385\{1-\exp[-0.6396(x_2-2)]\}$ for District 2
X_3=traffic delay in minutes	30	0	$u_3(x_3) = (30-x_3)/30$ for both Districts
X_4=equivalent annual cost in $ per lane-mile	10000	300	$u_4(x_4) = (10000-x_4)/9700$ for both Districts

Scaling Constants

District	K_1	K_2	K_3	K_4
1	0.70	0.42	0.292	0.378
7	0.685	0.216	0.036	0.70

The significant differences between the two utility functions are with respect to the tradeoffs between attributes and the resulting scaling constants. The order of decreasing relative importance of the four attributes for the District 1 function is: skid number, PSI, cost, and traffic delay. The decision maker with this preference structure would be willing to pay $9700 per year per lane-mile in order to improve the skid number from 25 to 45 and the same amount of money to improve the PSI from 2 to 3.8.

The utility function for District 7 indicates that the order of decreasing rleative importance of the attributes was: cost, skid number, PSI, and traffic delay. In this case the decision maker would be willing to pay $9500 per year per lane-mile only if the skid number improved from 25 to 100 and he would pay up to $3000 per year per lane-mile to improve the PSI from 2 to 4.

APPENDIX C

USER'S MANUAL FOR THE COMPUTER PROGRAM SOMSAC

CONTENTS

USER'S MANUAL FOR THE COMPUTER PROGRAM SOMSAC

INTRODUCTION

The computer program SOMSAC (acronym for Selection of Optimum Maintenance Strategy for Asphalt Concrete Pavements) is prepared as a part of the pavement management system developed for the Arizona Department of Transportation. The program SOMSAC generates a number of feasible maintenance strategies for a given pavement section, makes predictions of pavement performance under each strategy, and ranks all the alternative strategies on the basis of their overall desirability. This User's Manual gives a brief description of the analytical methods used in the program, discusses input requirements and output characteristics, and provides a summary of the program operations in the main program and in the subroutines.

The analysis in the program SOMSAC consists of the following parts:

1. Selection of feasible maintenance strategies,
2. Prediction of pavement performance under each feasible strategy,
3. Calculation of expected utility of each feasible strategy, and
4. Ranking of all the feasible strategies on the basis of their expected utilities.

A brief description of these parts is given below.

Selection of Feasible Maintenance Strategies. A maintenance strategy consists of different maintenance actions or alternatives to be adopted at specific times during the designated analysis period. Feasible maintenance strategies are determined from the consideration of limiting skid number for the pavement section, limiting roughness index, and desired reliabilities for not exceeding these limiting values. Both corrective maintenance (maintenance immediately after reaching unacceptable pavement condition) and preventive maintenance (maintenance prior to reaching unacceptable condition) are considered in selecting feasible strategies. The program first checks whether an unacceptable condition in terms of either the skid number or the roughness index would ever be reached if only routine maintenance is performed during the analysis period. If such a condition would be reached, the program adopts some corrective major maintenance alternative from the list of alternatives specified by the engineer. Following the first major maintenance action, the program checks for the necessity of a second corrective action. A maximum of three possible actions are considered during the analysis period. In preventive maintenance mode, a major maintenance alternative is adopted prior to reaching an unacceptable condition and subsequent pavement performance is examined. If after adopting a particular major maintenance alternative the pavement condition does not exceed the limiting value for roughness index, more expensive maintenance alternatives are not considered. The program also has a provision for eliminating some specified maintenance alternative if cracking is observed on the pavement. In the case of new construction, the program considers alternative initial designs and, for each design, selects feasible major maintenance alternatives. A maximum of two major maintenance alternatives are considered following the initial design.

Prediction of Pavement Performance Under Each Feasible Strategy. Four factors are used for evaluating pavement performance. These are skid number, roughness index, traffic delay in minutes due to maintenance activity, and equivalent annual cost in dollars per lane-mile. Regression equations are used for calculating expected value and variance of skid number and roughness index at each time period during the analysis period. Traffic delays for different maintenance actions are specified as a part of the input data. The equivalent annual cost is calculated by converting all costs to their present worth values and multiplying the present worth cost by a factor dependent on effective interest rate and analysis period. The cost components considered in this calculation are routine maintenance cost, major maintenance cost, and salvage value. Routine maintenance cost in each year is calculated as a function of roughness index and age. Costs of different major maintenance alternatives are inputs to the program. Salvage value is considered as negative cost and is calculated by multiplying the ratio of usable life still left in the pavement at the end of the analysis period and the total life of the last major maintenance action by the cost of that action.

<u>Calculation of Expected Utility of Each Feasible Strategy</u>. A multiattribute utility function is used for calculating the expected utility of each strategy. A multiplicative form as shown below is applicable:

$$(1 + Ku) = \prod_{i=1}^{4} (1 + KK_i u_i) \qquad \text{(C-1)}$$

where u is the overall utility function; u_i's are individual utility functions for the four attributes of skid number, roughness index, traffic delay, and cost; and K and K_i's are scaling constants. Either linear or exponential functions can be specified for the u_i's. The scaling constants K_i's are a part of the input data and the constant K is calculated in the program. Using the individual utility functions and the predicted values of mean and variance, a single equivalent number is obtained for each attribute under each feasible strategy. These equivalent values are then used in equation 1 to obtain the expected utility of each strategy.

In addition to expected utility, the net benefit of the best strategy over each of the other feasible strategies is calculated. The net benefit is a dollar quantity which represents the advantage of implementing the top strategy over some other strategy.

<u>Ranking of all the Feasible Strategies</u>. All the feasible strategies are ranked on the basis of their expected utilities. The higher the expected utility, the more desirable the strategy.

OPERATIONAL CHARACTERISTICS OF THE PROGRAM SOMSAC

Description of the Program Operations. The program SOMSAC consists of one main program and nine subroutines. A schematic representation of the program is shown in Figure C-1. A brief description of the operations in the main program and the subroutines is given below.

Main Program. The main program reads the number of pavement sections to be analyzed, prints the title page, and calls the subroutines SDATA, SOFMS, EXPUT, and RESULT successively for each of the sections.

Subroutine SDATA. This subroutine reads and prints input data. Annual traffic numbers are also calculated in this subroutine from the input parameters of initial traffic and annual traffic growth factor.

Subroutine SOFMS. This subroutine selects feasible maintenance strategies on the basis of predicted pavement condition, and specified limiting values and reliabilities for skid number and roughness index. Both corrective and preventive maintenance modes are considered. Equivalent skid number, roughness index, traffic delay, and annual cost of each feasible strategy are calculated by calling the subroutines PERFM and PREDT.

Subroutine PERFM. This subroutine calculates expected value and variance of skid number and roughness index at each time period following a given major maintenance alternative or initial design. Utilities of the certainty equivalents of the predicted distributions for skid number and roughness index are also calculated using the specified utility functions.

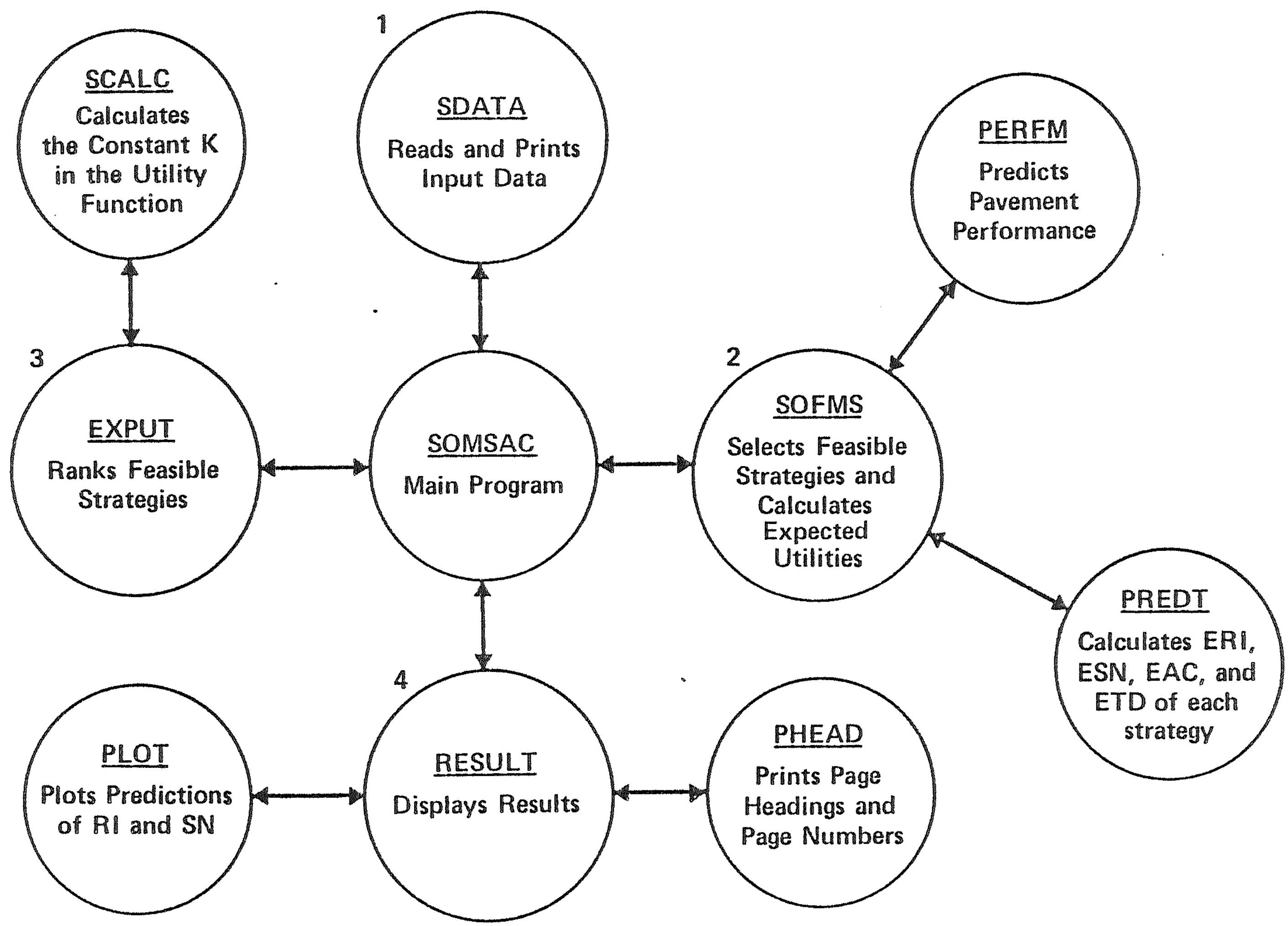

Figure C-1. SCHEMATIC REPRESENTATION OF THE COMPUTER PROGRAM SOMSAC

Subroutine PREDT. This subroutine calculates equivalent skid number, roughness index, traffic delay, and annual cost for each maintenance strategy selected in the subroutine SOFMS. For skid number and roughness index, utilities of the certainty equivalents at each time period during the analysis period are summed and the average utility is found. Using the average utility, a single equivalent number is obtained from the appropriate utility function. Regarding traffic delay, the utilities of certainty equivalents of traffic delays during different major maintenance activities included in the given strategy are summed, the average utility is calculated, and the equivalent traffic delay is obtained for the strategy. For costs, the sum of present values of routine maintenance costs and major maintenance costs is obtained, the present value of the salvage value is subtracted from this sum, and then the net present worth cost is multiplied by an appropriate interest factor to obtain the equivalent annual cost of the strategy.

Subroutine EXPUT. This subroutine calculates the expected utility of each feasible maintenance strategy using equation C-1. Utilities of the equivalent skid number, roughness index, traffic delay, and annual cost obtained in the subroutine PREDT are used in the calculation of the expected utility. All the feasible strategies are then ranked in a decreasing order of expected utility. The net benefit in equivalent dollars of the top strategy over other strategies is also calculated in this subroutine.

Subroutine SCALC. The constant K in equation C-1 is calculated in this subroutine and returned to the subroutine EXPUT.

Subroutine RESULT. This subroutine displays the results of the analysis.

Subroutine PLOT. This subroutine is called by RESULT for plotting predictions of skid number and roughness index for some of the top maintenance strategies.

Subroutine PHEAD. This subroutine is called by RESULT for printing page headings and page numbers.

Flexibility and Limitations of the Program SOMSAC. The following comments are pertinent with respect to flexibility and limitations of the program:

1. The program is written in Fortran IV language and it conforms with the standard ANSI Fortran requirements.
2. The program is modular in nature. Any changes in the prediction models, cost models, traffic models, or utility functions can be easily accommodated with minimum modifications in the program. All the parameters for the prediction models are initialized in Block Data Subprogram SOMDAT through the use of DATA declaration statements. If the prediction equations are refined in the future on the basis of field observations, the new parameters can be specified as the inputs without any modification in the program. The cost and traffic information is read for each pavement section to be analyzed. Thus, different costs and traffic levels for different pavement sections can be easily accommodated in the program. With regard to utility functions, the program assumes linear form for cost and exponential form for skid number. For the remaining attributes of roughness index and traffic delay either linear or exponential form can be specified. The constants in the individual utility functions as well as the scaling constants in the overall utility function are input through DATA statement cards.
3. The program can handle a maximum analysis period of 15 time periods (30 years) and a maximum number of 15 maintenance alternatives including routine maintenance and initial designs. Also, a maximum of 500 feasible maintenance strategies can be analyzed in the program. These provisions are adequate for the analysis of most practical problems.
4. The order of the maintenance alternatives to be specified must be as follows: routine maintenance, chip seal (optional), initial designs in an increasing order of cost (optional), and major maintenance alternatives in an increasing order of cost.

5. Any number of pavement sections can be analyzed in one run.
6. Execution time for program SOMSAC is highly variable, and depends, for the most part, on how many feasible maintenance strategies are generated. Experience to date indicates run times ranging from 1/2 second for the analysis of 10 strategies to 90 seconds for 464 strategies (CDC 7600, MNF OBJECT CODE).

INPUT REQUIREMENTS FOR THE PROGRAM SOMSAC

Introduction

Certain conventions have been adopted for ease of use of this write-up with respect to batch set-up for execution of SOMSAC:

1. Problems may be "stacked" in one run with use of Card A - the number of problems card.

2. Certain options require additional input cards, hence, slight modifications to the input stream. Parentheses around the card-label-character indicate the card(s) is optional. All other input cards are mandatory.

3. Right-justify all integer input; floating point format is expressed generally in this write-up. As long as the decimal point is punched on the card, data may appear anywhere within the limits of the field. For example, suppose the format specification for a certain data field was F10.0 in columns 1-10, and the data point to be entered in those columns had the value 3.33. As long as these four characters (3.33) are placed contiguously within the ten-column field specified, the value will be correctly interpreted.

4. Certain problems may require more data than will fit on one card. In this case, simply "extend" the data card by continuing entries on another card starting the next data field in column one.

5. The input stream is essentially maintenance alternative-specific. Enter the maintenance alternatives always in ascending order of cost beginning with routine maintenance (then initial designs or chip seal coat if appropriate). Other alternative-related data (that is, costs, traffic delays, deflections, thicknesses, etc.) should be input respectively.

Figure C-2 shows the arrangement of input data cards required for batch execution of this program. For ease of identification, all input

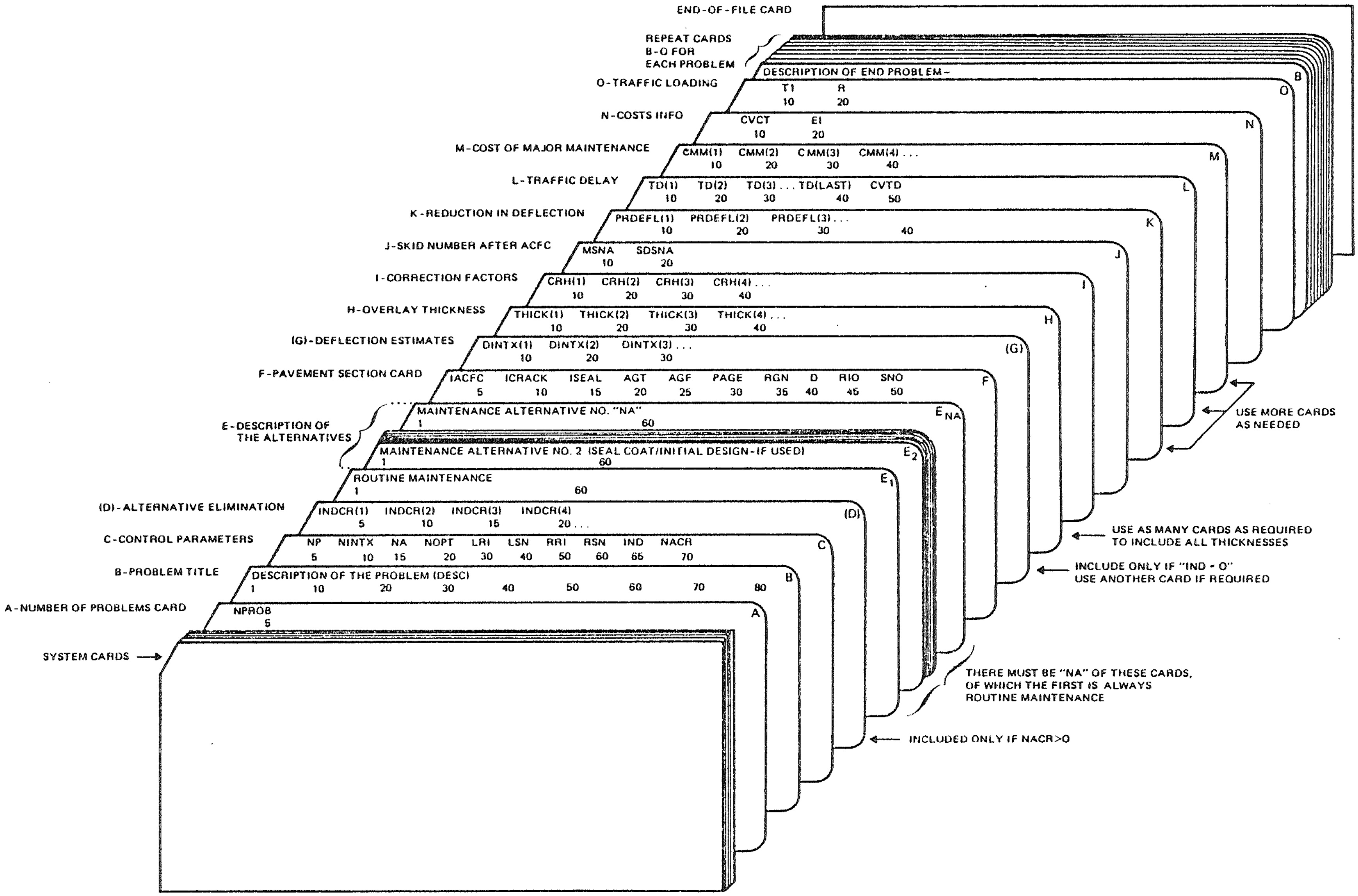

Figure C-2. ARRANGEMENT OF INPUT DATA CARDS has been identified with both an alphameric character and general label describing the information to be included on the input card (or group of similar cards). A more detailed explanation of input requirements follows:

A. Number-of-Problems Card - (One card per batch run)

Cols. 1-5	NPROB =	Total number of problems included in this run in I5 format

B. Problem Description Card

Cols. 1-80	DESC =	Enter a maximum of 80 columns of alphanumeric information describing the problem. (Read in 20A4 format.)

C. Control Parameters Card

Cols. 1-5	NP =	The total number of time periods to be included in the analysis in I5 format. (The program assumes that one time period is equal to two years.) Maximum = 15
Cols. 6-10	NINTX =	The total number of feasible initial designs included in the analysis in I5 format. If none are to be considered, enter a zero in column 10.
Cols. 11-15	NA =	Total number of alternatives to be considered (in I5 format). The total number of alternatives includes routine maintenance, seal coat and initial designs if used, and major maintenance alternatives in that order. The routine maintenance alternative is always specified as the first one in the list of alternatives. If chip seal is one of the alternatives to be considered, this should always be specified as the second alternative. A maximum of 15 alternatives can be specified in any given problem and should be specified in an increasing order of cost. (See Card E.)

C. Control Parameters Card (continued)

Cols. 16-20 NOPT = A user option to either print-input-data-only (a nice way to check your data set before spending money on execution) or print input data and execute the program. For print only, enter a zero in column 20; to print and execute, enter the number one.

Cols. 21-30 LRI = The limiting value of roughness index in F10.0 format.

Cols. 31-40 LSN = The limiting value of skid number in F10.0 format.

Cols. 41-50 RRI = The reliability level for not exceeding the limiting value of roughness index (LRI) in F10.0 format. A reliability level of, say, 90% implies that there is less than 10% chance that the limiting value specified by the analyst could be exceeded. A table of reliability factors for different reliability levels is shown below.

Reliability Level	Reliability Factor
.50	0
.55	.126
.60	.253
.65	.385
.70	.524
.75	.674
.80	.842
.85	1.036
.90	1.282
.95	1.645
.99	2.326

Cols. 51-60 RSN = Reliability level for not exceeding the limiting value of skid number (LSN) in F10.0 format. (See comments for RRI.)

Cols. 61-65 IND = If initial (new) designs are to be considered, enter a zero in column 65, otherwise enter the number one.

C. <u>Control Parameters Card</u> (continued)

Cols. 66-70 NACR = The total number of alternatives to be eliminated due to cracking. If significant cracking is observed on the pavement section under analysis just prior to implementing the program and if some major maintenance is warranted at the present time, the engineer may specify that maintenance alternatives which do not have any provisions for cracking should not be considered. For example, any maintenance alternatives without either rubber coat or heat scarifier may be eliminated in case of cracking. The parameter NACR is read by the program in I5 format.

D. <u>Alternative Elimination Card</u> - (Optional)

Include this card <u>only if</u> NACR is greater than zero.

Cols. 1-5 INDCR(1) = The index number of the 1st maintenance alternative to be eliminated due to cracking (I5 format).*

Cols. 6-10 INDCR(2) = The index number of the 2nd maintenance alternative to be eliminated due to cracking.

Cols. 11-50: Continue listing indexes in 5-column fields and in increasing order of magnitude until all eliminations have been specified. The number of entries must equal NACR and NACR must not exceed a total of ten.

E. <u>Description of the Alternatives Cards</u>

Cols. 1-60 DESCM = For each alternative (routine maintenance, seal coat, initial designs and major maintenance) a 60-column alphanumeric description must be provided. One card per alternative is required. The first must be routine maintenance, followed by either initial design or chip seal if specified, to a total of 15 cards. Each card is read in 15A4 format.

*For example: If INDRC(1) = 4, then the fourth maintenance alternative input is to be eliminated. Entries on this card should be in ascending order.

F. Pavement Section Card

Col. 5	IACFC =	If ACFC is present on the pavement section, enter the number one in column 5; if not, enter zero.
Col. 10	ICRACK =	The number one in column 10 indicates that cracking is observed in the pavement section. A zero in column 10 indicates no cracking. (See comments under NACR.)
Col. 15	ISEAL =	If chip seal is to be considered in the analysis, the number one must appear in this column. If no chip seal is involved, enter zero.
Cols. 16-20	AGT =	Aggregate type of the pavement section at present time. Codes for AGT are: 1 - Basalt or Cinders 2 - Gravel 3 - Limestone AGT is read in F5.0 format.
Cols. 21-30	AGF =	Aggregate type to be used in <u>future</u> ACFC. Code the same as for AGT.
Cols. 26-30	PAGE =	Pavement age in years at the present time. If initial design is specified as an alternative, enter zero for PAGE.
Cols. 31-35	RGN =	is the environmental region of the pavement section: 1.0 = low altitude, low rainfall 2.0 = high altitude, high rainfall, no swelling clay 3.0 = high altitude, high rainfall, swelling clay.
Cols. 36-40	D =	Deflection (in inches) of the pavement section. If initial designs are specified, estimates for deflection must be input for each design. (See Card G.)
Cols. 41-45	RIO =	Present roughness index of the pavement section in F5.0 format.
Cols. 46-50	SNO =	Present skid number of the pavement section in F5.0 format.

(G.) Deflection Estimate(s) Card

Include this card only if IND (column 65 of Card C) is equal to zero.

Cols. 1-10 DINTX(1) = Enter deflection estimate for first initial design (F10.0).

Cols.11-20 DINTX(2) = Deflection estimate for second initial design.

Cols.21-30 DINTX(3) = Deflection estimate for third initial design and so on until all designs have been included.

H. Overlay Thickness Card(s)

Thickness for each overlay included in the list of maintenance alternatives must be specified on this card. Use more cards if required.

Cols. 1-10 THICK(1) = Thickness (in inches) for the first overlay specified (F10.0).

Cols.11-20 THICK(2) = Thickness (in inches) for the second overlay. Continue in this fashion until all overlays have been included.

I. Correction Factors Card

Enter correction factors (CRH) starting with the first major maintenance alternative.

Cols. 1-10 CRH(1) = Correction factor for first major maintenance alternative mentioned in input list (F10.0). Continue (in 10-column fields) for all major maintenance alternatives respectively.

Note — These parameters (CRH) specify a correction for taking into account the benefit of rubber coat or heat scarifier on the pavement. The change in roughness index is always calculated assuming that neither rubber coat nor heat scarifier is applied. This change in roughness index is then multiplied by CRH to obtain the appropriate change in roughness index.

I. <u>Correction Factors Card(s)</u> (continued)

For example, a correction factor of 0.7 for an alternative would imply that the change in roughness index is only 70% of the calculated change assuming neither rubber coat nor heat scarifier. To illustrate how the corrective factors may be specified, let us suppose that the following maintenance alternatives are to be considered:

Alternative No. 1: ROUTINE MAINTENANCE
Alternative No. 2: ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER
Alternative No. 3: ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
Alternative No. 4: ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
Alternative No. 5: 2" OVERLAY + ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER
Alternative No. 6: 2" OVERLAY + ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
Alternative No. 7: 2" OVERLAY + ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER

Since alternatives 2 and 5 contain neither rubber coat nor heat scarifier, there is no additional benefit to these alternatives and hence the correction factors (CRH(2) and CRH(5)) would be one (1.0).

Let us assume that application of heat scarifier and rubber coat with ACFC would increase the pavement life by 50% and 200% respectively. For 2" overlay + ACFC, let the increases in expected life for heat scarifier and rubber coat be 50% and 100% respectively. This implies that roughness index would not increase as rapidly with heat scarifier or rubber coat as it would if neither of them is used. In fact, a reasonable assumption for alternatives 3 and 4 would be the change in roughness index is 100/(100 + 50) = 0.67 times the calculated change with heat scarifier and 100/(100 + 200) = 0.33 times the calculated change with rubber coat. Similarly, factors for alternatives 6 and 7 would be 0.67 and 0.50. With these calculations, the factor CRH for the different maintenance alternatives can be specified as follows:

Cols.	Maintenance Alt.#	CRH
1-10	2	1.0
11-20	3	0.67
21-30	4	0.33
31-40	5	1.0
41-50	6	0.67
51-60	7	0.50

I. Correction Factors Card(s) (continued)

It should be noted that the factor CRH is not specified for routine maintenance, initial designs or chip seal coat.

J. Skid Number After ACFC Card

Cols. 1-10 MSNA = Enter expected mean value of skid number immediately after ACFC in F10.0 format.

Cols.11-20 SDSNA = Enter standard deviation of skid number immediately after ACFC in F10.0.

K. Reduction in Deflection Card

Entries on this card reflect the percentage reduction in pavement deflection following the application of some major maintenance alternative. On this card, enter percentage reduction estimates in 10-column fields beginning with the first maintenance alternative and maintain a one-to-one correspondence between entries here and the maintenance alternatives list:

Cols. 1-10 PRDEFL(1) = Percent reduction in deflection for first major maintenance alternative.

Cols. 11-20 PRDEFL(2) = Percent reduction in deflection for the second major maintenance alternative. Continue in this fashion for all major maintenance alternatives.

L. Traffic Delay Card(s)

Entries on this card represent traffic delay in minutes incurred due to the application of some major maintenance alternative. The last entry must be coefficient of variation in traffic delay (CVTD). Enter traffic delays beginning with the first major maintenance alternative and continue respectively until delays are specified for all appropriate alternatives. Follow the last traffic delay entry with CVTD as shown below:

Cols. 1-10 TD(1) = Traffic delay in minutes during major maintenance for the first appropriate maintenance alternative in F10.0 format.

Cols. 11-20 TD(2) = Traffic delay in minutes during major maintenance for the second appropriate maintenance alternative.

L. Traffic Delay Card(s) (continued)

Cols. 41-50 TD(5) = Last traffic delay entry.

Cols. 51-60 CVTD = Coefficient of variation of traffic delay in F10.0 format.

The above represents an example where 5 major maintenance alternatives were specified. Placement of CVTD depends on the number of traffic delay entries.

M. Costs of Major Maintenance Card(s)

Enter cost (units in dollars per lane-mile) in ten-column fields (F10.0 format) for each alternative excluding routine maintenance.

Cols. 1-10 CMM(1) = Dollar per-lane-mile cost of second major maintenance alternative.

Cols.11-20 CMM(2) = Dollar per-lane-mile cost of third appropriate alternative, and so on for all major maintenance alternatives.

N. Cost Variation and Interest Card

Cols. 1-10 CVCT = Enter to coefficient of variation of costs in F10.0 format.

Cols.11-20 EI = Enter effective interest rate in F10.0 format (that is, .06 = 6% interest rate).

O. Traffic Loading Card

Cols. 1-10 T1 = Average annual traffic during the first year of the analysis period.

Cols.11-20 R = Enter the rate of traffic growth (yearly) in percent (that is, 5.0 is 5% per year).

A tabular form of the input data cards is shown in Table C-1. A sample problem has been included in this manual to illustrate the input/output characteristics. Figure C-3 shows an actual card-image listing of the input data used in the sample problem. The program listing is given in Figure C-4.

Table C-1. USER'S SHORT FORM FOR CHECKING THE ARRANGEMENT OF INPUT DATA CARDS

CARD NAME (X)=OPTIONAL	INPUT ITEMS ON EACH CARD: ACRONYM	COLUMNS	DESCRIPTION OF DATA	CARD FORMAT	COMMENTS
A. Number of Problems	NPROB	1-5	Total number of problems included in the run	(I5)	One card/computer run
B. Problem Description	DESC	1-80	Description of the problem	(20A4)	One card/problem
C. Control Parameters	NP	1-5	Number of periods in the analysis (max.=15)		One card/problem
	NINTX	6-10	Number of feasible initial designs (max.=10)		
	NA	11-15	Number of alternatives (max.=15)	(4I5,4F10.0,2I5)	
	NOPT	16-20	Option for print-input-data-only 0=print only		
	LRI	21-30	Limiting value for roughness index		
	LSN	31-40	Limiting value for skid number		
	RRI	41-50	Reliability factor for not exceeding LRI value		
	RSN	51-60	Reliability factor for not exceeding LSN value		
	IND	61-65	Indicator for new design (0=new, 1=in-service)		
	NACR	66-70	Number of alternatives to be eliminated (max.=10)		
(D) Alternative Elimination	INDCR(1)	1-5	Number of the 1st alternative to be eliminated	(10I5)	List the number(s) in ascending order. Include this card only if NACR > 0
	INDCR(2)	6-10	Number of the 2nd alternative to be eliminated		
	⋮	⋮	⋮		
	INDCR(10)	46-50	Number of the 10th alternative to be eliminated		
E. Maintenance Alternatives	DESCM(1)	1-60	Description of maintenance alternative #1	(15A4)	List alternatives, one per card for a total of "NA" cards (max. = 15)
	DESCM(2)	1-60	Description of maintenance alternative #2		
	⋮	⋮	⋮		
	DESCM(NA)	1-60	Description of maintenance alternative #NA		
F. Pavement Section	IACFC	1-5	Indicator for presence of ACFC		Leave deflection (cols. 36-40) blank if new design
	ICRACK	6-10	Indicator for cracking		
	ISEAL	11-15	Indicator for using chip seal	(3I5,7F5.0)	
	AGT	16-20	Aggregate type in present condition		
	AGF	21-25	Aggregate type to be used in future ACFC		
	PAGE	26-30	Pavement age in years at present time		
	RGN	31-35	Environmental region of pavement section		
	D	36-40	Present deflection (in.) of pavement section		
	RIO	41-45	Present roughness index of pavement section		
	SNO	46-50	Present skid number of pavement section		
(G) Deflection Estimates	DINTX(1)	1-10	Estimated deflection for initial design #1		Include this card only if IND = 0
	DINTX(2)	17-20	Estimated deflection for initial design #2	(8F10.0)	
	⋮	⋮	⋮		
	DINTX(N)	71-80	Estimated deflection for final initial design		
H. Overlay Thickness	THICK(1)	1-10	Thickness (in.) of overlay #1		List thickness (only if appropriate) for given maintenance alternatives in same order as alternatives
	THICK(2)	11-20	Thickness (in.) of overlay #2	(8F10.0)	
	⋮	⋮	⋮		
	THICK(8)	71-80	Thickness (in.) of overlay #8		

Table C-1. USER'S SHORT FORM FOR CHECKING THE ARRANGEMENT OF INPUT DATA CARDS (Continued)

CARD NAME (X)=OPTIONAL	INPUT ITEMS ON EACH CARD			CARD FORMAT	COMMENTS
	ACRONYM	COLUMNS	DESCRIPTION OF DATA		
I. Correction Factors	CRH(1)	1-10	Correction factor for 1st alternative		Include CRH (only if appropriate) for given maintenance alternatives in same order as alternatives. Use more cards as needed.
	CRH(2)	11-20	Correction factor for 2nd alternative	(F10.0)	
	⋮	⋮	⋮		
	CRH(8)	71-80	Correction factor for 8th alternative		
J. SN Immediately After ACFC	MSNA	1-10	Average SN immediately after ACFC		
	SDSNA	11-20	Standard deviation of SN immediately after ACFC	(2F10.0)	
K. Reduction in Deflection Following Major Maint.	PRDEFL(1)	1-10	Percentage reduction in deflection for 1st alt.		Enter percentage (i.e., 5.0=5%) only if appropriate for a given maintenance alternative. Use another card if necessary.
	PRDEFL(2)	11-20	Percentage reduction in deflection for 2nd alt.		
	⋮	⋮	⋮		
	PRDEFL(8)	71-80	Percentage reduction in deflection for 8th alt.	(8F10.0)	
L. Traffic Delay	TD(1)	1-10	Traffic delay in minutes for 1st major maint. alt.		Traffic delays should be entered for major maintenance alternatives only. CVTD must follow last entry.
	TD(2)	11-20	Traffic delay in minutes for 2nd major maint. alt.	(8F10.0)	
	⋮	⋮	⋮		
	TD(N)		Traffic delay in minutes for last major maint.alt.		
	CVTD		Coefficient of variation of traffic delay		
M. Cost of Major Maintenance	CMM(1)	1-10	Cost for 1st major maintenance alternative	(8F10.0)	Use as many cards as required to enter costs for maintenance alternatives.
	CMM(2)	11-20	Cost for 2nd major maintenance alternative		
	⋮	⋮	⋮		
	CMM(8)	71-80	Cost for 8th major maintenance alternative		
N. Cost Information	CVCT	1-10	Coefficient of variation of cost estimates	(2F10.0)	
	EI	11-20	Effective interest rate (.06=6%)		
O. Traffic Loading	T1	1-10	Average annual traffic during 1st year of analysis	(2F10.0)	
	R	11-20	Annual rate of growth of traffic (5.0=5%)		

```
    1
STATE OF ARIZONA - DEPARTMENT OF TRANSPORTATION - EXAMPLE NO. 1
   10     0    10     1       40.0       43.0      0.842      1.282     1     0
ROUTINE MAINTENANCE
ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER
ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
1 IN OVLAY + ACFC WITHOUT RUBBER COAT,WITHOUT HEAT SCARIFIER
1 IN OVLAY + ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
1 IN OVLAY + ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
3 IN OVLAY + ACFC WITHOUT RUBBER COAT,WITHOUT HEAT SCARIFIER
3 IN OVLAY + ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
3 IN OVLAY + ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
    1     0     0  1.0  1.0  8.0  1.0 .015 27.0 55.0
     0.750      0.750      0.750        1.0        1.0        1.0        3.0        3.0
       3.0
      1.00       0.40       0.25       1.00       0.50       0.33       1.00       0.50
      0.33
      80.0      3.333
       0.0        0.0        0.0       10.0       10.0       10.0       20.0       20.0
      20.0
       7.0        7.0        7.0        7.0        7.0        7.0        7.0        7.0
       7.0       0.10
    5632.0     8448.0    11733.0    12766.0    15582.0    18867.0    27034.0    29850.0
   33135.0
      0.10       0.00
  182500.0       5.00
```

Figure C-3. INPUT DATA DECK FOR THE SAMPLE PROBLEM

OUTPUT CHARACTERISTICS OF THE PROGRAM SOMSAC

Introduction

SOMSAC output may be generally categorized as follows:

- Title Page
- Description of the input data and prediction models
- Maintenance alternative table
- Dictionary of acronyms
- Maintenance strategy table
- Pavement condition table
- Pavement condition plot

While the output was designed to be virtually self-explanatory, some comments pertaining to the above mentioned categories may prove helpful to the user. Sample output is shown in Figure C-5.

Any one problem may generate from 16 to 21 pages of output depending on the number of feasible maintenance strategies extracted. If the option to specify printing of input data only was specified (NOPT=1), output terminates after the second category — Description of Input Data and Prediction Models.

Title Page

The title page is always the first page output by SOMSAC and contains documentary information about the program.

Description of Input and Prediction Models

All data input to SOMSAC are regurgitated on these pages. Prediction models and the routine maintenance cost algorithm are additionally output. Optional data are output if specified.

Maintenance Alternative Table

A complete list of alternatives is printed and includes an ordered description of each alternative input to the program. When the cracking option is enabled, a message is printed next to alternatives which are to be eliminated from primary consideration in the selection of strategies.

Dictionary of Acronyms

This table provides definitions of the acronyms that are used as column headings in the Maintenance Strategy Table.

Maintenance Strategy Table

The Maintenance Strategy Table summarizes the maintenance strategies selected by SOMSAC. The strategies are output in decreasing order of magnitude in overall expected utility. The program provides space for a total of 500 strategies to be selected of which a maximum of the "best" 50 are output. The following parameters are summarized in this table for each maintenance strategy selected:

- Relative rank of the maintenance strategy
- Equivalent annual roughness index
- Equivalent annual skid number
- Average traffic delay
- Equivalent annual cost
- The expected utility
- Net benefit
- Time at which maintenance action is to be taken
- Specific maintenance alternative applied to pavement.

Pavement Condition Table

A probabilistic prediction of pavement condition in terms of roughness index and skid number is output for the top three maintenance strategies.

Expected values and standard deviations are output for each time interval in the analysis period. Routine, preventative or major maintenance applications are noted at each time interval as well. Expecte values for pavement condition just prior to the application of a maintenance alternative are noted in parentheses.

Pavement Condition Plot

Finally, SOMSAC generates plots depicting pavement condition for the top three maintenance strategies. Two plots, one for roughness index, the other for skid number, are output following each Pavement Condition Table. Expected value (the ordinate) is plotted against time (the abscissa) and is graphically represented by asterisks(*). Two standard deviations above and below the expected value are symbolized by shaded areas of plus (+) and minus (-) signs respectively. Drastic changes in expected value (that is, a significant drop in roughness index) indicate the application of some maintenance alternative on the pavement section of that particular point in the analysis period.

Figure C-4. LISTING OF THE PROGRAM SOMSAC

```
      PROGRAM SOMSAC (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C                 ************* PROGRAM SOMSAC *************
C
C                 SELECTION OF OPTIMUM MAINTENANCE STRATEGIES FOR
C                         ASPHALT CONCRETE PAVEMENTS
C
C                 THIS PROGRAM RANKS ALTERNATIVE MAINTENANCE
C                 STRATEGIES FOR AC PAVEMENTS ON THE BASIS OF THEIR
C                 OVERALL DESIRABILITY.  THE PROGRAM FIRST DETERMINES
C                 A FEASIBLE SET OF MAINTENANCE STRATEGIES FOR A
C                 GIVEN PAVEMENT SECTION CONSIDERING CORRECTIVE AS
C                 WELL AS PREVENTATIVE MAINTENANCE ALTERNATIVES.
C                 FOR EACH STRATEGY, PAVEMENT CONDITION IN TERMS OF
C                 SKID NUMBER AND ROUGHNESS INDEX IS THEN PREDICTED
C                 AT EACH TIME PERIOD DURING THE ANALYSIS PERIOD.
C                 THE COST AND TRAFFIC DELAYS ARE ALSO ESTIMATED FOR
C                 EACH STRATEGY.  THE PREDICTION MODELS ARE DEVELOPED
C                 ON THE BASIS OF MULTIPLE LINEAR REGRESSION ANALYSES
C                 USING BOTH SUBJECTIVE AND OBJECTIVE DATA.  FINNALY,
C                 PREFERENTIAL RANKING OF ALL THE FEASIBLE STRATEGIES
C                 IS DETERMINED ON THE BASIS OF EXPECTED UTILITIES
C                 OF THE STRATEGIES.  A MULTIATTRIBUTE UTILITY
C                 FUNCTION OVER SKID NUMBER, ROUGHNESS INDEX,
C                 TRAFFIC DELAY AND COST IS EMPLOYED IN THE
C                 CALCULATION OF EXPECTED UTILITIES.
C
C                 THE PROGRAM CONSISTS OF THE FOLLOWING PARTS ------
C
C                 (1) SUBROUTINE SDATA - READS AND PRINTS INPUT DATA.
C
C                 (2) SUBROUTINE SOFMS - SELECTS FEASIBLE
C                     MAINTENANCE STRATEGIES.
C
C                 (3) SUBROUTINE PREDT - PREDICTS PAVEMENT CONDITION,
C                     COST AND TRAFFIC DELAY OF EACH FEASIBLE
C                     STRATEGY.
C
C                 (4) SUBROUTINE PERFM - EVALUATES PAVEMENT
C                     PERFORMANCE FOR EACH FEASIBLE STRATEGY.
C
C                 (5) SUBROUTINE SCALC - CALCULATES THE K VALUE FOR
C                     THE UTILITY FUNCTIONS.
C
C                 (6) SUBROUTINE EXPUT - CALCULATES EXPECTED UTILITIES
C                     FOR THE MAINTENANCE STRATIEGIES AND THEN RANKS
C                     THEM IN ORDER OF MAGNITUDE.
C
C                 (7) SUBROUTINE RESULT - OUTPUTS THE RESULTS OF THE
C                     ANALYSIS.
C
C                 (8) SUBROUTINE PLOT - PRINTS A GRAPHIC REPRESENTAT-
C                     ION OF PAVEMENT CONDITION.
C
C                 (9) SUBROUTINE PHEAD - PRINTS PAGE HEADINGS.
C
C                 (10) BLOCK DATA SUBPROGRAM SOMDAT - INITIALIZE
C                      SOME DATA.
C
C
      REAL LRI,LSN,MRI,MSN,MSNA
C
```

```
      INTEGER AI,AJ,AK,AK1,AK2,AK3
      DIMENSION STAR(25)
C
      COMMON /IO/ IN,IOUT
      COMMON /SDATA/ NP,NINTX,NA,NOPT,LRI,LSN,RRI,RSN,IND,IACFC,ICRACK,A
     1GT,AGF,PAGE,RGN,D,RIO,SNC,THICK(15),DINTX(10),C11,C12,C13,C14,C15,
     2SECRI1,C21,C22,C23,C24,C25,C26,SECRI2,B11,B12,B13,B14,B15,SECSN1,C
     3RH(15),B21,B22,B23,B24,B25,SECSN2,XC0,XC1,XC2,SERIA,MSNA,SDSNA,PRD
     4EFL(15),TD(15),CVTD,CMM(15),CVCT,EI,TI,R,CU1,CU2,NACR,INDCR(10),IS
     5EAL,TRFC(70),UKI(4),UK,DESCM(15,15),DESC(20),IPAGE,NLINE,IPROB,AU1
     6,AU2,BU1,BU2,B31,B32,B33,B34,B35,SECSN3
C
      COMMON /PERFM/ MRI(15,20),VRI(15,20),MSN(15,20),VSN(15,20),NPRIOR,
     1NREM,KPRIOR,KCUR,DPRIOR,IRI(15),ISN(15),DPOST,ARI1(15,20),VRI1(15,
     220),ASN1(15,20),VSN1(15,20),URI(15,20),URI1(15,20),USN(15,20),USN1
     3(15,20)
C
      COMMON /SOFMS/ NTOTAL,IK1(500),IK2(500),IK3(500),AK1(500),AK2(500)
     1,AK3(500),RIA(500,15),RISD(500,15),SNA(500,15),SNSD(500,15),DF(40)
     2,FEAC,ARIB
C
      COMMON /PREDT/ AI,AJ,AK,K1,K2,K3,ICASE,ERI(500),ESN(500),EAC(500),
     1ETD(500),UERI(500),UESN(500),UEAC(500),UETD(500),JST
C
      COMMON /EXPUT/ IRANK(500),EXPT(500),BENFT(500)
C
C
      DATA STAR/25*4H****/
C
C                 READ THE NUMBER OF PAVEMENT SECTIONS TO BE ANALYZED
C                 IN THIS RUN.
      READ (IN,2) NSEC
C
C                 START A DO-LOOP FOR THE NUMBER OF PAVEMENT SECTIONS
C                 TO BE ANALYZED IN THIS RUN.
C
C
C                 PRINT PROGRAM TITLE.
C
C                 DESC=EIGHTY COLUMN DESCRIPTION OF THE PROGRAM.
C
      WRITE (IOUT,3) (STAR(J),J=1,22)
      WRITE (IOUT,4) (STAR(J),J=1,24)
      WRITE (IOUT,4) (STAR(J),J=1,24)
      WRITE (IOUT,5) (STAR(J),J=1,14)
      WRITE (IOUT,6) (STAR(J),J=1,11)
      WRITE (IOUT,7) (STAR(J),J=1,11)
      WRITE (IOUT,8) (STAR(J),J=1,17)
      WRITE (IOUT,9) (STAR(J),J=1,17)
      WRITE (IOUT,10) (STAR(J),J=1,18)
      WRITE (IOUT,11) (STAR(J),J=1,12)
      WRITE (IOUT,12) (STAR(J),J=1,11)
      WRITE (IOUT,13) (STAR(J),J=1,12)
      WRITE (IOUT,14) (STAR(J),J=1,20)
      WRITE (IOUT,14) (STAR(J),J=1,20)
      WRITE (IOUT,14) (STAR(J),J=1,20)
      WRITE (IOUT,15)
      DO 1 IPROB=1,NSEC
C
C                 READ AND PRINT INPUT DATA.
C
      CALL SDATA
```

```
C
C                 IF CNLY INPUT DATA IS TO BE PRINTED,GO TO END.
C
      IF (NOPT.EQ.0) GO TO 1
C
C                 CALL SUBRCUTINE SOFMS FOR SELECTION OF FEASIRLE
C                 MAINTENANCE STRATEGIES AND CALCULATION OF EXPECTED
C                 UTILITIES.
      CALL SOFMS
C
C                 CALL SUBROUTINE EXPUT FOR RANKING THE FEASIBLE
C                 STRATEGIES CN THE BASIS OF THEIR EXPECTED UTILITIES.
C
      CALL EXPUT
C
C                 CALL SUBROUTINE RESULT TO DISPLAY RESULTS OF THE
C                 ANALYSIS.
C
      CALL RESULT
1     CONTINUE
      STOP
C
2     FORMAT (I5)
3     FORMAT (1H1,10(/)10X,2(3A4,A3,4X)A4,7X,A4,3(4X,3A4,A3))
4     FORMAT (10X,2(3A4,A3,4X)A4,A1,5X,A4,A1,3(4X,3A4,A3))
5     FORMAT (10X,2(A4,7X,A4,4X),A4,A2,3X,A4,A2,3(4X,A4,7X,A4))
6     FORMAT (10X,A4,15X,A4,7X,A4,4X,A4,A3,1X,A4,A3,4X,A4,15X,A4,7X,A4,4
     1X,A4)
7     FORMAT (10X,A4,15X,A4,7X,A4,4X,3A4,A3,4X,A4,15X,A4,7X,A4,4X,A4)
8     FORMAT (10X,3A4,A3,4X,A4,7X,A4,4X,3A4,A3,4X,3A4,A3,4X,A4,7X,A4,4X,
     1A4)
      FORMAT (10X,3A4,A3,4X,A4,7X,A4,4X,A4,1X,A4,A1,1X,A4,4X,3A4,A3,4X,A
     14,7X,A4,4X,A4)
10    FORMAT (10X,3A4,A3,4X,A4,7X,A4,4X,A4,2X,A3,2X,A4,4X,3A4,A3,4X,3A4,
     1A3,4X,A4)
11    FORMAT (21X,A4,4X,A4,7X,A4,4X,A4,3X,A1,3X,A4,15X,A4,4X,3A4,A3,4X,A
     14)
12    FORMAT (21X,2(A4,4X,A4,7X)A4,15X,A4,4X,3A4,A3,4X,A4)
13    FORMAT (10X,6(A4,7X,A4,4X))
14    FORMAT (10X,2(3A4,A3,4X)A4,7X,A4,4X,3A4,A3,4X,A4,7X,A4,4X,3A4,A3)
15    FORMAT (/////26X,80H** SELECTION OF CPTIMUM MAINTENANCE STRATEGIES
     1 FOR ASPHALT CONCRETE PAVEMENTS **//////10X,111HA COMPUTER PROGRAM
     2 DEVELOPED UNDER CONTRACT TO THE ENVIRONMENTAL SYSTEMS DIVISION OF
     3 WOODWARD-CLYDE CONSULTANTS////63X,3HFOR////37X,52HTHE STATE OF AR
     4IZONA -- DEPARTMENT OF TRANSPORTATION////64X,2HBY////30X,27HDR. RA
     5MCHANDRA B. KULKARNI,,1X,41HMR. FRED N. FINN AND MR. JOHN K. MCMOR
     6RAN////60X,10H JUNE 1976)
      END
```

```fortran
      SUBROUTINE SOFMS
C
C               THIS SUBROUTINE SELECTS FEASIBLE MAINTENANCE
C               STRATEGIES ON THE BASIS OF PREDICTED PAVEMENT
C               CONDITION AND SPECIFIED LIMITING VALUES AND
C               RELIABILITIES.  BOTH CORRECTIVE AND PREVENTIVE
C               MAINTENANCE MODES ARE CONSIDERED.  EQUAVALENT
C               SKIC NUMBER, ROUGHNESS INDEX, TRAFFIC DELAY AND
C               ANNUAL COST OF EACH FEASIBLE STRATEGY
C               ARE CALCULATED BY CALLING THE SUBROUTINE PERFM
C               AND PREDT.
C
      REAL LRI,LSN,MRI,MSN,MSNA,MCSN,MCRI
      INTEGER AI,AJ,AK,AK1,AK2,AK3
      COMMON /SDATA/ NP,NINTX,NA,NOPT,LRI,LSN,RRI,RSN,IND,IACFC,ICRACK,A
     1GT,AGF,PAGE,RGN,C,RIO,SNO,THICK(15),DINTX(10),C11,C12,C13,C14,C15,
     2SECRI1,C21,C22,C23,C24,C25,C26,SECRI2,B11,B12,B13,B14,B15,SECSN1,C
     3RH(15),B21,B22,B23,B24,B25,SECSN2,XC0,XC1,XC2,SERIA,MSNA,SDSNA,PRD
     4EFL(15),TD(15),CVTD,CMM(15),CVCT,EI,TI,R,CU1,CU2,NACR,INDCR(10),IS
     5EAL,TRFC(70),UKI(4),UK,DESCM(15,15),DESC(20),IPAGE,NLINE,IPROB,AU1
     6,AU2,BU1,BU2,B31,B32,B33,B34,B35,SECSN3
C
      COMMON /PERFM/ MRI(15,20),VRI(15,20),MSN(15,20),VSN(15,20),NPRIOR,
     1NREM,KPRIOR,KCUR,DPRIOR,IRI(15),ISN(15),DPOST,ARI1(15,20),VRI1(15,
     220),ASN1(15,20),VSN1(15,20),URI(15,20),URI1(15,20),USN(15,20),USN1
     3(15,20)
C
      COMMON /SOFMS/ NTOTAL,IK1(500),IK2(500),IK3(500),AK1(500),AK2(500)
     1,AK3(500),RIA(500,15),RISD(500,15),SNA(500,15),SNSD(500,15),DF(40)
     2,FEAC,ARIB

      COMMON /PREDT/ AI,AJ,AK,K1,K2,K3,ICASE,ERI(500),ESN(500),EAC(500),
     1ETD(500),UERI(500),UESN(500),UEAC(500),UETD(500),JST
C
      COMMON /EXPUT/ IRANK(500),EXPT(500),BENFT(500)
      COMMON /IO/ IN,IOUT
C
C               SPECIAL UTILITY FUNCTION FOR SKID NUMBER
C
      UTSN(XM,VARX)=CU1*(1.0-EXP(-CU2*25.0+CU2*XM+0.5*CU2*CU2*VARX))
C
C                    IF THE UTILITY FUNCTION FOR ROUGHNESS INDEX
C                    IS LINEAR, USE THE NEXT FUNCTION----
C
      UTRI(XM,VARX)=1.06-0.0212*XM
C
C                    IF THE UTILITY FUNCTION FOR ROUGHNESS INDEX
C                    IS EXPONENTIAL, DEACTIVATE PREVIOUS FUNCTION BY
C                    PLACING A C IN COLUMN ONE AND ACTIVATE THE
C                    FOLLOWING FUNCTION BY REMOVING THE C IN COLUMN
C                    ONE.
C
C     UTRI(XM,VARX)=BU1*(1.0-EXP(BU2*2.12-BU2*0.0424*XM+0.5*BU2
C    1*0.0424*BU2*0.0424*VARX))
C
C
C               CALCULATE DISCOUNT FACTORS FOR CONVERTING
C               FUTURE CASHFLOWS TO THEIR PRESENT WORTH
C               VALUES
C
      NYEARS=2*NP
```

```
      DO 1 I=1,NYEARS
1     DF(I)=1.0/((1.0+EI)**I)
C
C                  CALCULATE THE FACTOR FOR EQUAVALENT
C                  ANNUAL COST.
C
      FEAC=0.0
      JST=0
      DO 2 J=1,NYEARS
2     FEAC=FEAC+1.0/((1.0+EI)**J)
      IL=2
C
C                  CHECK WHETHER THE CURRENT PROBLEM IS REGARDING
C                  SELECTION OF INITIAL DESIGN.
C
      IF (IND.EQ.0) GO TO 32
C
C                  INITIALIZE VARIABLES.
C
      KRI=0
      KSN=0
      IRI(1)=NP+1
      ISN(1)=NP+1
      AGE=PAGE
C
C                  DETERMINE WHETHER THE APAVEMENT WOULD FAIL IN
C                  SN OR RI IF ONLY ROUTINE MAINTENANCE
C                  IS SCHEDULED.
C
      COLN=C11+C13*ALOG(RGN)+C14*ALOG(D)
      BOLN=B11+B13*ALOG(RGN)+B14*ALOG(AGT)
      DO 9 I=1,NP
      II=2*I-1
      K=I-1
      AGE=AGE+2.0
      IF (KRI.GT.0) GO TO 5
      CILN=COLN+C12*ALOG(TRFC(II))
      XLMCRI=CILN+C15*ALOG(AGE)
      VLCRI=SECRI1*SECRI1
      MCRI=EXP(XLMCRI+0.5*VLCRI)
      CVCRI=SQRT(EXP(VLCRI)-1.0)
      VCRI=(CVCRI*MCRI)**2
      IF (I.NE.1) GO TO 3
      MRI(1,I)=RIO+MCRI
      VRI(1,I)=VCRI
      GO TO 4
3     MRI(1,I)=MRI(1,K)+MCRI
      VRI(1,I)=VRI(1,K)+VCRI
4     CONTINUE
      URI(1,I)=UTRI(MRI(1,I),VRI(1,I))
      SRI=SQRT(VRI(1,I))
      ZRI=(LRI-MRI(1,I))/SRI
      IF (ZRI.LT.RRI) KRI=KRI+1
      IF (KRI.EQ.1) IRI(1)=I
5     IF (KSN.GT.0) GO TO 8
      BILN=BOLN+B12*ALOG(TRFC(II))
      XLMCSN=BILN+B15*ALOG(AGE)
      VLCSN=SECSN1*SECSN1
      MCSN=EXP(XLMCSN+0.5*VLCSN)
      CVCSN=SQRT(EXP(VLCSN)-1.0)
      VCSN=(CVCSN*MCSN)**2
      IF (I.NE.1) GO TO 6
```

```
      MSN(1,I)=SNO-MCSN
      VSN(1,I)=VCSN
      GO TO 7
6     MSN(1,I)=MSN(1,K)-MCSN
      VSN(1,I)=VSN(1,K)+VCSN
7     CONTINUE
      USN(1,I)=UTSN(MSN(1,I),VSN(1,I))
      IF (USN(1,I).GT.1.0) USN(1,I)=1.0
      SSN=SQRT(VSN(1,I))
      ZSN=-(LSN-MSN(1,I))/SSN
      IF (ZSN.LT.RSN) KSN=KSN+1
      IF (KSN.EQ.1) ISN(1)=I
8     CONTINUE
      IF (KRI.GT.0.AND.KSN.GT.0) GO TO 10
9     CONTINUE
10    CONTINUE
      IF (SNO.LT.LSN) ISN=0
      IF (RIO.GT.LRI) IRI=0
      IF (ISN(1).GT.NP.AND.IRI(1).GT.NP) GO TO 11
      GO TO 12
11    JST=JST+1
C
C                 NO MAJOR MAINTENANCE IS NECESSARY DURING THE
C                 ANALYSIS PERIOD.
C
      IK1(JST)=99
      IK2(JST)=99
      IK3(JST)=99
      AK1(JST)=1
      AK2(JST)=1
      AK3(JST)=1
      ICASE=1
      CALL PREDT
      GO TO 63
12    CONTINUE
      IF (ISN(1).LE.NP.AND.IRI(1).GT.NP) GO TO 57
      IF (IRI(1).LE.ISN(1)) GO TO 31
C
C                 THE PAVEMENT WOULD FAIL BOTH IN SN AND RI;
C                 HOWEVER IMPROVEMENT IN SN IS NEEDED FIRST.
C
      KT1=ISN(1)
C
C                 IF THE PRESENT SN IS LESS THAN THE LIMITING
C                 VALUE, IMMEDIATE CORRECTIVE ACTION IS NECESSARY.
C
      K1=KT1
C
C                 APPLY ACFC OR SEAL COAT AT TIME PERIOD K1.
C
13    AI=2
C
C                 CHECK FOR CRACKING AT PRESENT TIME
C
14    IF (K1.NE.0.OR.ICRACK.EQ.0) GO TO 16
      DO 15 I=1,NACR
      IF (AI.NE.INOCR(I)) GO TO 15
      AI=AI+1
15    CONTINUE
      IF (AI.GT.NA) GO TO 63
16    CONTINUE
      KPRIOR=1
```

```
      KCUR=AI
      DPRIOR=D
      NREM=NP-K1
      NPRIOR=K1
      IF (K1.EQ.0) GO TO 17
      ARIB=MRI(KPRIOR,K1)
      VRIB=VRI(KPRIOR,K1)
      GO TO 18
17    ARIB=RIO
      VRIB=0.0
18    CONTINUE
C
C                     FIND WHETHER THE PAVEMENT WOULD FAIL
C                     IN RI FOLLOWING THE ACTION AI.
C
      CALL PERFM
      D1=DPOST
      IF (IRI(AI).GT.NREM) GO TO 19
      GO TO 20
19    JST=JST+1
      IK1(JST)=K1
      IK2(JST)=99
      IK3(JST)=99
      AK1(JST)=AI
      AK2(JST)=1
      AK3(JST)=1
      ICASE=2
      CALL PREDT
      GO TO 30
20    KT2=IRI(AI)
      K2=KT2
      KPRIOR=AI
      DPRIOR=D1
C
C                     APPLY ACTION AJ AT K2
C
21    AJ=2+ISEAL
      NPRIOR=K1+K2
      NREM=NP-K1-K2
      ARIB=ARI1(KPRIOR,K2)
      VRIB=VRI1(KPRIOR,K2)
22    CONTINUE
      KCUR=AJ
C
C                     FIND WHETHER THE PAVEMENT WOULD FAIL
C                     FOLLOWING THE ACTION AJ
C
      CALL PERFM
      IF (IRI(AJ).GT.NREM) GO TO 23
      GO TO 24
23    JST=JST+1
      IK1(JST)=K1
      IK2(JST)=K2
      IK3(JST)=99
      AK1(JST)=AI
      AK2(JST)=AJ
      AK3(JST)=1
      ICASE=3
      CALL PREDT
      GO TO 29
24    CONTINUE
      KT3=IRI(AJ)
```

```
      K3=KT3
C
C                 APPLY ACTION AK AT K3
C
25    AK=2+ISEAL
26    JST=JST+1
      IK1(JST)=K1
      IK2(JST)=K2
      IK3(JST)=K3
      AK1(JST)=AI
      AK2(JST)=AJ
      AK3(JST)=AK
      ICASE=4
      CALL PREDT
      NREM2=NP-K1-K2-K3
      IF (IRI(AK).LT.NREM2) GO TO 27
      GO TO 28
27    JST=JST-1
      AK=AK+1
      IF (AK.LE.NA) GO TO 26
C
C                 CONSIDER PREVENTIVE MAINTENANCE ALTERNATIVES
C
28    K3=K3-1
      IF (K3.GT.(KT3-IL).AND.K3.GT.0) GO TO 25
      AJ=AJ+1
      IF (AJ.LE.NA) GO TO 22
29    K2=K2-1
      IF (K2.GT.(KT2-IL).AND.K2.GT.0) GO TO 21
      AI=AI+1
      IF (AI.LE.NA) GO TO 14
      K1=K1-1
      IF (K1.GT.(KT1-IL).AND.K1.GE.0) GO TO 13
      GO TO 63
31    CONTINUE
C
C                 THE PAVEMENT WOULD FAIL IN RI BEFORE OR
C                 AT THE SAME TIME IT FAILS IN SN.
C
      KT1=IRI(1)
C
C                 IF THE PRESENT RI IS GREATER THAN THE LIMITING VALUE,
C                 AN IMMEDIATE CORRECTIVE ACTION IS NECESSARY.
C
      K1=KT1
      GO TO 33
32    CONTINUE
      K1=0
C
C                 APPLY ACTION AI (EITHER MAJOR MAINTENANCE OR
C                 INITIAL DESIGN) AT K1
C
33    AI=2+ISEAL
34    IF (K1.NE.0.OR.ICRACK.EQ.0) GO TO 36
      DO 35 I=1,NACR
      IF (AI.NE.INDCR(I)) GO TO 35
      AI=AI+1
35    CONTINUE
      IF (AI.GT.NA) GO TO 63
36    CONTINUE
37    CONTINUE
C
```

```
C                  CHECK WHETHER INITIAL DESIGN IS TO BE
C                  CONSIDERED
C
      IF (IND.EQ.0) GO TO 40
      KPRIOR=1
      KCUR=AI
      DPRIOR=D
      NREM=NP-K1
      NPRIOR=K1
      IF (K1.EQ.0) GO TO 38
      ARIB=MRI(KPRIOR,K1)
      VRIB=VRI(KPRIOR,K1)
      GO TO 39
 38   ARIB=RIO
      VRIB=0.0
 39   CONTINUE
      GO TO 41
 40   D=DINTX(AI)
      KPRIOR=1
      KCUR=AI
      NREM=NP
      K1=0
      NPRIOR=K1
 41   CONTINUE
C
C                  FIND WHETHER THE PAVEMENT WOULD FAIL IN RI
C                  FOLLOWING THE ACTION AI.
C
      CALL PERFM
      IF (IND.EQ.0) GO TO 42
      D1=DPOST
      GO TO 43
 42   D1=D
 43   CONTINUE
      IF (IRI(AI).GT.NREM) GO TO 44
      GO TO 45
 44   JST=JST+1
      IK1(JST)=K1
      IK2(JST)=99
      IK3(JST)=99
      AK1(JST)=AI
      AK2(JST)=1
      AK3(JST)=1
      ICASE=2
      CALL PREDT
      GO TO 56
 45   KT2=IRI(AI)
      K2=KT2
      KPRIOR=AI
      DPRIOR=D1
C
C                  APPLY ACTION AJ AT K2
C
 46   AJ=2+ISEAL+NINTX
      NPRIOR=K1+K2
      NREM=NP-K1-K2
      ARIB=ARI1(KPRIOR,K2)
      VRIB=VRI1(KPRIOR,K2)
 47   CONTINUE
      KCUR=AJ
C
C                  FIND WHETHER THE PAVEMENT WOULD FAIL IN
```

```
C                   RI FOLLOWING THE ACTION AJ
      CALL PERFM
      IF (IRI(AJ).GT.NREM) GO TO 48
      GO TO 49
48    JST=JST+1
      IK1(JST)=K1
      IK2(JST)=K2
      IK3(JST)=99
      AK1(JST)=AI
      AK2(JST)=AJ
      AK3(JST)=1
      ICASE=3
      CALL PREDT
      GO TO 54
49    CONTINUE
      KT3=IRI(AJ)
      K3=KT3
C
C                   APPLY ACTION AK AT K3
C
50    AK=2+ISEAL+NINTX
51    JST=JST+1
      IK1(JST)=K1
      IK2(JST)=K2
      IK3(JST)=K3
      AK1(JST)=AI
      AK2(JST)=AJ
      AK3(JST)=AK
      ICASE=4
      CALL PREDT
      NREM2=NP-K1-K2-K3
      IF (IRI(AK).LT.NREM2) GO TO 52
      GO TO 53
52    JST=JST-1
      AK=AK+1
      IF (AK.LE.NA) GO TO 51
C
C                   CONSIDER PREVENTIVE MAINTENANCE ALTERNATIVES
C
53    K3=K3-1
      IF (K3.GT.(KT3-IL).AND.K3.GT.0) GO TO 50
      AJ=AJ+1
      IF (AJ.LE.NA) GO TO 47
54    K2=K2-1
      IF (K2.GT.(KT2-IL).AND.K2.GT.0) GO TO 46
      AI=AI+1
      IF (IND.EQ.0) GO TO 55
      IF (AI.LE.NA) GO TO 34
      GO TO 56
55    IF (AI.LE.(1+NINTX)) GO TO 37
      GO TO 63
56    K1=K1-1
      IF (K1.GT.(KT1-IL).AND.K1.GE.0) GO TO 33
      GO TO 63
57    CONTINUE
C
C                   THE PAVEMENT FAILS IN SN BUT NOT IN RI DURING
C                   THE ANALYSIS PERIOD
C
      KT1=ISN(1)
C
C                   IF THE PRESENT SN IS LESS THAN THE
```

```
C                 LIMITING VALUE, AN IMMEDIATE CORRECTIVE ACTION
C                 IS NECESSARY
C
      IF (SNO.LT.LSN) KT1=0
      K1=KT1
C
C                 APPLY ACFC CR SEAL COAT AT K1
C
      KPRIOR=1
      DPRIOR=0
      AI=2
C
C                 CHECK FOR CRACKING
C
      IF (K1.NE.0.OR.ICRACK.EQ.0) GO TO 59
      DO 58 I=1,NACR
      IF (AI.NE.INDCR(I)) GO TO 58
      AI=AI+1
 58   CONTINUE
      IF (AI.GT.NA) GO TO 63
 59   CONTINUE
      KCUR=AI
 60   NREM=NP-K1
      NPRIOR=K1
      IF (K1.EQ.0) GO TO 61
      ARIB=MRI(KPRIOR,K1)
      VRIB=VRI(KPRIOR,K1)
      GO TO 62
 61   ARIB=RIO
      VRIB=0.0
 62   CONTINUE
      CALL PERFM
      JST=JST+1
      IK1(JST)=K1
      IK2(JST)=99
      IK3(JST)=99
      AK1(JST)=AI
      AK2(JST)=1
      AK3(JST)=1
      ICASE=2
      CALL PREDT
      K1=K1-1
      IF (K1.GT.(KT1-IL).AND.K1.GE.0) GO TO 60
C
C                 SET THE TOTAL NUMBER OF FEASIBLE MAINTENANCE
C                 STRATEGIES TO NTOTAL
C
 63   NTOTAL=JST
      RETURN
      END
```

```
      SUBROUTINE SDATA
C
C                 THIS SUBROUTINE  READS AND PRINTS INPUT DATA
C
      REAL LRI,LSN,MRI,MSN,MSNA
      COMMON /IO/ IN,IOUT
C
      COMMON /SDATA/ NP,NINTX,NA,NOPT,LRI,LSN,RRI,RSN,IND,IACFC,ICRACK,A
     1GT,AGF,PAGE,RGN,D,RIO,SNC,THICK(15),DINTX(10),C11,C12,C13,C14,C15,
     2SECRI1,C21,C22,C23,C24,C25,C26,SECRI2,B11,B12,B13,B14,B15,SECSN1,C
     3RH(15),B21,B22,B23,B24,B25,SECSN2,XC0,XC1,XC2,SERIA,MSNA,SDSNA,PRD
     4EFL(15),TD(15),CVTD,CMM(15),CVCT,EI,TI,R,CU1,CU2,NACR,INDCR(10),IS
     5EAL,TRFC(70),UKI(4),UK,DESCM(15,15),DESC(20),IPAGE,NLINE,IPROB,AU1
     6,AU2,BU1,BU2,B31,B32,B33,B34,B35,SECSN3
C
C
C                 INITIALIZE THE TRAFFIC DELAY VECTOR
C
      DO 1 I=1,15
1     TD(I)=0.0
      IPAGE=0
C
C                 READ AND PRINT PROJECT DESCRIPTION
C                 DESC= EIGHTY COLUMN ALPHANUMERIC DESCRIPTION OF
C                       THE PROJECT
      READ (IN,16) (DESC(I),I=1,20)
      CALL PHEAD (IPAGE,DESC,NLINE,IPROB)
C
C                 READ AND PRINT CONTROL PARAMETERS
C
                  NP= NUMBER OF PERIODS IN THE ANALYSIS
C                     (ONE PERIOD IS EQUAL TO TWO YEARS)
C                 NINTX= NUMBER OF FEASIBLE INITIAL DESIGNS
C                 NA= NUMBER OF INITIAL DESIGNS AND MAINTENANCE
C                     ALTERNATIVES
C                 NOPT= OPTION OF PRINTING INPUT DATA ONLY
C                          0= PRINT INPUT DATA ONLY
C                          1= EXECUTE THE PROGRAM
C                 LRI= LIMITING VALUE OF ROUGHNESS INDEX(RI)
C                 LSN= LIMITING VALUE OF SKID NUMBER(SN)
C                 RRI= RELIABILITY FACTOR FOR NOT EXCEEDING
C                      THE LIMITING RI VALUE LRI
C                 RSN= RELIABILITY FACTOR FOR NOT EXCEEDING
C                      THE LIMITING SN VALUE LSN
C                 IND= INDICATOR FOR NEW DESIGN
C                          0= NEW DESIGN OF PAVEMENT
C                          1= IN-SERVICE PAVEMENT
C                 NACR= NUMBER OF ALTERNATIVES TO BE ELIMINATED
C                       IF CRACKING IS OBSERVED AT PRESENT TIME
C
C
C                 READ AND PRINT CONTROL PARAMETERS
C
      READ (IN,17) NP,NINTX,NA,NOPT,LRI,LSN,RRI,RSN,IND,NACR
      WRITE (IOUT,18) NP,NINTX,NA,NOPT,LRI,LSN,RRI,RSN,IND,NACR
C
C                 CHECK THE NUMBER OF ALTERNATIVES TO BE ELIMINATED
C                 IF THEY EXIST.  IF  YES READ AND NOTE THEM IN
C                 THE ALTERNATIVE  DESCRIPTION LIST
C
      IF (NACR.EQ.0) GO TO 3
```

```
C
C              INDCR(I)= NUMBER OF THE ALTERNATIVE WHICH
C                        IS TO BE ELIMINATED IF CRACKING
C                        IS OBSERVED
C
      J=NACR+1
      DO 2 I=J,10
2     INDCR(I)=0
      READ (IN,19) (INDCR(I),I=1,NACR)
3     CONTINUE
C
C              READ AND PRINT DESCRIPTION OF MAINTENANCE
C              ALTERNATIVES.
C
      K=1
      WRITE (IOUT,20)
      DO 5 I=1,NA
      READ (IN,16) (DESCM(I,J),J=1,15)
      IF (NACR.NE.0.AND.INDCR(K).EQ.I) GO TO 4
      WRITE (IOUT,21) I,(DESCM(I,J),J=1,15)
      GO TO 5
4     WRITE (IOUT,22) I,(DESCM(I,J),J=1,15)
      K=K+1
5     CONTINUE
C
C              READ AND PRINT INFORMATION PERTINENT TO THE
C              PAVEMENT SECTION UNDER CONSIDERATION
C
C              IACFC= PRESENCE OR ABSENCE OF ACFC
C                     0= PAVEMENT WITH ACFC
C                     1= PAVEMENT WITHOUT ACFC
C              ICRACK= INDICATOR FOR CRACKING AT PRESENT TIME
C                      0= CRACKING NOT OBSERVED
C                      1= CRACKING OBSERVED
C              ISEAL= INDICATOR FOR USING SEAL COAT
C                     0= SEAL COAT NOT TO BE USED
C                     1= SEAL COAT TO BE USED
C              AGT= AGGREGATE TYPE IN PRESENT CONDITION
C                   1= BASALT OR CINDERS
C                   2= GRAVEL
C                   3= LIMESTONE
C              AGF= AGGREGATE TYPE TO BE USED IN FUTURE ACFC
C                   (CODE SAME AS FOR AGT, ABOVE)
C              PAGE= PAVEMENT AGE IN YEARS AT PRESENT TIME
C              RGN=  ENVIRONMENTAL REGION
C                    1= LOW ALTITUDE, LOW RAINFALL
C                    2= HIGH ALTITUDE, HIGH RAINFALL,
C                       NO SWELLING CLAY
C                    3= HIGH ALTITUDE, HIGH RAINFALL, SWELLING CLAY
C              D= CURRENT DEFLECTION-INCHES
C              RIO= PRESENT RI OF THE PAVEMENT
C              SNO= PRESENT SN OF THE PAVEMENT
C              THICK(I)= THICKNESS OF THE I-TH OVERLAY
C
      CALL PHEAD (IPAGE,DESC,NLINE,IPR(8)
      READ (IN,23) IACFC,ICRACK,ISEAL,AGT,AGF,PAGE,RGN,D,RIO,SNO
      WRITE (IOUT,24) IACFC,ICRACK
      WRITE (IOUT,25) ISEAL,AGT,AGF,PAGE,RGN,D
      WRITE (IOUT,26) RIO,SNO
C
C              IN CASE OF NEW DESIGN, READ AND WRITE
C              ESTIMATED DEFLECTION FOR ALTERNATIVE
```

```
C                INITIAL DESIGNS
C
      IF (IND.NE.0) GO TO 7
      I2=1+NINTX
      READ (IN,29) (DINTX(I),I=2,I2)
      WRITE (IOUT,27)
      DO 6 I=2,I2
      WRITE (IOUT,28) I,DINTX(I)
6     CONTINUE
7     CONTINUE
C
C                READ AND PRINT OVERLAY THICKNESS
C
      I1=2+NINTX+ISEAL
      READ (IN,29) (THICK(I),I=I1,NA)
      WRITE (IOUT,30)
      DO 8 I=I1,NA
      WRITE (IOUT,31) I,THICK(I)
8     CONTINUE
C                READ AND PRINT PARAMETERS OF PREDICTION
C                MODELS.  THE FOLLOWING REGRESSION EQUATIONS
C                AND STATISTICAL INFORMATION ARE TO BE
C                SPECIFIED¬
C
C                (1) CHANGE IN RI FOR NEW OR IN-SERVICE PAVEMENTS
C                    LN(CRI)=LN(C11)+C12*LN(TRAFFIC)+C13*LN(REGION)
C                            +C14*LN(DEFLECTION)+C15*LN(AGE)+E1
C                    WHERE E1 IS THE ERROR TERM WITH MEAN ZERO AND
C                    STANDARD DEVIATION SECRI1
C
      CALL PHEAD (IPAGE,DESC,NLINE,IPRCB)
      WRITE (IOUT,32)
      WRITE (IOUT,33) C11,C12,C13,C14,C15,SECRI1
C
C                (2) CHANGE IN RI FOLLOWING MAJOR MAINTENANCE
C                    LN(CRI)= LN(CRH)+LN(C21)+C22*LN(TRAFFIC)
C                             +C23*LN(REGION)+C24$LN(DEFLECTION)
C                             +C25*LN(THICKNESS)+C26*LN(AGE)+E2
C                    WHERE E2 IS THE ERROR TERM WITH MEAN ZERO
C                    AND STANDARD DEVIATION SECRI2, AND CRH IS A
C                    CORRECTION FACTOR FOR INDICATING EFFECT OF
C                    RUBBER COAT OR HEAT SCARIFIER ON PERFORMANCE
C
      WRITE (IOUT,34) C21,C22,C23,C24,C25,C26,SECRI2
      READ (IN,29) (CRH(I),I=I1,NA)
      WRITE (IOUT,35)
      DO 9 I=I1,NA
      WRITE (IOUT,36) I,CRH(I)
9     CONTINUE
C
C                (3) CHANGE IN SN FOR NEW OR IN-SERVICE PAVEMENT
C                    LN(CSN)= LN(B11)+B12*LN(TRAFFIC)+B13*LN(REGION)
C                             +B14*LN(AGG. TYPE)+BIS*LN(AGE)+E3
C                    WHERE E3 IS THE ERROR TERM WITH MEAN ZERO AND
C                    STANDARD DEVIATION SECSN1.
C
      IF (IACFC.EQ.1) GO TO 10
      B11=B21
      B12=B22
      B13=B23
      B14=B24
      B15=B25
```

```
      SECSN1=SECSN2
      GO TO 11
10    B11=B31
      B12=B32
      B13=B33
      B14=B34
      B15=B35
      SECSN1=SECSN3
11    CONTINUE
      WRITE (IOUT,37) B11,B12,B13,B14,B15,SECSN1
C
C                 (4) CHANGE IN SN FOLLOWING ACFC
C
C                     LN(CSN)= LN(B21)+B22*LN(TRAFFIC)+B23*LN(REGION)
C                              +B24*LN(AGG. TYPE)+B25*LN(AGE)+E4
C                     WHERE E4 IS THE ERROR TERM WITH MEAN ZERO AND
C                     STANDARC DEVIATION SECSN2.
C
      WRITE (IOUT,38) B21,B22,B23,B24,B25,SECSN2
C
C                 (5) RI IMMEDIATELY AFTER AN OVERLAY
C                     LN(RIA)=LN(XC0)+XC1*LN(RIB)+XC2*LN(T)+E5
C                     WHERE E5 IS THE ERROR TERM WITH MEAN ZERO
C                     AND STANDARD DEVIATION SERIA.
C                     T IS THICK(AI) WHICH EQUALS THE THICKNESSOF
C                                    THE I-TH MAJOR MAINTENCE
C                                    ALTERNATIVE
C
      WRITE (IOUT,39) XC0,XC1,XC2,SERIA
C
C                 (6) SN IMMEDIATELY AFTER ACFC-
                      TWO PARAMETERS ARE TO BE SPECIFIED.
C
C                     MSNA= AVERAGE SN IMMEDIATELY AFTER ACFC.
C                     SDSNA= STANDARD DEVIATION OF SN IMMEDIATELY
C                            AFTER ACFC.
C
      CALL PHEAD (IPAGE,DESC,NLINE,IPRCB)
      WRITE (IOUT,40)
      READ (IN,29) MSNA,SDSNA
      WRITE (IOUT,41) MSNA,SDSNA
C
C                 (7) REDUCTICN IN DEFLECTION FOLLOWING
C                     MAJOR MAINTENANCE-
C                     PRDEFL(I)= AVERAGE PERCENTAGE REDUCTION IN
C                                DEFLECTION FOLLOWING I-TH TYPE
C                                OF MAJOR MAINTENANCE.
C
      WRITE (IOUT,42)
      READ (IN,29) (PRDEFL(I),I=I1,NA)
      DO 12 I=I1,NA
      WRITE (IOUT,43) I,PRDEFL(I)
12    CONTINUE
C
C                 (8) TRAFFIC DELAY DURING MAJOR MAINTENANCE
C                     OPERATIONS-
C                     TD(I)= AVERAGE TRAFFIC DELAY ASSOCIATED WITH
                             I,TH TYPE OF MAJOR MAINTENANCE
C                     CVTD= COEFFICIENT OF VARIATION OF TRAFFIC DELAY
C
      I11=2+NINTX
      READ (IN,29) (TD(I),I=I11,NA),CVTD
```

```
      WRITE (IOUT,44)
      DO 13 I=I1,NA
      WRITE (IOUT,43) I,TD(I)
13    CONTINUE
      WRITE (IOUT,45) CVTD
r
L                   READ AND PRINT COST INFORMATION
C
C
C                   CMM(K)= COST OF K-TH TYPE OF MAJOR MAINTENANCE
C                           IN DOLLARS PER LANE MILE
C                   CVCT= COEFFICIENT OF VARIATION OF COST ESTIMATES
C
      CALL PHEAD (IPAGE,DESC,NLINE,IPRCB)
C
C                    PRINT ROUTINE MAINTENANCE FUNCTION
C
      WRITE (IOUT,46)
      READ (IN,29) (CMM(K),K=2,NA)
      READ (IN,29) CVCT,EI
      WRITE (IOUT,47)
      DO 14 I=2,NA
      WRITE (IOUT,48) I,CMM(I)
14    CONTINUE
      WRITE (IOUT,49) CVCT,EI
C
C                   READ AND PRINT TRAFFIC INFORMATION
C
C                   T1= AVERAGE ANNUAL TRAFFIC DURING THE FIRST
C                       YEAR OF ANALYSIS
C                   R= ANNUAL RATE OF GROWTH OF TRAFFIC
                       IN PERCENT
C
      READ (IN,29) T1,R
      WRITE (IOUT,50) T1,R
C
C                   CALCULATE ANNUAL TRAFFIC DURING THE ANALYSIS PERIOD
C
      DO 15 I=1,70
15    TRFC(I)=T1*((1.0+R/100.0)**I)
      RETURN
C
16    FORMAT (20A4)
17    FORMAT (4I5,4F10.0,2I5)
18    FORMAT (//1X,18HCONTROL PARAMETERS//15X,34HNUMBER OF PERIODS IN TH
     1E ANALYSIS ,36(1H-),I5/15X,35HNUMBER OF FEASIBLE INITIAL DESIGNS ,
     235(1H-),I5/15X,35HNUMBER OF MAINTENANCE ALTERNATIVES ,35(1H-),I5/1
     35X,35HOPTION OF PRINTING INPUT DATA ONLY ,35(1H-),I5/25X,26H(0= PR
     4INT INPUT DATA ONLY)/25X,24H(1= EXECUTE THE PROGRAM)/15X,21HLIMITI
     5NG VALUE OF RI ,49(1H-),F5.1/15X,21HLIMITING VALUE OF SN ,49(1H-),
     6F5.1/15X,59HRELIABILITY FACTOR FOR NOT EXCEEDING THE LIMITING RI V
     7ALUE ,11(1H-),F7.3/15X,59HRELIABILITY FACTOR FOR NOT EXCEEDING THE
     8 LIMITING SN VALUE ,11(1H-),F7.3/15X,25HINDICATOR FOR NEW DESIGN ,
     945(1H-),I5/25X,27H(0= NEW DESIGN OF PAVEMENT)/25X,24H(1= IN-SERVIC
     $E PAVEMENT)/15X,40HNUMBER OF ALTERNATIVES TO BE ELIMINATED ,30(1H-
     $),I5)
'     FORMAT (10I5)
L     FORMAT (/1X,39HDESCRIPTION OF MAINTENANCE ALTERNATIVES/)
21    FORMAT (15X,15HALTERNATIVE NO.,I2,3H ¬ ,15A4)
22    FORMAT (15X,15HALTERNATIVE NO.,I2,3H ¬ ,28HELIMINATED DUE TO CRACK
     1ING- ,15A4)
23    FORMAT (3I5,7F5.0)
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24    FORMAT (//1X,47HINFORMATION PERTINENT TO GIVEN PAVEMENT SECTION//1SDA 310
     15X,42HINDICATOR FOR PRESENCE OR ABSENCE OF ACFC ,28(1H-),I5/29X,14SDA 311
     2H(0= WITH ACFC)/29X,17H(1= WITHOUT ACFC)/15X,23HINDICATOR FOR CRACSDA 312
     3KING ,47(1H-),I5/29X,16H(0= NO CRACKING)/29X,13H(1= CRACKING))    SDA 313
25    FORMAT (15X,30HINDICATOR FOR USING CHIP SEAL ,40(1H-),I5/29X,29H(0SDA 314
     1= CHIP SEAL NOT TO BE USED)/29X,25H(1= CHIP SEAL TO BE USED)/15X,3SDA 315
     26HAGGREGATE TYPE IN PRESENT CONDITION ,34(1H-),F5.1/29X,22H(1= BASSDA 316
     3ALT OR CINDERS)/29X,11H(2= GRAVEL)/29X,14H(3= LIMESTONE)/15X,41HAGSDA 317
     4GREGATE TYPE TO BE USED IN FUTURE ACFC ,29(1H-),F5.1/29X,29H(CODE SDA 318
     5SAME AS PRESENT--ABOVE)/15X,38HPAVEMENT AGE IN YEARS AT PRESENT TISDA 319
     6ME ,32(1H-),F5.1/15X,47HENVIRONMENTAL REGION OF GIVEN PAVEMENT SECSDA 320
     7TION ,23(1H-),F5.1/29X,31H(1= LOW ALTITUDE, LOW RAINFALL)/29X,51H(SDA 321
     82= HIGH ALTITUDE, HIGH RAINFALL, NO SWELLING CLAY)/29X,48H(3= HIGHSDA 322
     9 ALTITUDE, HIGH RAINFALL, SWELLING CLAY)/15X,55HPRESENT DEFLECTIONSDA 323
     $ (IN INCHES) OF THE PAVEMENT SECTION ,15(1H-),F8.4)               SDA 324
26    FORMAT (15X,52HPRESENT RI(ROUGHNESS INDEX) OF THE PAVEMENT SECTIONSDA 325
     1 ,18(1H-),F5.1/15X,45HPRESENT SN(SKID NO.) OF THE PAVEMENT SECTIONSDA 326
     2 ,25(1H-),F5.1)                                                   SDA 327
27    FORMAT (//1X,52HNEW DESIGN INDICATED - ESTIMATES FOR DEFLECTION ARSDA 328
     1E¬//15X,43HINITIAL DESIGN NO.     ESTIMATED DEFLECTION/)          SDA 329
28    FORMAT (29X,I4,10X,F6.3)                                          SDA 330
29    FORMAT (8F10.0)                                                   SDA 331
30    FORMAT (//1X,17HOVERLAY THICKNESS,//15X,31HMAINT. ALT.   THICKNESSSDA 332
     1(INCHES))                                                         SDA 333
31    FORMAT (22X,I2,8X,F6.3)                                           SDA 334
32    FORMAT (//1X,17HPREDICTION MODELS)                                SDA 335
33    FORMAT (/5X,48H1) CHANGE IN RI FOR NEW OR IN-SERVICE PAVEMENTS-/9XSDA 336
     1,92HLN(CRI) = C11 + C12 * LN(TRAFFIC) + C13 * LN(REGION) + C14 * LSDA 337
     2N(DEFLECTION) + C15 * LN(AGE) /9X,24HREGRESSION COEFFICIENTS ,5H CSDA 338
     311=,F8.4,5H C12=,F8.4,5H C13=,F8.4,5H C14=,F8.4,5H C15=,F8.4/9X,15SDA 339
     4HSTANDARD ERROR=,8F8.4)                                           SDA 340
     1) = CRH + C21 + C22 * LN(TRAFFIC) + C23 * LN(REGION) + C24 * LN(DESDA 342
34    FORMAT (/5X,37H2) CHANGE IN RI FOLLOWING AN OVERLAY-/9X,119HLN(CRISDA 341
     2FLECTION) + C25 * LN(THICKNESS) + C26 * LN(AGE)/9X,39HREGRESSION CSDA 343
     3OEFFICIENTS(EXCLUDING CRH) ,5H C21=,F8.4,5H C22=,F8.4,5H C23=,F8.4SDA 344
     4,5H C24=,F8.4,5H C25=,F8.4,5H C26=,F8.4/9X,15HSTANDARD ERROR=,F8.4SDA 345
     5)                                                                 SDA 346
35    FORMAT (9X,102HCRH ARE CORRECTION FACTORS INDICATING EFFECT OF RUBSDA 347
     1BER COAT OR HEAT SCARIFIER ON PAVEMENT PERFORMANCE /9X,43HCORRECTISDA 348
     2ON FACTORS (CRH) FOR GIVEN OVERLAYS/9X,22HMAINT. ALT.        CRH) SDA 349
36    FORMAT (15X,I2,9X,F6.2)                                           SDA 350
37    FORMAT (/5X,47H3) CHANGE IN SN FOR NEW OR IN-SERVICE PAVEMENT-/9X,SDA 351
     190HLN(CSN) = B11 + B12 * LN(TRAFFIC) + B13 * LN(REGION) + B14 * LNSDA 352
     2(AGG. TYPE) + B15 * LN(AGE)/9X,24HREGRESSION COEFFICIENTS ,5H B11=SDA 353
     3,F8.4,5H B12=,F8.4,5H B13=,F8.4,5H B14=,F8.4,5H B15=,F8.4/9X,15HSTSDA 354
     4ANDARD ERROR=,F8.4)                                               SDA 355
38    FORMAT (/5X,31H4) CHANGE IN SN FOLLOWING ACFC-/9X,90HLN(CSN) = B21SDA 356
     1 + B22 * LN(TRAFFIC) + B23 * LN(REGION) + B24 * LN(AGG. TYPE) + B2SDA 357
     25 * LN(AGE)/9X,24HREGRESSION COEFFICIENTS ,5H B21=,F8.4,5H B22=,F8SDA 358
     3.4,5H B23=,F8.4,5H B24=,F8.4,5H B25=,F8.4/9X,15HSTANDARD ERROR=,F8SDA 359
     4.4)                                                               SDA 360
39    FORMAT (/5X,35H5) RI IMMEDIATELY AFTER AN OVERLAY-/9X,43HLN(RIA) =SDA 361
     1 XC0 + XC1 * LN(FIB) + XC2 * LN(T)/9X,24HREGRESSION COEFFICIENTS ,SDA 362
     25H XC0=,F8.4,5H XC1=,F8.4,5H XC2=,F8.4/9X,15HSTANDARD ERROR=,F8.4)SDA 363
40    FORMAT (//1X,29HPREDICTION MODELS - CONTINUED//)                  SDA 364
41    FORMAT (/5X,29H6) SN IMMEDIATELY AFTER ACFC-/9X,34HAVERAGE SN IMMESDA 365
     1DIATELY AFTER ACFC=,F5.1/9X,48HSTANDARD DEVIATION OF SN IMMEDIATELSDA 366
     2Y AFTER ACFC=,F6.3)                                               SDA 367
42    FORMAT (/5X,55H7) REDUCTION IN DEFLECTION FOLLOWING MAJOR MAINTENASDA 368
     1NCE-/9X,49HMAINT. ALT.    PERCENTAGE REDUCTION IN DEFLECTION)     SDA 369
43    FORMAT (15X,I2,7X,F5.1)                                           SDA 370
44    FORMAT (/5X,53H8) TRAFFIC DELAY DURING MAJOR MAINTENANCE OPERATIONSDA 371
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     1S-/9X,47HMAINT. ALT.    AVERAGE TRAFFIC DELAY IN MINUTES)         SDA 372
45    FORMAT (/9X,42HCOEFFICIENT OF VARIATION OF TRAFFIC DELAY=,F8.4)   SDA 373
46    FORMAT (///1X,26HROUTINE MAINTENANCE COSTS-//11X,70HCOSTS FOR ROUTSDA 374
     1INE MAINTENANCE ARE DERIVED FROM THE FOLLOWING FUNCTION-//11X,40HRSDA 375
     2MCOST = -200.0 + 10.0 * RI + 35.0 * AGE)                          SDA 376
'     FORMAT (///1X,22HMAJOR MAINTENANCE COST//11X,26HMAINT. ALT.    MAISDA 377
     1NT. COST)                                                         SDA 378
48    FORMAT (17X,I2,7X,F10.2)                                          SDA 379
49    FORMAT (/11X,33HCOEFFICIENT OF VARIATION OF COST=,F8.4//11X,24HEFFSDA 380
     1ECTIVE INTEREST RATE=,F5.2)                                       SDA 381
50    FORMAT (//1X,19HTRAFFIC INFORMATION//9X,53HAVERAGE ANNUAL TRAFFIC SDA 382
     1DURING FIRST YEAR OF ANALYSIS=,F10.2//9X,39HANNUAL TRAFFIC GROWTH SDA 383
     2RATE(IN PERCENT)=,F5.2)                                           SDA 384
      END                                                               SDA 385-
```

```
      SUBROUTINE SCALC (RK,N,VALK)
C
C  CALCULATE K (RETURNED AS VALK) FROM KI VALUES (RK)
C
      DIMENSION RK(20)
C        SK -- SUM OF KI
      SK=0.
C        SKIP --  SKIP INTERVAL
      SKIP=.1
      B=0.
      A=0.
      AGP=-.1
C        CALCULATE SUM OF KI
      DO 1 I=1,N
1     SK=SK+RK(I)
      IF (SK-1.) 2,2,9
2     AG=.1
3     ALFT=1.+AG
      RHS=1.0
      DO 4 I=1,N
      A=(1.+AG*RK(I))
4     RHS=A*RHS
      IF (ABS(ALFT-RHS)-.001) 8,8,5
5     IF (ALFT-RHS) 7,8,6
6     AG=AG+SKIP
      GO TO 3
7     SKIP=SKIP/2.
      AG=AG-SKIP
      GO TO 3
8     VALK=AG
      J=0
      RETURN
C        SUM OF KI .GT 1.0
9     ALFT=1.+AGP
C     RHS CALCULATION
      RHS=1.
      DO 10 I=1,N
      B=1.+AGP*RK(I)
10    RHS=RHS*B
      IF (ABS(ALFT-RHS)-.001) 14,14,11
11    IF (ALFT-RHS) 13,14,12
12    AGP=AGP-SKIP
      GO TO 9
13    SKIP=SKIP/2.0
      AGP=AGP+SKIP
      GO TO 9
14    VALK=AGP
      RETURN
      END
```

```
      SUBROUTINE PREDT
C
C                 THIS SUBROUTINE CALCULATES EQUIVALENT SKID
C                 NUMBER,ROUGHNESS INDEX,ANNUAL COST,AND TRAFFIC
C                 DELAY FOR EACH MAINTENANCE STRATEGY SELECTED
C                 IN THE SUBROUTINE SCFMS.
C
      REAL LRI,LSN,MRI,MSN,MSNA
      REAL MRIO,MCRI,MCSN,MSNO,ARI2(15,20),VRI2(15,20),ASN2(15,20),VSN2(
     115,20),URI2(15,20),USN2(15,20)
      INTEGER AI,AJ,AK,AK1,AK2,AK3
C
      COMMON /SDATA/ NP,NINTX,NA,NOPT,LRI,LSN,RRI,RSN,IND,IACFC,ICRACK,A
     1GT,AGF,PAGE,RGN,D,RIO,SNO,THICK(15),DINTX(10),C11,C12,C13,C14,C15,
     2SECRI1,C21,C22,C23,C24,C25,C26,SECRI2,B11,B12,B13,B14,B15,SECSN1,C
     3RH(15),B21,B22,B23,B24,B25,SECSN2,XC0,XC1,XC2,SERIA,MSNA,SDSNA,PRD
     4EFL(15),TD(15),CVTD,CMM(15),CVCT,EI,TI,R,CU1,CU2,NACR,INDCR(10),IS
     5EAL,TRFC(70),UKI(4),UK,DESCM(15,15),DESC(20),IPAGE,NLINE,IPROB,AU1
     6,AU2,BU1,BU2,B31,B32,B33,B34,B35,SECSN3
C
      COMMON /PERFM/ MRI(15,20),VRI(15,20),MSN(15,20),VSN(15,20),NPRIOR,
     1NREM,KPRIOR,KCUR,DPRIOR,IRI(15),ISN(15),DPOST,ARI1(15,20),VRI1(15,
     220),ASN1(15,20),VSN1(15,20),URI(15,20),URI1(15,20),USN(15,20),USN1
     3(15,20)
C
      COMMON /SOFMS/ NTOTAL,IK1(500),IK2(500),IK3(500),AK1(500),AK2(500)
     1,AK3(500),RIA(500,15),RISD(500,15),SNA(500,15),SNSD(500,15),DF(40)
     2,FEAC,ARIB
C
      COMMON /PREDT/ AI,AJ,AK,K1,K2,K3,ICASE,ERI(500),ESN(500),EAC(500),
     1ETD(500),UERI(500),UESN(500),UEAC(500),UETD(500),JST
      COMMON /IO/ IN,IOUT
C
C                    PROVIDE UTILITY FUNCTIONS AND FUNCTIONS
C                    FOR CALCULATING CERTAINTY EQUIVALENTS
C                    OF SN,RI,TD, AND EAC.
C
C
C                    SPECIAL UTILITY FUNCTION FOR SKID NUMBER
C
      UTSN(XM,VARX)=CU1*(1.0-EXP(-CU2*25.0+CU2*XM+0.5*CU2*CU2*VARX))
C
C                   IF THE UTILITY FUNCTION FOR ROUGHNESS INDEX
C                   IS LINEAR, USE THE FOLLOWING FUNCTION-----
C
      UTRI(XM,VARX)=1.06-0.0212*XM
C
C                   IF THE UTILITY FUNCTION FOR ROUGHNESS INDEX
C                   IS EXPONENTIAL, DEACTIVATE THE PREVIOUS
C                   FUNCTION BY PLACING A C IN COLUMN ONE AND
C                   ACTIVATE THE FOLLOWING FUNCTION BY REMOVING
C                   THE C(S) IN COLUMN ONE.
C
C     UTRI(XM,VARX)=BU1*(1.0-EXP(BU2*2.12-BU2*0.0424*XM+0.5*BU2*0.0424
C    1*BU2*0.0424*VARX))
C
C                   IF THE UTILITY FUNCTION FOR TRAFFIC DELAY IS
C                   LINEAR, USE THE FOLLOWING FUNCTION ---
C
      UTTD(XM,VARX)=1.0-XM/30.0
C
```

```
C                  IF THE UTILITY FUNCTION FOR TRAFFIC DELAY IS
C                  NONLINEAR, DEACTIVATE THE PREVIOUS FUNCTION
C                  BY PLACING A C IN COLUMN ONE AND ACTIVATE THE
C                  FOLLOWING FUNCTION BY REMOVING THE C(S) IN
C                  COLUMN ONE..........
C
C     UTTD(XM,VARX)=AU1*(1.0-EXP(-AU2*30.0+AU2*XM+0.5*AU2*AU2*VARX))
C
      UTEAC(X)=(10000.0-X)/9700.0
C
C                  PROVIDE FUNCTIONS FOR CALCULATING CERTAINTY
C                  EQUIVALENTS OF RI, SN, TD AND EAC.
C
      CESN(X)=(ALOG(1.0-X/CU1))/CU2+25.0
C
C                  IF THE UTILITY FUNCTION IS LINEAR FOR ROUGHNESS
C                  INDEX, USE THE FOLLOWING ----
C
      CERI(X)=(1.06-X)/0.0212
C
C                  IF THE UTILITY FUNCTION FOR RI IS NON-LINEAR,
C                  DEACTIVATE THE PREVIOUS FUNCTION BY PLACING A
C                  C IN COLUMN ONE AND ACTIVATE THE FOLLOWING FUNCTION
C                  BY REMOVING THE C(S) FROM COLUMN ONE.
C
C     CERI(X)=(2.12-(ALOG(1.0-X/BU1)/BU2))/0.0424
C
C
C                  IF THE UTILITY FUNCTION FOR TD IS LINEAR,
C                  USE THE FOLLOWING FUNCTION  ---
C
      CETD(X)=(1.0-X)*30.0
C
C                  IF THE UTILITY FUNCTION FOR TD IS NON-LINEAR,
C                  DEACTIVATE THE PREVIOUS FUNCTION BY REMOVING
C                  C IN COLUMN ONE AND ACTIVATE THE FOLLOWING
C                  FUNCTION BY REMOVING THE C(S) IN COLUMN ONE.
C
C     CETD(X)=(ALOG(1.0-X/AU1))/AU2+30.0
C
      CEEAC(X)=10000.0-9700.0*X
C
      RMCOST(X,Y)=-200.0+10.0*X+35.0*Y
C
      RNP=FLOAT(NP)
      NYEARS=2*NP
C
C                  SELECT THE APPROPRIATE CASE FOR THE CURRENT
C                  MAINTENANCE STRATEGY.
C
      GO TO (1,5,15,26),ICASE
1     CONTINUE
C
C                  CASE NUMBER 1- ONLY ROUTINE MAINTENANCE IS
C                  SCHEDULED DURING THE ANALYSIS PERIOD.
C
C                  CALCULATE EQUIVLENT RI  AND SN OF THE CURRENT
C                  MAINTENANCE STRATEGY.
C
      I1=1
      I2=NP
```

```
      AVU1=0.0
      AVU2=0.0
      PWTC=0.0
      DO 4 J=I1,I2
      RIA(JST,J)=MRI(1,J)
      RISD(JST,J)=SQRT(VRI(1,J))
      SNA(JST,J)=MSN(1,J)
      SNSD(JST,J)=SQRT(VSN(1,J))
      IF (J.EQ.1) GO TO 2
      X=RIA(JST,J-1)
      Y=2.0*FLOAT(J)-2.0
      JY=2*J-2
      RMC=RMCOST(X,Y)*2.0*DF(JY)
      GO TO 3
2     X=RIO
      Y=PAGE
      RMC=RMCOST(X,Y)*2.0
3     IF (RMC.LT.0.0) RMC=0.0
      PWTC=PWTC+RMC
      AVU1=AVU1+URI(1,J)
4     AVU2=AVU2+USN(1,J)
      UERI(JST)=AVU1/RNP
      UESN(JST)=AVU2/RNP
      ERI(JST)=CERI(UERI(JST))
      ESN(JST)=CESN(UESN(JST))
C
C                 CALCULATE EQUIVALENT ANNUAL COST OF THE
C                 CURRENT MAINTENANCE STRATEGY.
C
      EAC(JST)=PWTC/FEAC
      UEAC(JST)=UTEAC(EAC(JST))
C
C                 FIND EQUIVALENT TRAFFIC DELAY FOR THE CURRENT
C                 STRATEGY.
C
      ETD(JST)=0.0
      UETD(JST)=1.0
      GO TO 45
5     CONTINUE
C
C                 CASE NUMBER 2 ONLY ONE ACTION-AI AT KI-
C                 IS SCHEDUALED DURING THE ANALYSIS PERIOD.
C
C                 CALCULATE EQUIVALENT RI AND SN OF THE
C                 CURRENT MAINTENANCE STRATEGY.
C
      I1=1
      I2=K1
      AVU1=0.0
      AVU2=0.0
      PWTC=0.0
      IF (K1.EQ.0) GO TO 9
      DO 8 J=I1,I2
      RIA(JST,J)=MRI(1,J)
      RISD(JST,J)=SQRT(VRI(1,J))
      SNA(JST,J)=MSN(1,J)
      SNSD(JST,J)=SQRT(VSN(1,J))
      IF (J.EQ.1) GO TO 6
      X=RIA(JST,J-1)
      Y=2.0*FLOAT(J)-2.0+PAGE
      JY=2*J-2
      RMC=RMCOST(X,Y)*2.0*DF(JY)
```

```
      GO TO 7
6     X=RIO
      Y=PAGE
      RMC=RMCOST(X,Y)*2.0
7     IF (RMC.LT.0.0) RMC=0.0
      PWTC=PWTC+RMC
      AVU1=AVU1+URI(1,J)
8     AVU2=AVU2+USN(1,J)
9     I1=K1+1
      IF (I1.GT.NP) GO TO 12
      I2=NP
      IJJ=0
      DO 11 J=I1,I2
      IJJ=IJJ+1
      RIA(JST,J)=MRI(AI,IJJ)
      RISD(JST,J)=SQRT(VRI(AI,IJJ))
      SNA(JST,J)=MSN(AI,IJJ)
      SNSD(JST,J)=SQRT(VSN(AI,IJJ))
      JJ=J-I1+1
      IF (J.EQ.1) GO TO 10
      X=RIA(JST,J-1)
      Y=2.0*FLOAT(JJ)-2.0
      JY=2*J-2
      RMC=RMCOST(X,Y)*2.0*DF(JY)
10    IF (JJ.EQ.1) RMC=0.0
      IF (RMC.LT.0.0) RMC=0.0
      PWTC=PWTC+RMC
      AVU1=AVU1+URI(AI,IJJ)
11    AVU2=AVU2+USN(AI,IJJ)
12    UERI(JST)=AVU2/RNP
      UESN(JST)=AVU2/RNP
      ERI(JST)=CERI(UERI(JST))
      ESN(JST)=CESN(UESN(JST))
C
C                   ADD CONSTRUCTION COST OF THE ACTION AI.
C
      KK1=2*K1
      IF (KK1.EQ.0) GO TO 13
      PWTC=PWTC+CMM(AI)*DF(KK1)
      GO TO 14
13    PWTC=PWTC+CMM(AI)
14    CONTINUE
C
C                   SUBTRACT SALVAGE VALUE.
C
      NRLIFE=IRI(AI)-NREM
      XX=FLOAT(NRLIFE)/FLOAT(IRI(AI))
      SALV=CMM(AI)*XX*DF(NYEARS)
      PWTC=PWTC-SALV
C
C                   FIND EQUIVALENT DNNUAL COST OF THE CURRENT
C                   MAINTENANCE STRATEGY.
C
      EAC(JST)=PWTC/FEAC
      UEAC(JST)=UTEAC(EAC(JST))
C
C                   FIND EQUIVALENT TRAFFIC DELAY FOR THE CURRENT
C                   MAINTENANCE STRATEGY.
C
      AVX=TD(AI)
      VARX=(CVTD*AVX)**2
      UETD(JST)=UTTD(AVX,VARX)
```

```
      ETD(JST)=AVX
      GO TO 45
C
15    CONTINUE
C
C                    CASE NUMBER 3- TWO ACTIONS-AI AT K1 AND AJ AT
C                    K2-ARE SCHECUALED DURING THE ANALYSIS PERIOD.
C
C
C                    CALAULATE EQUIVALENT RI AND SN OF THE
C                    CURRENT MAINTENANCE STRATEGY.
C
      I1=1
      I2=K1
      AVU1=0.0
      AVU2=0.0
      PWTC=0.0
      IF (K1.EQ.0) GO TO 19
      DO 18 J=I1,I2
      RIA(JST,J)=MRI(1,J)
      RISD(JST,J)=SQRT(VRI(1,J))
      SNA(JST,J)=MSN(1,J)
      SNSD(JST,J)=SQRT(VSN(1,J))
      IF (J.EQ.1) GO TO 16
      X=RIA(JST,J-1)
      Y=2.0*FLOAT(J)-2.0+PAGE
      JY=2*J-2
      RMC=RMCOST(X,Y)*2.0*DF(JY)
      GO TO 17
16    X=RIO
      Y=PAGE
      RMC=RMCOST(X,Y)*2.0
17    IF (RMC.LT.0.0) RMC=0.0
      PWTC=PWTC+RMC
      AVU1=AVU1+URI(1,J)
18    AVU2=AVU2+USN(1,J)
19    I1=K1+1
      I2=K1+K2
      IJJ=0
      DO 21 J=I1,I2
      IJJ=IJJ+1
      RIA(JST,J)=ARI1(AI,IJJ)
      RISD(JST,J)=SQRT(VRI1(AI,IJJ))
      SNA(JST,J)=ASN1(AI,IJJ)
      SNSD(JST,J)=SQRT(VSN1(AI,IJJ))
      JJ=J-I1+1
      IF (J.EQ.1) GO TO 20
      X=RIA(JST,J-1)
      Y=2.0*FLOAT(JJ)-2.0
      JY=2*J-2
      RMC=RMCOST(X,Y)*2.0*DF(JY)
20    IF (JJ.EQ.1) RMC=0.0
      IF (RMC.LT.0.0) RMC=0.0
      PWTC=PWTC+RMC
      AVU1=AVU1+URI1(AI,IJJ)
21    AVU2=AVU2+USN1(AI,IJJ)
      I1=K1+K2+1
      IF (I1.GT.NP) GO TO 23
      I2=NP
      IJJ=0
      DO 22 J=I1,I2
      JJ=J-I1+1
```

```
      IJJ=IJJ+1
      RIA(JST,J)=MRI(AJ,IJJ)
      RISD(JST,J)=SQRT(VRI(AJ,IJJ))
      SNA(JST,J)=MSN(AJ,IJJ)
      SNSD(JST,J)=SQRT(VSN(AJ,IJJ))
      X=RIA(JST,J-1)
      Y=2.0*FLCAT(JJ)-2.0
      JY=2*J-2
      RMC=RMCOST(X,Y)*2.0*DF(JY)
      IF (JJ.EQ.1) RMC=0.0
      IF (RMC.LT.0.0) RMC=0.0
      PWTC=PWTC+RMC
      AVU1=AVU1+URI(AJ,IJJ)
22    AVU2=AVU2+USN(AJ,IJJ)
23    UERI(JST)=AVU1/RNP
      ERI(JST)=CERI(UERI(JST))
      UESN(JST)=AVU2/RNP
      ESN(JST)=CESN(UESN(JST))
C
C                ADD CONSTRUCTION COSTS OF ACTIONS AI AND AJ.
C
      KK1=2*K1
      KK2=2*K2+KK1
      IF (KK1.EQ.0) GO TO 24
      PWTC=PWTC+CMM(AI)*DF(KK1)+CMM(AJ)*DF(KK2)
      GO TO 25
24    PWTC=PWTC+CMM(AI)+CMM(AJ)*DF(KK2)
25    CONTINUE
C
C                SUBTRACT THE SALVAGE VALUE OF THE PAVEMENT FROM
C                THE TOTAL COST.

      NRLIFE=IRI(AJ)-NREM
      XX=FLOAT(NRLIFE)/FLOAT(IRI(AJ))
      SALV=CMM(AJ)*XX*DF(NYEARS)
      PWTC=PWTC-SALV
C
C                FIND EQUIVALENT ANNUAL COST OF THE CURRENT
C                MAINTENCE STRATEGY.
C
      EAC(JST)=PWTC/FEAC
      UEAC(JST)=UTEAC(EAC(JST))
C
C                FIND EQUIVALENT TRAFFIC DELAY FOR THE
C                CURRENT MAINTENANCE STRATEGY.
C
      AVX1=TD(AI)
      VARX1=(CVTD*AVX1)**2
      AVX2=TD(AJ)
      VARX2=(CVTD*AVX2)**2
      UX1=UTTD(AVX1,VARX1)
      UX2=UTTD(AVX2,VARX2)
      AVU=(UX1+UX2)/2.0
      UETD(JST)=AVU
      ETD(JST)=CETD(AVU)
      GO TO 45
C
      CONTINUE
C
C                CASE NUMBER 4- THREE ACTIONS-AI AT K1,AJ
C                AT K2 AND AK AT K3- ARE SCHEDULED DURING
C                THE ANALYSIS PERIOD.
```

```
C
C                 CALCULATE EQUIVALENT RI AND SN
C                 OF THE CURRENT MAINTENANCE STRATEGY.
C
      I1=1
      I2=K1
      AVU1=0.0
      AVU2=0.0
      PWTC=0.0
      IF (K1.EQ.0) GO TO 30
      DO 29 J=I1,I2
      RIA(JST,J)=MRI(1,J)
      RISD(JST,J)=SQRT(VRI(1,J))
      SNA(JST,J)=MSN(1,J)
      SNSD(JST,J)=SQRT(VSN(1,J))
      IF (J.EQ.1) GO TO 27
      X=RIA(JST,J-1)
      Y=2.0*FLOAT(J)-2.0+PAGE
      JY=2*J-2
      RMC=RMCOST(X,Y)*2.0*DF(JY)
      GO TO 28
27    X=RIO
      Y=PAGE
      RMC=RMCOST(X,Y)*2.0
28    IF (RMC.LT.0.0) RMC=0.0
      PWTC=PWTC+RMC
      AVU1=AVU1+URI(1,J)
29    AVU2=AVU2+USN(1,J)
30    I1=K1+1
      I2=K1+K2
      IJJ=0
      DO 32 J=I1,I2
      IJJ=IJJ+1
      RIA(JST,J)=ARI1(AI,IJJ)
      RISD(JST,J)=SQRT(VRI1(AI,IJJ))
      SNA(JST,J)=ASN1(AI,IJJ)
      SNSD(JST,J)=SQRT(VSN1(AI,IJJ))
      JJ=J-I1+1
      IF (J.EQ.1) GO TO 31
      X=RIA(JST,J-1)
      Y=2.0*FLOAT(JJ)-2.0
      JY=2*J-2
      RMC=RMCOST(X,Y)*2.0*DF(JY)
31    IF (JJ.EQ.1) RMC=0.0
      PWTC=PWTC+RMC
      AVU1=AVU1+URI1(AI,IJJ)
32    AVU2=AVU2+USN1(AI,IJJ)
      I1=K1+K2+1
      I2=K1+K2+K3
      IJJ=0
      DO 33 J=I1,I2
      IJJ=IJJ+1
      RIA(JST,J)=MRI(AJ,IJJ)
      RISD(JST,J)=SQRT(VRI(AJ,IJJ))
      SNA(JST,J)=MSN(AJ,IJJ)
      SNSD(JST,J)=SQRT(VSN(AJ,IJJ))
      JJ=J-I1+1
      X=RIA(JST,J-1)
      Y=2.0*FLOAT(JJ)-2.0
      JY=2*J-2
      RMC=RMCOST(X,Y)*2.0*DF(JY)
      IF (JJ.EQ.1) RMC=0.0
```

```
      PWTC=PWTC+RMC
      AVU1=AVU1+URI(AJ,IJJ)
33    AVU2=AVU2+USN(AJ,IJJ)
C
C                 FIND PAVEMENT CONDITION FOLLOWING THE ACTION AK.
C
      NREM1=NP-K1-K2-K3
      T=THICK(AK)
      D2=DPOST*(1.0-PRDEFL(AK)/100.0)
      COLN=ALOG(CRH(AK))+C21+C23*ALOG(RGN)+C24*ALOG(D2)+C25*ALOG(T)
      BOLN=B21+B23*ALOG(RGN)+B24*ALOG(AGF)
      ARIB=MRI(AJ,K3)
      XLMRIO=XC0+XC1*ALOG(ARIB)+XC2*ALOG(T)
      VLRIO=SERIA*SERIA
      VLRIO=SERIA*SERIA
      MRIO=EXP(XLMRIO+0.5*VLRIO)
      CVRIO=SQRT(EXP(VLRIO)-1.0)
      VRIO=(CVRIO*MRIO)**2
      MSNO=MSNA
      VSNO=SDSNA*SDSNA
      KRI=0
      IRI(AK)=16
      DO 39 I=1,15
      II=2*(K1+K2+K3+I)-1
      K=I-1
      C3LN=COLN+C22*ALOG(TRFC(II))
      XLMCRI=C3LN+C26*ALOG(FLOAT(2*I))
      VLCRI=SECRI2*SECRI2
      MCRI=EXP(XLMCRI+0.5*VLCRI)
      CVCRI=SQRT(EXP(VLCRI)-1.0)
      VCRI=(CVCRI*MCRI)**2
      IF (I.NE.1) GO TO 34
      ARI2(AK,I)=MRIO+MCRI
      VRI2(AK,I)=VRIO+VCRI
      GO TO 35
34    ARI2(AK,I)=ARI2(AK,K)+MCRI
      VRI2(AK,I)=VRI2(AK,K)+VCRI
35    CONTINUE
      SRI=SQRT(VRI2(AK,I))
      ZRI=(LRI-ARI2(AK,I))/SRI
      IF (ZRI.LT.RRI) KRI=KRI+1
      IF (KRI.EQ.1) IRI(AK)=I
      URI2(AK,I)=UTRI(ARI2(AK,I),VRI2(AK,I))
      IF (I.GT.NREM1) GO TO 38
      B3LN=BOLN+B22*ALOG(TRFC(II))
      XLMCSN=B3LN+B25*ALOG(FLOAT(2*I))
      VLCSN=SECSN2*SECSN2
      MCSN=EXP(XLMCSN+0.5*VLCSN)
      CVCSN=SQRT(EXP(VLCSN)-1.0)
      VCSN=(CVCSN*MCSN)**2
      IF (I.NE.1) GO TO 36
      ASN2(AK,I)=MSNO-MCSN
      VSN2(AK,I)=VSNO+VCSN
      GO TO 37
36    ASN2(AK,I)=ASN2(AK,K)-MCSN
      VSN2(AK,I)=VSN2(AK,K)+VCSN
37    CONTINUE
      USN2(AK,I)=UTSN(ASN2(AK,I),VSN2(AK,I))
      IF (USN2(AK,I).GT.1.0) USN2(AK,I)=1.0
38    IF (KRI.GT.0) GO TO 40
39    CONTINUE
40    CONTINUE
```

```
      IF (IRI(AK).LT.NREM1) GO TO 45
      I1=K1+K2+K3+1
      IF (I1.GT.NP) GO TO 42
      I2=NP
      IJJ=0
      DO 41 J=I1,I2
      IJJ=IJJ+1
      RIA(JST,J)=ARI2(AK,IJJ)
      RISD(JST,J)=SQRT(VRI2(AK,IJJ))
      SNA(JST,J)=ASN2(AK,IJJ)
      SNSD(JST,J)=SQRT(VSN2(AK,IJJ))
      JJ=J-I1+1
      X=RIA(JST,J-1)
      Y=2.0*FLOAT(JJ)-2.0
      JY=2*J-2
      RMC=RMCOST(X,Y)*2.0*DF(JY)
      IF (JJ.EQ.1) RMC=0.0
      PWTC=PWTC+RMC
      AVU1=AVU1+URI2(AK,IJJ)
 41   AVU2=AVU2+USN2(AK,IJJ)
 42   UERI(JST)=AVU1/RNP
      ERI(JST)=CERI(UERI(JST))
      UESN(JST)=AVU2/RNP
      ESN(JST)=CESN(UESN(JST))
      KK1=2*K1
      KK2=2*K2+KK1
      KK3=2*K3+KK2
C
C                  ADD CONSTRUCTION COSTS OF ACTIONS AI,AJ,AND
C                  AK
C
      IF (KK1.EQ.0) GO TO 43
      PWTC=PWTC+CMM(AI)*DF(KK1)+CMM(AJ)*DF(KK2)+CMM(AK)*DF(KK3)
      GO TO 44
 43   PWTC=PWTC+CMM(AI)+CMM(AJ)*DF(KK2)+CMM(AK)*DF(KK3)
 44   CONTINUE
C
C                  SUBTRACT SALVAGE VALUE OF THE PAVEMENT FROM
C                  THE TOTAL COST.
C
      NRLIFE=IRI(AK)-NREM1
      XX=FLOAT(NRLIFE)/FLOAT(IRI(AK))
      SALV=CMM(AK)*XX*DF(NYEARS)
      PWTC=PWTC-SALV
C
C                  FIND EQUIVALENT ANNUAL COST.
C
      EAC(JST)=PWTC/FEAC
      UEAC(JST)=UTEAC(EAC(JST))
C
C                  FIND EQUIVALENT TRAFFIC DELAY FOR THE CURRANT
C                  MAINTENANCE STRATEGY.
C
      AVX1=TD(AI)
      VARX1=(CVTD*AVX1)**2
      AVX2=TD(AJ)
      VARX2=(CVTD*AVX2)**2
      AVX3=TD(AK)
      VARX3=(CVTD*AVX3)**2
      UX1=UTTD(AVX1,VARX1)
      UX2=UTTD(AVX2,VARX2)
      UX3=UTTD(AVX3,VARX3)
```

```
      AVU=(UX1+UX2+UX3)/3.0                                             PRE 558
      UETD(JST)=AVU                                                     PRE 559
      ETD(JST)=CETC(AVU)                                                PRE 560
45    CONTINUE                                                          PRE 561
      RETURN                                                            PRE 562
      END                                                               PRE 563-
```

```
      SUBROUTINE PERFM
C
C                 THIS SUBROUTINE EVALUATES PAVEMENT PERFORMANCE
C                 IN TERMS OF RI AND SN FOLLOWING A GIVEN
C                 MAJOR MAINTENANCE ALTERNATIVE OR INITIAL
C                 DESIGN.  UTILITIES IF THE PREDICTED RI AND SN
C                 ARE ALSO CALCULATED USING THE SPECIFIED
C                 UTILITY FUNCTIONS.
C
      REAL LRI,LSN,MRI,MSN,MSNA
      REAL MRIO,MCRI,MCSN,MSNO
      INTEGER AI,AJ,AK,AK1,AK2,AK3
      COMMON /SDATA/ NP,NINTX,NA,NOPT,LRI,LSN,RRI,RSN,IND,IACFC,ICRACK,A
     1GT,AGF,PAGE,RGN,D,RIO,SNO,THICK(15),DINTX(10),C11,C12,C13,C14,C15,
     2SECRI1,C21,C22,C23,C24,C25,C26,SECRI2,B11,B12,B13,B14,B15,SECSN1,C
     3RH(15),B21,B22,B23,B24,B25,SECSN2,XC0,XC1,XC2,SERIA,MSNA,SDSNA,PRD
     4EFL(15),TO(15),CVTD,CMM(15),CVCT,EI,TI,R,CU1,CU2,NACR,INDCR(10),IS
     5EAL,TRFC(70),UKI(4),UK,DESCM(15,15),DESC(20),IPAGE,NLINE,IPROB,AU1
     6,AU2,BU1,BU2,B31,B32,B33,B34,B35,SECSN3
C
      COMMON /PERFM/ MRI(15,20),VRI(15,20),MSN(15,20),VSN(15,20),NPRIOR,
     1NREM,KPRIOR,KCUR,DPRIOR,IRI(15),ISN(15),DPOST,ARI1(15,20),VRI1(15,
     220),ASN1(15,20),VSN1(15,20),URI(15,20),URI1(15,20),USN(15,20),USN1
     3(15,20)
C
      COMMON /SOFMS/ NTOTAL,IK1(500),IK2(500),IK3(500),AK1(500),AK2(500)
     1,AK3(500),RIA(500,15),RISD(500,15),SNA(500,15),SNSD(500,15),DF(40)
     2,FEAC,ARIB
C
      COMMON /PREDT/ AI,AJ,AK,K1,K2,K3,ICASE,ERI(500),ESN(500),EAC(500),
     1ETD(500),UERI(500),UESN(500),UEAC(500),UETD(500),JST
C
      COMMON /EXPUT/ IRANK(500),EXPT(500),BENFT(500)
      COMMON /IO/ IN,IOUT
C
C
C                  SPECIAL UTILITY FOR SKID NUMBER
C
      UTSN(XM,VARX)=CU1*(1.0-EXP(-CU2*25.0+CU2*XM+0.5*CU2*CU2*VARX))
C
C                  IF THE UTILITY FUNCTION FOR ROUGHNESS INDEX
C                  IS LINEAR, USE THE FOLLOWING FUNCTION ---
C
      UTRI(XM,VARX)=1.06-0.0212*XM
C
C                  IF THE UTILITY FUNCTION FOR ROUGHNESS INDEX
C                  IS EXPONENTIAL, DEACTIVATE THE PREVIOUS
C                  FUNCTIONN BY PLACING A C IN COLUMN ONE AND
C                  ACTIVATE THE FOLLOWING FUNCTION BY REMOVING
C                  THE C(S) IN COLUMN ONE.
C
C      UTRI(XM,VARX)=BU1*(1.0-EXP(BU2*2.12-BU2*0.0424*XM+0.5*BU2*0.0424
C    1*BU2*0.0424*VARX))
C
      IF (IND.EQ.0.AND.KCUR.LE.(1+ISEAL+NINTX)) GO TO 1
      IF (ISEAL.EQ.1.AND.KCUR.EQ.2) GO TO 2
      T=THICK(KCUR)
      DPOST=DPRIOR*(1.0-PRDEFL(KCUR)/100.0)
      COLN=ALOG(CRH(KCUR))+C21+C23*ALOG(RGN)+C24*ALOG(DPOST)+C25*ALOG(T)
      XLMRIO=XC0+XC1*ALOG(ARIB)+XC2*ALOG(T)
      VLRIO=SERIA*SERIA
```

```
      MRIO=EXP(XLMRIO+0.5*VLRIO)
      CVRIO=SQRT(EXP(VLRIO)-1.0)
      VRIO=(CVRIO*MRIO)**2
      GO TO 2
 1    CONTINUE
      COLN=C11+C13*ALOG(RGN)+C14*ALOG(D)
      BOLN=B11+B13*ALOG(RGN)+B14*ALOG(AGT)
      MRIO=RIO
      VRIO=0.0
      MSNO=SNO
      VSNO=0.0
      GO TO 3
 2    CONTINUE
      IF (ISEAL.EQ.1.AND.KCUR.EQ.2) DPOST=DPRIOR
      BOLN=B21+B23*ALOG(RGN)+B24*ALOG(AGF)
      MSNO=MSNA
      VSNO=SDSNA*SDSNA
 3    KRI=0
      IRI(KCUR)=16
C
C                   PREDICT ROUGHNESS INDEX OF THE PAVEMENT
C
      DO 10 I=1,15
      II=2*(NPRIOR+I)-1
      K=I-1
      IF (KRI.GT.0) GO TO 11
      IF (IND.EQ.0.AND.KCUR.LE.(1+ISEAL+NINTX)) GO TO 4
      IF (ISEAL.EQ.1.AND.KCUR.EQ.2) GO TO 7
      C3LN=COLN+C22*ALOG(TRFC(II))
      XLMCRI=C3LN+C26*ALOG(FLOAT(2*I))
      VLCRI=SECRI2*SECRI2
      GO TO 5
 4    C3LN=COLN+C12*ALOG(TRFC(II))
      XLMCRI=C3LN+C15*ALOG(FLOAT(II+1))
      VLCRI=SECRI1*SECRI1
 5    MCRI=EXP(XLMCRI+0.5*VLCRI)
      CVCRI=SQRT(EXP(VLCRI)-1.0)
      VCRI=(CVCRI*MCRI)**2
      IF (I.NE.1) GO TO 6
      MRI(KCUR,I)=MRIO+MCRI
      VRI(KCUR,I)=VRIO+VCRI
      GO TO 8
 6    MRI(KCUR,I)=MRI(KCUR,K)+MCRI
      VRI(KCUR,I)=VRI(KCUR,K)+VCRI
      GO TO 8
 7    KJ=K1+I
      MRI(KCUR,I)=MRI(1,KJ)
      VRI(KCUR,I)=VRI(1,KJ)
 8    CONTINUE
      URI(KCUR,I)=UTRI(MRI(KCUR,I),VRI(KCUR,I))
      IF (KPRIOR.NE.1) GO TO 9
      ARI1(KCUR,I)=MRI(KCUR,I)
      VRI1(KCUR,I)=VRI(KCUR,I)
      URI1(KCUR,I)=URI(KCUR,I)
 9    CONTINUE
      SRI=SQRT(VRI(KCUR,I))
      ZRI=(LRI-MRI(KCUR,I))/SRI
      IF (ZRI.LT.RRI) KRI=KRI+1
      IF (KRI.EQ.1) IRI(KCUR)=I
 10   CONTINUE
 11   CONTINUE
C
```

```
C                      PREDICT SN AND CALCULATE ITS UTILITY
C
      DO 16 I=1,NREM
      II=2*(NPRIOR+I)-1
      K=I-1
      IF (IND.EQ.0.AND.KCUR.LE.(1+ISEAL+NINTX)) GO TO 12
      B3LN=B0LN+B22*ALOG(TRFC(II))
      XLMCSN=B3LN+B25*ALOG(FLOAT(2*I))
      VLCSN=SECSN2*SECSN2
      GO TO 13
12    B3LN=B0LN+B12*ALOG(TRFC(II))
      XLMCSN=B3LN+B15*ALOG(FLOAT(II+1))
      VLCSN=SECSN1*SECSN1
13    MCSN=EXP(XLMCSN+0.5*VLCSN)
      CVCSN=SQRT(EXP(VLCSN)-1.0)
      VCSN=(CVCSN*MCSN)**2
      IF (I.NE.1) GO TO 14
      MSN(KCUR,I)=MSN0-MCSN
      VSN(KCUR,I)=VSN0+VCSN
      GO TO 15
14    MSN(KCUR,I)=MSN(KCUR,K)-MCSN
      VSN(KCUR,I)=VSN(KCUR,K)+VCSN
15    CONTINUE
      USN(KCUR,I)=UTSN(MSN(KCUR,I),VSN(KCUR,I))
      IF (USN(KCUR,I).GT.1.0) USN(KCUR,I)=1.0
      IF (KPRIOR.NE.1) GO TO 16
      ASN1(KCUR,I)=MSN(KCUR,I)
      VSN1(KCUR,I)=VSN(KCUR,I)
      USN1(KCUR,I)=USN(KCUR,I)
16    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PHEAD (IPAGE,DESC,NLINE,IPROB)
C
C                ********** SUBROUTINE PHEAD *********
C
C                OUTPUT PAGE HEADINGS ANC KEEP TRACK OF QUANTITY
C                OF LINES(NLTNE) AND PAGES(IPAGE)
C
      DIMENSION DESC(20)
      COMMON /IO/ IN,ICUT
      IPAGE=IPAGE+1
      NLINE=0
      WRITE (IOUT,1) IPROB,DESC,IPAGE
      RETURN
C
1     FORMAT (1H1,1X,11HPROBLEM NO.,I3,3H - ,20A4,12X,4HPAGE,I4)
      END
```

```
      SUBROUTINE RESULT
C
C                   THIS SUBROUTINE OUTPUTS RESULTS OF THE ANALYSIS
C
      DIMENSION X(20), Y(20), SD(20)
      REAL LRI,LSN,MRI,MSN,MSNA
      REAL MRIO,MCRI,MCSN,MSNO
      INTEGER AI,AK,AJ,AK1,AK2,AK3
      COMMON /IO/ IN,IOUT
      COMMON /SDATA/ NP,NINTX,NA,NCPT,LRI,LSN,RRI,RSN,IND,IACFC,ICRACK,A
     1GT,AGF,PAGE,RGN,D,RIO,SNO,THICK(15),DINTX(10),C11,C12,C13,C14,C15,
     2SECRI1,C21,C22,C23,C24,C25,C26,SECRI2,B11,B12,B13,B14,B15,SECSN1,C
     3RH(15),B21,B22,B23,B24,B25,SECSN2,XC0,XC1,XC2,SERIA,MSNA,SDSNA,PRD
     4EFL(15),TD(15),CVTD,CMM(15),CVCT,EI,TI,R,CU1,CU2,NACR,INDCR(10),IS
     5EAL,TRFC(70),UKI(4),UK,DESCM(15,15),DESC(20),IPAGE,NLINE,IPROB,AU1
     6,AU2,BU1,BU2,B31,B32,B33,B34,B35,SECSN3
C
      COMMON /PERFM/ MRI(15,20),VRI(15,20),MSN(15,20),VSN(15,20),NPRIOR,
     1NREM,KPRIOR,KCUR,DPRIOR,IRI(15),ISN(15),DPOST,ARI1(15,20),VRI1(15,
     220),ASN1(15,20),VSN1(15,20),URI(15,20),URI1(15,20),USN(15,20),USN1
     3(15,20)
C
      COMMON /SOFMS/ NTOTAL,IK1(500),IK2(500),IK3(500),AK1(500),AK2(500)
     1,AK3(500),RIA(500,15),RISD(500,15),SNA(500,15),SNSD(500,15),DF(40)
     2,FEAC,ARIB
C
      COMMON /PREDT/ AI,AJ,AK,K1,K2,K3,ICASE,ERI(500),ESN(500),EAC(500),
     1ETD(500),UERI(500),UESN(500),UEAC(500),UETD(500),JST
C
      COMMON /EXPUT/ IRANK(500),EXPT(500),BENFT(500)

C                   OUTPUT PAGE HEADING
C
      CALL PHEAD (IPAGE,DESC,NLINE,IPROB)
C
C                   OUTPUT DESCRIPTION OF THE MAINTENANCE ALTERNATIVES
C
      WRITE (IOUT,25)
      K=1
      DO 2 I=1,NA
      IF (NACR.NE.0.AND.INDCR(K).EQ.I) GO TO 1
      WRITE (IOUT,26) I,(DESCM(I,J),J=1,15)
      GO TO 2
    1 WRITE (IOUT,27) I,(DESCM(I,J),J=1,15)
      K=K+1
    2 CONTINUE
C
C                   OUTPUT STRATEGY INFORMATION
C
      CALL PHEAD (IPAGE,DESC,NLINE,IPROB)
      WRITE (IOUT,28)
      WRITE (IOUT,29)
      WRITE (IOUT,30)
      WRITE (IOUT,31)
      WRITE (IOUT,30)
      WRITE (IOUT,29)
      WRITE (IOUT,30)
      WRITE (IOUT,32)
      WRITE (IOUT,30)
      WRITE (IOUT,33)
      WRITE (IOUT,30)
```

```
      WRITE (IOUT,34)
      WRITE (IOUT,30)
      WRITE (IOUT,35)
      WRITE (IOUT,30)
      WRITE (IOUT,36)
      WRITE (IOUT,30)
      WRITE (IOUT,37)
      WRITE (IOUT,30)
      WRITE (IOUT,38)
      WRITE (IOUT,30)
      WRITE (IOUT,39)
      WRITE (IOUT,30)
      WRITE (IOUT,40)
      WRITE (IOUT,30)
      WRITE (IOUT,29)
C
C                  PRINT MAINTENANCE STRATEGIES
C
      CALL PHEAD (IPAGE,DESC,NLINE,IPRCB)
      NTOP=50
      IF (NTOTAL.LT.50) NTOP=NTOTAL
      WRITE (IOUT,41) NTOTAL,NTOP
      WRITE (IOUT,42)
      WRITE (IOUT,43)
      WRITE (IOUT,44)
      WRITE (IOUT,43)
      WRITE (IOUT,42)
      NLINE=12
      DO 7 I=1,NTOP
      K=IRANK(I)
      IF (IK1(K).NE.99) IK1(K)=IK1(K)*2
      IF (IK2(K).NE.99) IK2(K)=IK2(K)*2
      IF (IK3(K).NE.99) IK3(K)=IK3(K)*2
      IF (IK1(K).EQ.99) GO TO 4
      J1=IK1(K)
      J=AK1(K)
      IF (IK2(K).EQ.99) GO TO 3
      WRITE (IOUT,45) J1,(DESCM(J,N),N=1,15)
      NLINE=NLINE+1
      J=AK2(K)
      J1=IK1(K)+IK2(K)
      IF (IK3(K).EQ.99) GO TO 3
      WRITE (IOUT,45) J1,(DESCM(J,N),N=1,15)
      NLINE=NLINE+1
      J=AK3(K)
      J1=IK1(K)+IK2(K)+IK3(K)
3     WRITE (IOUT,46) I,ERI(K),ESN(K),ETD(K),EAC(K),EXPT(K),BENFT(K),J1,
     1(DESCM(J,N),N=1,15)
      NLINE=NLINE+1
      GO TO 5
4     WRITE (IOUT,47) I,ERI(K),ESN(K),ETD(K),EAC(K),EXPT(K),BENFT(K),(DE
     1SCM(J,N),N=1,15)
      NLINE=NLINE+1
5     WRITE (IOUT,42)
      NLINE=NLINE+1
      IF (NLINE.GE.60) GO TO 6
      GO TO 7
6     CALL PHEAD (IPAGE,DESC,NLINE,IPRCB)
      WRITE (IOUT,41) NTOTAL,NTOP
      WRITE (IOUT,42)
      WRITE (IOUT,43)
      WRITE (IOUT,44)
```

```
      WRITE (IOUT,43)
      WRITE (IOUT,42)
      NLINE=12
    7 CONTINUE
C
C                   PRINT PROBABILISTIC PREDICTION OF PAVEMENT CONDITION
C
      NTOP1=3
      N=NP+1
      DO 24 I=1,NTOP1
      CALL PHEAD (IPAGE,DESC,NLINE,IPR(8))
      WRITE (IOUT,48) I
      K=IRANK(I)
      X(1)=0.0
      DO 19 J=1,N
      WRITE (IOUT,49)
      J1=(J-1)*2
      J4=J-1
      IF (IK1(K).EQ.J1) GO TO 11
      IF (IK1(K)+IK2(K).EQ.J1) GO TO 10
      IF (IK1(K)+IK2(K)+IK3(K).EQ.J1) GO TO 9
      IF (J.EQ.1) GO TO 18
      MRI(1,J)=RIA(K,J4)
      VRI(1,J)=RISD(K,J4)
      MSN(1,J)=SNA(K,J4)
      VSN(1,J)=SNSD(K,J4)
    8 WRITE (IOUT,50) J1,MRI(1,J),VRI(1,J),MSN(1,J),VSN(1,J),(DESCM(1,J3
     1),J3=1,15)
      GO TO 19
    9 J2=AK3(K)
      GO TO 12
      J2=AK2(K)
      GO TO 12
   11 J2=AK1(K)
      IF (J.NE.1) GO TO 12
      IF (IND.EQ.0) GO TO 15
      IF (ISEAL.EQ.1.AND.J2.EQ.2) GO TO 15
      ARIB=RIO
      T=THICK(J2)
      GO TO 14
   12 IF (ISEAL.EQ.0) GO TO 13
      IF (J2.NE.2) GO TO 13
      MRI(1,J)=RIA(K,J4)
      VRI(1,J)=RISD(K,J4)
      GO TO 16
   13 ARIB=RIA(K,J4)
      T=THICK(J2)
   14 XLMRIO=XC0+XC1*ALOG(ARIB)+XC2*ALOG(T)
      VLRIO=SERIA*SERIA
      MRIO=EXP(XLMRIO+0.5*VLRIO)
      CVRIO=SQRT(EXP(VLRIO)-1.0)
      VRI(1,J)=CVRIO*MRIO
      MRI(1,J)=MRIO
      GO TO 16
   15 MRI(1,J)=RIO
      VRI(1,J)=0.0
      MSN(1,J)=MSNA
      VSN(1,J)=SDSNA
      IF (J.EQ.1) GO TO 17
      WRITE (IOUT,51) J1,RIA(K,J4),MRI(1,J),RISD(K,J4),VRI(1,J),SNA(K,J4
     1),MSN(1,J),SNSD(K,J4),VSN(1,J),(DESCM(J2,J3),J3=1,15)
      GO TO 19
```

```
17    WRITE (IOUT,51) J1,RIO,MRI(1,J),X(1),VRI(1,J),SNO,MSN(1,J),X(1),VS
     1N(1,J),(DESCM(J2,J3),J3=1,15)
      GO TO 19
18    MRI(1,J)=RIO
      VRI(1,J)=0.0
      MSN(1,J)=SNO
      VSN(1,J)=0.0
      GO TO 8
19    CONTINUE
      WRITE (IOUT,49)
      WRITE (IOUT,52)
      WRITE (IOUT,53)
      WRITE (IOUT,54)
      WRITE (IOUT,53)
      J1=IPAGE+1
      J2=IPAGE+2
      WRITE (IOUT,55) J1,J2
      WRITE (IOUT,53)
      WRITE (IOUT,56)
      WRITE (IOUT,53)
      WRITE (IOUT,57)
      CALL PHEAD (IPAGE,DESC,NLINE,IPRCB)
      WRITE (IOUT,58) I
      DO 21 J=1,N
      IF (J.EQ.1) GO TO 20
      X(J)=2*(J-1)
      Y(J)=RIA(K,J-1)
      SD(J)=RISD(K,J-1)
      GO TO 21
20    X(J)=0.0
      Y(J)=RIO
      SD(J)=0.0
21    CONTINUE
      CALL PLOT (X,Y,N,SD,1)
      CALL PHEAD (IPAGE,DESC,NLINE,IPRCB)
      WRITE (IOUT,59) I
      DO 23 J=1,N
      IF (J.EQ.1) GO TO 22
      X(J)=2*(J-1)
      Y(J)=SNA(K,J-1)
      SD(J)=SNSD(K,J-1)
      GO TO 23
22    X(J)=0.0
      Y(J)=SNO
      SD(J)=0.0
23    CONTINUE
      CALL PLOT (X,Y,N,SD,0)
24    CONTINUE
      RETURN
C
25    FORMAT (////15X,95H* * * * * * * * * * * * DESCRIPTION OF THE MA
     1INTENANCE ALTERNATIVES * * * * * * * * * * * * *////15X,16HMAINT.
     2ALT. CODE,20X,11HDESCRIPTION/15X,16H----------------,5X,60(1H-))
26    FORMAT (/25X,I4,7X,15A4)
27    FORMAT (/25X,I4,7X,28HELIMINATED DUE TO CRACKING- ,15A4)
28    FORMAT (///)
29    FORMAT (10X,100(1H*))
30    FORMAT (10X,1H*,98X,1H*)
31    FORMAT (10X,1H*,10X,46HDICTIONARY OF ACRONYMS USED IN COLUMN HEADI
     1NGS,42X,1H*)
32    FORMAT (10X,1H*,2X,31HACRONYM   DEFINITION OF ACRONYM,65X,1H*/10X,
     11H*,2X,31H-------   --------------------,65X,1H*)
```

```
33    FORMAT (10X,1H*,6X,39HMSC = MAINTENANCE STRATEGY CODE NUMBER.,53X,RES 248
     11H*)                                                                RES 249
34    FORMAT (10X,1H*,6X,78HERI = EQUIVALENT ANNUAL ROUGHNESS INDEX OF TRES 250
     1HE SPECIFIED MAINTENANCE STRATEGY.,14X,1H*)                         RES 251
35    FORMAT (10X,1H*,6X,74HESN = EQUIVALENT ANNUAL SKID NUMBER OF THE SRES 252
     1PECIFIED MAINTENANCE STRATEGY.,18X,1H*)                             RES 253
36    FORMAT (10X,1H*,6X,80HETC = AVERAGE TRAFFIC DELAY FOR THE SPECIFIERES 254
     1D MAINTENANCE STRATEGY. (IN MINUTES),12X,1H*)                       RES 255
37    FORMAT (10X,1H*,6X,93HEAC = EQUIVALENT ANNUAL COST OF THE SPECIFIERES 256
     1D MAINTENANCE STRATEGY(IN DOLLARS PER LANE MILE)*)                  RES 257
38    FORMAT (10X,1H*,1X,66HEXP.UTL. = EXPECTED UTILITY OF THE SPECIFIEDRES 258
     1 MAINTENANCE STRATEGY.,31X,1H*)                                     RES 259
39    FORMAT (10X,1H*,2X,73HBENEFIT = NET BENEFIT (IN DOLLARS) OF THE SPRES 260
     1ECIFIED MAINTENANCE STRATEGY.,23X,1H*)                              RES 261
40    FORMAT (10X,1H*,5X,80HYEAR = YEAR AT WHICH THE MAINTENANCE ALTERNARES 262
     1TIVE (OR INITIAL DESIGN) IS ADOPTED.,13X,1H*)                       RES 263
41    FORMAT (///1X,1HI,128(1H-),1HI/1X,1HI,128X,1HI/1X,72HI * * M A I NRES 264
     1 T E N A N C E   S T R A T E G I E S * *  NOTE - A TOTAL OF,I3,55HRES 265
     2 FEASIBLE MAINTENANCE STRATEGIES HAVE BEEN SELECTED.  I/1X,1HI,61XRES 266
     3,8HTHE TOP ,I2,58H ARE DESCRIBED IN THIS TABLE FROM BEST TO WORST.RES 267
     4         I)                                                         RES 268
42    FORMAT (1X,7HI------,3(8HI-------),3(10HI---------),1HI,67(1H-),1HRES 269
     1I)                                                                  RES 270
43    FORMAT (1X,1HI,6X,3(1HI,7X),3(1HI,9X),1HI,67X,1HI)                  RES 271
44    FORMAT (1X,130HI MSC  I  ERI  I  ESN  I  ETD  I   EAC   I EXP UTL RES 272
     1I BENEFIT I YEAR -AND- MAINTENANCE ALTERNATIVE THAT IS ADOPTED      RES 273
     2         I)                                                         RES 274
45    FORMAT (1X,1HI,6X,3(1HI,7X),3(1HI,9X),1HI,1X,I2,3H - ,15A4,1X,1HI)RES 275
46    FORMAT (1X,1HI,I4,2X,3(1HI,F6.1,1X),1HI,F8.2,1X,1HI,F7.4,2X,1HI,F8RES 276
     1.2,1X,1HI,1X,I2,3H - ,15A4,1X,1HI)                                  RES 277
47    FORMAT (1X,1HI,I4,2X,3(1HI,F6.1,1X),1HI,F8.2,1X,1HI,F7.4,2X,1HI,F8RES 278
     1.2,1X,1HI,1X,6HALL - ,15A4,1HI)                                     RES 279
48    FORMAT (////1X,1HI,128(1H-),1HI/1X,1HI,128X,1HI/1X,1HI,1X,11(2H *)RES 280
     1,76H PROBABILISTIC PREDICTION OF PAVEMENT CONDITION FOR MAINTENANCRES 281
     2E STRATEGY NO.,I3,1X,11(2H *),3X,1HI/1X,1HI,128X,1HI/1X,1HI,7(1H-)RES 282
     3,1HI,28(1H-),1HI,28(1H-),1HI,62(1H-),1HI/1X,1HI,7X,1HI,28X,1HI,28XRES 283
     4,1HI,62X,1HI/1X,9HI  YEAR I,6X,15HROUGHNESS INDEX,7X,1HI,8X,11HSKIRES 284
     5D NUMBER,9X,1HI,18X,23HMAINTENANCE ALTERNATIVE,21X,1HI/1X,1HI,7(1HRES 285
     6-),1HI,28(1H-),1HI,28(1H-),1HI,62(1H-),1HI/1X,1HI,7X,1HI,2(3X,22HERES 286
     7XP. VAL.     STD. DEV.,3X,1HI),62X,1HI)                             RES 287
49    FORMAT (1X,1HI,7X,1HI,28X,1HI,28X,1HI,62X,1HI)                      RES 288
50    FORMAT (1X,1HI,I5,2X,1HI,2(5X,F7.1,5X,F8.2,3X,1HI),1X,15A4,1X,1HI)RES 289
51    FORMAT (1X,1HI,I5,2X,1HI,2(1X,1H(,F4.1,1H),F5.1,2X,1H(,F4.2,1H),F5RES 290
     1.2,3X,1HI),1X,15A4,1X,1HI)                                          RES 291
52    FORMAT (1X,1HI,7(1H-),1HI,28(1H-),1HI,28(1H-),1HI,62(1H-),1HI)      RES 292
53    FORMAT (1X,1HI,128X,1HI)                                            RES 293
54    FORMAT (1X,1HI,5X,28(2H* ),5HNOTE ,28(2H* ),6X,1HI)                 RES 294
55    FORMAT (1X,130HI      EXPECTED VALUES(THE VERTICAL AXIS) FOR ROUGHNRES 295
     1ESS INDEX AND SKID NUMBER ARE PLOTTED AGAINST TIME(THE HORIZONTAL RES 296
     2AXIS)        I/1X,14HI      ON PAGES,I3,4H AND,I3,106H.  AN ASTERISKRES 297
     3(*) INDICATES EXPECTED VALUE.  TWO STANDARD DEVIATIONS ABOVE AND BRES 298
     4ELOW THE EXPECTED          I/1X,86HI      VALUE ARE SYMBOLIZED BY SHARES 299
     5DED AREAS OF PLUS(+) AND MINUS(-) SIGNS RESPECTIVELY.,43X,1HI)      RES 300
56    FORMAT (1X,130HI      DRASTIC CHANGES IN EXPECTED VALUE INDICATE THRES 301
     1E APPLICATION OF SOME MAINTENANCE ALTERNATIVE ON THE PAVEMENT SECTRES 302
     2ION          I/1X,87HI      AT THAT PARTICULAR POINT IN THE ANALYSISRES 303
     3 PERIOD AS SUMMARIZED IN THE ABOVE TABLE.,42X,1HI)                  RES 304
57    FORMAT (1X,1HI,128(1H-),1HI)                                        RES 305
58    FORMAT (//1X,11(2H* ),41H ROUGHNESS INDEX PLOTTED AGAINST TIME FORRES 306
     1,28H MAINTENANCE STRATEGY NUMBER,I3,11(2H *)//)                     RES 307
59    FORMAT (//1X,11(2H *),41H   SKID NUMBER   PLOTTED AGAINST TIME FORRES 308
     1,28H MAINTENANCE STRATEGY NUMBER,I3,11(2H *)//)                     RES 309
```

```
      SUBROUTINE EXPUT
C
C                 THIS SUBROUTINE CALCULATES THE EXPECTED
C                 UTILITY OF EACH MAINTENANCE STRATEGY
C                 SELECTED IN THE SUBROUTINE SOFMS.  ALL THE
C                 FAESIBLE STRATEGIES ARE THEN RANKED ON THE
C                 BASIS OF THEIR EXPECTED UTILITIES.
C
      REAL LRI,LSN,MRI,MSN,MSNA
      INTEGER AI,AJ,AK,AK1,AK2,AK3
      COMMON /SDATA/ NP,NINTX,NA,NCPT,LRI,LSN,RRI,RSN,IND,IACFC,ICRACK,A
     1GT,AGF,PAGE,RGN,D,PIO,SNO,THICK(15),DINTX(10),C11,C12,C13,C14,C15,
     2SECRI1,C21,C22,C23,C24,C25,C26,SECRI2,B11,B12,B13,B14,B15,SECSN1,C
     3RH(15),B21,B22,B23,B24,B25,SECSN2,XC0,XC1,XC2,SERIA,MSNA,SDSNA,PRD
     4EFL(15),TD(15),CVTD,CMM(15),CVCT,EI,TI,R,CU1,CU2,NACR,INDCR(10),IS
     5EAL,TRFC(70),UKI(4),UK,DESCM(15,15),DESC(20),IPAGE,NLINE,IPROB,AU1
     6,AU2,BU1,BU2,B31,B32,B33,B34,B35,SECSN3
C
      COMMON /PERFM/ MRI(15,20),VRI(15,20),MSN(15,20),VSN(15,20),NPRIOR,
     1NREM,KPRIOR,KCUR,DPRIOR,IRI(15),ISN(15),DPOST,ARI1(15,20),VRI1(15,
     220),ASN1(15,20),VSN1(15,20),URI(15,20),URI1(15,20),USN(15,20),USN1
     3(15,20)
C
      COMMON /SOFMS/ NTOTAL,IK1(500),IK2(500),IK3(500),AK1(500),AK2(500)
     1,AK3(500),RIA(500,15),RISD(500,15),SNA(500,15),SNSD(500,15),DF(40)
     2,FEAC,ARIB
C
      COMMON /PREDT/ AI,AJ,AK,K1,K2,K3,ICASE,ERI(500),ESN(500),EAC(500),
     1ETD(500),UERI(500),UESN(500),UEAC(500),UETD(500),JST
C
      COMMON /EXPUT/ IRANK(500),EXPT(500),BENFT(500)
C
      CEEAC(X)=10000.0-9700.0*X
C
      CON(X)=(1.0+UK*X)/CON4
C
C                 CALCULATE THE CONSTANT K IN THE OVERALL
C                 UTILITY FUNCTION.
C
      CALL SCALC (UKI,4,UK)
C
C                 CALCULATE THE OVERALL EXPECTED UTILITY OF EACH
C                 FEASIBLE MAINTENANCE STRATEGY OVER THE ATTRIBUTES
C                 OF SKID NUMEER, ROUGHNES INDEX, TRAFFIC
C                 DELAY AND ANNUAL COST.
C
      DO 1 I=1,NTOTAL
      PROD=(1.0+UK*UKI(1)*UESN(I))*(1.0+UK*UKI(2)*UERI(I))*(1.0+UK*UKI(3
     1)*UETD(I))*(1.0+UK*UKI(4)*UEAC(I))
      EXPT(I)=(PROD-1.0)/UK
1     CONTINUE
C
C                 RANK THE FEASIBLE MAINTENANCE STRATEGIES
C                 ON THE BASIS OF THEIR EXPECTED UTILITIES
C
      J=0
2     J=J+1
      UMAX=0.0
      I=0
3     I=I+1
      IF (J.EQ.1) GO TO 5
```

```
      I11=0
      J1=J-1
      DO 4 K=1,J1
      IF (I.EQ.IRANK(K)) I11=I11+1
4     CONTINUE
      IF (I11.NE.0) GO TO 7
      IF (EXPT(I).GE.UMAX) GO TO 6
      GO TO 7
6     UMAX=EXPT(I)
      IRANK(J)=I
7     IF (I.LT.NTOTAL) GO TO 3
      IF (J.LT.NTOTAL) GO TO 2
      K=IRANK(1)
      CON1=1.0+UK*UKI(1)*UESN(K)
      CON2=1.0+UK*UKI(2)*UERI(K)
      CON3=1.0+UK*UKI(3)*UETO(K)
      CON4=CON1*CON2*CON3
      BENFT(K)=0.0
      J=IRANK(1)
      DO 8 I=2,JST
      K=IRANK(I)
      CC=EXPT(K)
      CC1=CON(CC)
      U4=(CC1-1.0)/(UK*UKI(4))
      C4=CEEAC(U4)
      BENFT(K)=C4-EAC(J)
8     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PLOT (X,Y,NXY,SDY,IS)
      DIMENSION X(22), Y(20), SDY(20), B(20), XM(20), IBUF(101), SDSL(20
     1), SDB(20)
      REAL LRI,LSN,MRI,MSN,MSNA
C
      REAL MRIO,MCRI,MCSN,MSNO
C
      INTEGER AI,AJ,AK,AK1,AK2,AK3
C
      COMMON /IO/ IN,IOUT
      COMMON /SDATA/ NP,NINTX,NA,NOPT,LRI,LSN,RRI,RSN,IND,IACFC,ICRACK,A
     1GT,AGF,PAGE,RGN,D,RIO,SNC,THICK(15),DINTX(10),C11,C12,C13,C14,C15,
     2SECRI1,C21,C22,C23,C24,C25,C26,SECRI2,B11,B12,B13,B14,B15,SECSN1,C
     3RH(15),B21,B22,B23,B24,B25,SECSN2,XC0,XC1,XC2,SERIA,MSNA,SDSNA,PRD
     4EFL(15),TD(15),CVTD,CMM(15),CVCT,EI,TI,R,CU1,CU2,NACR,INDCR(10),IS
     5EAL,TRFC(70),UKI(4),UK,DESCM(15,15),DESC(20),IPAGE,NLINE,IPROB,AU1
     6,AU2,BU1,BU2,B31,B32,B33,B34,B35,SECSN3
C
      COMMON /PERFM/ MRI(15,20),VRI(15,20),MSN(15,20),VSN(15,20),NPRIOR,
     1NREM,KPRIOR,KCUR,DPRIOR,IRI(15),ISN(15),DPOST,ARI1(15,20),VRI1(15,
     220),ASN1(15,20),VSN1(15,20),URI(15,20),URI1(15,20),USN(15,20),USN1
     3(15,20)
C
      COMMON /SOFMS/ NTOTAL,IK1(500),IK2(500),IK3(500),AK1(500),AK2(500)
     1,AK3(500),RIA(500,15),RISD(500,15),SNA(500,15),SNSD(500,15),DF(40)
     2,FEAC,ARIB
C
      COMMON /PREDT/ AI,AJ,AK,K1,K2,K3,ICASE,ERI(500),ESN(500),EAC(500),
     1ETD(500),UERI(500),UESN(500),UEAC(500),UETD(500),JST
C
      COMMON /EXPUT/ IRANK(500),EXPT(500),BENFT(500)
C
      DATA IP,IR,IM,IB/1H+,1H*,1H-,1H /
C
      XINC=0.20
      XMIN=0.0
      YMIN=999999.
      YMAX=0.0
      SD2=0.0
      IF (IS.EQ.0) GO TO 2
      DO 1 I=1,NXY
      IF (SDY(I).GT.SD2) SD2=SDY(I)
      IF (VRI(1,I).GT.SD2) SD2=VRI(1,I)
      IF (Y(I).LT.YMIN) YMIN=Y(I)
      IF (MRI(1,I).LT.YMIN) YMIN=MRI(1,I)
      IF (Y(I).GT.YMAX) YMAX=Y(I)
      IF (MRI(1,I).GT.YMAX) YMAX=MRI(1,I)
1     CONTINUE
      GO TO 4
2     DO 3 I=1,NXY
      IF (SDY(I).GT.SD2) SD2=SDY(I)
      IF (VSN(1,I).GT.SD2) SD2=VSN(1,I)
      IF (Y(I).LT.YMIN) YMIN=Y(I)
      IF (MSN(1,I).LT.YMIN) YMIN=MSN(1,I)
      IF (Y(I).GT.YMAX) YMAX=Y(I)
      IF (MSN(1,I).GT.YMAX) YMAX=MSN(1,I)
3     CONTINUE
4     YMIN=YMIN-2.0*SD2
      YMAX=YMAX+2.0*SD2
      YINC=(YMAX-YMIN)/50.0
      YMAX1=YMAX
```

```
      DO 9 I=2,NXY
      J=I-1
      XM(J)=(Y(I)-Y(J))/(X(I)-X(J))
      IF (IS.EQ.1.AND.XM(J).LT.0.0) GO TO 5
      IF (IS.EQ.0.AND.XM(J).GT.0.0) GO TO 6
      GO TO 8
      Y(J)=MRI(1,J)
      SDY(J)=VRI(1,J)
      GO TO 7
6     Y(J)=MSN(1,J)
      SDY(J)=VSN(1,J)
7     XM(J)=(Y(I)-Y(J))/(X(I)-X(J))
8     B(J)=Y(J)-XM(J)*X(J)
      SD1=2.0*SDY(J)+Y(J)
      SD2=2.0*SDY(I)+Y(I)
      SDSL(J)=(SD2-SD1)/(X(I)-X(J))
      SDB(J)=SD1-SDSL(J)*X(J)
9     CONTINUE
      NX=NP
10    NIBUF=NX*10
      IF (NIBUF.GT.100) NIBUF=100
      NIBUF=NIBUF+1
      DO 11 I=NIBUF,101
11    IBUF(I)=IB
      YMAX=YMAX+YINC+YINC
      WRITE (IOUT,22) YMAX,YMAX
      WRITE (IOUT,19)
      K=1
      XMIN1=XMIN
      YMAX=YMAX-YINC
      DO 15 I=1,52
      YMAX=YMAX-YINC
      XXMIN=XMIN-XINC
      J2=0
      J1=1
      IF (NP.GT.NX) J1=11
      DO 13 J=1,NIBUF
      J2=J2+1
      XXMIN=XXMIN+XINC
      SIGP=XXMIN*SDSL(J1)+SDB(J1)
      YHAT=XXMIN*XM(J1)+B(J1)
      SIGM=YHAT-(SIGP-YHAT)
      IBUF(J)=IB
      IF (YMAX.GT.YHAT.AND.YMAX.LE.SIGP) IBUF(J)=IP
      IF (ABS(YMAX-YHAT).LE.YINC.AND.YMAX.GT.YHAT) IBUF(J)=IR
      IF (YMAX.LT.YHAT.AND.YMAX.GE.SIGM) IBUF(J)=IM
      IF (J2.EQ.10) GO TO 12
      GO TO 13
12    J2=0
      J1=J1+1
      IF (NP.LE.10.AND.J1.EQ.NXY) J1=J1-1
      IF (NP.GT.10.AND.J1.EQ.NXY) J1=J1-1
13    CONTINUE
      IF (K.EQ.1) GO TO 14
      WRITE (IOUT,20) (IBUF(N),N=1,101)
      K=1
      GO TO 15
      K=0
      WRITE (IOUT,21) YMAX,(IBUF(N),N=1,101),YMAX
15    CONTINUE
      YMAX=YMAX-YINC
      WRITE (IOUT,22) YMAX,YMAX
```

```
      YHAT=XINC*10.0
      X(1)=XMIN1
      DO 16 I=2,11
      X(I)=X(I-1)+YHAT
16    CONTINUE
      WRITE (IOUT,23) (X(I),I=2,11)
      IF (NX.GT.10) GO TO 17
      GO TO 18
17    NX=NP-10
      CALL PHEAD (IPAGE,DESC,NLINE,IPROB)
      WRITE (IOUT,24)
      YMAX=YMAX1
      XMIN=20.0
      GO TO 10
18    RETURN
C
19    FORMAT (10X,1HI,101X,1HI)
20    FORMAT (10X,1HI,101A1,1HI)
21    FORMAT (1X,F8.1,2H +,101A1,1H+,F5.1)
22    FORMAT (1X,F8.1,3H -+,10(10H----+----+),1H-,F5.1)
23    FORMAT (8X,5H  0.0,10F10.1)
24    FORMAT (//1X,16HPLOT CONTINUED -//)
      END
```

```
      BLOCK DATA
      COMMON /IO/ IN,IOUT
      COMMON /SDATA/ NP,NINTX,NA,NOPT,LRI,LSN,RRI,RSN,IND,IACFC,ICRACK,A
     1GT,AGF,PAGE,RGN,D,RID,SNC,THICK(15),DINTX(10),C11,C12,C13,C14,C15,
     2SECRI1,C21,C22,C23,C24,C25,C26,SECRI2,B11,B12,B13,B14,B15,SECSN1,C
     3RH(15),B21,B22,B23,B24,B25,SECSN2,XC0,XC1,XC2,SERIA,MSNA,SDSNA,PRO
     4EFL(15),TD(15),CVTD,CMM(15),CVCT,EI,TI,R,CU1,CU2,NACR,INDCR(10),IS
     5EAL,TRFC(70),UKI(4),UK,DESCM(15,15),DESC(20),IPAGE,NLINE,IPROB,AU1
     6,AU2,BU1,BU2,B31,B32,B33,B34,B35,SECSN3
C
      COMMON /PERFM/ MRI(15,20),VRI(15,20),MSN(15,20),VSN(15,20),NPRIOR,
     1NREM,KPRIOR,KCUR,DPRIOR,IRI(15),ISN(15),DPOST,ARI1(15,20),VRI1(15,
     220),ASN1(15,20),VSN1(15,20),URI(15,20),URI1(15,20),USN(15,20),USN1
     3(15,20)
C
      COMMON /SOFMS/ NTOTAL,IK1(500),IK2(500),IK3(500),AK1(500),AK2(500)
     1,AK3(500),RIA(500,15),RISD(500,15),SNA(500,15),SNSD(500,15),DF(40)
     2,FEAC,ARIB
C
      COMMON /PREDT/ AI,AJ,AK,K1,K2,K3,ICASE,ERI(500),ESN(500),EAC(500),
     1ETD(500),UERI(500),UESN(500),UEAC(500),UETD(500),JST
      COMMON /EXPUT/ IRANK(500),EXPT(500),BENFT(500)
      DATA AU1,AU2/-0.3091,-0.04811/
      DATA BU1,BU2/1.385,-0.6396/
      DATA CU1,CU2/1.081,-0.03448/
      DATA UKI(1),UKI(2),UKI(3),UKI(4)/0.7,0.42,0.292,0.378/
      DATA IN,IOUT/5,6/
      DATA C11/1.6600/
      DATA C12/.1900/
      DATA C13/.8820/
      DATA C14/.6960/
      DATA C15/.4220/
      DATA SECRI1/.2120/
      DATA C21/1.2740/
      DATA C22/.0718/
      DATA C23/.8744/
      DATA C24/.3281/
      DATA C25/.0375/
      DATA C26/.4618/
      DATA SECRI2/.2206/
      DATA B31/1.9720/
      DATA B32/.1007/
      DATA B33/.1147/
      DATA B34/.9393/
      DATA B35/-1.4590/
      DATA SECSN3/.2198/
      DATA B21/1.9420/
      DATA B22/.0594/
      DATA B23/.0294/
      DATA B24/.0649/
      DATA B25/-1.0050/
      DATA SECSN2/.3040/
      DATA XC0/1.6280/
      DATA XC1/.3090/
      DATA XC2/-.2370/
      DATA SERIA/.0990/
      END
```

Figure C-5. SAMPLE OUTPUT OF THE PROGRAM SOMSAC

SOMSAC

** SELECTION OF OPTIMUM MAINTENANCE STRATEGIES FOR ASPHALT CONCRETE PAVEMENTS **

A COMPUTER PROGRAM DEVELOPED UNDER CONTRACT TO THE ENVIRONMENTAL SYSTEMS DIVISION OF WOODWARD-CLYDE CONSULTANTS

FOR

THE STATE OF ARIZONA -- DEPARTMENT OF TRANSPORTATION

BY

DR. RAMCHANDRA B. KULKARNI, MR. FRED N. FINN AND MR. JOHN K. MCMORRAN

JUNE 1976

PROBLEM NO. 1 - STATE OF ARIZONA - DEPARTMENT OF TRANSPORTATION - EXAMPLE NO. 1

CONTROL PARAMETERS

```
NUMBER OF PERIODS IN THE ANALYSIS ------------------------------------   10
NUMBER OF FEASIBLE INITIAL DESIGNS -----------------------------------    0
NUMBER OF MAINTENANCE ALTERNATIVES -----------------------------------   10
OPTION OF PRINTING INPUT DATA ONLY -----------------------------------    1
          (0= PRINT INPUT DATA ONLY)
          (1= EXECUTE THE PROGRAM)
LIMITING VALUE OF RI ------------------------------------------------- 40.0
LIMITING VALUE OF SN ------------------------------------------------- 43.0
RELIABILITY FACTOR FOR NOT EXCEEDING THE LIMITING RI VALUE -----------  .842
RELIABILITY FACTOR FOR NOT EXCEEDING THE LIMITING SN VALUE ----------- 1.282
INDICATOR FOR NEW DESIGN ---------------------------------------------    1
          (0= NEW DESIGN OF PAVEMENT)
          (1= IN-SERVICE PAVEMENT)
NUMBER OF ALTERNATIVES TO BE ELIMINATED ------------------------------    0
```

DESCRIPTION OF MAINTENANCE ALTERNATIVES

```
ALTERNATIVE NO. 1 : ROUTINE MAINTENANCE
ALTERNATIVE NO. 2 : ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER
ALTERNATIVE NO. 3 : ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
ALTERNATIVE NO. 4 : ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
ALTERNATIVE NO. 5 : 1 IN OVLAY + ACFC WITHOUT RUBBER COAT,WITHOUT HEAT SCARIFIER
ALTERNATIVE NO. 6 : 1 IN OVLAY + ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
ALTERNATIVE NO. 7 : 1 IN OVLAY + ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
ALTERNATIVE NO. 8 : 3 IN OVLAY + ACFC WITHOUT RUBBER COAT,WITHOUT HEAT SCARIFIER
ALTERNATIVE NO. 9 : 3 IN OVLAY + ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
ALTERNATIVE NO.10 : 3 IN OVLAY + ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
```

```
INFORMATION PERTINENT TO GIVEN PAVEMENT SECTION
          INDICATOR FOR PRESENCE OR ABSENCE OF ACFC ----------------------------   1
                        (0= WITH ACFC)
                        (1= WITHOUT ACFC)
          INDICATOR FOR CRACKING ---------------------------------------------   0
                        (0= NO CRACKING)
                        (1= CRACKING)
          INDICATOR FOR USING CHIP SEAL ---------------------------------------   0
                        (0= CHIP SEAL NOT TO BE USED)
                        (1= CHIP SEAL TO BE USED)
          AGGREGATE TYPE IN PRESENT CONDITION --------------------------------- 1.0
                        (1= BASALT OR CINDERS)
                        (2= GRAVEL)
                        (3= LIMESTONE)
          AGGREGATE TYPE TO BE USED IN FUTURE ACFC ---------------------------- 1.0
                        (CODE SAME AS PRESENT--ABOVE)
          PAVEMENT AGE IN YEARS AT PRESENT TIME ------------------------------- 8.0
          ENVIRONMENTAL REGION OF GIVEN PAVEMENT SECTION ----------------------- 1.0
                        (1= LOW ALTITUDE, LOW RAINFALL)
                        (2= HIGH ALTITUDE, HIGH RAINFALL, NO SWELLING CLAY)
                        (3= HIGH ALTITUDE, HIGH RAINFALL, SWELLING CLAY)
          PRESENT DEFLECTION (IN INCHES) OF THE PAVEMENT SECTION --------------- .0150
          PRESENT RI(ROUGHNESS INDEX) OF THE PAVEMENT SECTION ----------------- 27.0
          PRESENT SN(SKID NO.) OF THE PAVEMENT SECTION ------------------------ 55.0

OVERLAY THICKNESS

          MAINT. ALT.   THICKNESS(INCHES)
                2            .750
                3            .750
                4            .750
                5           1.000
                6           1.000
                7           1.000
                8           3.000
                9           3.000
               10           3.000
```

```
PREDICTION MODELS

  1) CHANGE IN RI FOR NEW OR IN-SERVICE PAVEMENTS-
       LN(CRI) = C11 + C12 * LN(TRAFFIC) + C13 * LN(REGION) + C14 * LN(DEFLECTION) + C15 * LN(AGE)
       REGRESSION COEFFICIENTS  C11=  1.6600 C12=   .1900 C13=   .8820 C14=   .6960 C15=   .4220
       STANDARD ERROR=   .2120

  2) CHANGE IN RI FOLLOWING AN OVERLAY-
       LN(CRI) = CRH + C21 + C22 * LN(TRAFFIC) + C23 * LN(REGION) + C24 * LN(DEFLECTION) + C25 * LN(THICKNESS) + C26 * LN(AGE)
       REGRESSION COEFFICIENTS(EXCLUDING CRH)  C21=  1.2740 C22=   .0718 C23=   .8744 C24=   .3281 C25=   .0375 C26=   .4618
       STANDARD ERROR=   .2206
       CRH ARE CORRECTION FACTORS INDICATING EFFECT OF RUBBER COAT OR HEAT SCARIFIER ON PAVEMENT PERFORMANCE
       CORRECTION FACTORS (CRH) FOR GIVEN OVERLAYS
       MAINT. ALT.         CRH
              2           1.00
              3            .40
              4            .25
              5           1.00
              6            .50
              7            .33
              8           1.00
              9            .50
             10            .33

  3) CHANGE IN SN FOR NEW OR IN-SERVICE PAVEMENT-
       LN(CSN) = B11 + B12 * LN(TRAFFIC) + B13 * LN(REGION) + B14 * LN(AGG. TYPE) + B15 * LN(AGE)
       REGRESSION COEFFICIENTS  B11=  1.9720 B12=   .1007 B13=   .1147 B14=   .9393 B15= -1.4590
       STANDARD ERROR=   .2198

  4) CHANGE IN SN FOLLOWING ACFC-
       LN(CSN) = B21 + B22 * LN(TRAFFIC) + B23 * LN(REGION) + B24 * LN(AGG. TYPE) + B25 * LN(AGE)
       REGRESSION COEFFICIENTS  B21=  1.9420 B22=   .0594 B23=   .0294 B24=   .0649 B25= -1.0050
       STANDARD ERROR=   .3040

  5) RI IMMEDIATELY AFTER AN OVERLAY-
       LN(RIA) = XC0 + XC1 * LN(RIB) + XC2 * LN(T)
       REGRESSION COEFFICIENTS  XC0=  1.6280 XC1=   .3090 XC2=  -.2370
       STANDARD ERROR=   .0990
```

PREDICTION MODELS - CONTINUED

6) SN IMMEDIATELY AFTER ACFC-
AVERAGE SN IMMEDIATELY AFTER ACFC= 80.0
STANDARD DEVIATION OF SN IMMEDIATELY AFTER ACFC= 3.333

7) REDUCTION IN DEFLECTION FOLLOWING MAJOR MAINTENANCE-

MAINT. ALT.	PERCENTAGE REDUCTION IN DEFLECTION
2	0
3	0
4	0
5	10.0
6	10.0
7	10.0
8	20.0
9	20.0
10	20.0

8) TRAFFIC DELAY DURING MAJOR MAINTENANCE OPERATIONS-

MAINT. ALT.	AVERAGE TRAFFIC DELAY IN MINUTES
2	7.0
3	7.0
4	7.0
5	7.0
6	7.0
7	7.0
8	7.0
9	7.0
10	7.0

COEFFICIENT OF VARIATION OF TRAFFIC DELAY= .1000

ROUTINE MAINTENANCE COSTS-

COSTS FOR ROUTINE MAINTENANCE ARE DERIVED FROM THE FOLLOWING FUNCTION-

RMCOST = -200.0 + 10.0 * RI + 35.0 * AGE

MAJOR MAINTENANCE COST

MAINT. ALT.	MAINT. COST
2	5632.00
3	8448.00
4	11733.00
5	12766.00
6	15582.00
7	18867.00
8	27034.00
9	29850.00
10	33135.00

COEFFICIENT OF VARIATION OF COST= .1000

EFFECTIVE INTEREST RATE= 0

TRAFFIC INFORMATION

AVERAGE ANNUAL TRAFFIC DURING FIRST YEAR OF ANALYSIS= 182500.00

ANNUAL TRAFFIC GROWTH RATE(IN PERCENT)= 5.00

* * * * * * * * * * * * * DESCRIPTION OF THE MAINTENANCE ALTERNATIVES * * * * * * * * * * * * *

MAINT. ALT. CODE	DESCRIPTION
1	ROUTINE MAINTENANCE
2	ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER
3	ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
4	ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
5	1 IN OVLAY + ACFC WITHOUT RUBBER COAT,WITHOUT HEAT SCARIFIER
6	1 IN OVLAY + ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
7	1 IN OVLAY + ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
8	3 IN OVLAY + ACFC WITHOUT RUBBER COAT,WITHOUT HEAT SCARIFIER
9	3 IN OVLAY + ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
10	3 IN OVLAY + ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER

DICTIONARY OF ACRONYMS USED IN COLUMN HEADINGS

ACRONYM	DEFINITION OF ACRONYM
MSC	= MAINTENANCE STRATEGY CODE NUMBER.
ERI	= EQUIVALENT ANNUAL ROUGHNESS INDEX OF THE SPECIFIED MAINTENANCE STRATEGY.
ESN	= EQUIVALENT ANNUAL SKID NUMBER OF THE SPECIFIED MAINTENANCE STRATEGY.
ETD	= AVERAGE TRAFFIC DELAY FOR THE SPECIFIED MAINTENANCE STRATEGY. (IN MINUTES)
EAC	= EQUIVALENT ANNUAL COST OF THE SPECIFIED MAINTENANCE STRATEGY(IN DOLLARS PER LANE MILE)
EXP.UTL.	= EXPECTED UTILITY OF THE SPECIFIED MAINTENANCE STRATEGY.
BENEFIT	= NET BENEFIT (IN DOLLARS) OF THE SPECIFIED MAINTENANCE STRATEGY.
YEAR	= YEAR AT WHICH THE MAINTENANCE ALTERNATIVE (OR INITIAL DESIGN) IS ADOPTED.

* * M A I N T E N A N C E   S T R A T E G I E S * *   NOTE - A TOTAL OF 10 FEASIBLE MAINTENANCE STRATEGIES HAVE BEEN SELECTED. THE TOP 10 ARE DESCRIBED IN THIS TABLE FROM BEST TO WORST.

MSC	ERI	ESN	ETD	EAC	EXP UTL	BENEFIT	YEAR -AND- MAINTENANCE ALTERNATIVE THAT IS ADOPTED
1	13.2	62.1	7.0	710.69	.9059	0	2 - ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
2	13.5	61.4	7.0	694.32	.9034	215.09	4 - ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
3	25.0	65.1	7.0	677.74	.8855	1762.21	2 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER 10 - ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
4	26.8	66.1	7.0	762.77	.8828	1998.18	2 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER 10 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER 18 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER
5	26.0	63.4	7.0	739.46	.8772	2479.79	2 - ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER 18 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER
6	29.1	65.1	7.0	749.59	.8748	2689.45	2 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER 10 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER 20 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER
7	29.4	65.1	7.0	695.63	.8748	2691.53	2 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER 12 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER
8	29.8	64.0	7.0	704.15	.8702	3092.18	4 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER 12 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER
9	27.9	62.1	7.0	754.77	.8681	3271.80	2 - ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER 20 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER
10	30.8	63.8	7.0	663.22	.8678	3293.66	4 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER 14 - ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER

* * * * * * * * * * * PROBABILISTIC PRECIDTION OF PAVEMENT CONDITION FOR MAINTENANCE STRATEGY NO. 1 * * * * * * * * * * *

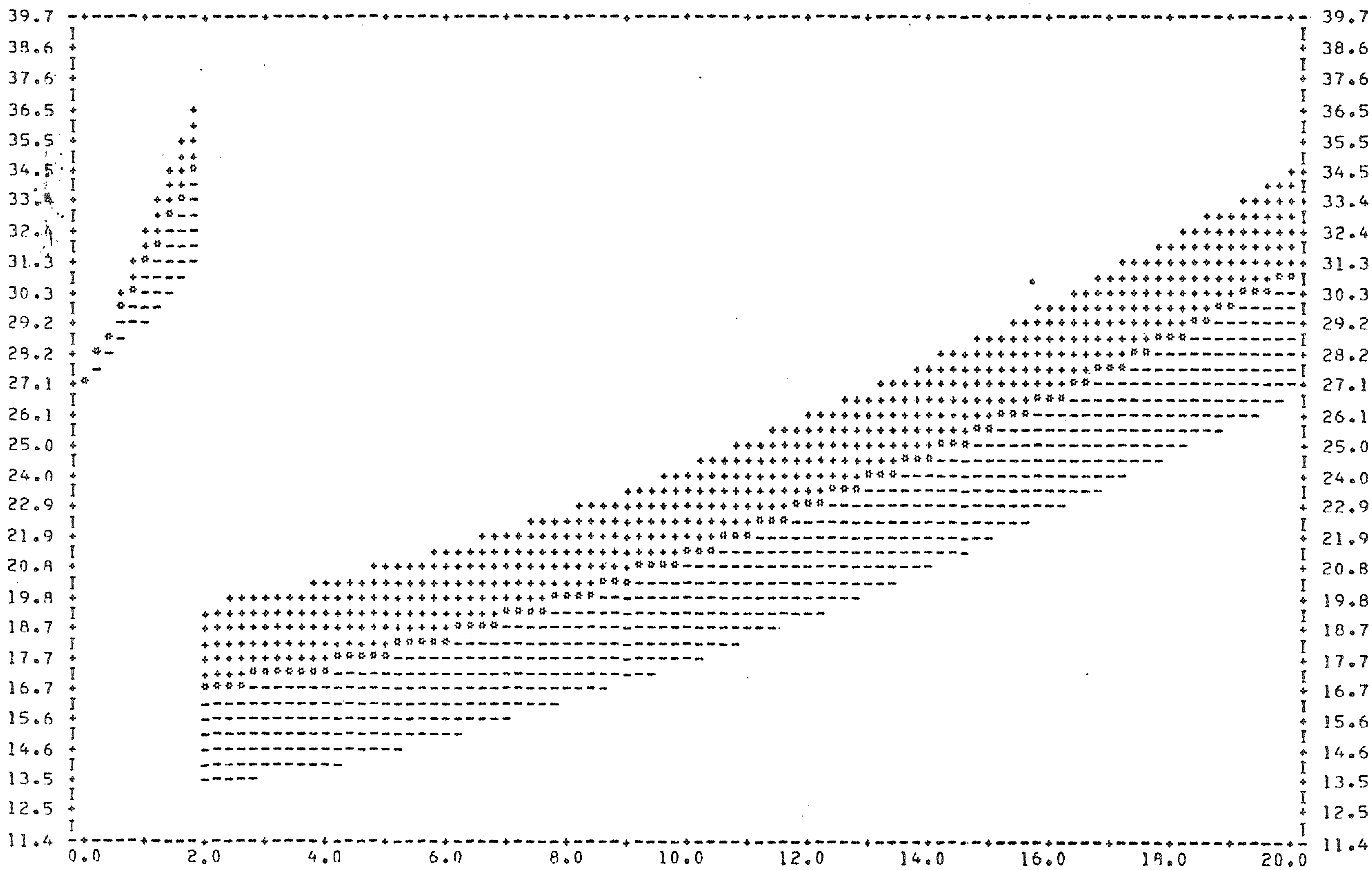
YEAR	ROUGHNESS INDEX		SKID NUMBER		MAINTENANCE ALTERNATIVE
	EXP. VAL.	STD. DEV.	EXP. VAL.	STD. DEV.	
0	27.0	0	55.0	0	ROUTINE MAINTENANCE
2	(34.7) 16.4	(1.65) 1.63	(54.1) 80.0	(.19) 3.33	ACFC WITH RUBBER COAT, WITHOUT HEAT SCARIFIER
4	17.2	1.64	72.5	4.08	ROUTINE MAINTENANCE
6	18.2	1.65	68.7	4.24	ROUTINE MAINTENANCE
8	19.5	1.68	66.2	4.31	ROUTINE MAINTENANCE
10	21.0	1.71	64.3	4.35	ROUTINE MAINTENANCE
12	22.6	1.75	62.7	4.38	ROUTINE MAINTENANCE
14	24.4	1.79	61.4	4.40	ROUTINE MAINTENANCE
16	26.3	1.85	60.3	4.41	ROUTINE MAINTENANCE
18	28.4	1.90	59.4	4.42	ROUTINE MAINTENANCE
20	30.6	1.97	58.5	4.43	ROUTINE MAINTENANCE

* NOTE *

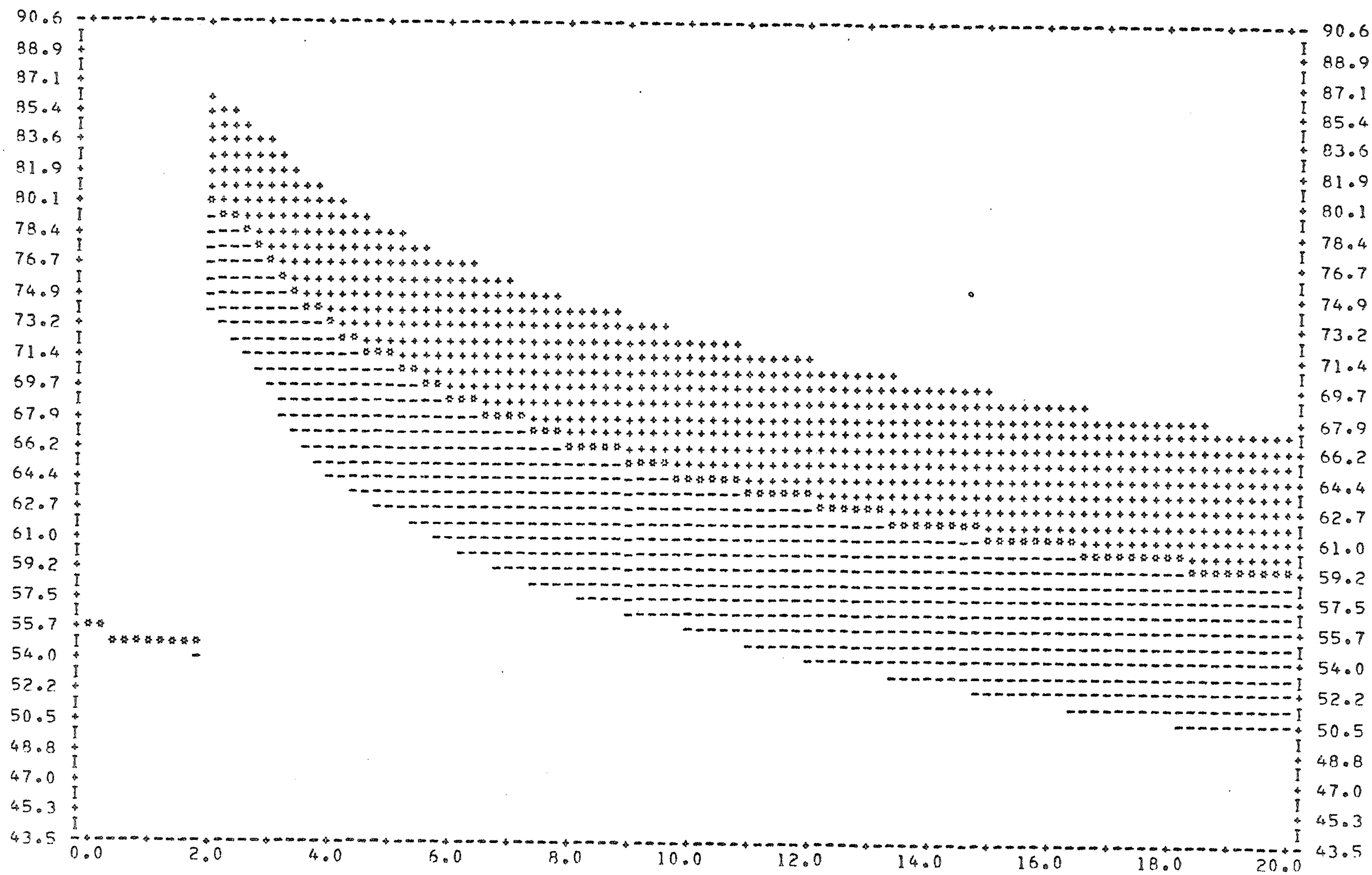
EXPECTED VALUES(THE VERTICAL AXIS) FOR ROUGHNESS INDEX AND SKID NUMBER ARE PLOTTED AGAINST TIME(THE HORIZONTAL AXIS) ON PAGES 10 AND 11. AN ASTERISK(*) INDICATES EXPECTED VALUE. TWO STANDARD DEVIATIONS ABOVE AND BELOW THE EXPECTED VALUE ARE SYMBOLIZED BY SHADED AREAS OF PLUS(+) AND MINUS(-) SIGNS RESPECTIVELY.

DRASTIC CHANGES IN EXPECTED VALUE INDICATE THE APPLICATION OF SOME MAINTENANCE ALTERNATIVE ON THE PAVEMENT SECTION AT THAT PARTICULAR POINT IN THE ANALYSIS PERIOD AS SUMMARIZED IN THE ABOVE TABLE.

* * * * * * * * * * * ROUGHNESS INDEX PLOTTED AGAINST TIME FOR MAINTENANCE STRATEGY NUMBER 1 * * * * * * * * * * *



* * * * * * * * * * * SKID NUMBER PLOTTED AGAINST TIME FOR MAINTENANCE STRATEGY NUMBER 1 * * * * * * * * * * *



PROBABILISTIC PREDICTION OF PAVEMENT CONDITION FOR MAINTENANCE STRATEGY NO. 2

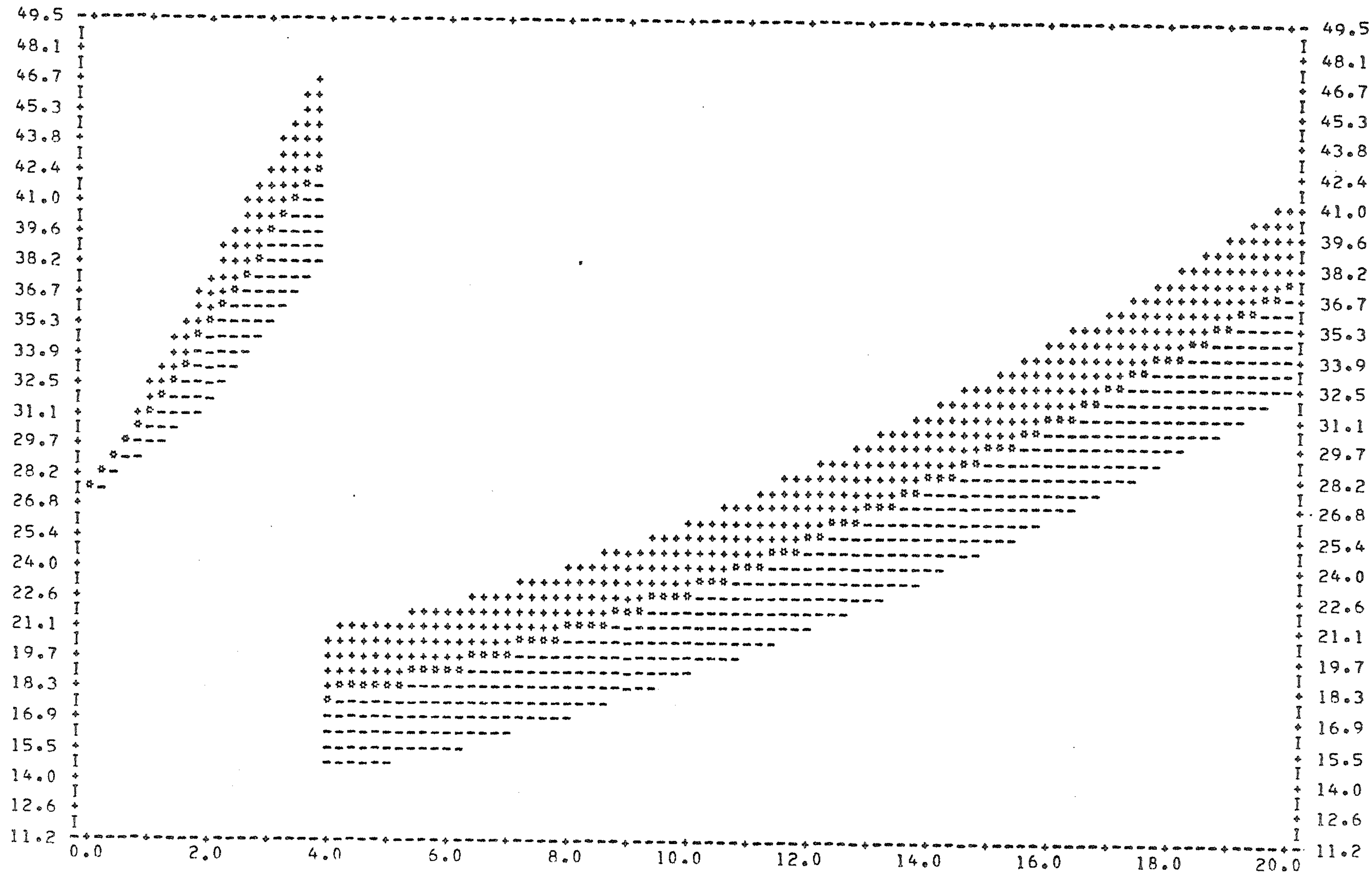
YEAR	ROUGHNESS INDEX EXP. VAL.	ROUGHNESS INDEX STD. DEV.	SKID NUMBER EXP. VAL.	SKID NUMBER STD. DEV.	MAINTENANCE ALTERNATIVE
0	27.0	0	55.0	0	ROUTINE MAINTENANCE
2	34.7	1.65	54.1	.19	ROUTINE MAINTENANCE
4	(43.2) 17.5	(2.46) 1.74	(53.5) 80.0	(.24) 3.33	ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
6	18.8	1.76	72.4	4.08	ROUTINE MAINTENANCE
8	20.5	1.80	68.6	4.25	ROUTINE MAINTENANCE
10	22.5	1.86	66.1	4.32	ROUTINE MAINTENANCE
12	24.9	1.93	64.2	4.36	ROUTINE MAINTENANCE
14	27.5	2.02	62.6	4.39	ROUTINE MAINTENANCE
16	30.4	2.12	61.3	4.41	ROUTINE MAINTENANCE
18	33.6	2.24	60.2	4.42	ROUTINE MAINTENANCE
20	36.9	2.36	59.2	4.43	ROUTINE MAINTENANCE

NOTE

EXPECTED VALUES(THE VERTICAL AXIS) FOR ROUGHNESS INDEX AND SKID NUMBER ARE PLOTTED AGAINST TIME(THE HORIZONTAL AXIS) ON PAGES 13 AND 14. AN ASTERISK(*) INDICATES EXPECTED VALUE. TWO STANDARD DEVIATIONS ABOVE AND BELOW THE EXPECTED VALUE ARE SYMBOLIZED BY SHADED AREAS OF PLUS(+) AND MINUS(-) SIGNS RESPECTIVELY.

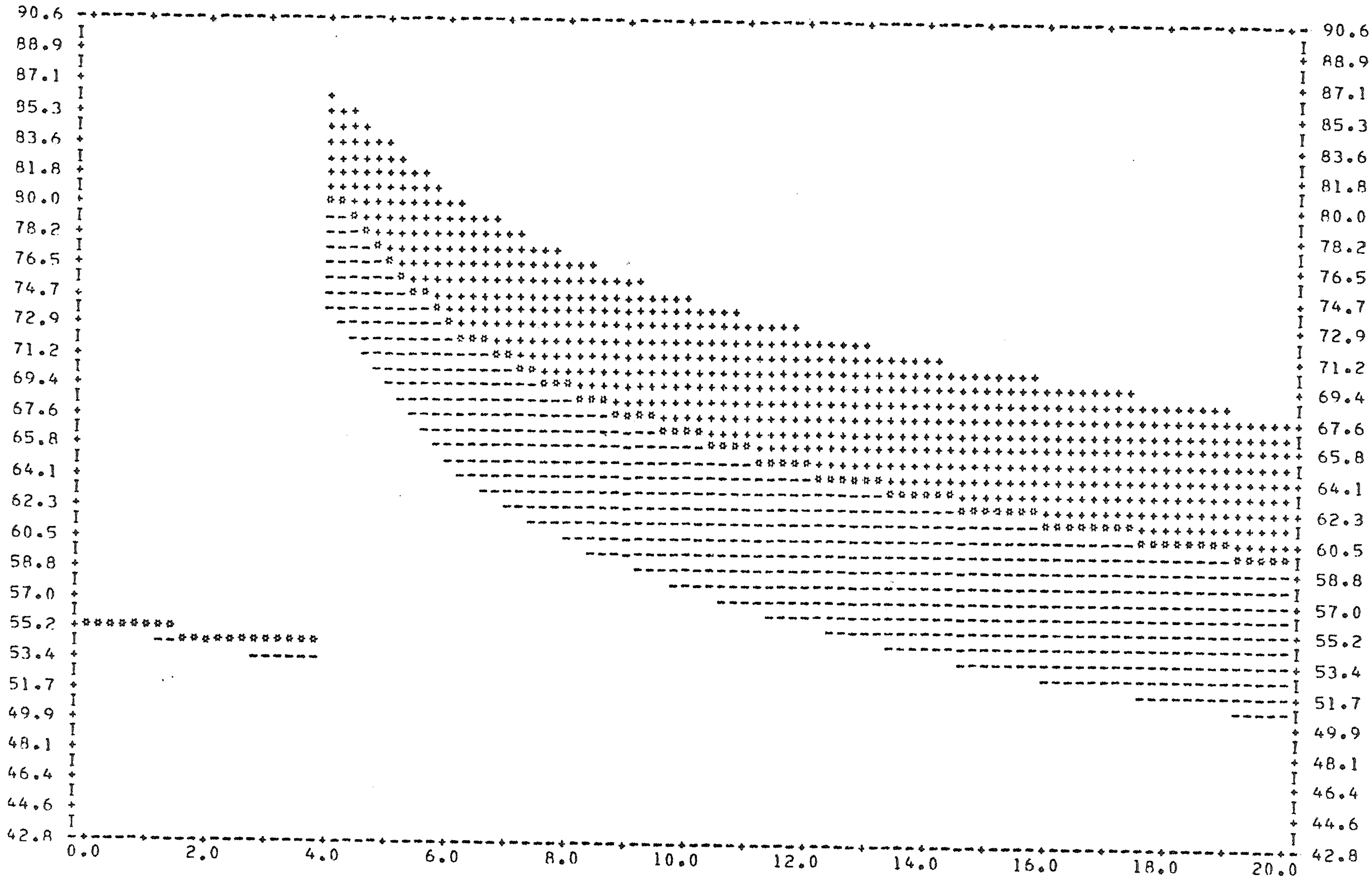
DRASTIC CHANGES IN EXPECTED VALUE INDICATE THE APPLICATION OF SOME MAINTENANCE ALTERNATIVE ON THE PAVEMENT SECTION AT THAT PARTICULAR POINT IN THE ANALYSIS PERIOD AS SUMMARIZED IN THE ABOVE TABLE.

* * * * * * * * * * * ROUGHNESS INDEX PLOTTED AGAINST TIME FOR MAINTENANCE STRATEGY NUMBER 2 * * * * * * * * * * *



PROBLEM NO. 1 - STATE OF ARIZONA - DEPARTMENT OF TRANSPORTATION - EXAMPLE NO. 1

* * * * * * * * * * * SKID NUMBER PLOTTED AGAINST TIME FOR MAINTENANCE STRATEGY NUMBER 2 * * * * * * * * * * *



* * * * * * * * * * * PROBABILISTIC PREDICTION OF PAVEMENT CONDITION FOR MAINTENANCE STRATEGY NO. 3 * * * * * * * * * * *

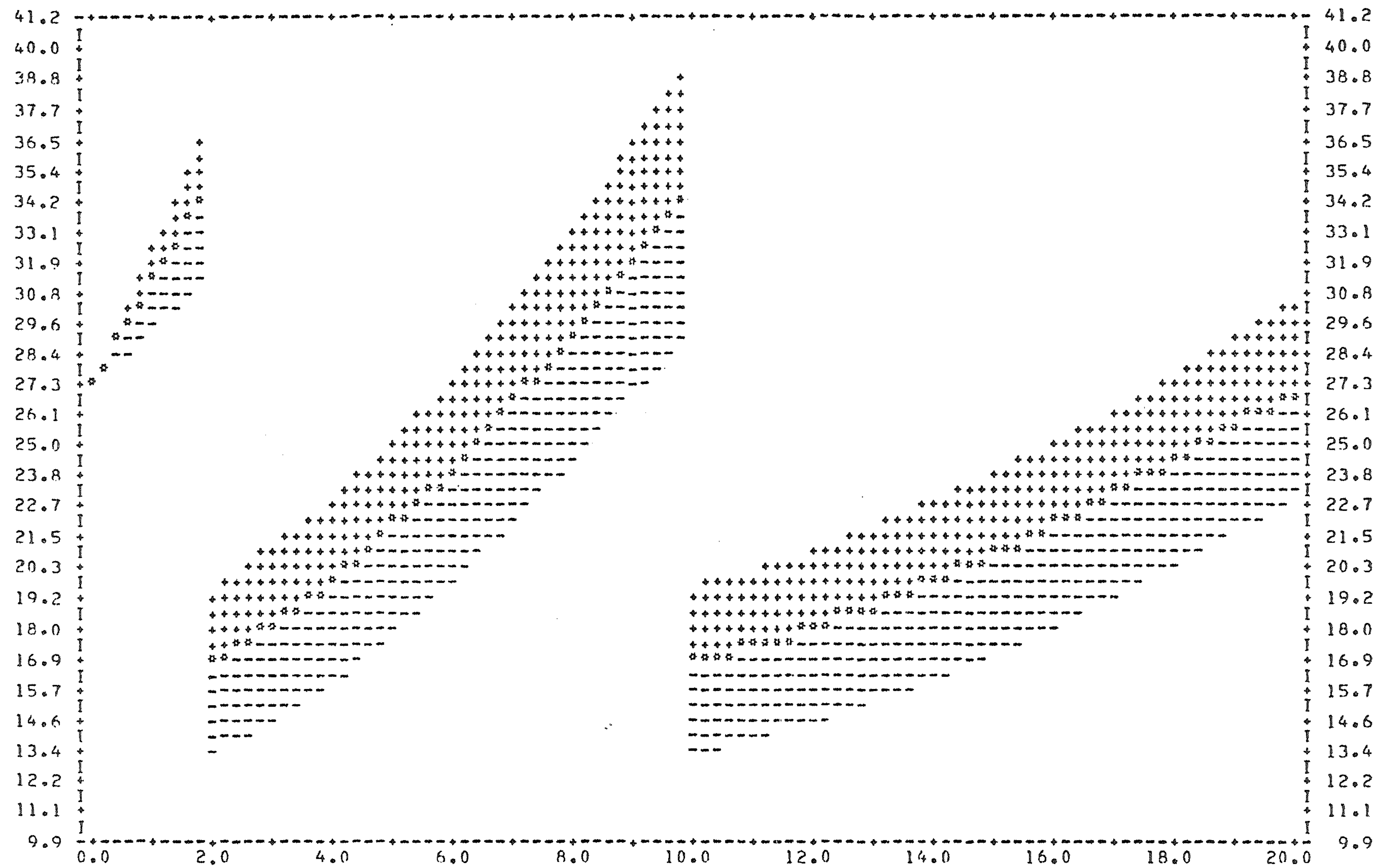
YEAR	ROUGHNESS INDEX		SKID NUMBER		MAINTENANCE ALTERNATIVE
	EXP. VAL.	STD. DEV.	EXP. VAL.	STD. DEV.	
0	27.0	0	55.0	0	ROUTINE MAINTENANCE
2	(34.7) 16.4	(1.65) 1.63	(54.1) 80.0	(.19) 3.33	ACFC WITHOUT RUBBER COAT, WITHOUT HEAT SCARIFIER
4	19.4	1.76	72.5	4.08	ROUTINE MAINTENANCE
6	23.6	2.00	68.7	4.24	ROUTINE MAINTENANCE
8	28.8	2.30	66.2	4.31	ROUTINE MAINTENANCE
10	(34.6) 16.4	(2.65) 1.63	(64.3) 80.0	(4.35) 3.33	ACFC WITHOUT RUBBER COAT, WITH HEAT SCARIFIER
12	17.7	1.66	72.3	4.11	ROUTINE MAINTENANCE
14	19.4	1.70	68.4	4.28	ROUTINE MAINTENANCE
16	21.5	1.77	65.8	4.35	ROUTINE MAINTENANCE
18	24.0	1.85	63.9	4.40	ROUTINE MAINTENANCE
20	26.7	1.94	62.3	4.42	ROUTINE MAINTENANCE

* NOTE *

EXPECTED VALUES(THE VERTICAL AXIS) FOR ROUGHNESS INDEX AND SKID NUMBER ARE PLOTTED AGAINST TIME(THE HORIZONTAL AXIS) ON PAGES 16 AND 17. AN ASTERISK(*) INDICATES EXPECTED VALUE. TWO STANDARD DEVIATIONS ABOVE AND BELOW THE EXPECTED VALUE ARE SYMBOLIZED BY SHADED AREAS OF PLUS(+) AND MINUS(-) SIGNS RESPECTIVELY.

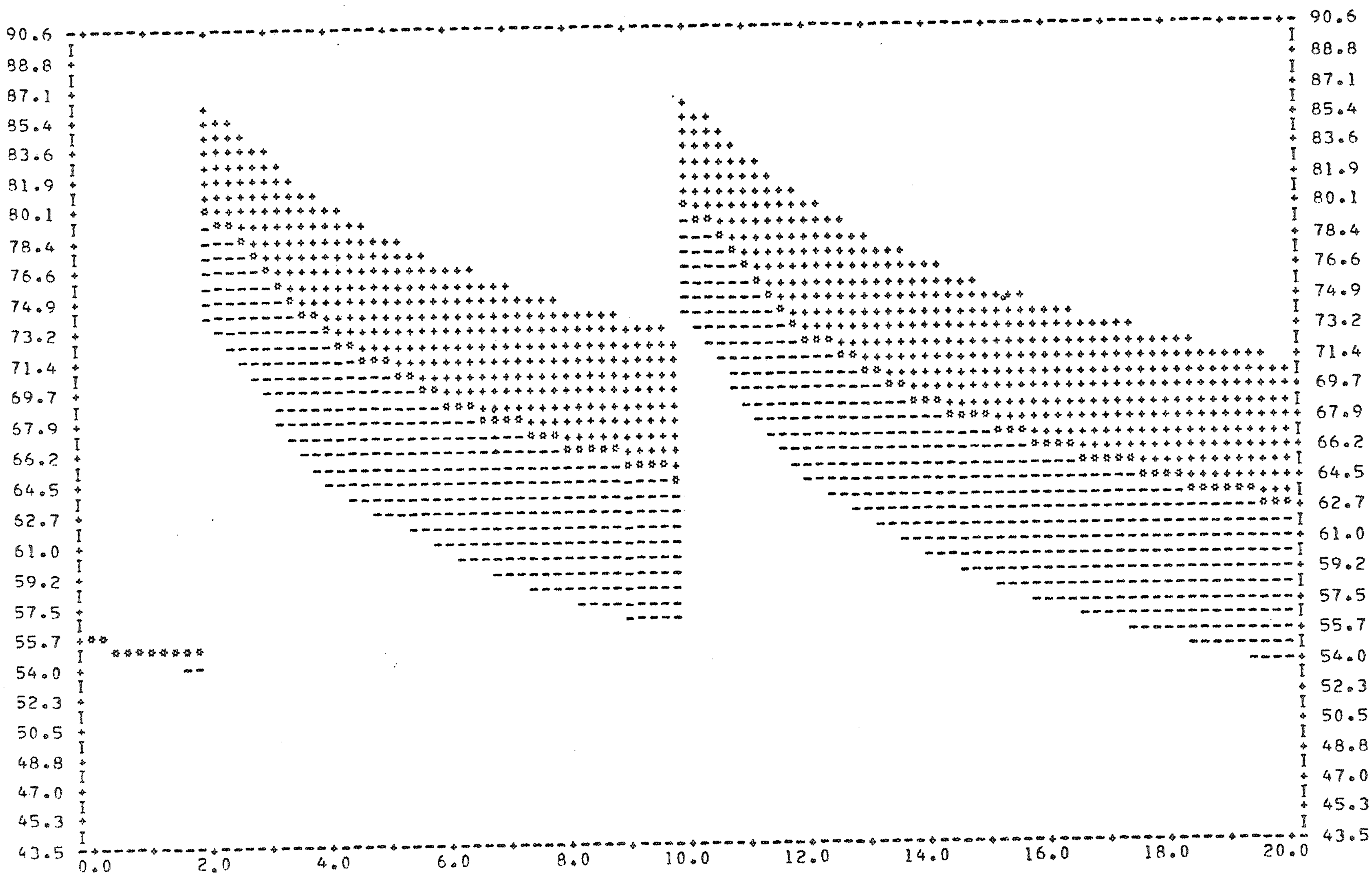
DRASTIC CHANGES IN EXPECTED VALUE INDICATE THE APPLICATION OF SOME MAINTENANCE ALTERNATIVE ON THE PAVEMENT SECTION AT THAT PARTICULAR POINT IN THE ANALYSIS PERIOD AS SUMMARIZED IN THE ABOVE TABLE.

* * * * * * * * * * * POUGHNESS INDEX PLOTTED AGAINST TIME FOR MAINTENANCE STRATEGY NUMBER 3 * * * * * * * * * * * *



PROBLEM NO. 1 - STATE OF ARIZONA - DEPARTMENT OF TRANSPORTATION - EXAMPLE NO. 1

* * * * * * * * * * * SKID NUMBER PLOTTED AGAINST TIME FOR MAINTENANCE STRATEGY NUMBER 3 * * * * * * * * * * *



APPENDIX D

IMPLEMENTATION PROPOSAL FOR THE PAVEMENT MANAGEMENT SYSTEM FOR ARIZONA DOT

BACKGROUND

In Phase I of this investigation, a framework for the development of a pavement management system has been prepared for the Arizona Department of Transportation. Phase II is proposed in order to prepare the system for implementation and to carry out field trials for reliability check.

To date, a management system for flexible (asphalt) pavements has been completed. Approximately 80 percent of the basic information required for a rigid pavement system has been obtained and is readily available for analysis and development of a management system.

A series of solutions (128) illustrating the operational characteristics of the pavement management system, Selection of Optimum Maintenance Strategies for Asphalt Concrete Pavements (SOMSAC), have been obtained. An analysis and review of these parametric solutions indicate the need for further refinements in specific aspects of the system as part of Phase II, implementation phase. No modification in the basic approach is considered necessary at this time; therefore, with only minor changes in utility values the flexible system should be ready for field trials.

It is proposed that a continuation of Phase I be undertaken as soon as possible which will involve four tasks: (1) refinements in flexible system, (2) procedures for interfacing management system programs with data bank information currently projected by DOT, (3) finalize rigid management system, and (4) field trials with selected projects.

Task 1. Refinements in Flexible Management System - SOMSAC

It is proposed to undertake an in-depth evaluation of SOMSAC to determine if optimum decisions obtained from computer programs reflect the preferred criteria of decision-makers within the DOT. For example, do the trade-offs between cost and performance represent the preferences of those persons responsible for making decisions regarding major maintenance?

Two specific areas can be modified in order to improve the reliability of the system: (1) performance prediction models and (2) utility functions.

Adjustments in prediction model can be obtained by comparisons with specific field experience. In all probability some modifications in prediction models will be necessary in order to accommodate variations in thickness of the asphalt layer, for example, conventional thicknesses and full-depth.

Several items will need to be resolved with regard to the utility function(s), specifically: (1) how many utility functions are to be used or available to the program and (2) the specific names of persons to be incorporated in each utility function.

Based on information in Phase I, it can be concluded that differences in individual utility functions can have a significant effect on the recommended maintenance strategies produced by SOMSAC. These differences represent the individual preferences, experience and present assignment of the person for whom the utility function has been developed. To have individual preferences representing 10 to 12 persons within the DOT would create confusion in implementing SOMSAC.

In all probability, two sets of utility functions will be useful: one for interstate, major primary and primary, and one for secondary and others.

In order to obtain a reasonable consensus for each utility function required, it is proposed to pool the separate utilities of selected DOT representatives. Such selections to be made by DOT management should include at least six assessors at the District Engineer level or equivalent in terms of present input for decision-making.

In summary, Task 1 will adjust the SOMSAC system in order to obtain maintenance strategies judged to be reasonable by decision-makers within Arizona DOT.

Task 2. Interface SOMSAC With Data Bank Information

At the present time, the Arizona DOT is acquiring all of the types of information required by SOMSAC. The purpose of this task will be to prepare the necessary electronic data processing procedures needed to access this information.

Two programs currently on line by Arizona DOT are SAMP6 (Systems Analysis Model for Flexible Pavement Design) and PMIS (Pavement Management Information System).

SAMP6 is a structural design model which considers the influence of overlays on the selection of initial designs. This program is based completely on the performance prediction models from the AASHO Road Test in Illinois. SAMP6 is expected to produce cost information for the best design strategies based on the AASHO Road Test prediction model. SOMSAC is designed to accept information from SAMP6 including specifically: structural designs (thickness and materials), and cost information (flexible pavement only). SOMSAC will then proceed to select the design and maintenance strategy appropriate to Arizona.

PMIS contains the data base of information required for the performance prediction and cost models including traffic, deflection (in service), environment, age and construction costs. Project limits and other pertinent identification information will also be obtained from PMIS.

Information pertinent to the initial deflection of new construction will need to be developed either through regression analyses or by the use of the layered system structural program called PSAD. It is proposed under this task to develop procedures for interfacing SOMSAC with SAMP6 and PMIS. If possible, it will be desirable to complete such programs as are necessary to achieve this goal; however, within the funds available this may not be possible. As a minimum, procedures for such interfacing will be completed.

In summary, Task 2 will provide the necessary data processing capability to access appropriate data sources necessary for the implementation of SOMSAC.

Task 3. Finalize Rigid Pavement Management System (Optional)

Task 3 is considered optional in order to stay within available funding without detracting from the completion of SOMSAC for flexible pavements. It is proposed that this task be deferred in order to take advantage of the experience obtained in Tasks 1 and 2. When completed, this task will produce the same type of information as obtained from SOMSAC for flexible pavements. Information regarding alternate designs for initial construction will need to be developed external to the management system program. This is not considered a significant deficiency since the number of alternate designs can reasonably be limited to approximately 6 to 10.

Task 4. Field Trials

It is proposed that implementation be undertaken by applying the SOMSAC program to selected projects within the state. Projects should be selected which represent a variety of circumstances and environments and need not be from one specific district. In selecting projects, consideration will need to be given to the availability of the necessary information (inputs) required for SOMSAC.