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16. Abstract

This report describes the analytical procedures for a) estimating maintenance and rehabilitation needs b) prioritizing projects and c) evaluating the consequences of various funding levels on the Texas highway network. A prototype microcomputer software package has been built incorporating the procedure. It is envisioned that this procedure will form the core of the Texas DOT Pavement Management System which is scheduled for Phase I implementation in February 1992.

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PROTOTYPE NEEDS ESTIMATING AND PROJECT RANKING SOFTWARE FOR THE TxDOT PMS

by

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Submitted by

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Sponsored by

Texas Department of Transportation

November, 1992

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in²	square inches	645.2	centimetres squared	cm ²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

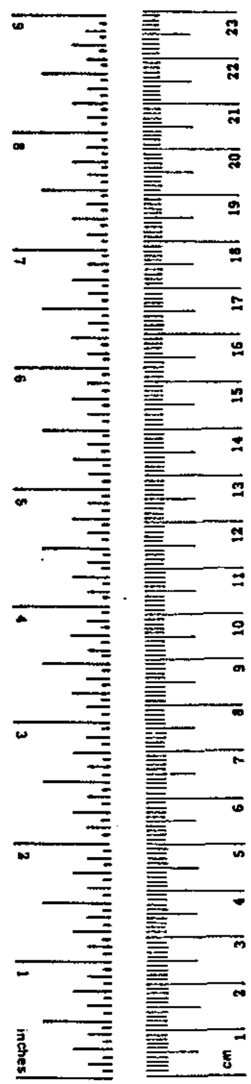
Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements



APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac

MASS (weight)

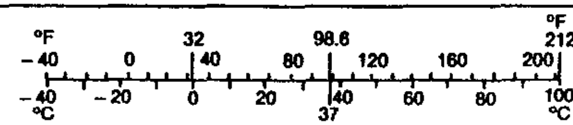
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

IMPLEMENTATION STATEMENT

This study describes an analytical procedure that has been developed to provide the capabilities of generating long term M&R needs estimates and of evaluating the consequences of variations in funding level. The system is being incorporated into the TxDOT Pavement Management System scheduled for release in early 1993.

DISCLAIMER

The contents of this report reflect the view of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation. This report does not constitute a standard, specifications, or regulations.

There is no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent law of the United States of America or any foreign country. This report is not intended for construction, bidding or permit purposes.

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INTRODUCTION

The Texas Department of Transportation, as well as every other DOT, is busy trying to comply with the Federal Requirements of implementing a Pavement Management System by early 1993. TxDOT has been working on preliminary PMS concepts and systems for the past 20 years. The Pavement Evaluation System (1) implemented in 1982 is the foundation upon which the current PMS system is being built. PES concepts of pavement data collection and score calculation are retained with only slight modification in the new system.

The analytical procedures described in this report are intended as one of the major components of the planned PMS. They are intended for use with all the flexible pavement types in Texas. The rigid analysis system is under developed in a companion study (2). These procedures will give TxDOT the capability of

a) estimating network level maintenance and rehabilitation funding requirements for flexible pavements over a planning horizon (typically 10 years);
b) prioritizing needs using a simple cost/benefit ranking scheme; and
c) determining the consequences of varying fund levels on network condition and levels of service.

The equations, decision trees and pavement performance curves used were adopted and modified from earlier TTI research studies. Research Report 207-3 (3) describes the RAMS-District Optimization system and pavement survivor curves. These form the basis of the curves used in this system. Research Report 409-1 (4) describes the decision trees used to estimate maintenance and rehabilitation requirements in an unconstrained funding case. The decision trees used in this system are a simplification of the original trees.

This version of the system was strongly influenced by TxDOT's desire to have a simple system which is easy to explain to District staff and DOT administrators. The major features of the proposed procedure are as follows.

1) The pavement's condition is measured in terms of visual distresses and ride. The distresses are combined into a Unweighted Visual Utility (UVU) Score (range 0 to 1.0); the ride is converted to a Ride Utility Score (SIU) (range 0 to 1.0). In practice UVU and SIU are multiplied by 100 for reporting purposes.
2) The pavement aging process ages the individual distresses, such as rutting, alligator cracking, etc., and the ride value. S-Shaped curves weighted for traffic, environment and subgrade type are used to project condition into the future.
3) Only 4 levels of treatment are used within the system representing the following broad cost categories;

   a) Preventative Maintenance
   b) Light Rehabilitation
   c) Medium Rehabilitation
   d) Heavy Rehabilitation/Reconstruction

   When conditions dictate, one of these cost categories will be assigned. The authors believe that this level of detail is both appropriate and realistic for network level PMS applications. Examples of the typical treatments in each of these cost categories are shown in Table 1.
4) Decision Trees, developed in house by senior TxDOT engineers, are used to relate pavement distresses and ride levels to the appropriate cost categories.
5) In the ranking procedure, the benefit of a particular cost category is defined as the area between a UVU and SIU curve with and without treatment, multiplied by traffic and project length weighting factors. The total benefit is simply the ride and condition benefits added together.
6) In the ranking procedure only the cost category identified by the decision trees is considered (one treatment per section). No lesser treatments are considered.

7) Sections which should be repaired but are not because of funding restrictions are considered backlog and routine maintenance costs, and are assigned and accumulated.
8) The selection process works on the worst first principle (highest benefit/cost ratio).

Table 1. Suggested Cost Category Treatments for Estimating Costs

Cost Category	Pavement Types					
	1	2, 3	4, 5, 9	6	10	7, 8
Preventative Maintenance	Joint Seal	Joint Seal	Crack Seal Surface Seal	Crack Seal Surface Seal	Surface Seal	Crack Seal Surface Seal
Light Rehabilitation	CPR	CPR	Thin Overlay	Thin Overlay	---	Thin Overlay
Moderate Rehabilitation	Patch & AC Overlay	Patch & AC Overlay	Thick Overlay	Mill & Overlay	Surface Seal with heavy patching	Mill & Overlay
Heavy Rehabilitation or Reconstruction	PCC Overlay	PCC Overlay	Remove AC & Replace Rework Base	Reconstruct	Rework Base and Surface Seal	Remove AC & Replace Repair PCC Base

Pavement Types:

1 = Continuously reinforced concrete pavement
2 = Jointed reinforced concrete pavement
3 = Jointed plain concrete pavement
4 = Thick asphalt concrete pavement > 5.5 inches
5 = Medium asphalt concrete pavement < 5.5 inches
6 = Thin asphalt concrete pavement < 2.5 inches
7 = Composite pavement
8 = Widened composite pavement
9 = Overlaid and widened asphalt concrete pavement
10 = Surface treatment pavement

DESCRIPTION OF MAJOR SUBROUTINES

The procedures that comprises the NEEDS ESTIMATE and RANKING SYSTEM are described in this section of the report. They were developed by the Texas Transportation Institute for the Texas Department of Transportation on Study 1918 entitled "Incorporating District Requirements into MICRO-PES."

These procedures allow the user to make predictions of future maintenance and rehabilitation needs for a pavement section based on the present condition of the pavement section. This system also permits the user to evaluate the impact of various funding levels over the planning horizon.

A flowchart of the software system based on these procedures is shown in Figure 1. The four major subroutines are listed below;

1) AGER - predicts the yearly growth in distress and loss of serviceability for a pavement section over the planning horizon.
2) NDTREE - assigns a maintenance and rehabilitation cost category to the pavement section according to the distresses and ride levels existing on the pavement section. This program uses decision trees developed by TxDOT personnel.
3) SLPMSC - computes the added utility value when the selected cost category is applied to a pavement section and optimizes the maintenance funds budget by selecting the sections with the highest Benefit Cost Ratio.
4) STAGE - updates the distress and ride values for a pavement section from the date that maintenance is applied to the end of the analysis period.

Each of the subroutines listed above will be described in more detail on the following pages.

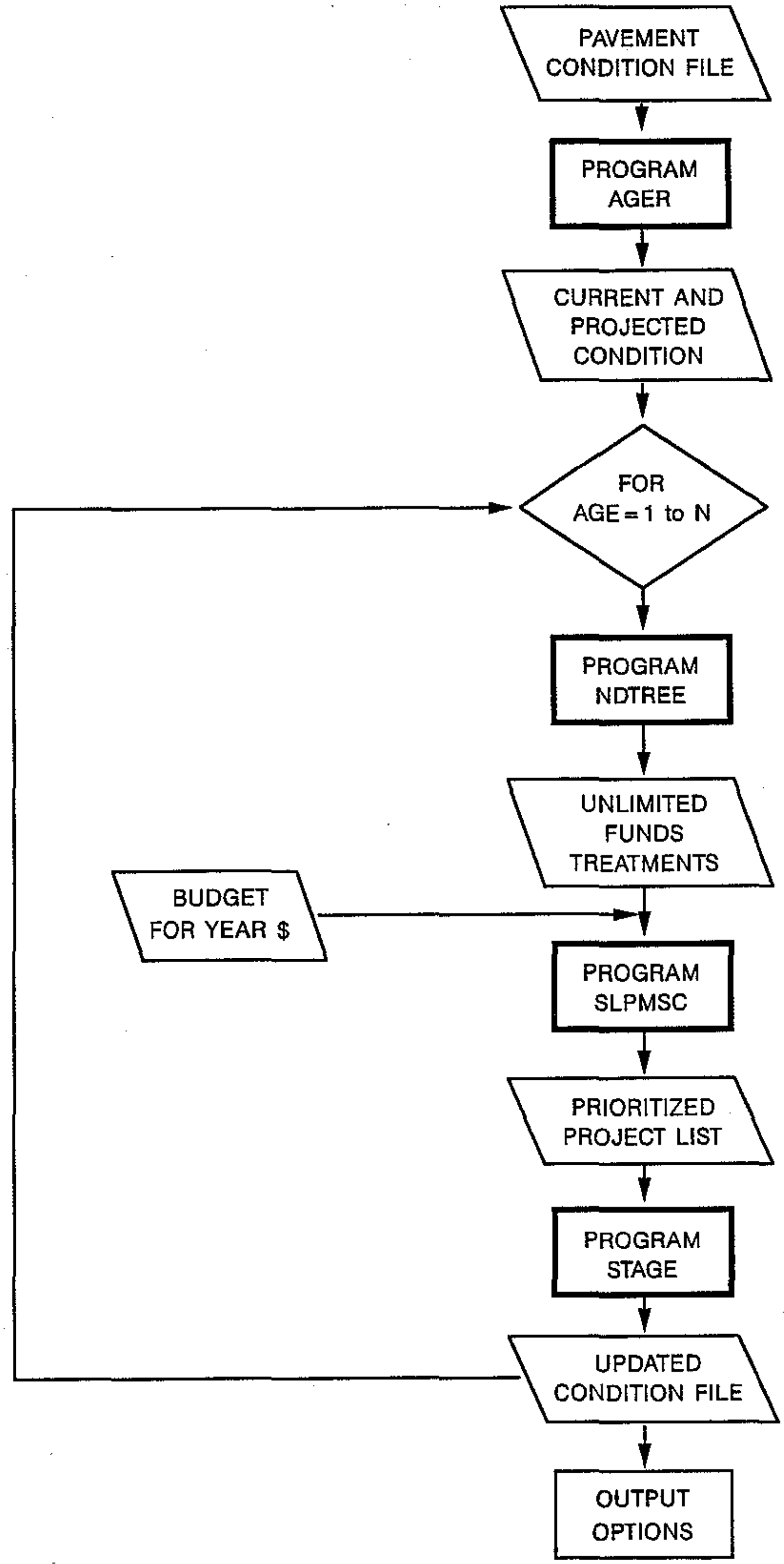

Figure 1. Flowchart of the Prototype Need Estimating and Ranking Software.

a) **Subroutine AGER**

AGER is used to project the yearly distress and ride condition of a pavement section. S-shaped pavement performance curves developed by the Texas Transportation Institute for each pavement distress type are used to predict the year by year increase in distress or loss of ride. The procedure starts from the initial observed distress condition and proceeds for a certain number of years, assuming no maintenance at all is applied during this time.

These S-shaped curves are of the form;

$$D_N = \alpha \exp - \left[\frac{\chi\varepsilon\sigma\rho}{N}\right]^{\beta} \quad (1)$$

where: N is the age of the section in years

D_N is the percentage of distress

- for rutting, alligator, block cracking = % distress
- for failures = number per mile
- for longitudinal cracking = linear feet/station
- for transverse cracking = number/station

For ride (PSI) D_N is defined as follows

$$D_N = \frac{P_I - P}{P_I - P_f}$$

where: P_I = Initial PSI set to 4.5

P = PSI measured on section

P_f = Final PSI for this section based on ADT*SPEED

*For ADT * SPEED > 165,000	P_f = 1.50
ADT * SPEED > 27501	P_f = 1.0
ADT * SPEED < 27500	P_f = 0.5

α = maximum range of distress

- for rutting, alligator, block cracking = 100 (100%)
- for failures = 20 failures/mile

- for longitudinal = 500 linear feet/station
- for transverse = 20 per station
- for ride = 1.0

ρ and β = parameter which defined the curve (see actual values in Table 2)

χ = traffic adjustment factor (Table 3)

ϵ = climatic adjustment factor

σ = subgrade support factor (Table 4)

An example of typical distress and serviceability prediction curves is shown in Figure 2. The system is currently applied to flexible pavement predictions only. The types of pavement distress that are predicted by the AGER program are listed below:

1) Shallow Rutting
2) Deep Rutting
3) Block Cracking
4) Failures
5) Alligator Cracking
6) Longitudinal Cracking
7) Transverse Cracking
8) Serviceability Index (Ride).

The α, β and ρ coefficients, from Equation 1, used to project condition are shown in Table 2. The traffic adjustment factor χ is generated using Equation 2 with the factors in Table 3, and typical subgrade support factors are shown in Table 4. The traffic adjustment factors χ and subgrade support factors σ are applied to the load associated distresses only. These being rutting, alligator cracking and ride. These factors were considered necessary as the initial pavement performance curves were generated in one location in the State of Texas. The traffic factors were obtained from multiple runs of a mechanistic design program (TFPS) recently developed by the Texas Transportation Institute for TxDOT.

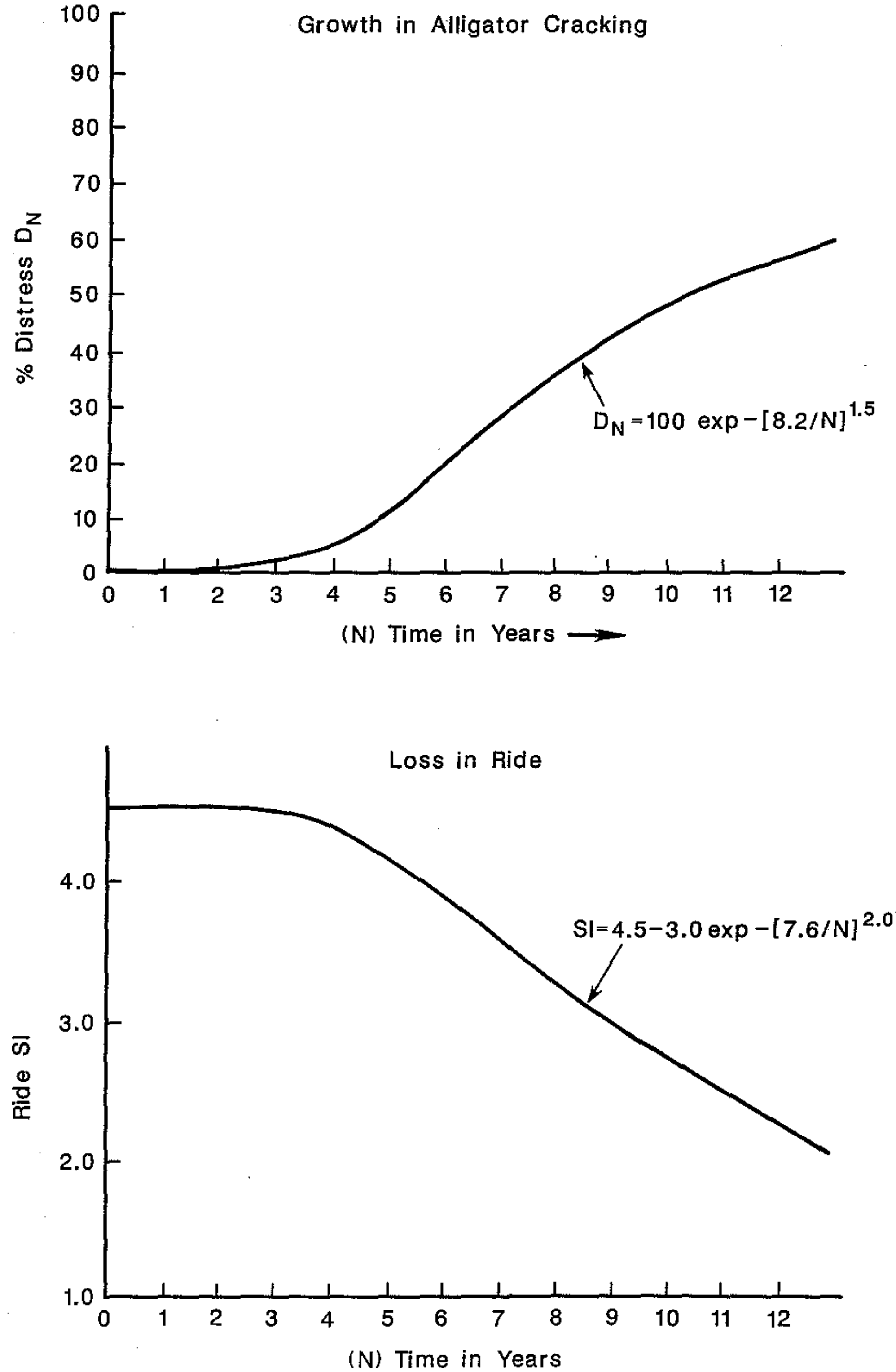

Figure 2. Typical Alligator Cracking and Ride Prediction Curves.

The traffic factor χ (chi) is a function of projected 18-kip Equivalent Single Axle Loads and pavement type. The χ equation takes the sigmoidal form;

$$\chi = A - B \exp - \left[\frac{\rho}{n}\right] \quad (2)$$

where: χ is the traffic adjustment factor used in Equation 1

A is maximum value of χ

ß and ρ are constants see Table 3

N is projected 20 years 18 kip ESAL's

The pavement types shown in Table 3 are the seven flexible pavement types used with the Texas Pavement Management System. As shown in Table 1, pavement type 4 is a thick hot mix pavement through to type 10 which is a typical surface treated Farm-to-Market highway.

The subgrade support factors are based on the average country subgrade strength values obtained from Falling Weight Deflectometer data collected in the annual TxDOT network level deflection surveys. The initial ß and ρ values from Table 2 were derived from pavement survivor curves developed in Study 207 (3). This information was based on pavement performance information and expert opinion from one District in Texas, that being District 21 in Pharr. The subgrade in that district is relatively poor. These subgrade support adjustment factors are an attempt to relate these original curves to support conditions found around the state. Although the variations in support are accommodated in the Department's pavement design process, the support adjustment factors are required because

a) many of the older pavements did not use the current design process,

b) considerable differences in performance are observed around the state.

Table 3. Parameters Used in Equation 2 to Generate the Traffic Adjustment Factor X

For Rutting (Shallow and Deep):

Coefficient	PMIS Pavement Type						
	4	5	6	7	8	9	10
A	1.1800	1.1800	1.1800	1.1800	1.1800	1.1800	1.1800
B	1.4800	1.1400	1.1300	1.3400	1.1800	1.0900	0.9600
ρ	33.2800	13.5600	5.1300	33.9700	24.1800	10.1300	1.6500
Minimum	0.8300	0.8300	0.8300	0.8300	0.8300	0.8300	0.8300

For Cracking (Alligator, Block):

Coefficient	PMIS Pavement Type						
	4	5	6	7	8	9	10
A	1.3000	1.3000	1.3000	1.3000	1.3000	1.3000	1.3000
B	3.1600	2,3400	2.3100	2.8400	2.4300	2.2400	1.9200
ρ	37.3500	15.3700	5.8100	38.5300	27.4100	11.4800	1.8700
Minimum	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000

For Ride Quality:

Coefficient	PMIS Pavement Type						
	4	5	6	7	8	9	10
A	1.1200	1.1200	1.1200	1.1200	1.1200	1.1200	1.1200
B	0.6300	0.5000	0.5000	0.5800	0.5200	0.4900	0.4400
ρ	27.5800	11.2000	4.2400	28.1400	19.9900	8.36000	1.3600
Minimum	0.9400	0.9400	0.9400	0.9400	0.9400	0.9400	0.9400

Table 4. Subgrade Support Factors Used Within Equation 1. Factors are by County and Based on Average Falling Weight Deflectometer Results.

PAVEMENT MANAGEMENT INFORMATION SYSTEM (PMIS)

County Subgrade Support Values (Sigma) -- ACP

Value	Description	SUBGRADE SUPPORT FACTORS -- ACP		
		Rutting	*Cracking*	*Ride*
1	Very Good	1.80	1.80	1.19
2	Good	1.61	1.61	1.14
3	Fair	1.42	1.42	1.08
4	Poor	1.21	1.21	1.04
5	Very Poor	1.00	1.00	1.00

NOTE: County Values Derived From 19?? PES Annual Report, Figure ?.?

DISTRICT	COUNTY NO.	COUNTY NAME	SUBGRADE SUPPORT	σ		
				Rutting	*Cracking*	*Ride*
1	60	Delta	5	1.00	1.00	1.00
1	75	Fannin	3	1.42	1.42	1.08
1	81	Franklin	4	1.21	1.21	1.04
1	92	Grayson	1	1.80	1.80	1.19
1	113	Hopkins	4	1.21	1.21	1.04
1	117	Hunt	1	1.80	1.80	1.19
1	139	Lamar	4	1.21	1.21	1.04
1	190	Rains	4	1.21	1.21	1.04
1	194	Red River	4	1.21	1.21	1.04
2	73	Erath	2	1.61	1.61	1.14
2	112	Hood	1	1.80	1.80	1.19
2	120	Jack	1	1.80	1.80	1.19
2	127	Johnson	3	1.42	1.42	1.08
2	182	Palo Pinto	1	1.80	1.80	1.19
2	184	Parker	1	1.80	1.80	1.19
2	213	Somervell	1	1.80	1.80	1.19
2	220	Tarrant	1	1.80	1.80	1.19
2	249	Wise	2	1.61	1.61	1.14
3	5	Archer	4	1.21	1.21	1.04
3	12	Baylor	4	1.21	1.21	1.04
3	39	Clay	3	1.42	1.42	1.08
3	49	Cooke	1	1.80	1.80	1.19
3	169	Montague	1	1.80	1.80	1.19
3	224	Throckmorton	4	1.21	1.21	1.04
3	243	Wichita	4	1.21	1.21	1.04
3	244	Wilbarger	4	1.21	1.21	1.04
3	252	Young	3	1.42	1.42	1.08
4	6	Armstrong	4	1.21	1.21	1.04
4	33	Carson	4	1.21	1.21	1.04
4	56	Dallam	4	1.21	1.21	1.04
4	59	Deaf Smith	4	1.21	1.21	1.04

Currently the environmental factor ϵ in equation 1 is set to a default value of 1.0. Efforts are underway to incorporate the influence of freeze-thaw cycles on surface cracking.

There are no pavement performance curves for patching. Within the system the growth of patching is tied to the predicted levels of failures on the pavement. It has been found historically that few if any failures are present on the TxDOT network. Localized failures are always patched by maintenance crews on a routine basis. The pavement performance equations predicted a growth of failures with age assuming no maintenance, not even routine maintenance, which is unrealistic. In reality it is rare to find over 2 failures per mile in the network level survey. Accordingly, if the equations predict more than two failures per mile, the patching area on the section is increased by 5%, and two failures per mile are subtracted from the total projected number of failures. This routine is repeated through the predicted life of the section and patching is allowed to grow in 5% increments with failures remaining few in number.

Computation Process Within AGER

The AGER program was written to access the PMIS pavement condition data file. Only the flexible pavements, those sections whose pavement type value is between 4 and 10, are selected from the PMIS pavement condition file. The section ID (district, county, highway, beginning & ending mile point), lane width, section length, pavement type, functional class, ADT, ESAL, speed, and the rated distress and measured serviceability index are read from the file for each flexible pavement section.

These initial pavement distress values and the SI (Serviceability Index) are then "aged" using the S-shaped pavement performance curves (Equation 1) for each distress type as described above for the specified time period (usually, ten years). The curve coefficient RHO is adjusted for climatic, traffic, and soil support effects for rutting, alligator cracking, and for serviceability index. If the rated value of a particular distress is 0% present (i.e. distress not found on section) then a curve similar to Figure 2 would be used with year 1 representing the level of distress next year. However, if the current section does have some distress present, then Figure 2 would still be used. This time a theoretical age would be calculated based on the recorded level of surface distress. For example, if the section was manually rated to have 10% alligator cracking at the start of the analysis period, then from the curve, the theoretical age would be set to 4.6 years. It would then be a matter of sliding up the curve in one year increments to determine the growth of alligator cracking (i.e. next year use N = 5.6, then 6.6, etc.).

Calculation of Utility Scores

The aging process ages the individual distress in terms of percentage of rutting, number of failures, etc. In the Texas PMS these distresses are combined using utility theory to produce a composite pavement condition score called the UVU (Unweighted Visual Utility) score. The UVU ranges from 0 to 100, with 100 being perfect. The UVU is defined as shown in Equation 3

$$UVU = [U_r * U_b * U_f * U_p * U_a * U_L * U_t *] * 100 \qquad (3)$$

where = U_r is the utility value for rutting

= U_b is the utility value for block cracking etc.

The general form of the individual utility curves which relate percentage distress to a utility value (range 0 to 1) is sigmoidal in shape as shown in equation 4.

$$U_i = 1 - \alpha \exp - \left[\frac{\rho}{N}\right]^{\beta} \qquad (4)$$

where

U_i is the utility value for distress i

α, ß and ρ are constants obtained from Table 5

N is the value of distress (e.g. for rutting N = % of section with rutting, for failures N = number of failures)

Table 5. α, ß, and ρ Coefficients for Distress Utility Equations. Flexible are Pavements Types 4, 5, 6, 9, 10; Composites are Pavement Types 7 and 8.

DISTRESS	Flexible			Composite		
	α	ß	ρ	α	ß	ρ
Shallow Rutting	0.3100	1.0000	19.7200	0.2300	1.0000	17.5500
Deep Rutting	0.6900	1.0000	16.2700	0.3200	1.0000	9.0400
Patching	0.4500	1.0000	10.1500	0.3200	1.0000	17.2800
Failures	1.0000	1.0000	4.7000	1.0000	1.0000	4.7000
Block Crk.	0.4900	1.0000	9.7800	0.3100	1.0000	13.7900
Allig. Crk.	0.5300	1.0000	8.0100	0.4200	1.0000	18.7700
Long. Crk.	0.8700	1.0000	184.000	0.3700	1.0000	136.90000
Trans Crk.	0.6900	1.0000	10.3900	0.4300	1.0000	9.5600

The utility value of any distress starts at 1.0 when the distress is not present and asymptotes at 1-α when the section is completely covered by the distress. The multiplicative utility equation is favored over the standard additive system because if a single major distress level becomes critical, then the UVU for the section will become critical.

The UVU contains a single utility value for rutting. However, in the evaluation both shallow and deep rutting are recorded. A utility value for each is calculated and combined using the following equation.

$$U_{RUTTING} = U_{R\text{-}SHALLOW} + U_{R\text{-}DEEP} - 1 \qquad (5)$$

The other major indicator of pavement condition used in Texas is the Ride Utility value. The measured ride value is input into an equation similar to Equation 4 but this time the N value is dependent upon the product of AADT * Speed as shown below

If ADT*Speed between 1 and 27,500 ("low traffic, low speed"):

$$N = 100\ X\left[\frac{2.5-SI}{2.5}\right] \qquad (6)$$

If ADT*Speed between 27,501 and 165,000 ("medium traffic, medium speed"):

$$N = 100\ X\left[\frac{3.0-SI}{3.0}\right] \qquad (7)$$

If ADT*Speed between 165,001 and 999,999 ("high traffic, high speed"):

$$N = 100\ X\left[\frac{3.5 - SI}{3.5}\right] \qquad (8)$$

where the SI is the measured pavement serviceability index (range 0 to 5.0). The α, ß and ρ values for the flexible pavement ride utilities are shown in Table 6.

Table 6. Ride Utility Coefficients to be used with Equation 4.

ADT*Speed Limit	α	ß	ρ
1-27,500	1.8180	1.0000	58.50000
27,501-165,000	1.7600	1.0000	48.1000
165,001+	1.7300	1.0000	41.0000

These calculated distress utility scores, along with the section ID and the other values read from the input data file, are written to an output file that is used by the NDTREE, SLPMSC, and STAGE programs to assign the maintenance level, optimize the maintenance budget, and "re-age" or re-predict the distress scores after maintenance is applied. A typical entry in this file for a single section is shown in Table 7. The input (rated) pavement condition is shown in the first line of the Table. The following ten lines show the projected condition without treatment and the calculated UVU and ride utility score for each of the 10 years in the analysis period.

The AGER program repeats the steps of reading the PMIS pavement condition input file, predicting the distress and SI scores for the specified number of years, calculating the distress utility scores, and writing the data to the output file until all the data in the PMIS pavement condition input file has been read and processed. The output file is generated once, and it includes the 10 years projected condition. As shown in the flowchart in Figure 1, the following programs NDTREE, SLPMSC and STAGE are each run sequentially one year at a time.

Table 7. The Output of AGER for a Single Section Showing Predicting Aged Condition for 10 Years. Distresses are

1 - Shallow Rutting (%)
2 - Deep Rutting (%)
3 - Block Cracking (%)
4 - Patching (%)
5 - Failure (Number)
6 - Alligator (%)
7 - Longitudinal (length)
8 - Transverse (number)

The UVU and Ride Utility are calculated fields.

Section ID	Section Info	Traffic	Distresses								UVU	SI	Ride Utility
			1	2	3	4	5	6	7	8			
12170FM0140 0440 +000442	+R5505502018	5500029320	10	0	0	0	2	15	0	2	0.594	4.100	1.000
12170FM0149 0440 +000442	+R5505502018	5500029320	17	0	0	5	1	18	0	3	0.544	3.783	1.000
12170FM0149 0440 +000442	+R5505502018	5500029320	26	0	0	5	2	22	0	4	0.436	3.471	1.000
12170FM0149 0440 +000442	+R5505502018	5500029320	35	0	0	10	2	26	2	5	0.348	3.191	1.000
12170FM0149 0440 +000442	+R5505502018	5500029320	43	0	1	15	1	29	9	6	0.323	2.952	1.000
12170FM0149 0440 +000442	+R5505502018	5500029320	50	1	4	15	2	33	18	7	0.262	2.752	0.995
12170FM0149 0440 +000442	+R5505502018	5500029320	56	2	8	20	1	36	30	8	0.225	2.586	0.946
12170FM0149 0440 +000442	+R5505502018	5500029320	62	4	13	20	2	39	43	9	0.170	2.448	0.871
12170FM0149 0440 +000442	+R5505502018	5500029320	66	6	19	20	2	42	57	9	0.143	2.332	0.797
12170FM0149 0440 +000442	+R5505502018	5500029320	70	8	25	25	1	45	71	10	0.123	2.236	0.733
12170FM0149 0440 +000442	+R5505502018	5500029320	74	10	30	25	2	48	85	11	0.093	2.154	0.680

b) Subroutine NDTREE

NDTREE is used to determine which of the four cost categories to apply to a pavement section based on the distress condition, the serviceability index (Ride), the AADT and the functional class of the pavement section. The cost categories shown previously in Table 1 include preventative maintenance, light, moderate and heavy rehabilitation. This is the unlimited funds situation where a cost category is chosen to address the existing pavement condition. For each section it is this and only this category that is considered when funding constraints are applied. The decision trees are shown in Figure 3, they were initially developed in Study 930 by using questionnaires and interviews with senior TxDOT engineers. The original decision trees were more specific than these in that they produced recommended treatments and also dealt with rigid pavements. They were made more general to meet the current needs of the Texas PMS.

Program NDTREE uses the file shown in Table 7 to determine the cost category to apply to each section. The program evaluates the condition of every section in this file for a single year of the analysis period to establish the cost category for that year only. This is done on a year by year basis because the ranking program may select this section for repair based on available funds. If this is the case, the STAGE program will then adjust the condition and ride values for the remainder of the analysis period to reflect the work performed.

After all the pavement sections for a given year are checked and assigned a cost category, the ranking program SLPMSC and the re-aging program STAGE are run for the same year.

STRATEGY 4 HEAVY REHAB/RECONSTR. (TYPES 4-10)

PSI < 2.5 and ADT/Lane > 5000
PSI < 2.0 and ADT/Lane > 750
PSI < 1.5
Deep Rutting > 50%
Alligator > 50% and ADT/Lane > 750 and PSI < 3.0
Alligator > 50% and PSI < 2.5

STRATEGY 3 MODERATE REHABILITATION (TYPES 4-10)

PSI < 3.0 and ADT/Lane > 5000
PSI < 2.5 and ADT/Lane > 750
PSI < 2.0
Deep Rutting > 25% and ADT/Lane > 750
Alligator > 10% and ADT/Lane > 5000
Alligator > 50%
Failures > 6 and ADT/Lane > 750
Failures > 10
Block > 50% and ADT/Lane > 750

Traffic Classification

Functional Class	~~1~~	~~2~~	~~3~~	4	5	6	7
Low ADT/Lane <	~~7500~~	~~7500~~	~~7500~~	3000	2000	2000	2000

STRATEGY 2 LIGHT REHAB (TYPES 4-10)

Slight Rutting > 25% and ADT/Lane = HIGH
Slight Rutting > 50%
Deep Rutting > 10%
PSI , 3.0 and ADT/Lane = HIGH

STRATEGY 1 PREVENTATIVE MAINTENANCE (TYPES 4-10)

Block > 5%
Failures > 1
Alligator > 5%
Longitudinal > 50 and ADT/Lane = HIGH
Longitudinal > 150
Transverse > 2 and ADT/Lane = HIGH
Transverse > 4

Figure 3. Decision Trees Flex Pavements Types 4 Thru 10.

c) **Subroutine SLPMSC**

This is the ranking subroutine which determines based on the available budget which of the candidate sections should be repaired using the cost category defined by the decision trees. Several ranking and optimization procedures were reviewed by the Texas PMS Steering Committee (5). Their major objective was to, at least initially, implement a simple procedure which was easy to explain to senior administrators and district personnel. It was decided to implement a benefit/cost ranking procedure, with benefit defined as the "area under the curve" of the Visual and Ride Utility curves. The total benefit is the summation of the two areas divided by the total area of the project and multiplied by a traffic weighting factor. Details of the benefit calculation procedure are given below. The cost from each project will be eventually calculated from district level unit cost tables for each pavement type. It is planned that each Texas district will supply typical cost information for standard contractor prices for their specific location. Example treatments within each cost category as shown in Table 1 will be used for guidance in developing costs. Each section will only consider applying the cost category recommended by the decision tree program. No lesser treatments will be considered; the PMS committee thought the system should apply the treatment required, or hold the section with routine maintenance until sufficient funds become available. This subroutine, therefore, calculates a benefit/cost ratio for each project then ranks them highest to lowest. Projects are repaired on a worst first basis (highest benefit/cost) until funds are exhausted. All of the sections which were recommended for repair by the decision tree program, but were not recommended because of fund restrictions, are placed in a backlog category, and an appropriate routine maintenance cost is estimated.

The benefit calculation within the SLPMSC subroutine proceeds as follows

1) Given an input distress level, serviceability index and recommended cost category, the applied strategy is assumed, at the moment of application, to return each distress level to the perfect condition (0%) and to improve the serviceability index as shown below;

Table 8. Impact of Strategies on PSI.

Cost Category	Change in Serviceability
1	+0.5 (max = 4.2)
2	+1.0 (max = 4.2)
3	Set to 4.2
4	Set to 4.2

2) For each cost category, the pavement is then deteriorated using Equation 1 with the α, β and ρ values obtained from Table 9. Note the values shown earlier in Table 2 are those from cost category 4 (Heavy Rehab). Traffic, subgrade support and environmental factors are used as defined previously. After deteriorating the distresses and serviceability index, the Utility values for both condition and ride are computed as described earlier. The UVU versus Time and the SIU versus Time graph will now contain two lines, one before treatment and one after treatment.

3) The area between the two curves is then calculated. However, one important addition is the inclusion of a minimum tolerable condition criteria. It is assumed that unless the strategy increases the UVU or SIU above this minimum level, then no benefit will be generated. Also, when the condition of the section falls below the minimum level, then no additional benefit will be accumulated. The current minimum utility levels are set to 0.50, but these are subjected to review. The area computation uses the trapezoidal area calculation method shown in Figure 4 for the standard case. In this demonstration example, the UVU was multiplied by 100 and the minimum level of 80 was set.

In programming the benefit computation, at least 5 different cases were identified. These are shown schematically in Figure 5. The benefit is accumulated until the improved utility curve hits the untreated utility curve (Case III) or until the treated utility curve hits the minimum level (Cases I and II). Case IV is possible particularly with the ride utility calculation. Case V is only possible if a section with a very low ride is recommended a cost category 1 or 2 (very unlikely).

4) The total benefit is a summation of UVU and SIU "areas under the curves." This number is divided by the section area to get benefit per square yard.

Table 9. Pavement Deterioration Factors Used with Equation 1 to Calculate Levels of Distress After Treatment.

Distress	Prev. Maint. (PM)			Light Rehab (LRhb)		
	α	ß	ρ	α	ß	ρ
Rutting, Shallow	100	4.5	5.0	100	2.75	7.53
Rutting, Deep	100	2.47	6.78	100	1.37	11.91
Failures	20	2.17	5.5	20	2.29	5.85
Allig. Crk.	100	3.38	6.6	100	1.95	9.29
Block Crk.	100	2.51	7.08	100	1.64	10.11
Long Crk.	500	0.81	8.39	500	1.12	6.16
Trans. Crk.	20	1.94	5.57	20	2.08	5.41
Ride Quality	1.000	2.000	3.2000	1.0000	2.0000	6.3000

Note: There are no performance curves for patching.

Distress	Medium Rehab (MRhb)			Heavy Rehab/ Reconstruction (HRhb)		
	α	ß	ρ	α	ß	ρ
Rutting, Shallow	100	2.67	7.52	100	2.55	6.76
Rutting, Deep	100	1.33	12.08	100	1.00	13.45
Failures	20	1.34	8.52	20	1.36	8.97
Allig. Crk.	100	1.75	9.67	100	1.69	10.41
Block Crk.	100	1.45	10.65	100	1.43	11.43
Long Crk.	500	1.78	6.72	500	0.90	19.06
Trans. Crk.	20	2.36	6.60	20	1.54	12.06
Ride Quality	1.000	2.000	7.7000	1.0000	2.0000	6.3000

Note: There are no performance curves for patching.

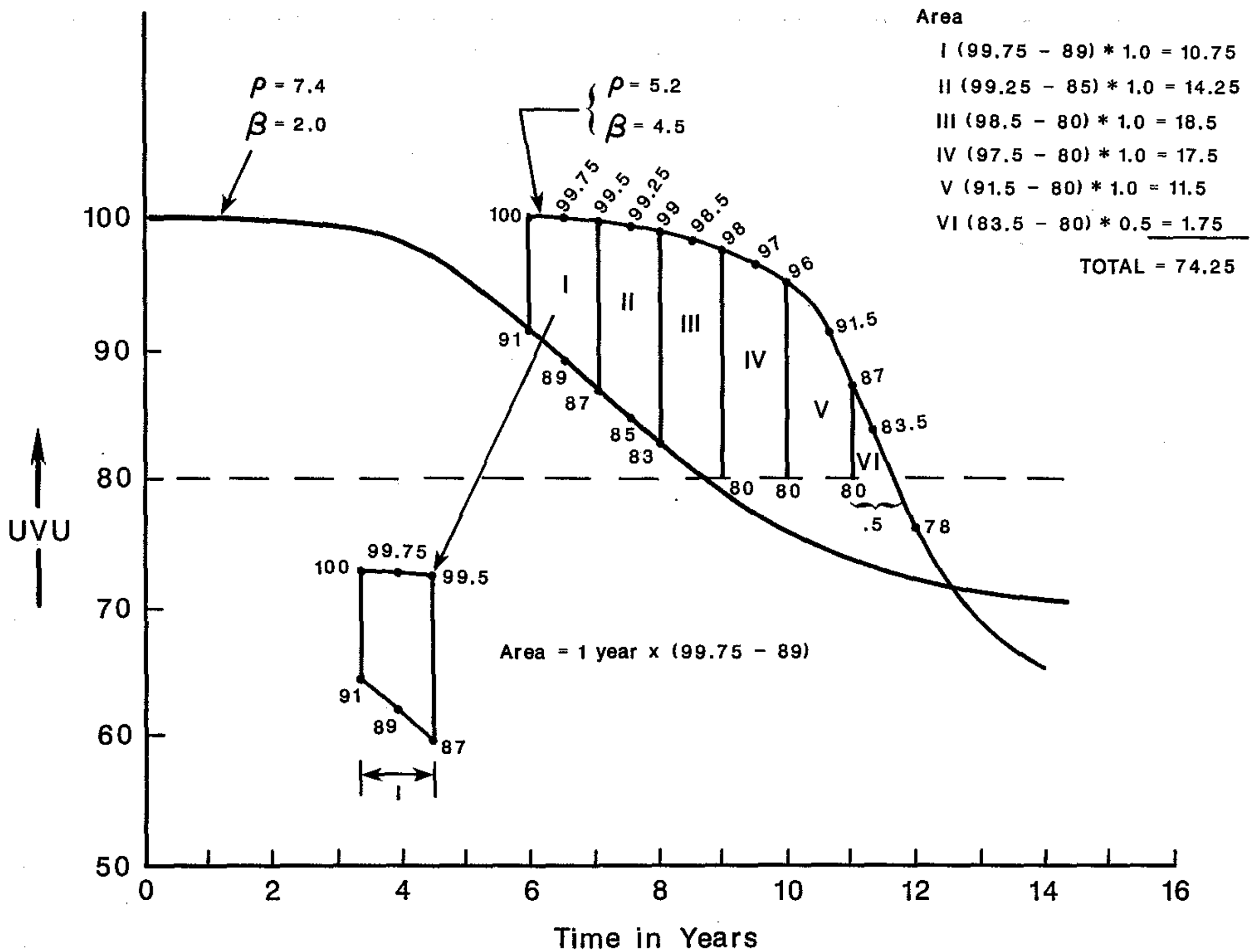

Figure 4. Example Calculation of Area Between Repaired and Unrepaired UVU Curves.

CASES IN BENEFIT CALCULATION

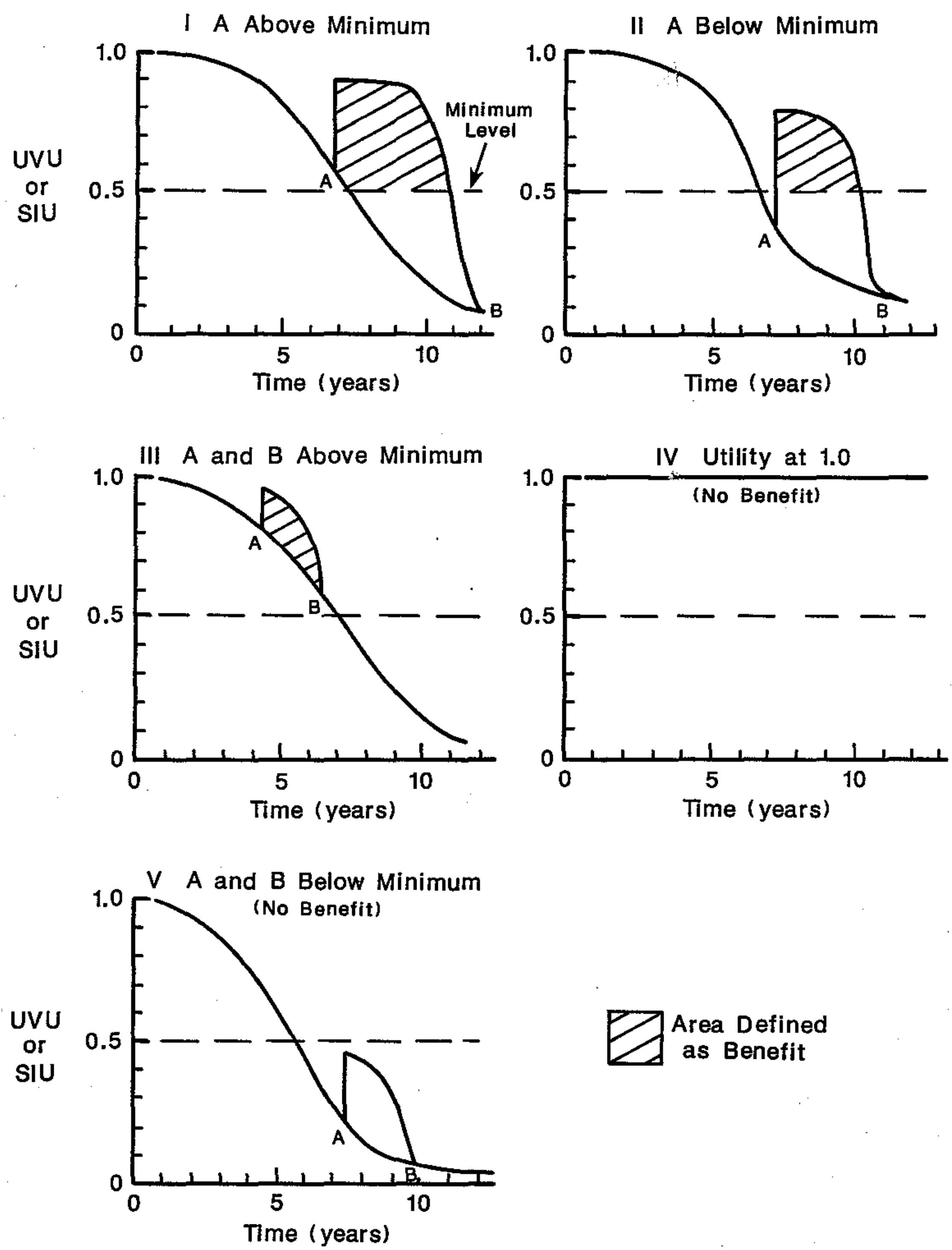

Figure 5. Cases in the Benefit Calculation.

It is then multiplied by a traffic function which has tentatively been set at Log_{10} (AADT).

The appropriate procedure for including traffic into the benefit calculation was the subject of much discussion. Simply multiplying BENEFIT by AADT would result in only high volume roads being selected. Ignoring AADT would mean that if two identical highways were being considered for the same treatment, then the low volume road would generate higher benefit than the high volume road (because of slower deterioration after repair). Neither extreme positions are acceptable; therefore, a compromise procedure (log_{10}) was recommended. This is an area where future efforts should be concentrated, the use of any traffic adjustment factor has a great influence on the final rankings.

<u>Cost and Budget Level</u>

The current unit cost used within the system are tabulated below. This will clearly be subject to change when the individual district cost information is available.

Table 10. Cost Per $/sq Yard Currently Used in System.

Pav. Type	4	5	6	7	8	9	10
Strat 1	0.95	0.95	0.85	0.85	0.85	0.90	0.75
Strat 2	2.00	2.00	1.50	1.75	1.75	1.75	1.50
Strat 3	6.50	5.50	4.00	4.50	4.50	4.50	3.20
Strat 4	11.0	8.00	7.50	8.00	8.00	8.00	7.50

Another input to this routine is the annual budget level. This clearly is user defined and changed from run to run. In a 10 year analysis problem, the user would define budget levels such as those shown in Table 11.

Table 11. User Desired Budget Levels in $.

Year	$ Available
1	5,000,000.00
2	5,000,000.00
3	2,000,000.00
4	5,000,000.00
5	10,000,000.00
6	5,000,000.00
7	7,000,000.00
8	8,000,000.00
9	3,000,000.00
10	5,000,000.00

The output of the SLPMSC subroutine is a list of sections which have been accepted for repair subject to the input budget level. These sections, together with the recommended cost category, are input into the last subroutine where the distress and serviceability deterioration curves are adjusted.

d) **Subroutine Stage**

This program is run to adjust the pavement distresses and ride values for those sections selected for repair by the ranking routine. The process is simply to improve the condition of those sections selected using the improved pavement condition curves calculated with the α, β, and ρ values from Table 9. The condition is improved and the section is allowed to deteriorate until the end of the analysis period. If the section is not selected for repair, it is merely skipped in this process, and the deterioration curves generated by AGER remain in effect.

An example of the STAGE subroutine function is given in Tables 12 and 13. Table 12 shows the section deterioration curves before a cost category was applied. In this example a Category 3 (moderate rehabilitation) was applied in year 5, and the predicted change in distresses, serviceability and Utilities are shown in Table 13.

At the end of the Stage subroutine, the analysis for the year of interest is complete. The next year in the analysis period is then processed starting with the decision trees. The process is repeated until each year in the analysis period is completed. Once complete the user is then given several options on how to output the results; these are described in the next section of the report.

Table 12. Pavement Condition as Predicted by AGER Before Repair.

Section ID;; FM 149 MP 440 To MP 442											
********************Change in Distress********************											
YEAR	RUT SHLW	RUT CRACK	BLOCK CRACK	PATCH	FAILR	ALGR. CRACK	LONG. CRACK	TRAN. CRACK	UVU	RIDE	SIU
0	10	0	0	0	2	15	0	1	.594	4.100	1.000
1	18	0	0	5	1	19	0	2	.533	3.718	1.000
2	28	0	0	5	2	23	0	3	.428	3.332	1.000
3	37	0	0	10	2	27	2	4	.343	2.986	1.000
4	45	0	1	15	1	31	9	5	.317	2.693	0.984
5	52	1	4	15	2	34	18	6	.258	2.449	0.872
6	59	3	8	20	1	38	30	7	.222	2.248	0.742
7	64	5	13	20	2	41	43	8	.165	2.083	0.635
8	69	7	19	20	2	44	57	9	.138	1.946	0.553
9	72	9	25	25	1	47	71	10	.118	1.832	0.489
10	76	12	30	25	2	50	85	11	.086	1.737	0.438

Table 13. Pavement Condition with Medium Rehabilitation in Year 5 as Predicted by STAGE.

Section ID;; FM 149 MP 440 To MP 442											
********************Change in Distress********************											
YEAR	RUT SHLW	RUT CRACK	BLOCK CRACK	PATCH	FAILR	ALGR. CRACK	LONG. CRACK	TRAN. CRACK	UVU	RIDE	SIU
0	10	0	0	0	2	15	0	2	.594	4.100	1.000
1	18	0	0	0	1	19	0	3	.533	3.718	1.000
2	28	0	0	0	2	23	0	4	.428	3.332	1.000
3	37	0	0	0	2	27	2	5	.343	2.986	1.000
4	45	0	1	15	1	31	9	6	.317	2.693	0.984
5	0	0	0	0	0	0	0	0	1.000	4.200*	1.000
6	0	0	0	0	0	0	0	0	1.000	3.896	1.000
7	0	0	0	0	0	0	0	0	1.000	3.562	1.000
8	0	0	0	0	0	0	9	0	1.000	3.240	1.000
9	0	0	1	0	1	0	44	0	.978	2.950	1.000
10	0	0	5	0	2	0	97	3	.716	2.698	0.985
MAINTENANCE STRATEGY: MEDIUM REHABILITATION APPLIED IN YEAR 5											

PROTOTYPE MICROCOMPUTER SOFTWARE

The analysis procedure described in section 2 of this report has been programmed onto a microcomputer for testing purposes. A description of the software package, as well as the output generated, will be presented in this section. The software follows the flowchart shown in Figure 1; the code is written in Fortran, and a source listing has been supplied in the Appendix.

Input Record Format

The Texas DOT has slightly modified its pavement inspection procedures over those used since 1982 with the PES system. The modifications include

1) The rating of two severities of rutting (shallow and deep >1")

2) The use of a more precise measure of area of coverage as shown below:

Rutting (shallow and deep)	- % of wheelpaths
Block cracking	- % of total area
Patching	- % of total area
Failures	- Number per lane
Alligator Cracking	- % of wheel mile paths
Longitudinal Cracking	- Linear feet per 100 ft.
Transverse Cracking	- Number per 100 ft.

The first year of data collection with these new inspection guidelines was Fall of 1992. At the time of writing this report, no data in the new format is available for processing through the prototype software package. Mainframe storage routines are being built, and it is anticipated that actual data will be available in early 1993.

However, to exercise the software package developed in this study, synthetic data was generated in the same format as that anticipated from the final system. The input record format used is shown in Table 14.

Table 14. Input Record Format.

Variable	(A)lpha (N)umeric	Columns	Decimal Places	Example
District Number	N	1-2		12
County Number	N	3-5		170
Highway Prefix	A	6-7		FM
Highway Number	N	8-11		0149
Highway Suffix	A	12		5
Beginning Reference Marker	N	13-16		0440
B. Offset Sign	A	17-18		+
B. Offset Distance	N	19-20	1	00
Ending Reference Marker	N	21-24		0442
E. Offset Sign	A	25-26		+
E. Offset Distance	N	27-28	1	00
Lane	A	29		R
% Shallow Ruts	N	31-33		010
% Deep Ruts	N	34-36		000
% Block Cr	N	37-39		025
% Patching	N	40-42		005
# Failures	N	43-45		000
% Alligator Cr	N	46-48		000
Length Longitudinal Cr	N	49-51		200
# Transverse Cr	N	52-54		001
Ride (SI)	N	55-56	1	25
Speed (MPH)	N	62-63		55
Pavement Type	N	64-65		05
Functional Class	N	66		3
Number of Lanes	N	67-68		2
Surface Width (ft)	N	69-71		38
AADT	N	72-77		005920
20-Year 18kip ('000)	N	78-82		06721
Section Length (miles)	N	83-84	1	20

Running the Software

The software is supplied on one high density diskette. It should be loaded into a directory on the hard disk. To run the system, type "OPTIMIZE," and the introductory screen shown in Figure 6 will appear. After pressing "ENTER," the main menu screen appears (Figure 7). From the main menu, the user has one of 4 options:

1. Modify budget levels - total $ amounts per year used in prioritization;
2. Run Optimization - to sequentially execute the four subroutines discussed in Section 2 (AGER, NDTREE, SLPMSC, STAGE);
3. Output Results - as described in the next section, outputs options include predictions for a single segment of highway, as well as average network trends;
4. Exit to DOS.

Selecting option 1, the budget modification screen shown in Figure 8 will appear. When option 2 "Run Optimization" is chosen, the variable control screen shown in Figure 9 appears. The user must first input the name of the file containing the pavement information formated as shown in Table 14. The user may wish to subdivide the highway network into numerous categories for analysis, for example, by functional class or pavement type, or by county or type of highway (e.g. Interstates only). This subdivision is performed externally to this prototype software. The other two inputs on Figure 9, NYEARS and SDATE, have been fixed at default values in this version of the code. NYEARS is the number of years in the analysis period it has been fixed at 10. In later versions, as in the TxDOT mainframe version, this will be a user defined input. SDATE is the data at which the user wants the analysis period to begin. For this version, the SDATE is set at one year after the date when the pavement condition data was collected. In the software package all of the distresses and ride will be aged one year using the deterioration procedure described in section 2 to the starting year of the analysis period. It will then be aged an additional 10 years (as specified by the variable NYEARS) for analysis. In the final system each input record (Table 14) will contain one additional data item, that of

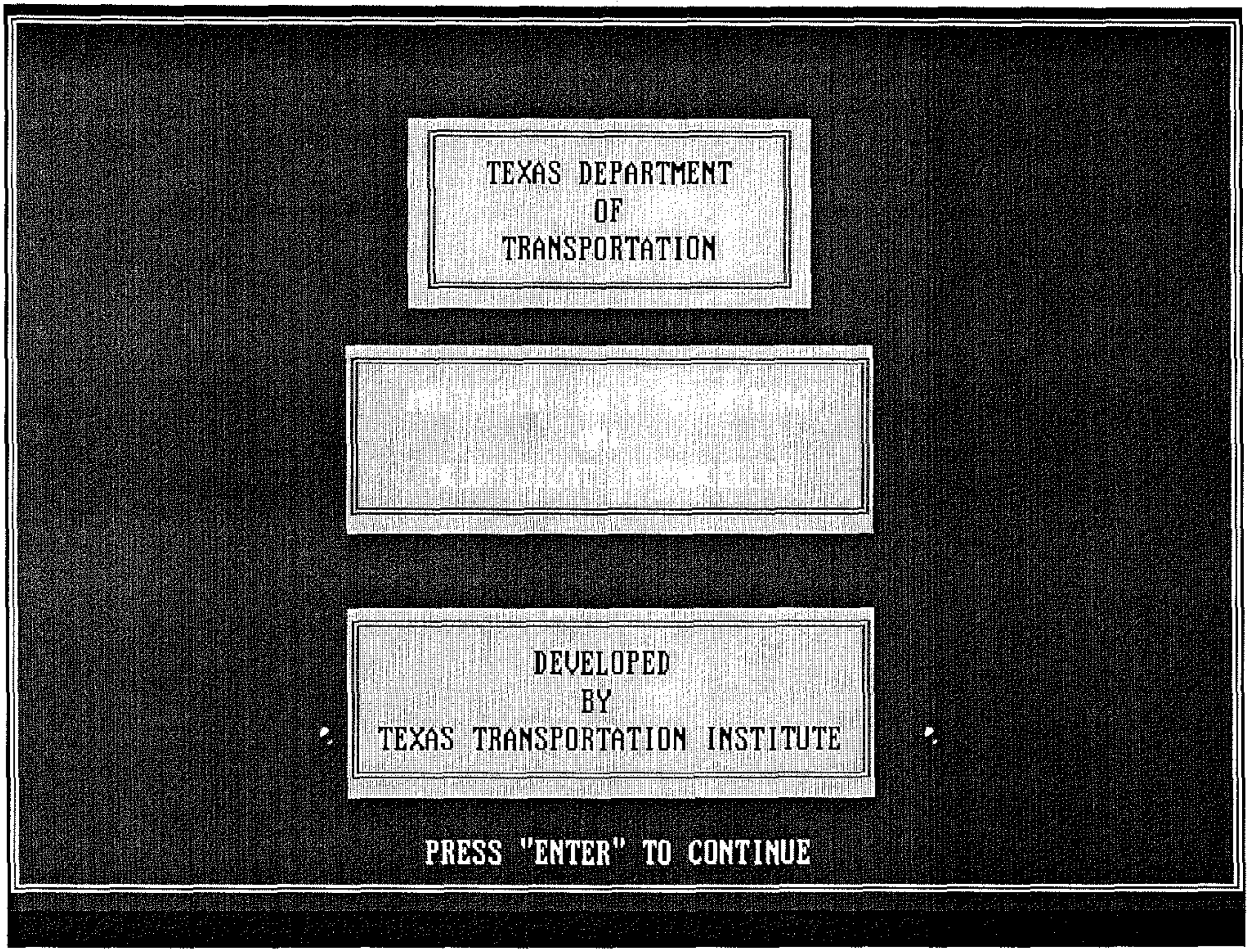

Figure 6. Introductory Screen in Prototype PMS Software.

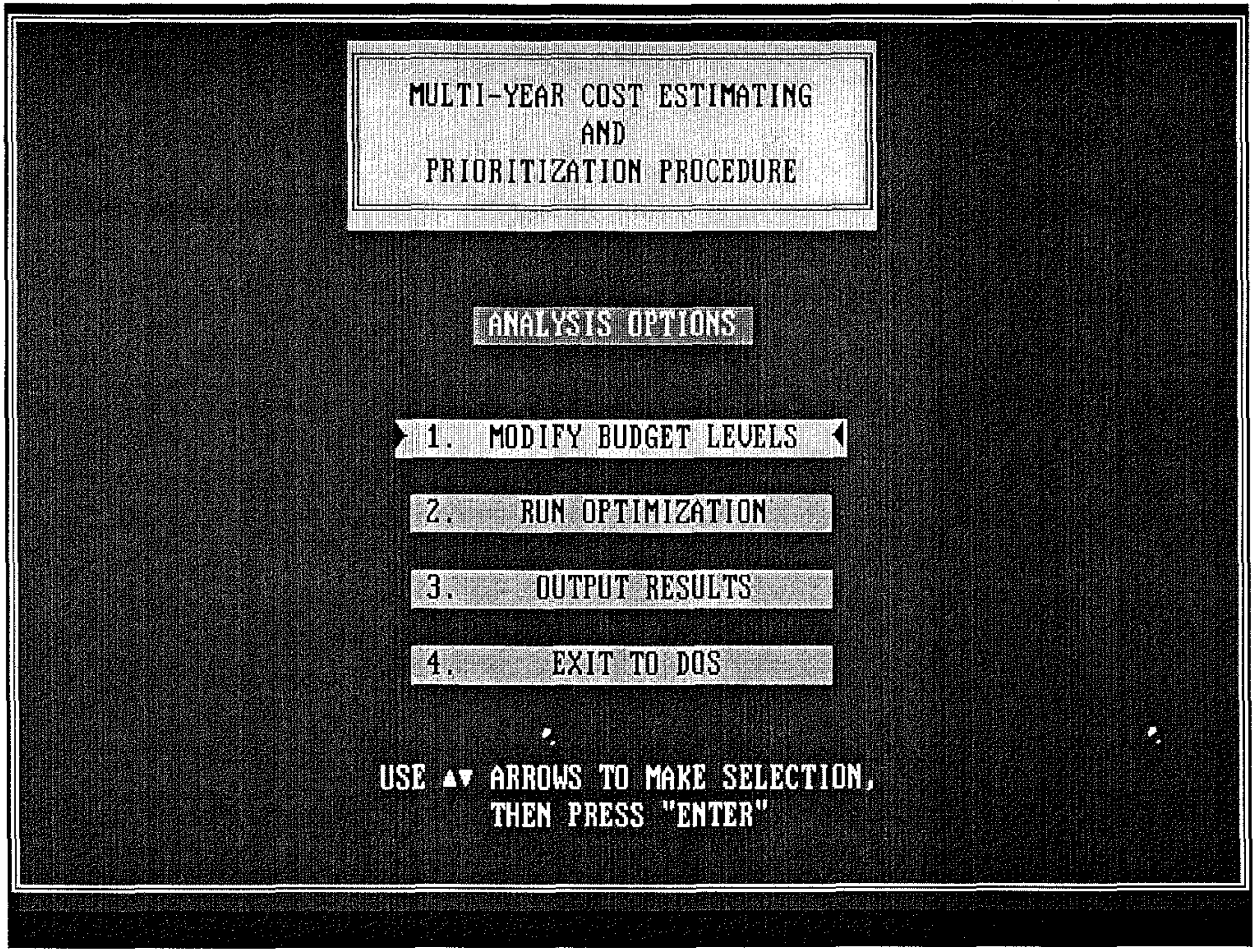

Figure 7. Main Menu Screen.

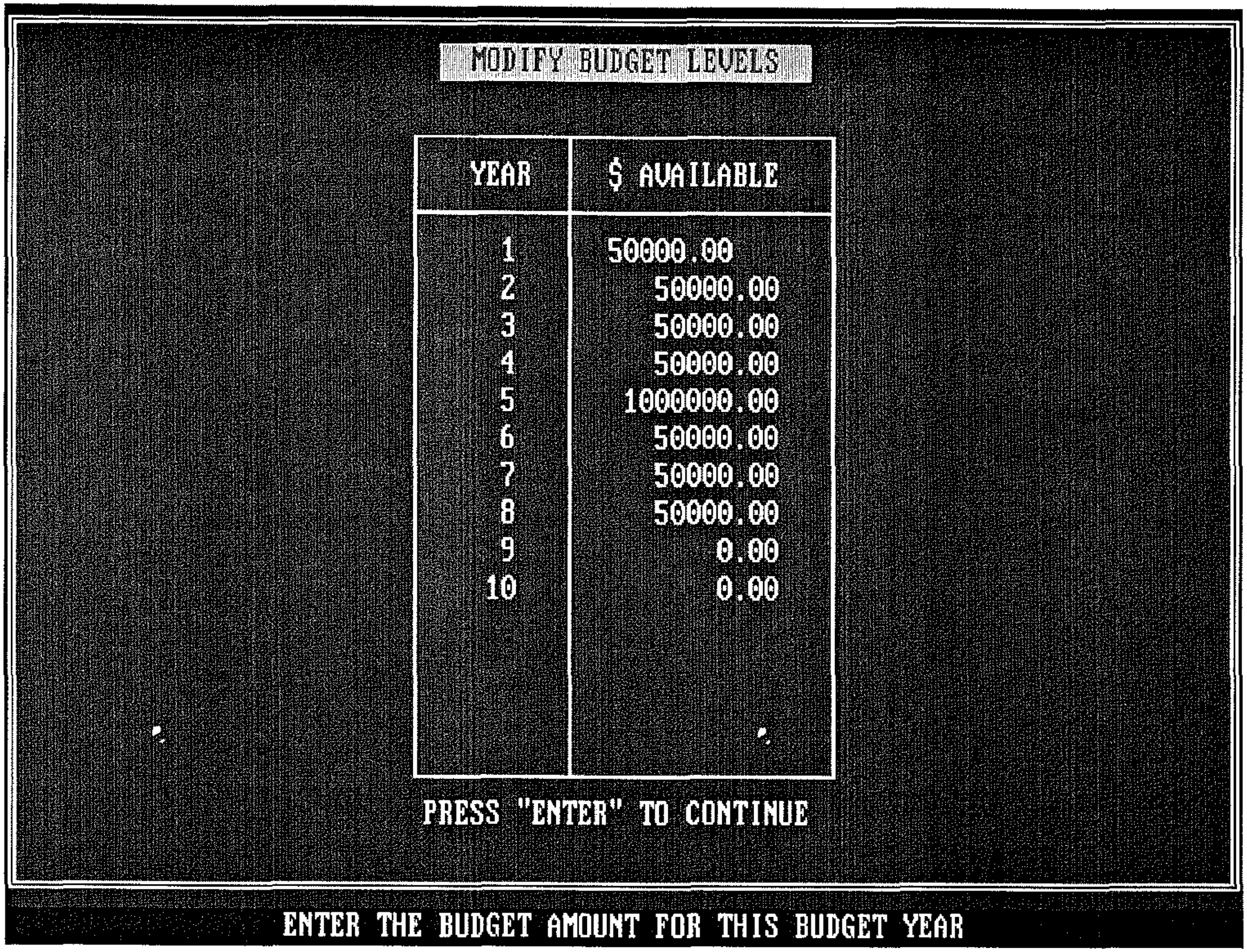

Figure 8. Input Available Budget Level in $.

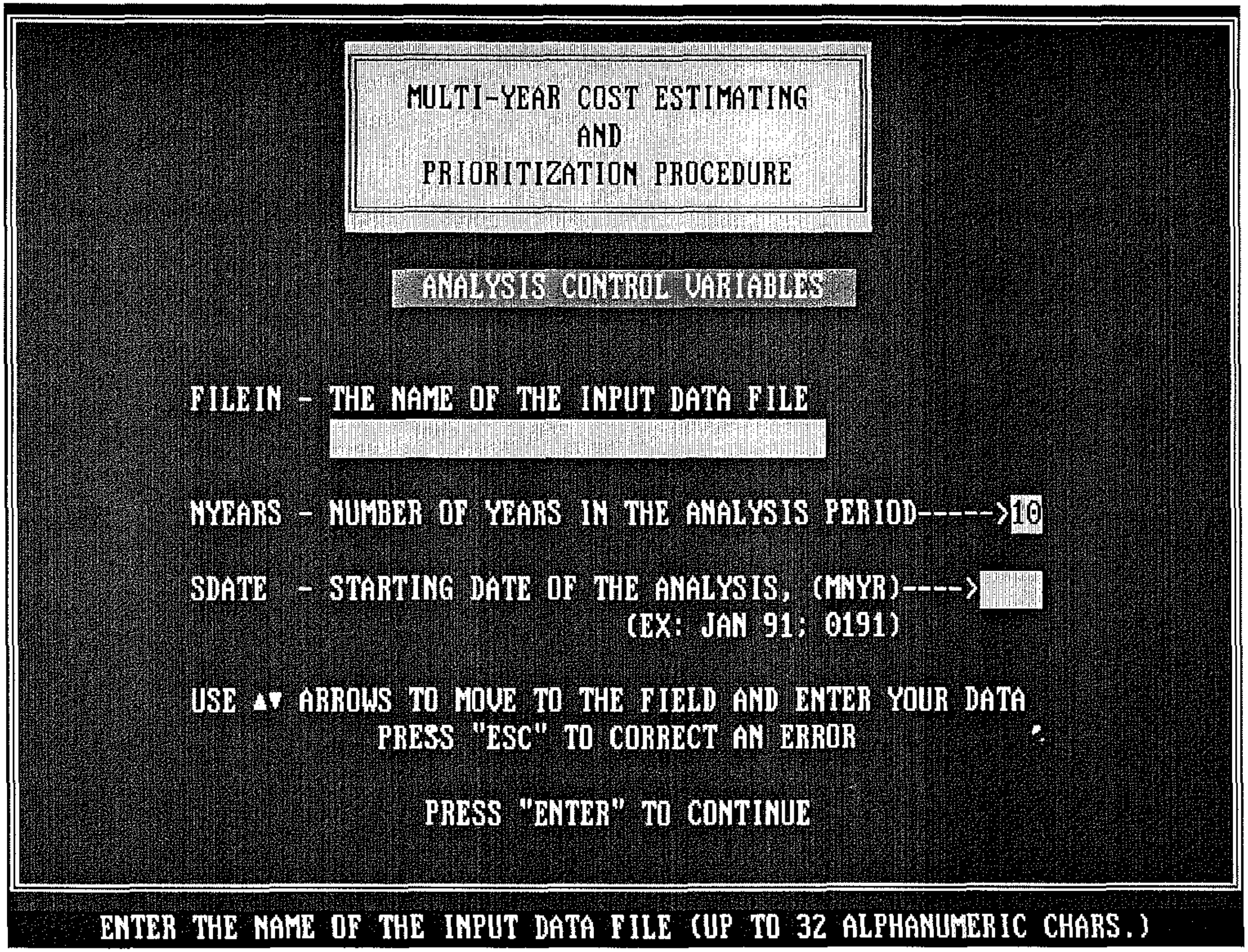

Figure 9. Set up Screen for Prioritization Procedure.

the Date of Condition Survey. When the system is fully operational, one major requirement is to run the analysis package on the entire Texas highway network (100% of highways). However, in the long term, not every highway will be inspected every year. Therefore for a particular section the condition data may be 1 or 2 years old. Using the SDATE value, the condition data will be aged to the same starting data so that analysis can proceed.

Once "ENTER" is input, the analysis will begin, and a message will be shown on the screen indicating which section is currently being processed.

Output options

Once the analysis program is complete, the output control variable screen shown in Figure 10 is displayed. The user has two types of reports available-the project level reports where the predicted performance and cost requirements for a single section can be displayed, or network level reports where the condition and needs of the entire network are presented.

If the user selects Network Reports, then Figure 11 is displayed showing the types of network level reports available. The four available reports are :

1) Level of Service Reports - shown in Figure 12, 13 and 14 which show the impact of the input budget levels on the TxDOT defined level of service. These are grouped as Desirable, Acceptable, Tolerable and Intolerable for the following three major indicators: Ride, Alligator Cracking and Rutting. The plot in Figures 12, 13 and 14 shows what percentage of the network falls in each grouping for each year in the analysis period. The definitions of each grouping were adapted from the maintenance levels of service guidelines published by TxDOT in Administrative Circular AC 5-92; these are shown in Table 15.
2) Average Score Report - shown in Figure 15 shows the average Unweighted Visual Utility score for the network against time for both the "do nothing" and "optimal repair solution" as recommended by the system.

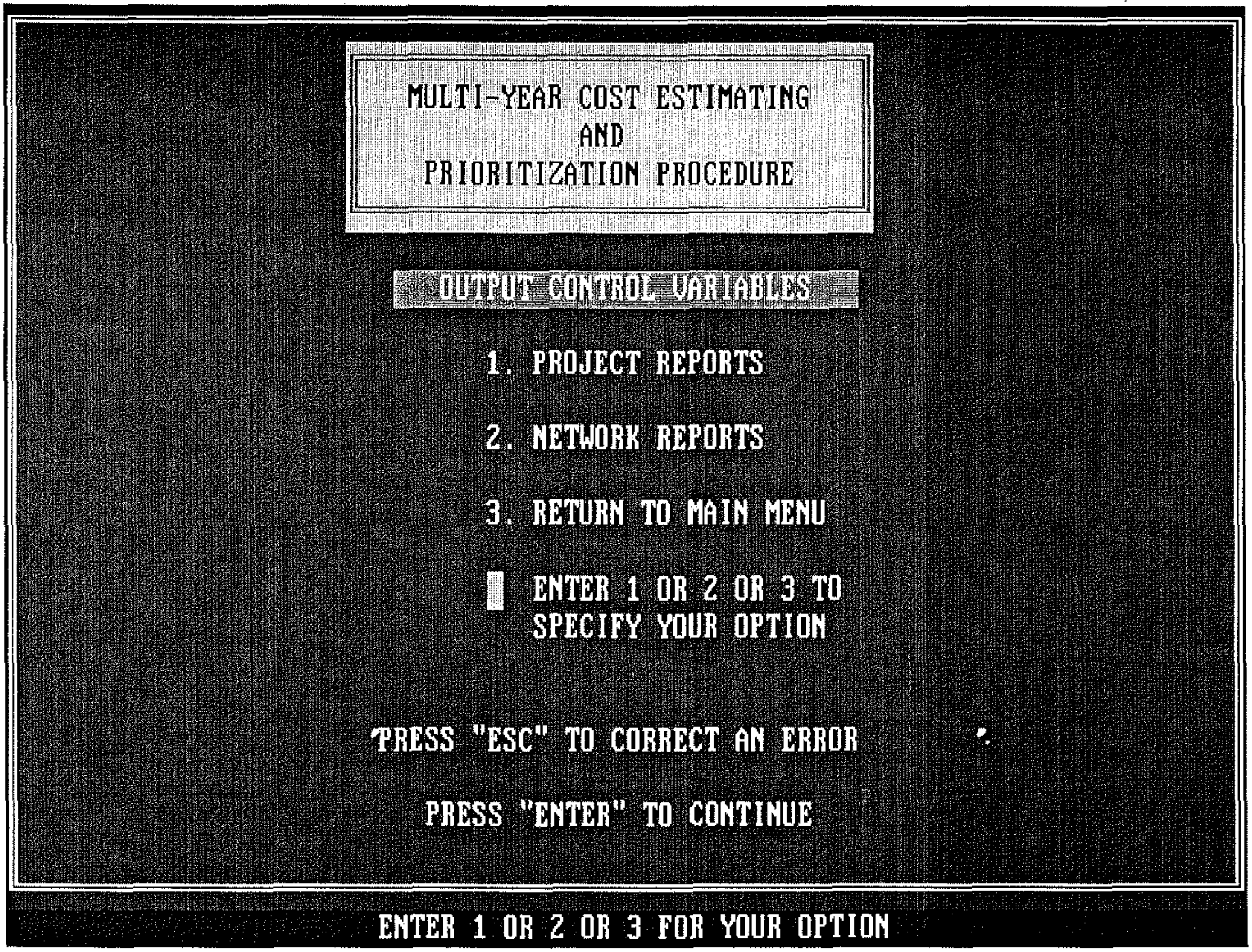

Figure 10. Output Option for Prototype PMS Software.

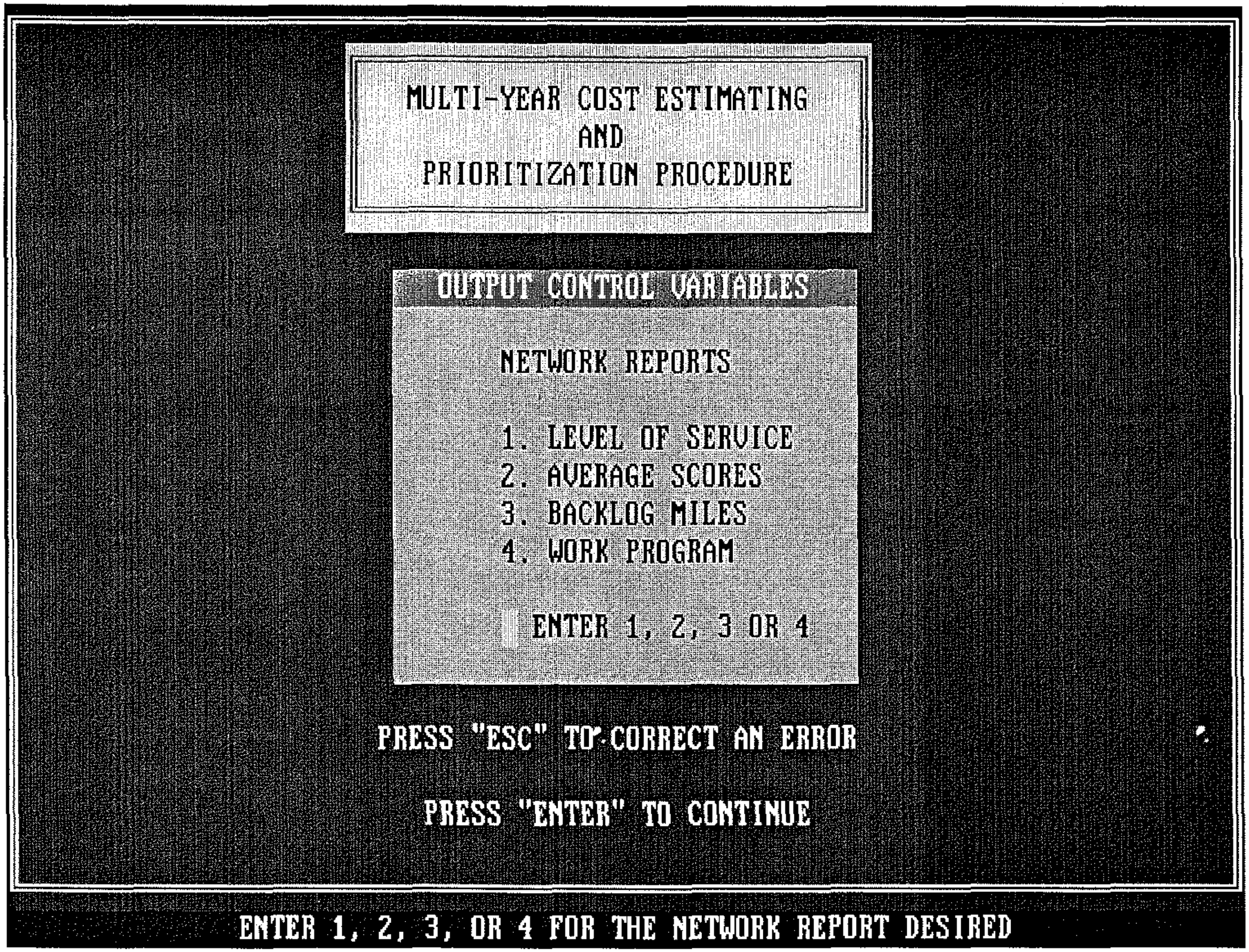

Figure 11. Listing of Network Level Reports Available.

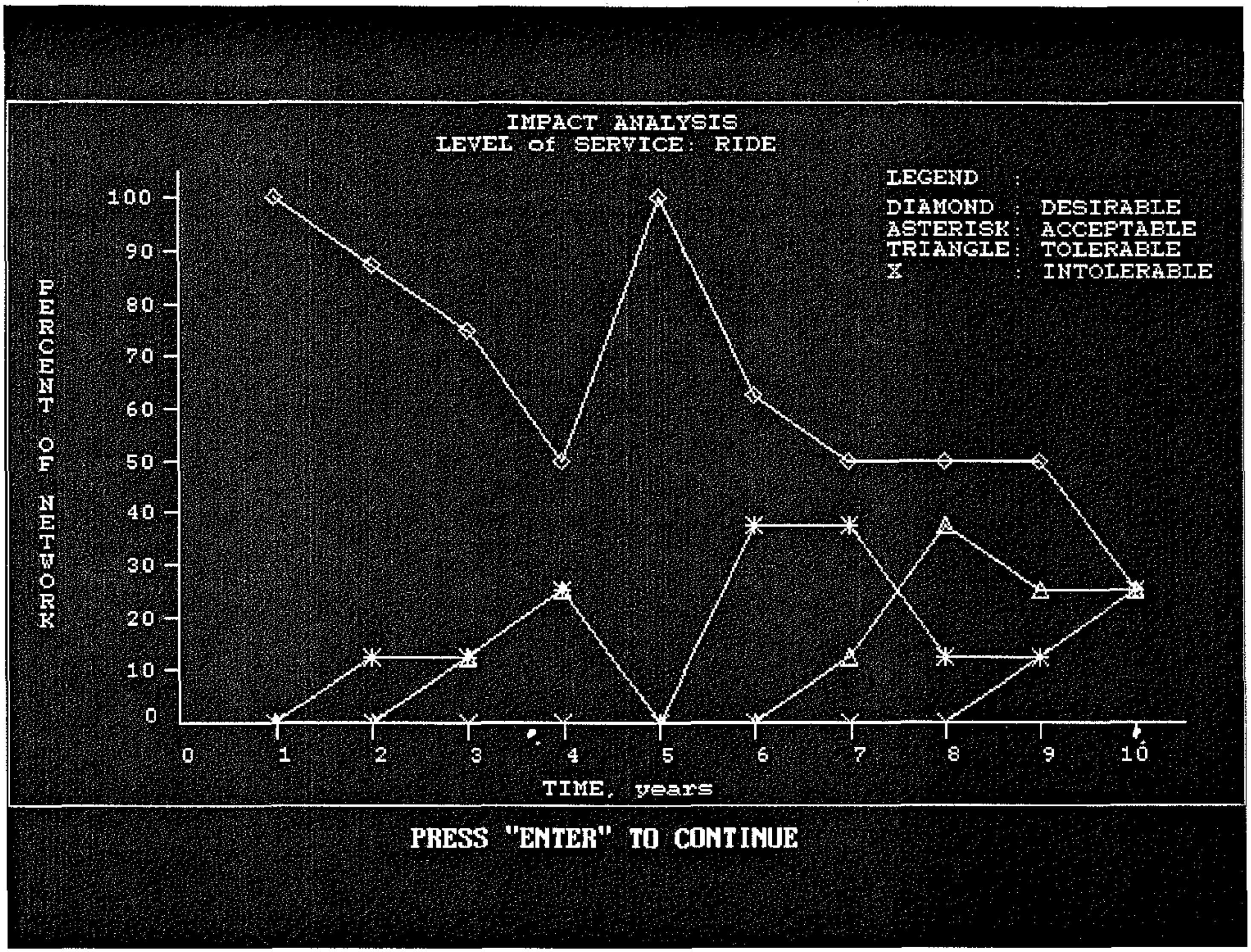

Figure 12. Example of Network Level of Service Report (Option 1) for Ride.

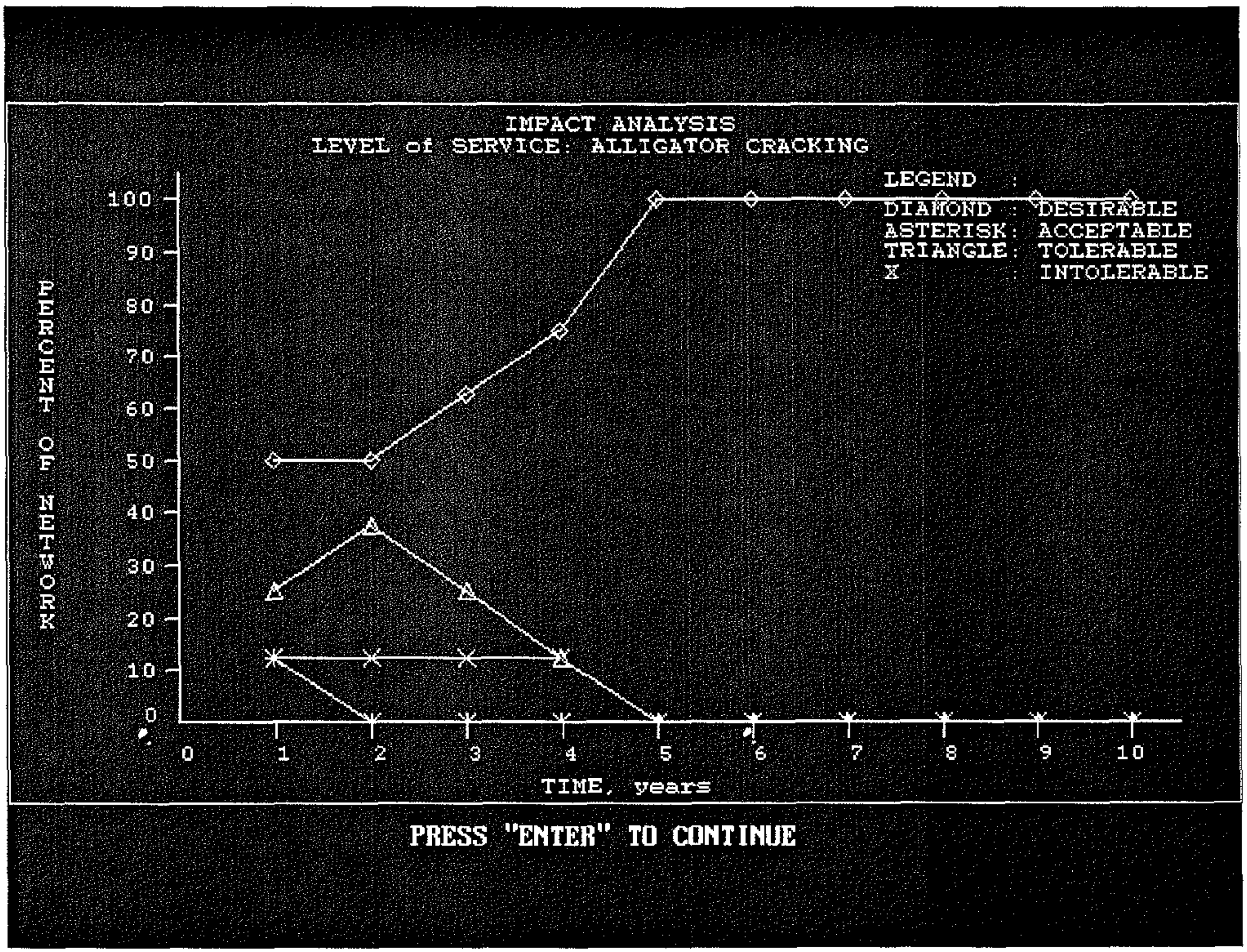

Figure 13. Example of Network Level of Service Report (Option 1) for Alligator Cracking.

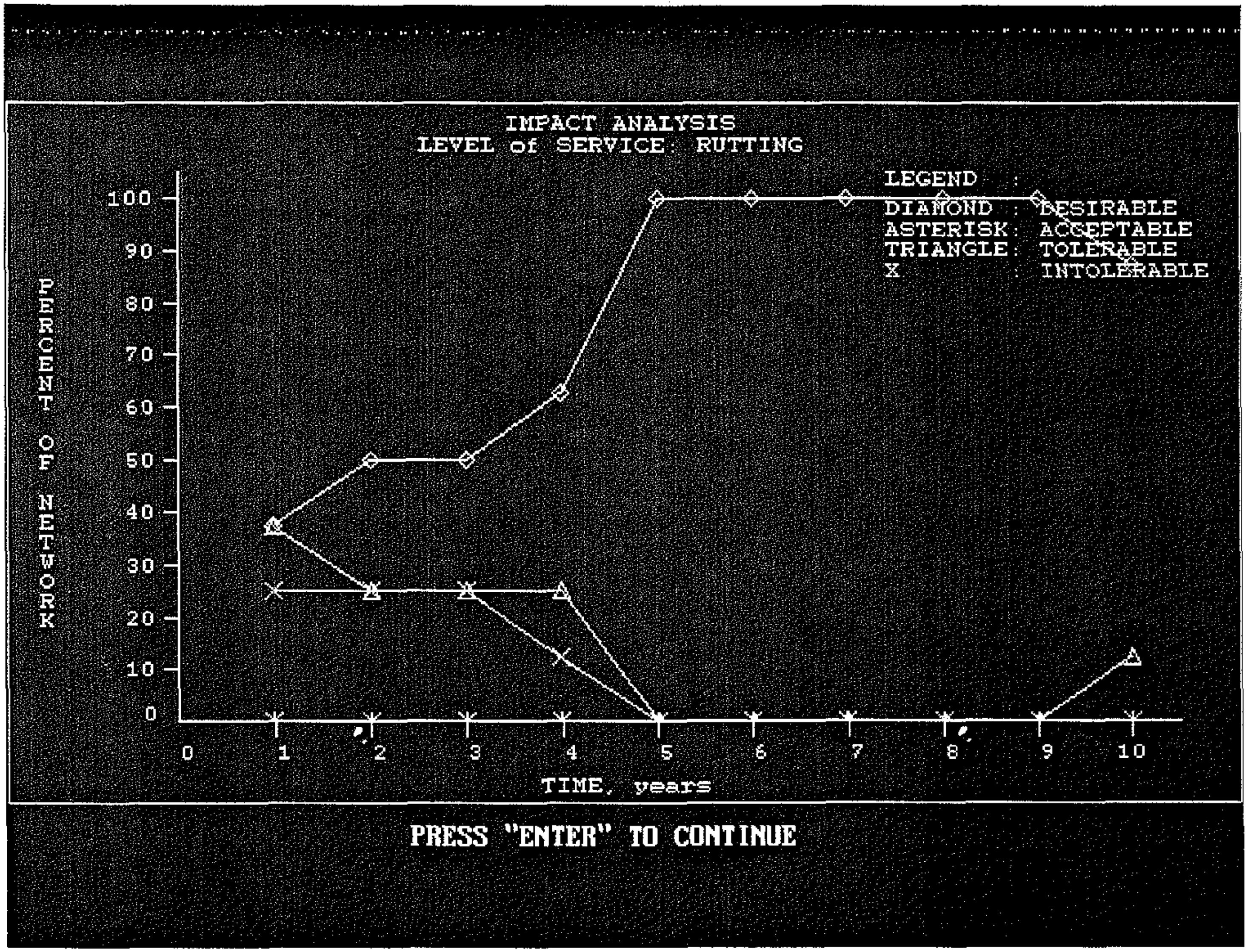

Figure 14. Example of Network Level of Service Report (Option 1) for Rutting.

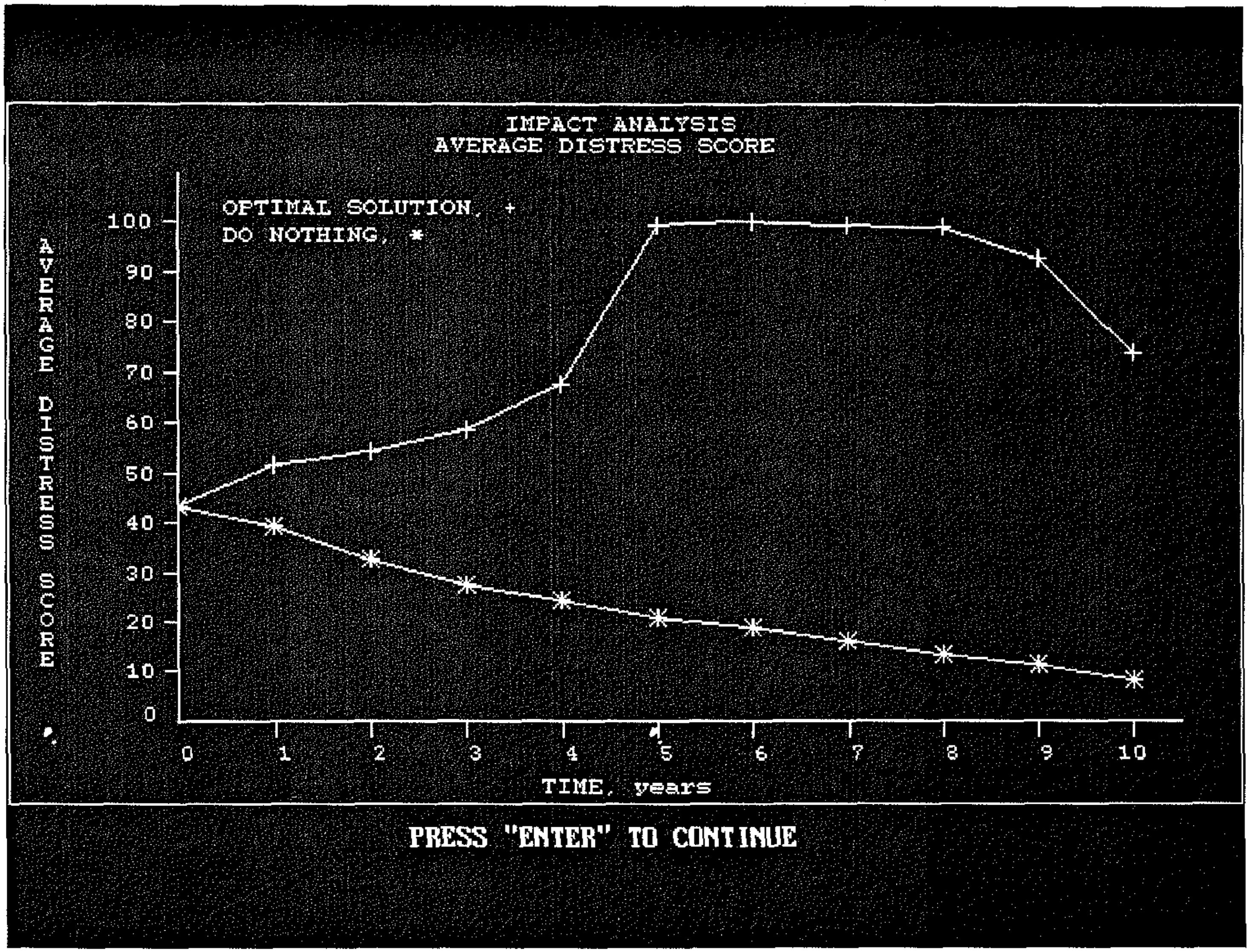

Figure 15. Example of Network Level Average Score Report (Option 2).

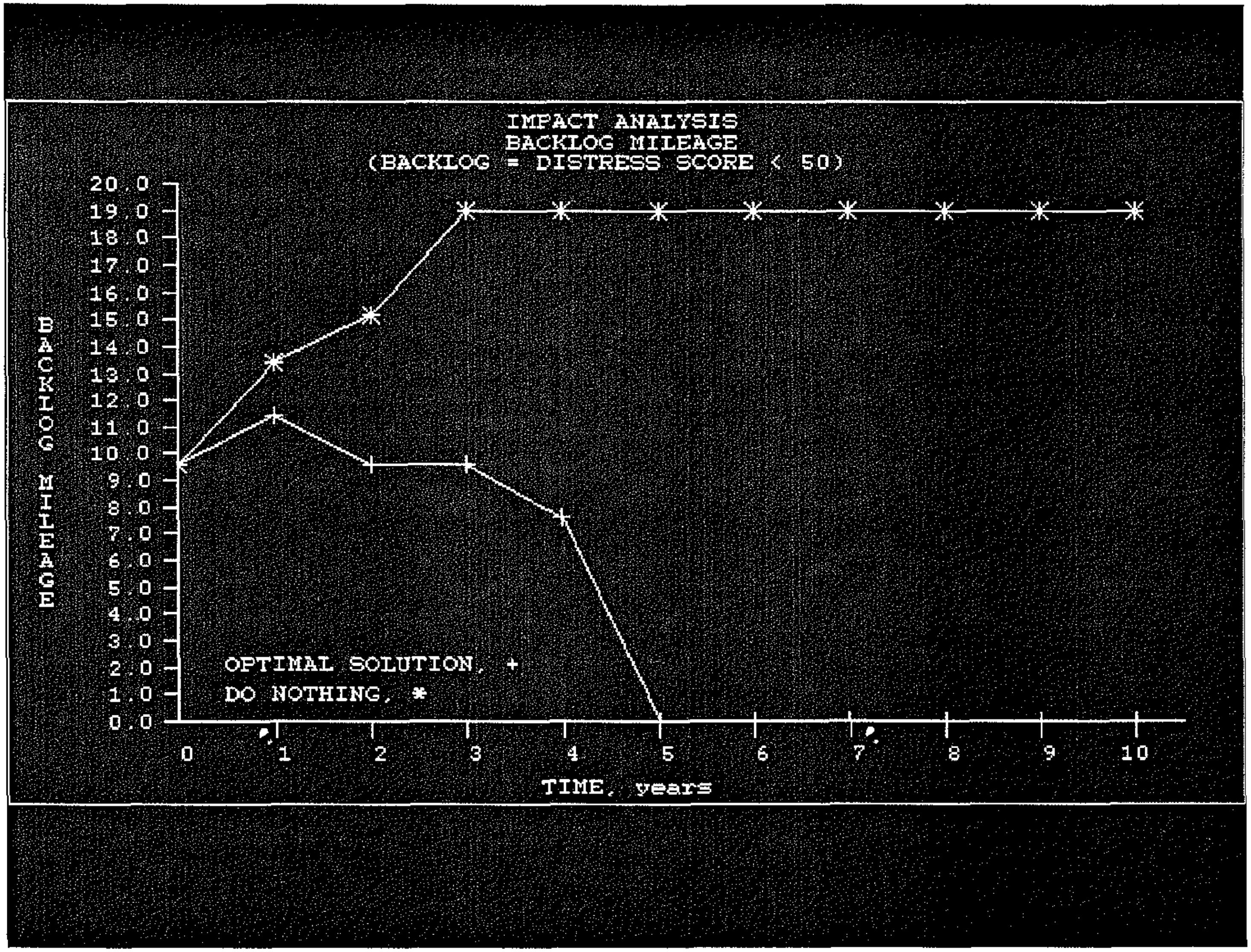

Figure 16. Example of Network Level Backlog Report (Option 3).

Table 15. Maintenance Level of Service Guidelines (TxDOT AC 5-92).

PAVEMENT MANAGEMENT			
Condition	Desirable Level (Highest)	Acceptable Level	Tolerable Level (Lowest)
Longitudinal Rutting	(Priority 1)	(Priority 1)	(Priority 1)
	Maintain as follows:	Maintain as follows:	Maintain as follows:
0 - 500 ADT	< ½" & < 25% per wheel path	< ½" & <50% per wheel path	< 1" & ≤ 50 % per wheel path
501-10,000 ADT	< ½" & < 25% per wheel path	< ½" & <50% per wheel path	< 1" & ≤ 50 % per wheel path
10,001 & up ADT	< ½" & < 25% per wheel path	< 1" & 25% per wheel path	< 1" & ≤ 50 % per wheel path
Alligator Cracking	(Priority 1)	(Priority 1)	(Priority 1)
For all ADT's	Maintain with no visible cracks	Maintain with visible cracks ≤ 10% per wheel path	Maintain with visible cracks ≤ 50% per wheel path
Ride Quality	(Priority 2)	(Priority 1)	(Priority 1)
	Maintain as follows:	Maintain as follows:	Maintain as follows:
0 - 500 ADT	...... > 2.5 SI	...... > 2.0 SI	...... < 1.5 SI
501-10,000 ADT	...... > 3.0 SI	...... > 2.5 SI	...... < 2.0 SI
10,001 & up ADT	...... > 3.5 SI	...... > 3.0 SI	...... < 2.5 SI

Terminology:

- Longitudinal Rutting - depressions that form under traffic in wheel paths.
- Alligator Cracking - interconnected or interlaced cracks forming a series of small polygons that resemble an alligator's hide. Alligator cracking is measured as a percentage of the length of the wheel paths in a travel lane.
- Ride Quality - a measure of the pavement's roughness.
- SI - serviceability index, as developed at the American Association of State Highway and Transportation Officials (AASHTO) road test. A scale of zero to five is used, with five being extremely smooth pavement and zero being extremely rough.

3) Backlog Miles Report - shown in Figure 16 is a representation of what percentage of the network will be below a User defined criticallevel for both the "do nothing" and "optimal solutions." For this example the critical level was defined as a UVU score of 50.

4) Work Program Report - shown in Figure 17 is the recommendations from the SLPMSC subroutine of which sections should be repaired in each year of the analysis period. The recommended cost category (PM = preventative maintenance, LRHb = Light Rehabilitation, etc). are also given.

If on Figure 10 the user selects project reports, then he must then specify which of the input sections he wishes to review. Within the current software the record number is used for simplicity. Once a record number is specified, the three reports shown in Figure 18, 19 and 20 are automatically generated.

Figure 18 shows the predicted change in pavement score (UVU) if no maintenance or rehabilitation is applied to the pavement section.

Figure 19 shows the anticipated repair requirements from the Decision Trees if no repairs are made. The example given indicates that preventative maintenance would be adequate up to year 4, but after that time Light Rehabilitation would be necessary.

Figure 20 shows the condition of the section assuming the "optimal solution" is applied. The example in Figure 20 had a Preventative Maintenance treatment applied in year 1.

TEXAS PAVEMENT MANAGEMENT INFORMATION SYSTEM (PMIS)
LIST SECTIONS WHICH CAN BE TREATED (OPTIMIZATION)

YEAR	DISTRICT	COUNTY	HIGHWAY	REFERENCE MARKERS FROM		TO		TREATMENT
1	12	170	FM0149	0440	+00	0442	+00	PM
1	12	170	FM0149	0450	+00	0452	+00	PM
2	12	170	FM0149	0454	+00	0456	+00	LRhb
3	12	170	FM0149	0446	+00	0448	+00	PM
4	12	170	FM0149	0442	+00	0444	+00	LRhb
5	12	170	FM0149	0440	+00	0442	+00	MRhb
5	12	170	FM0149	0444	+00	0446	+00	LRhb
5	12	170	FM0149	0448	+00	0450	+00	HRhb
5	12	170	FM0149	0450	+00	0452	+00	MRhb
5	12	170	FM0149	0452	+00	0454	+00	LRhb
5	12	170	FM0149	0446	+00	0448	+00	MRhb
6	12	170	FM0149	0454	+00	0456	+00	PM
8	12	170	FM0149	0442	+00	0444	+00	PM

Figure 17. Example of Network Level Work Program Report (Option 4).

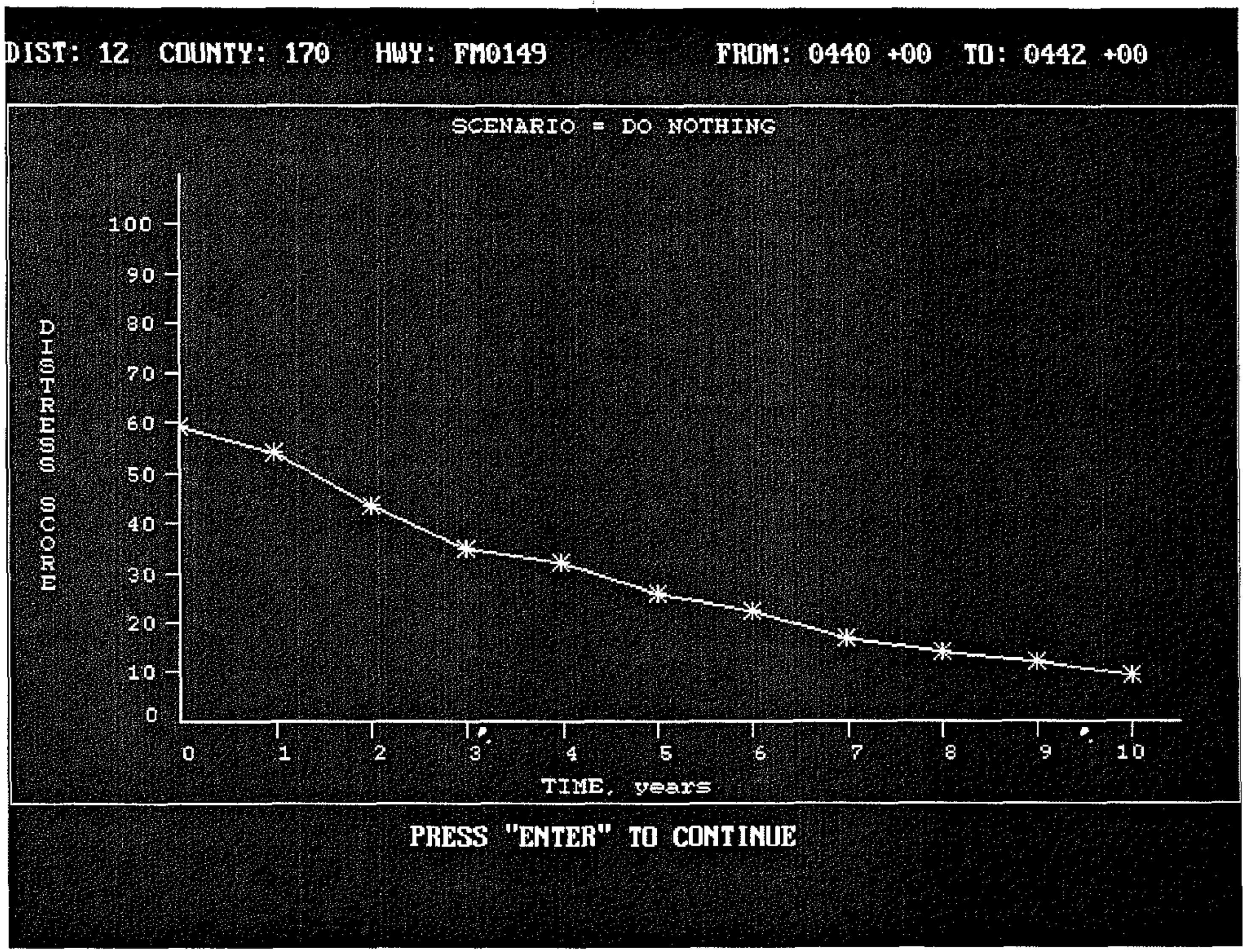

Figure 18. Example of Project Specific Report Showing the Effect of "Do Nothing" Scenario on Pavement Score.

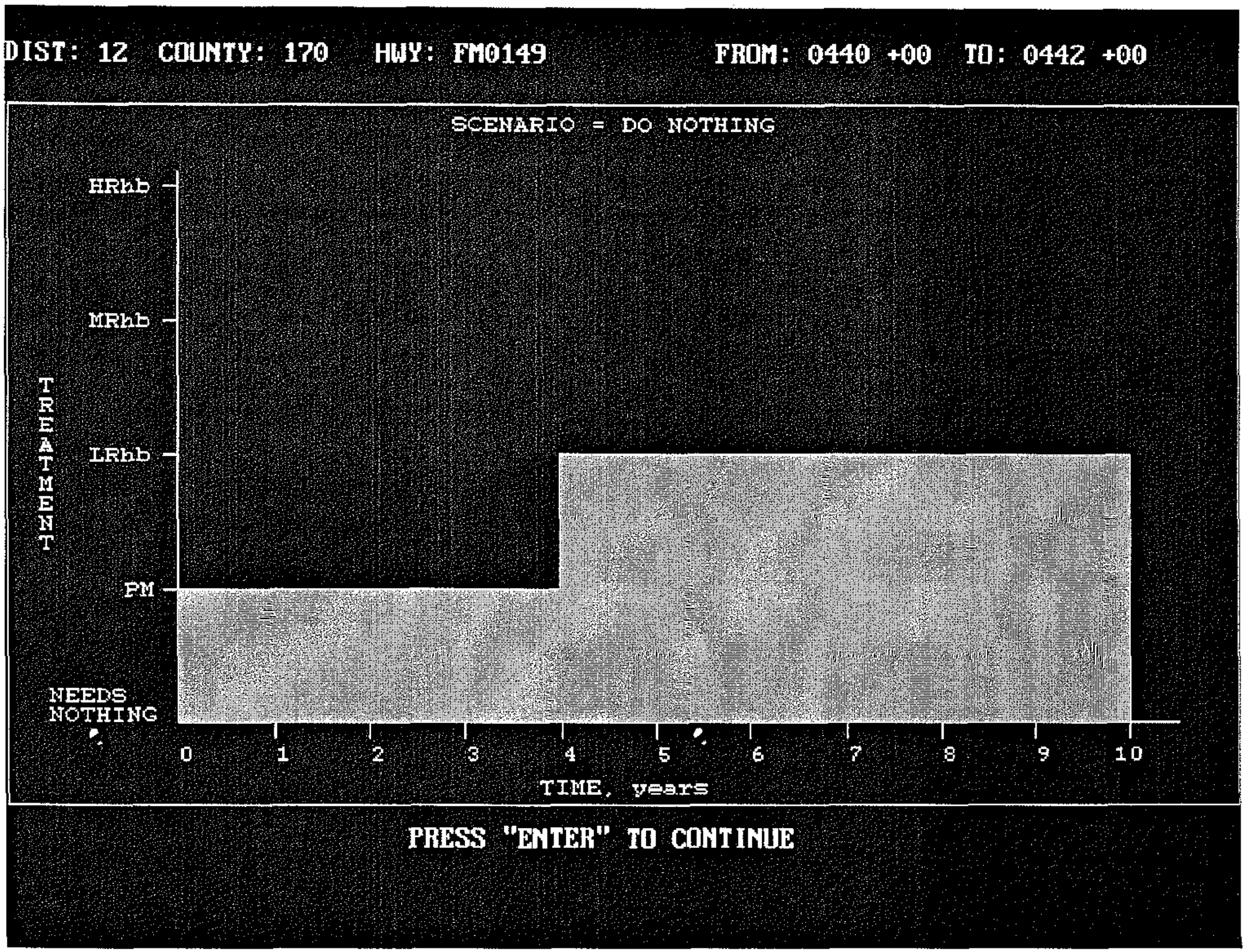

Figure 19. Example of Project Report Showing Recommended Decision Tree Treatment (Do Nothing Scenario).

CONCLUSIONS AND RECOMMENDATIONS

The analytical procedure described in this report is currently being adapted for implementation within the TxDOT Pavement Management System scheduled for release in early 1993. The strengths of the package are as follows;

1) It meets the FHWA mandate for a rationale procedure for estimating funding requirements and determining the consequences of fund variations.
2) It was developed largely by the work of the TxDOT Pavement Management Steering Committee accommodating as many of their requirements as possible
3) The definition of benefit in terms of area under the UVU and SIU Utility curves facilitates comparison of different pavement types (i.e. concrete vs asphalt)
4) The selection of a treatment cost category based on projected distresses (rather than composite index) was a major TxDot requirement. Attempting to define needs in terms of a composite index has been found to be extremely difficult.
5) The decision trees have been found to provide reasonable estimates of needs in several rural districts, when their recommendations were compared with district planned activities.
6) The level of detail used is considered appropriate for a Network level system. Strategies can only be selected as a part of the pavement design process.

The weaknesses of the system are as follows:

1) The best method of incorporating AADT into the definition of benefit is currently under review. The multiplication factor of $\log_{10}$ (AADT) is preliminary.
2) The deterioration curves were built from a limited set of performance data collected in one area of the State of Texas. How well they relate to other areas is under research. Performance

information from the Strategic Highway Research Program's sections in Texas is being assembled to compare actual performance with that generated using the S-shaped curves described in this report. Other performance information from the existing Pavement Evaluation System and from Flexible Pavement Research data bases are being assembled.

3) The application of this (and any condition driven Pavement Management System) to large high growth, capacity driven, networks such as Houston or Dallas is open to question. In these areas it is capacity rather than condition that drives rehabilitation work. Most of the work is widening with rehabilitation performed as a secondary function. Pure rehabilitation work is often performed as a "holding" function until added capacity funds become available. Because of the link between repair and capacity improvements, the Decision Trees may need to be expanded for use in these Urban areas.

REFERENCES

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2. "Development of PMS Models for Rigid Pavements," PMS Engineering Contract 3 Between TxDOT and The Center for Transportation Research, October, 1991.

3. Ahmed, N.W., et al., "The Texas Rehabilitation and Maintenance District Optimization System," TTI Report 207-3, 1978.

4. "Estimating Flexible Pavement Maintenance and Rehabilitation Fund Requirements for a Transportation Network," TTI Report 409-1, February 1988.

5. Smith, R.E. and Scullion, T., "Texas Department of Transportation - Pavement Management Description," Interim Report to PMS Steering Committees, TxDOT Study 0249, August 1991.

APPENDIX A

SOURCE CODE LISTING OF PROTOTYPE PMS SOFTWARE

```
      SUBROUTINE AGER
C
C**********************************************************************C
C                                                                      C
C     PROGRAM TO READ PAVEMENT CONDITION AND RIDE DATA FROM THE PMIS   C
C     DATABASE AND USE PAVEMENT PERFORMANCE CURVES TO PREDICT THE      C
C     DISTRESS AND RIDE SCORES FOR A SECTION FOR THE NUMBER OF YEARS   C
C     IN THE ANALYSIS PERIOD (NYEARS) AND CREATE AN OUTPUT FILE OF THE C
C     PREDICTED DISTRESS AND RIDE SCORES TO BE USED FOR THE MAINTEN-   C
C     ENCE FUND BUDGET OPTIMIZATION                                    C
C                                                                      C
C           >>>>>>>>>>     PROGRAM AGER     <<<<<<<<<<                 C
C                                                                      C
C**********************************************************************C
C
C
      CHARACTER DATA1*29, DATA2*23, FILEIN*32, FILLER*5
      CHARACTER BEG*3, BEGX(3), ENDH
C
      INTEGER*4 AGEDIS, CALDIS, DISTRS, FAIL, PAT
C
      DIMENSION AGEDIS(9,10), CALDIS(10), DISTRS(9), DSA(10)
      DIMENSION AGEDUT(9,10), UV(9)
C
      EQUIVALENCE (BEG, BEGX)
C
      COMMON/FIL/ FILEIN
      COMMON/CON/ IYR, NSEC, NYEARS
      COMMON/UTV/ IADT, ICASE, ISPEED
      COMMON/AGE/ SIA(10), PSIMIN
      COMMON/ADJ/ ESAL, ICNTY, IPTYPE
      COMMON/FAC/ ADJUST(3), CRKFAC, PSIFAC, RUTFAC, TRFFAC(9)
      COMMON/BRO/ IS, IYA
      COMMON/SUP/ CRKADJ(5), PSIADJ(5), RUTADJ(5)
      COMMON/DAG/ DAL(4,9), DBT(4,9), DRO(4,9)
C
C     INITIALIZE THE MARKERS
C
      BEGX(1) = CHAR(19)
      BEGX(2) = CHAR(255)
      BEGX(3) = CHAR(1)
      ENDH    = CHAR(1)
C
C     DISPLAY AGERSCRN.AID
C
      WRITE(*,*) BEG,'USE,AGERSCRN.AID',ENDH
      WRITE(*,*) BEG,'DISPLAY,NYEARS,=',NYEARS,ENDH
C
C     INITIALIZE REHAB ACTION AND FUND REQUIREMENTS
C
      NSEC   = 0
      FILLER = '     '
C
      OPEN(UNIT=1,FILE=FILEIN,STATUS='UNKNOWN')
      OPEN(UNIT=2,FILE='FILE1.OUT',STATUS='UNKNOWN')
      OPEN(UNIT=3,FILE='DISADFAC.DAT',STATUS='UNKNOWN')
      OPEN(UNIT=4,FILE='INITUTIL.OUT',STATUS='UNKNOWN')
C
C     READ THE ADJUSTMENT FACTORS
C
```

```
C      SKIP THE TREATMENT COST TABLE, AND RATE OF GAIN TABLE
C
      DO 5 IS = 1, 15
    5 READ(3,102)
C
C     READ THE SUBGRADE SUPPORT VALUES
C
      READ(3,104) (RUTADJ(I),I=1,5), (CRKADJ(I),I=1,5),
     +            (PSIADJ(I),I=1,5)
  104 FORMAT( 8X, 5F7.4/ 8X, 5F7.4/ 8X, 5F7.4 )
C
C     READ THE PAVEMENT PERFORMANCE CURVE COEFFICIENTS
C     ALPHA, BETA, AND RHO FOR THE PAVEMENT DISTRESSES
C
      READ(3,*)
      READ(3,*)
      READ(3,*)
      DO 7 K = 1, 4
    7 READ(3,102) (DAL(K,I),I=1,9)
      READ(3,*)
      READ(3,*)
      DO 8 K = 1, 4
    8 READ(3,102) (DBT(K,I),I=1,9)
      READ(3,*)
      READ(3,*)
      DO 9 K = 1, 4
    9 READ(3,102) (DRO(K,I),I=1,9)
  102 FORMAT( 8X, 9F7.4 )
C
C     READ THE PMIS PAVEMENT CONDITION DATABASE FILE
C
   10 READ(1,605,END=900) DATA1, (DISTRS(I),I=1,8), SI, DATA2, ISPEED,
     +                    IPTYPE, IFC, IADT, ESAL, ICNTY
  605 FORMAT( A29, 1X, 8I3, F2.1,5X,A23, T62, 2I2,I1,5X,I6,F5.3,T3,I3)
C
C     CHECK FOR FLEXIBLE PAVEMENTS ONLY
C
      IF( IPTYPE .LT. 4 .OR. IPTYPE .GT. 10 ) GO TO 10
C
      NSEC = NSEC + 1
C
C     AGE THE INITIAL DISTRESS SCORES AND CALCULATE THE DISTRESS UTILITY
C     SCORES AND CALCULATE THE UVU SCORE FROM THE DISTRESS AND SI DATA
C
C     ADJUST THE INITIAL FAILURE AND SET THE INITIAL PATCHING SCORE
C
      FAIL = DISTRS(5)
C
      CALL ADJDIS ( FAIL, PAT )
C
      DISTRS(4) = PAT
      DISTRS(5) = FAIL
C
      SI0 = SI
C
C     AGE EACH DISTRESS SCORE FOR THE NUMBER OF YEARS DESIRED
C
C     FIND THE SI(min) VALUE TO USE
C
      ICASE = IADT*ISPEED
```

```
C
      IF( ICASE .LE. 27500 )                         PSIMIN = 1.0
      IF( ICASE .GT. 27500 .AND. ICASE .LE. 165000 ) PSIMIN = 1.5
      IF( ICASE .GT. 165000 )                        PSIMIN = 2.0
C
C     SET IS = 4 TO USE THE STRATEGY 4 BETAS & RHOS FOR INITIAL AGEING
C     SET IYA = 1 TO AGE THE INITIAL DISTRESS SCORES FOR NYEARS
C
      IS        = 4
      IYA       = 1
      DISTRS(9) = SI
C
      DO 25 ID  = 1, 9
      DSI       = DISTRS(ID)
C
      CALL DISAGE( ID, DSI, SI, DSA )
C
      DO 20 IT       = 1, NYEARS
   20 AGEDIS(ID,IT) = DSA(IT)
   25 CONTINUE
C
C     ADJUST THE AGED FAILURES AND SET THE AGED PATCHING SCORES
C
      DO 30 IT = 1, NYEARS
C
      FAIL = AGEDIS(5,IT)
C
      CALL ADJDIS ( FAIL, PAT )
C
      AGEDIS(4,IT) = PAT
      AGEDIS(5,IT) = FAIL
   30 CONTINUE
C
      IYA = 0
C
      CALL UTVAL( DISTRS, SI, UV )
C
C     CALCULATE INITIAL UVU SCORE
C
      RUC = UV(1)+UV(2) - 1.
      UVU = RUC*UV(3)*UV(4)*UV(5)*UV(6)*UV(7)*UV(8)
C
C
C     WRITE THE INITIAL DISTRESS SCORES TO THE OUTPUT FILE
C
      WRITE(2,610) DATA1, DATA2, (DISTRS(I),I=1,8), UVU, SI,
     +             UV(9), FILLER
      WRITE(4,610) DATA1, DATA2, (DISTRS(I),I=1,8), UVU, SI,
     +             UV(9), FILLER
  610 FORMAT( A29, A23, 8I5, 3F6.3, A5 )
C
C     CALCULATE THE PREDICTED UTILITY SCORES FROM THE PREDICTED DISTRESS
C     SCORES.  CALCULATE THE UVU FOR THE PREDICTED UTILITY SCORES AND
C     WRITE THE PREDICTED DISTRESS AND UTILITY SCORES TO THE OUTPUT FILE
C
      DO 39 IT = 1, NYEARS
C
C     USE THE AGED DISTRESS SCORES
C
      DO 36 ID  = 1, 8
```

```
   36 CALDIS(ID) = AGEDIS(ID,IT)
      SII        = SIA(IT)
C
      CALL UTVAL( CALDIS, SII, UV )
C
      DO 37 ID = 1, 9
   37 AGEDUT(ID,IT) = UV(ID)
C
      AGERUC   = AGEDUT(1,IT)+AGEDUT(2,IT) - 1.
      AGEUVU   = AGERUC*AGEDUT(3,IT)*AGEDUT(4,IT)
     +          *AGEDUT(5,IT)*AGEDUT(6,IT)*AGEDUT(7,IT)*AGEDUT(8,IT)
      WRITE(2,610) DATA1, DATA2, (AGEDIS(I,IT),I=1,8), AGEUVU,
     +             SIA(IT), AGEDUT(9,IT), FILLER
   39 WRITE(4,610) DATA1, DATA2, (AGEDIS(I,IT),I=1,8), AGEUVU,
     +             SIA(IT), AGEDUT(9,IT), FILLER
C
C
      GO TO 10
C
  900 CLOSE(1)
      CLOSE(2)
      CLOSE(3)
      CLOSE(4)
C
      RETURN
      END
C
C
C
      SUBROUTINE ADJDIS ( FAIL, PAT )
C
C     ADJUST THE FAILURE AND PATCHING DISTRESS SCORES
C
      INTEGER*4 FAIL, PAT
C
      PAT = 0
C
      IF( FAIL .LE. 2 ) RETURN
C
   10 IF( FAIL .GT. 2 ) THEN
         FAIL = FAIL - 2
         PAT  = PAT + 5
      ENDIF
C
      IF( FAIL .GT. 2 ) GO TO 10
C
      RETURN
      END
C
C
      SUBROUTINE UTVAL( DISTRS, SI, UV )
C
C     USE THE S-SHAPED DISTRESS UTILITY CURVES TO CONVERT THE DISTRESS
C     AND RIDE SCORES INTO DISTRESS UTILITY SCORES IN THE RANGE 0 TO 1
C
      INTEGER*4   DISTRS(9)
C
      COMMON/ADJ/ ESAL, ICNTY, IPTYPE
      COMMON/BRO/ IS, IYA
      COMMON/UTV/ IADT, ICASE, ISPEED
```

```
C
      DIMENSION DAL(8), DBT(8), DRO(8), DCAL(8), DCBT(8), DCRO(8)
      DIMENSION UV(9)
C
C     CURVE COEFFICIENTS FOR THE DISTRESS UTILITY CURVES
C
C     FLEX ALPHA  S.R.   D.R.  BLCK    PTCH  FAIL   ALGR   LONG  TRAN
      DATA DAL/   0.31,  0.69, 0.49,   0.45, 1.00,  0.53,  0.87, 0.69/
C
C     FLEX BETA   S.R.   D.R.  BLCK    PTCH  FAIL   ALGR   LONG  TRAN
      DATA DBT/   1.00,  1.00, 1.00,   1.00, 1.00,  1.00,  1.00, 1.00/
C
C     FLEX RHO    S.R.   D.R.  BLCK    PTCH  FAIL   ALGR   LONG  TRAN
      DATA DRO/  19.72, 16.27, 9.78,  10.15, 4.70,  8.01, 184.0,10.39/
C
C     COMP ALPHA  S.R.   D.R.  BLCK    PTCH  FAIL   ALGR   LONG  TRAN
      DATA DCAL/  0.23,  0.32, 0.31,   0.32, 1.00,  0.42,  0.37, 0.43/
C
C     COMP BETA   S.R.   D.R.  BLCK    PTCH  FAIL   ALGR   LONG  TRAN
      DATA DCBT/  1.00,  1.00, 1.00,   1.00, 1.00,  1.00,  1.00, 1.00/
C
C     COMP RHO    S.R.   D.R.   BLCK   PTCH  FAIL   ALGR   LONG  TRAN
      DATA DCRO/ 17.55,  9.04, 13.79, 17.28, 4.70, 18.77, 136.9, 9.56/
C
C
C     CALCULATE THE DISTRESS UTILITY VALUES
C
      IF( IPTYPE .EQ. 7 .OR. IPTYPE .EQ. 8 ) THEN
          DO  5 I = 1, 8
          IF( DISTRS(I) .EQ. 0 ) THEN
              UV(I) = 1.0
              GO TO 5
      ENDIF
          TRM = (-(DCRO(I)/DISTRS(I))**DCBT(I))
          IF( TRM .GT.  88.0 ) TRM =  88.0
          IF( TRM .LT. -88.0 ) TRM = -88.0
          UV(I)     = 1.0 - DCAL(I)*EXP(TRM)
C         CALDIS(I) = -DCRO(I)/ALOG((1.-UV(I))/DCAL(I))
    5     CONTINUE
C
      ELSE
C
          DO 15 I = 1, 8
          IF( DISTRS(I) .EQ. 0 ) THEN
              UV(I) = 1.0
              GO TO 15
      ENDIF
          TRM = (-(DRO(I)/DISTRS(I))**DBT(I))
          IF( TRM .GT.  88.0 ) TRM =  88.0
          IF( TRM .LT. -88.0 ) TRM = -88.0
          UV(I)     = 1.0 - DAL(I)*EXP(TRM)
C         CALDIS(I) = -DRO(I)/ALOG((1.-UV(I))/DAL(I))
   15     CONTINUE
C
      ENDIF
C
C     CALCULATE THE RIDE UTILITY VALUE
C
   25 ICASE = IADT*ISPEED
C
```

```
      IF( ICASE .LE. 27500 ) THEN
          IF( SI .GE. 2.5 ) THEN
              SIU = 1.0
              GO TO 35
          ENDIF
          XN  = ABS(100.*((2.5-SI)/2.5))
          RAL = 1.818
          RBT = 1.0
          RRO = 58.5
          GO TO 30
      ENDIF
C
      IF( ICASE .GT. 27500 .AND. ICASE .LE. 165000 ) THEN
          IF( SI .GE. 3.0 ) THEN
              SIU = 1.0
              GO TO 35
          ENDIF
          XN  = ABS(100.*((3.0-SI)/3.0))
          RAL = 1.76
          RBT = 1.0
          RRO = 48.1
          GO TO 30
      ENDIF
C
      IF( ICASE .GT. 165000 ) THEN
          IF( SI .GE. 3.5 ) THEN
              SIU = 1.0
              GO TO 35
          ENDIF
          XN  = ABS(100.*((3.5-SI)/3.5))
          RAL = 1.73
          RBT = 1.0
          RRO = 41.0
      ENDIF
C
   30 CONTINUE
C
      TRM   = (-(RRO/XN)**RBT)
      IF( TRM .GT.  88.0 ) TRM =  88.0
      IF( TRM .LT. -88.0 ) TRM = -88.0
      SIU   = 1.0 - RAL*EXP(TRM)
      IF( RAL*EXP(TRM) .GE. 1.0 ) SIU = 1.0
   35 UV(9) = SIU
C
      RETURN
      END
C
C
      SUBROUTINE DISAGE( ID, DSI, SI, DSA )
C
C     USE THE PAVEMENT PERFORMANCE CURVES FOR THE HEAVY REHAB/RECON-
C     STRUCTION MAINTENENCE LEVEL TO PREDICT THE DISTRESS AND RIDE
C     SCORES FOR THE NUMBER OF YEARS IN THE ANALYSIS PERIOD
C
      COMMON/UTV/ IADT, ICASE, ISPEED
      COMMON/AGE/ SIA(10), PSIMIN
      COMMON/ADJ/ ESAL, ICNTY, IPTYPE
      COMMON/BRO/ IS, IYA
      COMMON/DAG/ DAL(4,9), DBT(4,9), DRO(4,9)
C
```

```
      DIMENSION DSA(10)
C
C     SET A DEFAULT VALUE FOR PATCHING
C
      IF( ID .EQ. 4 ) THEN
          DO 10 IT = IYA, 10
   10     DSA(IT)  = DSI
          RETURN
      ENDIF
C
C     ADJUST THE RHO VALUES FOR BLOCK AND ALLIGATOR CRACKING, RUTTING,
C     AND PSI FOR THE SUBGRADE SUPPORT EFFECTS AND THE TRAFFIC EFFECTS
C
      RHOADJ = DRO(IS,ID)
C
      IF(ID.EQ.1 .OR. ID.EQ.2 .OR. ID.EQ.6 .OR. ID.EQ.9 )
     +    CALL ADJRHO( ID, DRO(IS,ID), RHOADJ )
C
C     CALCULATE THE PREDICTED PSI VALUES
C
      IF( ID .EQ. 9 ) THEN
          IF( SI .GE. 4.5 ) THEN
              PIT = 0.1
              GO TO 11
          ENDIF
          PIT = (4.5 - SI)/(4.5 - PSIMIN)
C
   11     IF( PIT .GT. 1.0 ) PIT = 1.0
          IF( PIT .LT. 0.0 ) PIT = 0.0
          IF( PIT .EQ. 1.0 ) THEN
              TO = 0.0
              GO TO 12
      ENDIF
C
          TO  = RHOADJ/((-ALOG(PIT/DAL(IS,ID)))**(1.0/DBT(IS,ID)) )
C
   12 ITC = 0
      DO 15 IT = IYA, 10
C     IF INITIAL PSI < 1.5, SET AGED PSI TO 1.5
      IF( SI .LT. 1.5 ) THEN
          SIA(IT) = 1.5
          GO TO 15
      ENDIF
      ITC = ITC + 1
          TI      = TO + FLOAT(ITC)
          T4      = (-(RHOADJ/TI)**DBT(IS,ID))
          IF( T4 .GT.  88.0 ) T4 =  88.0
          IF( T4 .LT. -88.0 ) T4 = -88.0
          PT      = DAL(IS,ID)*EXP( T4 )
          SIA(IT) = 4.5 - (PT * (4.5 - PSIMIN))
          PSI     = SIA(IT)
C
   15 DSA(IT) = SIA(IT)
      RETURN
      ENDIF
C
C     CALCULATE THE PREDICTED DISTRESS VALUES FOR ALL OTHER DISTRESS
C
      IF( DSI .EQ. 0.0 ) THEN
          TO = 0.1
```

```
            GO TO 17
         ENDIF
C
         PIT =  DSI
         TO  = RHOADJ/((-ALOG(PIT/DAL(IS,ID))) ** (1.0/DBT(IS,ID)) )
C
      17 ITC = 0
         DO 20 IT = IYA, 10
C
C        SKIP CALCULATION IF INITIAL DISTRESS > 0.95 OF THE MAXIMUM DISTRESS
C
         IF( DSI .GT. 0.95*DAL(IS,ID) ) THEN
            DSA(IT) = 0.95*DAL(IS,ID)
            GO TO 20
         ENDIF
         ITC = ITC + 1
         TI       = TO + FLOAT(ITC)
         T4       = (-(RHOADJ/TI)**DBT(IS,ID))
         IF( T4 .GT.  88.0 ) T4 =  88.0
         IF( T4 .LT. -88.0 ) T4 = -88.0
         PT       = DAL(IS,ID)*EXP( T4 )
         DSA(IT)  =  PT
         IF( DSA(IT) .GT. (0.95*DAL(IS,ID)) ) DSA(IT) = 0.95*DAL(IS,ID)
      20 CONTINUE
C
         RETURN
         END
C
C
         SUBROUTINE ADJRHO( ID, RHO, RHOADJ )
C
C        ADJUST THE RHO CURVE COEFFICIENT FOR CLIMATE, SUBGRADE, AND TRAFFIC
C        EFFECTS FOR RUTTING, BLOCK AND ALLIGATOR CRACKING, AND RIDE
C
         COMMON/ADJ/ ESAL, ICNTY, IPTYPE
         COMMON/FAC/ ADJUST(3), CRKFAC, PSIFAC, RUTFAC, TRFFAC(9)
C
         INTEGER*2 SGSUP1(122), SGSUP2(132), SGRSUP(254)
C
         COMMON/SUP/ CRKADJ(5), PSIADJ(5), RUTADJ(5)
C
         DIMENSION CA(10), CB(10), CR(10), RA(10), RB(10), RR(10)
         DIMENSION SA(10), SB(10), SR(10)
C
C        PAVEMENT TYPE    4       5      6       7       8       9      10
         DATA CA/3*0.0,  1.30,   1.30, 1.30,   1.30,   1.30,   1.30, 1.30 /
         DATA CB/3*0.0,  3.16,   2.34, 2.31,   2.84,   2.43,   2.24, 1.92 /
         DATA CR/3*0.0, 37.35,  15.37, 5.81,  38.53,  27.41,  11.48, 1.87 /
C
         DATA RA/3*0.0,  1.18,   1.18, 1.18,   1.18,   1.18,   1.18, 1.18 /
         DATA RB/3*0.0,  1.48,   1.14, 1.13,   1.34,   1.18,   1.09, 0.96 /
         DATA RR/3*0.0, 33.28,  13.56, 5.13,  33.97,  24.18,  10.13, 1.65 /
C
         DATA SA/3*0.0,  1.12,   1.12, 1.12,   1.12,   1.12,   1.12, 1.12 /
         DATA SB/3*0.0,  0.63,   0.50, 0.50,   0.58,   0.52,   0.49, 0.44 /
         DATA SR/3*0.0, 27.58,  11.20, 4.24,  28.14,  19.99,   8.36, 1.36 /
C
C        SUBGRADE SUPPORT VALUES, BY COUNTY NUMBER
C
         DATA SGSUP1/ 3,2,4,5,4,4,4,4,4,1,4,4,4,1,1,1,4,1,3,5,1,2,4,4,2,4,
```

```
     + 1,4,5,1,5,3,4,3,4,5,3,4,3,3,2,2,3,4,3,1,2,3,1,1,4,1,1,4,1,4,2,4,
     + 4,5,1,3,4,4,3,4,1,1,1,4,2,2,4,3,3,4,4,4,5,4,4,4,3,4,4,1,4,3,4,4,
     + 1,3,4,3,4,4,1,4,3,5,4,3,4,4,1,4,4,5,1,4,1,4,4,3,3,1,4,2,1,5,3,3/
      DATA SGSUP2/
     + 5,3,5,3,4,5,5,1,4,4,1,1,3,2,5,4,4,4,1,4,4,4,4,4,4,4,4,1,1,4,4,4,
     + 3,3,1,5,3,1,2,5,2,1,2,4,1,1,1,3,4,3,3,4,4,3,3,5,4,4,5,1,4,1,4,1,
     + 4,4,4,4,4,4,1,4,1,5,5,4,4,3,3,4,4,4,5,1,1,3,2,4,4,3,1,4,2,2,2,1,
     + 4,1,2,1,3,4,4,3,1,5,2,3,3,2,1,4,4,3,4,1,3,4,5,4,4,4,5,1,4,2,2,3,
     + 3,3,4,4 /
C
      DO 10 I   = 1, 122
   10 SGRSUP(I) = SGSUP1(I)
C
      DO 15 I         = 1, 132
   15 SGRSUP(122 + I) = SGSUP2(I)
C
C     ADJUST RHO FOR SUBGRADE SUPPORT EFFECTS
C
      IF( ID .EQ. 9 ) THEN
          RHOADJ = RHO * PSIADJ(SGRSUP(ICNTY))
          PSIFAC = PSIADJ(SGRSUP(ICNTY))
      ENDIF
      IF( ID .EQ. 6 ) THEN
          RHOADJ = RHO * CRKADJ(SGRSUP(ICNTY))
          CRKFAC = CRKADJ(SGRSUP(ICNTY))
      ENDIF
      IF( ID .EQ. 1 .OR. ID .EQ. 2 ) THEN
          RHOADJ = RHO * RUTADJ(SGRSUP(ICNTY))
          RUTFAC = RUTADJ(SGRSUP(ICNTY))
      ENDIF
C
C     ADJUST RHO FOR THE TRAFFIC EFFECTS ACCORDING TO THE DISTRESS
C     AND THE PAVEMENT TYPE
C
      BETA   = 1.0
C
C     RUTTING: SHALLOW & DEEP
C
      IF( ID .EQ. 1 .OR. ID .EQ. 2 ) THEN
          TRM = (-(RR(IPTYPE)/ESAL)**BETA)
          IF( TRM .GT.  88.0 ) TRM =  88.0
          IF( TRM .LT. -88.0 ) TRM = -88.0
          TRFADJ = RA(IPTYPE) - RB(IPTYPE)*EXP(TRM)
          IF( TRFADJ .LT. 0.83 ) TRFADJ = 0.83
      ENDIF
C
C     CRACKING: BLOCK & ALLIGATOR
C
      IF( ID .EQ. 6 ) THEN
          TRM = (-(CR(IPTYPE)/ESAL)**BETA)
          IF( TRM .GT.  88.0 ) TRM =  88.0
          IF( TRM .LT. -88.0 ) TRM = -88.0
          TRFADJ = CA(IPTYPE) - CB(IPTYPE)*EXP(TRM)
          IF( TRFADJ .LT. 0.70 ) TRFADJ = 0.70
      ENDIF
C
C     RIDE QUALITY:
C
      IF( ID .EQ. 9 ) THEN
          TRM = (-(SR(IPTYPE)/ESAL)**BETA)
```

```
         IF( TRM .GT.  88.0 ) TRM =  88.0
         IF( TRM .LT. -88.0 ) TRM = -88.0
         TRFADJ = SA(IPTYPE) - SB(IPTYPE)*EXP(TRM)
         IF( TRFADJ .LT. 0.94 ) TRFADJ = 0.94
      ENDIF
   20 RHOADJ     = RHOADJ * TRFADJ
      TRFFAC(ID) = TRFADJ
C
      IF( ID .EQ. 1 .OR. ID .EQ. 2 ) ADJUST(1) = RHOADJ/RHO
      IF( ID .EQ. 3 .OR. ID .EQ. 6 ) ADJUST(2) = RHOADJ/RHO
      IF( ID .EQ. 9 )                ADJUST(3) = RHOADJ/RHO
C
      RETURN
      END
C
```

```
      SUBROUTINE NDTREE
C
C*****************************************************************C
C                                                                 C
C     DECISION TREE PROGRAM TO ASSIGN THE MAINTENENCE LEVEL FOR A  C
C     PAVEMENT SECTION BASED ON THE CONDITION OF THE PAVEMENT AT A C
C     GIVEN TIME.  THE MAINTENENCE LEVEL ASSIGNED IS ALSO BASED ON C
C     THE ADT AND THE FUNCTIONAL CLASS OF THE PAVEMENT SECTION.    C
C     THE DECISION TREES WERE DEVELOPED BY Tx DOT PERSONNEL.       C
C                                                                 C
C          >>>>>>>>>>     PROGRAM NDTREE     <<<<<<<<<<           C
C                                                                 C
C*****************************************************************C
C
      COMMON/CON/ IYR, NSEC, NYEARS
C
      CHARACTER ALPH1*31, ALPH2*3, ALPH3*7, ALPH5*6, ALPH6*6
      CHARACTER BEG*3, BEGX(3), ENDH, FILL2*2, FILLER*5
      INTEGER*4 ALG, BLK, FAIL, LNG, RUTD, RUTS, PAT, TRN
C
      EQUIVALENCE (BEG, BEGX)
C
C     INITIALIZE THE MARKERS
C
      FILLER  =  '     '
      FILL2   =  '  '
C
      BEGX(1) = CHAR(19)
      BEGX(2) = CHAR(255)
      BEGX(3) = CHAR(1)
      ENDH    = CHAR(1)
C
C     DISPLAY NDECSCRN.AID
C
C     IYR    = 1
C     NYEARS = 10
C     NSEC   = 1
C
      WRITE(*,*) BEG,'USE,OPTSCRN.AID',ENDH
      WRITE(*,*) BEG,'DISPLAY,IYR,=',IYR,ENDH
      WRITE(*,*) BEG,'DISPLAY,NYEARS,=',NYEARS,ENDH
      WRITE(*,*) BEG,'DISPLAY,NSEC,=',NSEC,ENDH
C
      OPEN(UNIT=10,FILE='FILE1.OUT',STATUS='UNKNOWN')
C
C     START OF THE CALCULATION LOOP
C
      DO 900 I=1,NSEC
C
      KNT     = I
      WRITE(*,*) BEG,'DISPLAY,KNT,=',KNT,ENDH
C
      ISTR=0
C
C     SKIP THE NUMBER OF RECORDS TO GET THE CORRECT RECORD FOR THE YEAR
C
      DO 20 JX = 1, IYR
      READ(10,*)
   20 CONTINUE
C
```

```
C     READ THE RECORD FOR THE YEAR OF INTEREST
C
      READ(10,210)ALPH1,NPVMT,NFUNC,NML,ALPH2,NADT,ALPH3,RUTS,RUTD,
     *                 BLK,PAT,FAIL,ALG,LNG,TRN,ALPH5,PSI,ALPH6,
     +                 FILLER
  210 FORMAT(A31,I2,I1,I2,A3,I6,A7, 8I5, A6, F6.3, A6, A5 )
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCC                                                                 CCC
CCC          STRATEGY 4 (HEAVY REHAB/RECONSTRUCTION)                CCC
CCC                                                                 CCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(NML.EQ.0)GO TO 905
      NADT=NADT/NML
      IF( PSI  .LE. 2.5 .AND. NADT.GE.5000 ) ISTR = 4
      IF( PSI  .LE. 2.0 .AND. NADT.GE.750 )  ISTR = 4
      IF( PSI  .LE. 1.5 )                    ISTR = 4
      IF( RUTD .GE. 50  )                    ISTR = 4
      IF( ALG  .GE. 50 .AND. NADT .GE. 750 .AND. PSI .LE. 3.0 )ISTR = 4
      IF( ALG  .GE. 50 .AND. PSI  .LE. 2.5 )                   ISTR = 4
      IF( ISTR .EQ. 4 ) GO TO 101
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCC                                                                 CCC
CCC           STRATEGY 3 (MEDIUM REHABILITATION)                    CCC
CCC                                                                 CCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF( PSI .LE. 3.0 .AND. NADT .GE. 5000 ) ISTR = 3
      IF( PSI .LE. 2.5 .AND. NADT .GE. 750  ) ISTR = 3
      IF( PSI .LE. 2.0 )                      ISTR = 3
      IF( RUTD.GE. 25 .AND. NADT .GE. 750)    ISTR = 3
      IF( ALG .GE. 10 .AND. NADT .GE. 5000)   ISTR = 3
      IF( ALG .GE. 50 )                       ISTR = 3
      IF(FAIL .GE.  6 .AND. NADT .GE. 750)    ISTR = 3
      IF(FAIL .GE. 10)                        ISTR = 3
      IF(BLK .GE. 50 .AND. NADT .GE. 750)     ISTR = 3
      IF( ISTR .EQ. 3 ) GO TO 101
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCC                                                                 CCC
CCC           STRATEGY 2 (LIGHT REHABILITATION)                     CCC
CCC                                                                 CCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF( NFUNC .EQ. 4 ) NHI = 3000
      IF( NFUNC .GE. 5 .AND. NFUNC .LE. 10 ) NHI = 2000
C
      IF( RUTS .GE. 25 .AND. NADT .GE. NHI ) ISTR = 2
      IF( RUTS .GE. 50 )                     ISTR = 2
      IF( RUTD .GE. 10 )                     ISTR = 2
      IF( PSI  .LE. 3.0 .AND. NADT .GE. NHI )ISTR = 2
      IF( ISTR .EQ. 2 ) GO TO 101
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCC                                                                 CCC
CCC           STRATEGY 1 (PREVENTATIVE MAINTENENCE)                 CCC
CCC                                                                 CCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(  BLK .GE. 5 ) ISTR = 1
      IF( FAIL .GE. 1 ) ISTR = 1
      IF(  ALG .GE. 5 ) ISTR = 1
      IF(  LNG .GE.  50 .AND. NADT .GE. NHI ) ISTR = 1
      IF(  LNG .GE. 150 )                     ISTR = 1
      IF(  TRN .GE.   2 .AND. NADT .GE. NHI ) ISTR = 1
```

```
      IF(  TRN .GE.   4 )                      ISTR = 1
  101 CONTINUE
C
C     WRITE THE UPDATED RECORD WITH THE MAINTENENCE LEVEL TO THE OUTPUT FILE
C
      NADT = NADT * NML
C
       BACKSPACE 10
C
      WRITE(10,220)ALPH1,NPVMT,NFUNC,NML,ALPH2,NADT,ALPH3,RUTS,RUTD,
     *      BLK,PAT,FAIL,ALG,LNG,TRN,ALPH5,PSI,ALPH6,ISTR,
     +           FILL2
  220 FORMAT(A31,I2,I1,I2,A3,I6,A7,8I5,A6,F6.3, A6, I3, A2 )
C
C     SKIP THE REMAINING RECORDS FOR THIS SECTION
C
      IF( IYR .EQ. 10 ) GO TO 900
      DO 25 JX = IYR+1, NYEARS
   25 READ(10,*)
C
  900 CONTINUE
C
C     END OF THE CALCULATION LOOP
C
  905 CLOSE (UNIT=10,STATUS='KEEP')
C
      RETURN
      END
```

```
      SUBROUTINE SLPMSC
C*********************************************************************C
C                                                                     C
C     PROGRAM TO APPLY THE MAINTENENCE TREATMENT TO A PAVEMENT SECTION C
C     AT A GIVEN YEAR, COMPUTE THE BENEFIT OF THE TREATMENT, COMPUTE   C
C     THE COST/BENEFIT RATIO, RANK THE SECTIONS FROM LARGEST TO SMALL- C
C     EST COST/BENEFIT RATIO, AND OPTIMIZE THE MAINTENENCE FUNDS FOR   C
C     THE YEAR BY SELECTING THE SECTIONS FOR MAINTENENCE WITH THE LAR- C
C     GEST COST/BENEFIT RATIOS UNTIL THE FUNDS ARE USED UP             C
C                                                                     C
C*********************************************************************C
C                                                                     C
C          >>>>>>>>>>     PROGRAM SLPMSC     <<<<<<<<<<               C
C                                                                     C
C*********************************************************************C
C
      REAL CR(4,10)
      INTEGER*4 CALDIS(9), FAIL, ORGDIS, PAT
C
      DIMENSION DSA(10), UV(10)
      DIMENSION ORGUVU(10), TRTDUT(9,10), TRTUVU(10)
      DIMENSION ORGDIS(9,10), SIO(10), SIORUT(10), TRTDIS(9,10)
      DIMENSION COST(300), CBR(300), IFLAG(300), INDX(300)
C
      COMMON/AGE/ TRTSIU(10), PSIMIN
      COMMON/ADJ/ ESAL, ICNTY, IPTYPE
      COMMON/BRO/ ISTR1, IYA
      COMMON/CON/ IYR, NSEC, NYEARS
      COMMON/DAG/ DAL(4,9), DBT(4,9), DRO(4,9)
      COMMON/SUP/ CRKADJ(5), PSIADJ(5), RUTADJ(5)
      COMMON/UTV/ IADT, ICASE, ISPEED
C
      CHARACTER DATA1*24, DATA2*3
      CHARACTER BEG*3, BEGX(3), ENDH, FILLER*2
C
      EQUIVALENCE (BEG, BEGX)
C
C     INITIALIZE THE MARKERS
C
      BEGX(1) = CHAR(19)
      BEGX(2) = CHAR(255)
      BEGX(3) = CHAR(1)
      ENDH    = CHAR(1)
C
      FILLER = '  '
      NS     = 4
      NT     = 10
C
      OPEN(UNIT=10,FILE='FILE1.OUT',STATUS='UNKNOWN')
      OPEN(UNIT=11,FILE='DISADFAC.DAT',STATUS='UNKNOWN')
      OPEN(UNIT=14,FILE='BUDGET.DAT',STATUS='UNKNOWN')
C
C     READ THE BUDGET DATA FILE
C     SKIP THE COLUMN HEADINGS AND THE UNWANTED YEARS
C
      DO  8 JX = 1, IYR
    8 READ(14,208)
C
C     READ THE BUDGET DATA FILE FOR THE YEAR OF INTEREST
C
```

```
      READ(14,208) MYEARS,  BGTAMT
  208 FORMAT( I5, F15.2 )
C
C     READ THE TREATMENT COST TABLE
C
      READ(11,208)
      READ(11,208)
      DO 10 J=1,NS
      READ(11,205)(CR(J,II),II=4,NT)
   10 CONTINUE
  205 FORMAT(8X,F5.2, 6F7.2)
C
C     SKIP THE RATE OF GAIN TABLE
C
      DO 11 IJ = 1, 6
   11 READ(11,205)
C
C     READ THE SUBGRADE SUPPORT VALUES
C
      READ(11,104) (RUTADJ(I),I=1,5), (CRKADJ(I),I=1,5),
     +             (PSIADJ(I),I=1,5)
  104 FORMAT( /// 8X, 5F7.4/ 8X, 5F7.4/ 8X, 5F7.4 )
C
C     READ THE PAVEMENT PERFORMANCE CURVE COEFFICIENTS
C
      READ(11,*)
      READ(11,*)
      READ(11,*)
      DO 16 K = 1, 4
   16 READ(11,102) (DAL(K,I),I=1,9)
  102 FORMAT( 8X, 9F7.4 )
      READ(11,*)
      READ(11,*)
      DO 17 K = 1, 4
   17 READ(11,102) (DBT(K,I),I=1,9)
      READ(11,*)
      READ(11,*)
      DO 18 K = 1, 4
   18 READ(11,102) (DRO(K,I),I=1,9)
C
   20 CONTINUE
C
C     READ THE FILE TO SEE IF MAINTENENCE SHOULD BE APPLIED TO THIS
C     SECTION FOR THE YEAR BEING CONSIDERED
C
C     START OF THE CALCULATION LOOP
C
      DO 900 JS = 1, NSEC
      KNT = JS
C
      COST(JS)  = 0.0
      CBR(JS)   = 0.0
      IFLAG(JS) = 0
      INDX(JS)  = 0
C
      WRITE(*,*) BEG,'DISPLAY,KNT,=',KNT,ENDH
C
C     SKIP THE RECORDS BEFORE THE RECORD OF INTEREST
C
      DO 22 JX = 1, IYR
```

```
   22 READ(10,*)
C
C     READ THE RECORD OF INTEREST
C
      BENFIT = 0.0
C
      READ(10,200) IDIST, ICNTY, DATA1, ISPEED, IPTYPE, DATA2, L1,
     +      IADT, IESAL, L2, (ORGDIS(IU,IYR),IU=1,8),
     +      ORGUVU(IYR), SIO(IYR), SIORUT(IYR), ISTR1, FILLER
  200 FORMAT( I2,I3, A24, 2I2, A3, I3, I6, I5, I2, 8I5, 3F6.3,
     +        I3, A2 )
C
C     READ THE ORIGONAL UVU AND SI UTILITY SCORES FROM THE ORIGONAL
C     CURVE FOR THE REMAINING YEARS FOR THE SECTION
C
      IF( IYR .EQ. 10 ) GO TO 26
      DO 25 JX = IYR+1, NYEARS
   25 READ(10,202) ORGUVU(JX), SIORUT(JX)
  202 FORMAT( 92X, F6.3, 6X, F6.3 )
C
   26 CONTINUE
C
C     CHECK FOR TREATMENT TO APPLY.  IF NONE, DO NOTHING
C
      IF( ISTR1 .EQ. 0 ) GO TO 900
C
      ESAL = FLOAT(IESAL)/1000.
C
C     APPLY THE MAINTENENCE LEVEL AND PREDICT THE DISTRESS SCORES
C     FROM THE YEAR OF TREATMENT TO NYEARS
C
C     SET IYA = YEAR + 1 TO PREDICT DISTRESS SCORES FROM THIS YEAR TO NYEARS
C
      IYA = IYR + 1
C
C     SET THE DISTRESS SCORES TO ZERO FOR THE YEAR A TREATMENT WAS APPLIED
C
      DO 55 IU = 1, 8
      ORGDIS(IU,IYR) = 0
   55 CONTINUE
C
C     ADJUST THE SI SCORE FOR THE MAINTENENCE LEVEL APPLIED
C
      GO TO ( 56, 57, 58, 58 ), ISTR1
      GO TO 59
C     STRATEGY NO. 1 (PREVENTATIVE MAINTENENCE)
   56 SIM = SIO(IYR)
      IF( SIM .GT. 4.2 ) SIM = 4.2
      GO TO 59
C     STRATEGY NO. 2 (LIGHT REHABILITATION)
   57 SIM = SIO(IYR) + 0.5
      IF( SIM .GT. 4.2 ) SIM = 4.2
      GO TO 59
C     STRATEGY 3 & 4 (MEDIUM AND HEAVY REHABILITATION)
   58 SIM = 4.2
C
   59 CONTINUE
C
      ICASE = IADT*ISPEED
C
```

```
C     CALL DISAGE TO PREDICT THE ORIGINAL DISTRESS SCORES FROM THE YEAR THE
C     MAINTENENCE WAS APPLIED TO NYEARS TO GET THE TREATED DISTRESS SCORES
C
      DO 61 ID = 1, 9
      DSI      = ORGDIS(ID,IYR)
C
      CALL DISAGE( ID, DSI, SIM, DSA )
C
      DO 60 IT      = IYA, NYEARS
   60 TRTDIS(ID,IT) = DSA(IT)
   61 CONTINUE
C
C     ADJUST THE TREATED FAILURES AND SET THE TREATED PATCHING SCORES
C
      DO 63 IT = IYA, NYEARS
C
      FAIL = TRTDIS(5,IT)
C
      CALL ADJUST( FAIL, PAT )
C
      TRTDIS(4,IT) = PAT
   63 TRTDIS(5,IT) = FAIL
C
C     CALCULATE THE TREATED UTILITY SCORES FROM THE TREATED DISTRESS SCORES
C     CALCULATE THE TREATED UVU FROM THE TREATED UTILITY SCORES
C
      IYA      = IYR
      DO 79 IT = IYA, NYEARS
C
C     USE THE TREATED DISTRESS SCORES
C
      DO 76 ID   = 1, 9
   76 CALDIS(ID) = TRTDIS(ID,IT)
      SII        = SIM
C     SII        = TRTDIS(9,IT)
C
      CALL UTVAL( CALDIS, SII, UV )
C
      DO 78 ID = 1, 9
   78 TRTDUT(ID,IT) = UV(ID)
      TRTSIU(IT)    = UV(9)
   79 CONTINUE
C
C     CALCULATE THE UVU FOR THE TREATED UTILITY SCORES
C
      IYA  = IYR
C
      DO 80 IT = IYA, NYEARS
      TRTRUC   = TRTDUT(1,IT)+TRTDUT(2,IT) - 1.
      TRTUVU(IT) = TRTRUC*TRTDUT(3,IT)*TRTDUT(4,IT)
     +           *TRTDUT(5,IT)*TRTDUT(6,IT)*TRTDUT(7,IT)*TRTDUT(8,IT)
   80 CONTINUE
C
C     CALCULATE THE BENEFIT OF THE TREATMENT, THE COST/BENEFIT RATIO,
C     AND RANK THE SECTIONS BY SORTING ON COST/BENEFIT RATIO
C
      CALL UTBEN( IYA, NYEARS, ORGUVU, TRTUVU, BNFTUT )
      CALL SIBEN( IYA, NYEARS, SIORUT, TRTSIU, BNFTSI )
C
      BENFIT = BNFTUT + BNFTSI
```

```
C
C     CALCULATE THE COST OF THE PROJECT & COST BENEFIT RATIO
C
      COST(JS) = L1*L2*CR(ISTR1,IPTYPE)*(1760./3.)/10.
      CBR(JS)  = BENFIT/COST(JS)
C
  900 CONTINUE
C
C     END OF THE CALCULATION LOOP FOR THE YEAR OF INTEREST
C     SORT THE COST BENEFIT RATIOS FROM LARGEST TO SMALLEST
C
      CALL SORTIT( NSEC, CBR, INDX )
C
C     SET THE FEASIBILITY FLAG TO ZERO INITIALLY (INFEASIBLE)
C
      DO 85 IF  = 1, NSEC
   85 IFLAG(IF) = 0
C
C     SELECT SECTIONS TO FIX UP STARTING WITH THE LARGEST COST BENEFIT
C     RATIOS UNTIL THE BUDGET HAS BEEN USED UP
C
      TCOST = 0.0
C
      DO 88 JS = 1, NSEC
      TCOST = TCOST + COST(INDX(JS))
      IF( TCOST .GE. BGTAMT ) GO TO 88
      IF( COST(INDX(JS)) .EQ. 0.0 ) GO TO 88
C
C     SET THE FEASIBILITY FLAG TO 1 IF THE SECTION WAS SELECTED
C
      IFLAG(INDX(JS)) = 1
   88 CONTINUE
C
C     RE-READ THE FILE AND WRITE THE RANKINGS
C
      REWIND (UNIT=10)
C
      DO 95 I = 1, NSEC
C
      KNT = I
C
      WRITE(*,*) BEG,'DISPLAY,KNT,=',KNT,ENDH
C
C     SKIP THE UNWANTED RECORDS
C
      DO 90 JX = 1, IYR
   90 READ(10,*)
C
C     READ THE RECORD OF INTEREST
C
      READ(10,200) IDIST, ICNTY, DATA1, ISPEED, IPTYPE, DATA2, L1,
     +        IADT, IESAL, L2, (ORGDIS(IU,IYR),IU=1,8),
     +        ORGUVU(IYR), SIO(IYR), SIORUT(IYR), ISTR1, FILLER
C
      BACKSPACE 10
C
C     WRITE THE UPDATED RECORD WITH THE MAINTENENCE FEASIBILITY FLAG
C
      WRITE(10,210) IDIST, ICNTY, DATA1, ISPEED, IPTYPE, DATA2, L1,
     +         IADT, IESAL, L2, (ORGDIS(IU,IYR),IU=1,8),
```

```
     +       ORGUVU(IYR), SIO(IYR), SIORUT(IYR), ISTR1, IFLAG(I)
  210 FORMAT( I2,I3, A24, 2I2, A3, I3, I6, I5, I2, 8I5, 3F6.3,
     +       I3, I2 )
C
C     SKIP THE REMAINING RECORDS FOR THIS SECTION
C
      IF( IYR .EQ. 10 ) GO TO 95
      DO 92 JX = IYR+1, NYEARS
   92 READ(10,*)
C
   95 CONTINUE
C
      CLOSE(10)
      CLOSE(11)
      CLOSE(14)
C
      RETURN
      END
C
C
      SUBROUTINE ADJUST ( FAIL, PAT )
C
C     ADJUST THE FAILURE AND PATCHING DISTRESS SCORES
C
      INTEGER*4 FAIL, PAT
C
      PAT = 0
C
      IF( FAIL .LE. 2 ) RETURN
C
   10 IF( FAIL .GT. 2 ) THEN
          FAIL = FAIL - 2
          PAT  = PAT + 5
      ENDIF
C
      IF( FAIL .GT. 2 ) GO TO 10
C
      RETURN
      END
C
C
      SUBROUTINE SORTIT( NSEC, CBR, INDX )
C
C***********************************************************************
C  SUBROUTINE SORTS HIGHWAYS IN ACCENDING ORDER ACCORDING TO EFF. BEN.
C  Order of accending benefit saved in index, array order is unchanged
C***********************************************************************
C
      DIMENSION CBR(300), INDX(300)
C
C
      IF( NSEC .EQ. 1 ) GO TO 40
C
      DO 10 J=1,NSEC
        INDX(J)=J
10    CONTINUE
      L=NSEC/2+1
      IR=NSEC
20    CONTINUE
        IF(L.GT.1)THEN
```

```
            L=L-1
            INDXT=INDX(L)
            Q=CBR(INDXT)
          ELSE
            INDXT=INDX(IR)
            Q=CBR(INDXT)
            INDX(IR)=INDX(1)
            IR=IR-1
            IF(IR.EQ.1)THEN
              INDX(1)=INDXT
C
              RETURN
            ENDIF
          ENDIF
          I=L
          J=L+L
30        IF(J.LE.IR)THEN
            IF(J.LT.IR)THEN
              IF(CBR(INDX(J)).GT.CBR(INDX(J+1)))J=J+1
            ENDIF
            IF(Q.GT.CBR(INDX(J)))THEN
              INDX(I)=INDX(J)
              I=J
              J=J+J
            ELSE
              J=IR+1
            ENDIF
          GO TO 30
          ENDIF
          INDX(I)=INDXT
        GO TO 20
C
   40   CONTINUE
C
        RETURN
        END
C
C
        SUBROUTINE UTBEN( IYA, NYEARS, ORGUVU, TRTUVU, BNFTUT )
C
C       CALCULATE THE ADDED UTILITY BENEFIT OF A MAINTENENCE LEVEL
C
        DIMENSION ORGUVU(300), TRTUVU(300)
C
        BNFTUT = 0.0
C
C       FIND THE CASE.  USE 0.5 AS THE MINIMUM UTILITY SCORE
C
        IF( ORGUVU(IYA) .GT. 0.5 .AND. ORGUVU(NYEARS) .LE. 0.5 ) ICASE = 1
        IF( ORGUVU(IYA) .LE. 0.5 .AND. TRTUVU(IYA) .GT. 0.5 )    ICASE = 2
        IF( ORGUVU(IYA) .GT. 0.5 .AND. ORGUVU(NYEARS) .GT. 0.5 ) ICASE = 3
        IF( ORGUVU(IYA) .LE. 0.5 .AND. TRTUVU(IYA) .LE. 0.5 )    ICASE = 4
        IF( ORGUVU(IYA) .EQ. 1.0 .AND. ORGUVU(NYEARS) .EQ. 1.0 ) ICASE = 5
C
        IF( ICASE .GE. 4 ) RETURN
C
C       FIND THE NUMBER OF AREAS UNDER THE UVU CURVE WITH UVU SCORES > 0.5
C
        DO 10 IA = IYA, NYEARS
        IF( TRTUVU(IA) .LE. 0.5 ) GO TO 15
```

```
   10 CONTINUE
   15 NAREAS = IA - IYA
C
C     CALCULATE & SUM THE AREAS
C
      SUMA = 0.0
      IA   = 0
      DO 20 IF = 1, NAREAS
      IF( TRTUVU(IYA+IA) .LT. 0.5 ) TRTUVU(IYA+IA) = 0.5
      IF( ORGUVU(IYA+IA) .LT. 0.5 ) ORGUVU(IYA+IA) = 0.5
      IF( TRTUVU(IYA+IA+1) .LT. 0.5 ) TRTUVU(IYA+IA+1) = 0.5
      IF( ORGUVU(IYA+IA+1) .LT. 0.5 ) ORGUVU(IYA+IA+1) = 0.5
C
      AVGTRT = (TRTUVU(IYA+IA) + TRTUVU(IYA+IA+1))/2.
      AVGUVU = (ORGUVU(IYA+IA) + ORGUVU(IYA+IA+1))/2.
      AREA   = (AVGTRT - AVGUVU) * 1.0
      SUMA   = SUMA + AREA
   20 IA = IA + 1
C
      BNFTUT = SUMA
C
      RETURN
      END
C
C
      SUBROUTINE SIBEN( IYA, NYEARS, SIORUT, TRTSIU, BNFTSI )
C
C     CALCULATE THE ADDED SI BENEFIT OF THE MAINTENENCE LEVEL
C
      DIMENSION SIORUT(300), TRTSIU(300)
C
C
      BNFTSI = 0.0
C
C     FIND THE CASE. USE 0.5 AS THE MINIMUM SI UTILITY SCORE
C
      IF( SIORUT(IYA) .GT. 0.5 .AND. SIORUT(NYEARS) .LE. 0.5 ) ICASE = 1
      IF( SIORUT(IYA) .LE. 0.5 .AND. TRTSIU(IYA) .GT. 0.5 )    ICASE = 2
      IF( SIORUT(IYA) .GT. 0.5 .AND. SIORUT(NYEARS) .GT. 0.5 ) ICASE = 3
      IF( SIORUT(IYA) .LE. 0.5 .AND. TRTSIU(IYA) .LE. 0.5 )    ICASE = 4
      IF( SIORUT(IYA) .EQ. 1.0 .AND. SIORUT(NYEARS) .EQ. 1.0 ) ICASE = 5
C
      IF( ICASE .GE. 4 ) RETURN
C
C     FIND THE NUMBER OF AREAS UNDER THE SI UTILITY CURVE WITH SI UTILITY
C     > 0.5
C
      DO 10 IA = IYA, NYEARS
      IF( TRTSIU(IA) .LE. 0.5 ) GO TO 15
   10 CONTINUE
   15 NAREAS = IA - IYA
C
C     CALCULATE & SUM THE AREAS
C
      SUMA = 0.0
      IA   = 0
      DO 20 IF = 1, NAREAS
      IF( TRTSIU(IYA+IA) .LT. 0.5 ) TRTSIU(IYA+IA) = 0.5
      IF( SIORUT(IYA+IA) .LT. 0.5 ) SIORUT(IYA+IA) = 0.5
      IF( TRTSIU(IYA+IA+1) .LT. 0.5 ) TRTSIU(IYA+IA+1) = 0.5
```

```
      IF( SIORUT(IYA+IA+1) .LT. 0.5 ) SIORUT(IYA+IA+1) = 0.5
C
      AVGTRT = (TRTSIU(IYA+IA) + TRTSIU(IYA+IA+1))/2.
      AVGUVU = (SIORUT(IYA+IA) + SIORUT(IYA+IA+1))/2.
      AREA   = (AVGTRT - AVGUVU) * 1.0
      SUMA   = SUMA + AREA
   20 IA = IA + 1
C
      BNFTSI = SUMA
C
C
      RETURN
      END
```

```
      SUBROUTINE STAGE
C
C*******************************************************************C
C     PROGRAM TO APPLY A MAINTENENCE LEVEL AT A GIVEN YEAR, AND TO   C
C     PREDICT THE PAVEMENT CONDITION ACCORDING TO THE MAINTENENCE    C
C     APPLIED TO THE END OF THE SPECIFED TIME PERIOD                 C
C                                                                    C
C         >>>>>>>>>>>     SUBROUTINE STAGE     <<<<<<<<<<            C
C                                                                    C
C*******************************************************************C
C
      CHARACTER BEG*3, BEGX(3), ENDH
C
      CHARACTER DATA1*24, DATA2*6, DATA3*2
      CHARACTER FILL*2
      INTEGER*4 AGEDIS, CALDIS, FAIL, PAT
C
      DIMENSION AGEDIS(9,10), AGEDUT(9,10), UV(9)
      DIMENSION CALDIS(10), DSA(10)
C
      COMMON/CON/ IYR, NSEC, NYEARS
      COMMON/UTV/ IADT, ICASE, ISPEED
      COMMON/AGE/ SIA(10), PSIMIN
      COMMON/ADJ/ ESAL, ICNTY, IPTYPE
      COMMON/FAC/ CRKFAC, PSIFAC, RUTFAC, TRFFAC(9)
      COMMON/BRO/ ISTR1, IYA
      COMMON/SUP/ CRKADJ(5), PSIADJ(5), RUTADJ(5)
      COMMON/DAG/ DAL(4,9), DBT(4,9), DRO(4,9)
C
      EQUIVALENCE (BEG, BEGX)
C
C     INITIALIZE THE MARKERS
C
      BEGX(1) = CHAR(19)
      BEGX(2) = CHAR(255)
      BEGX(3) = CHAR(1)
      ENDH    = CHAR(1)
C
      FILL = '  '
C
      OPEN(UNIT=1,FILE='FILE1.OUT',STATUS='UNKNOWN')
      OPEN(UNIT=3,FILE='DISADFAC.DAT')
C
C     READ THE ADJUSTMENT FACTOR FILE
C
C     SKIP THE TREATMENT COST TABLE & RATE OF GAIN TABLE
C
      DO 1 IS = 1, 12
    1 READ(3,102)
C
  102 FORMAT(  8X, 9F7.4 )
C
C     READ THE SUBGRADE SUPPORT VALUES
C
      READ(3,104) (RUTADJ(I),I=1,5), (CRKADJ(I),I=1,5),
     +           (PSIADJ(I),I=1,5)
  104 FORMAT( /// 8X, 5F7.4/ 8X, 5F7.4/ 8X, 5F7.4 )
C
C     READ THE PAVEMENT PERFORMANCE CURVE COEFFICIENTS
C
```

```
      READ(3,*)
      READ(3,*)
      READ(3,*)
      DO 16 K = 1, 4
   16 READ(3,102) (DAL(K,I),I=1,9)
      READ(3,*)
      READ(3,*)
      DO 17 K = 1, 4
   17 READ(3,102) (DBT(K,I),I=1,9)
      READ(3,*)
      READ(3,*)
      DO 18 K = 1, 4
   18 READ(3,102) (DRO(K,I),I=1,9)
C
C
   10 CONTINUE
C
C     START OF THE CALCULATION LOOP
C
      DO 900 JS = 1, NSEC
      KNT = JS
C
      WRITE(*,*) BEG,'DISPLAY,KNT,=',KNT,ENDH
C
C     SKIP THE RECORDS PRIOR TO THE YEAR OF INTEREST
C
      DO 20 JX = 1, IYR
   20 READ(1,*)
C
C     READ THE RECORD OF INTEREST
C
      READ(1,200) IDIST, ICNTY, DATA1, ISPEED, IPTYPE, DATA2, IADT,
     +            IESAL, DATA3, (AGEDIS(IU,IYR),IU=1,8),
     +            AGEUVU, SIA(IYR), AGEDUT(9,IYR), ISTR1, IFLAG
  200 FORMAT( I2,I3, A24, 2I2, A6, I6, I5, A2, 8I5, 3F6.3,
     +       I3, I2 )
C
C     CHECK TO SEE IF MAINTENENCE IS TO BE APPLIED THIS YEAR
C

      IF( ISTR1 .EQ. 0 .OR. IFLAG .EQ. 0 ) THEN
C
C     DO NOTHING. NO MAINTENENCE WAS APPLIED
C
C     SKIP THE REST OF THE RECORDS FOR THIS SECTION
C
      IF( IYR .EQ. 10 ) GO TO 900
      DO 25 JX = IYR+1, NYEARS
   25 READ(1,*,END=26)
      GO TO 900
   26 WRITE(*,*) ' END OF FILE '
      PAUSE
      GO TO 900
      ENDIF
C
      ESAL = FLOAT(IESAL)/1000.
C
C     APPLY THE MAINTENENCE LEVEL AND PREDICT THE DISTRESS AND UTILITY
C     SCORES FROM THIS YEAR TO NYEARS
C
```

```
C     SET IYA = YEAR + 1 TO AGE FROM THIS YEAR TO NYEARS
C
      IYA = IYR + 1
C
C     SET THE DISTRESS SCORES TO ZERO FOR THE YEAR MAINTENENCE WAS APPLIED
C
      DO 55 IU = 1, 8
      AGEDIS(IU,IYR) = 0
   55 CONTINUE
C
C     ADJUST THE SI SCORE FOR THE MAINTENENCE TO BE APPLIED
C
      GO TO ( 56, 57, 58, 58 ), ISTR1
      GO TO 59
C     STRATEGY NO. 1 (PREVENTATIVE MAINTENENCE)
   56 SIA(IYR) = SIA(IYR)
      IF( SIA(IYR) .GT. 4.2 ) SIA(IYR) = 4.2
      GO TO 59
C     STRATEGY NO. 2 (LIGHT REHABILITATION)
   57 SIA(IYR) = SIA(IYR) + 0.5
      IF( SIA(IYR) .GT. 4.2 ) SIA(IYR) = 4.2
      GO TO 59
C     STRATEGY 3 & 4 (MEDIUM AND HEAVY REHABILITATION)
   58 SIA(IYR) = 4.2
C
   59 CONTINUE
C
C     SET THE INITIAL SI SCORE FOR THE YEAR SELECTED
C
      SIM   = SIA(IYR)
      ICASE = IADT*ISPEED
C
C
C     CALL DISAGE TO PREDICT THE DISTRESS SCORES FROM THE YEAR OF
C     TREATMENT TO NYEARS
C
      DO 61 ID = 1, 9
      DSI       = AGEDIS(ID,IYR)
C
      CALL STDAGE( ID, DSI, SIM, DSA )
C
      DO 60 IT       = IYA, NYEARS
   60 AGEDIS(ID,IT) = DSA(IT)
   61 CONTINUE
C
C     ADJUST THE PREDICTED FAILURES AND SET THE PREDICTED PATCHING SCORES
C
      DO 63 IT = IYA, NYEARS
C
      FAIL = AGEDIS(5,IT)
C
      CALL STAJST( FAIL, PAT )
C
      AGEDIS(4,IT) = PAT
   63 AGEDIS(5,IT) = FAIL
C
C     CALCULATE THE PREDICTED DISTRESS UTILITY SCORES FROM THE PREDICTED
C     DISTRESS SCORES.  CALCULATE THE UVU FOR THE PREDICTED DISTRESS
C     UTILITY SCORES
C
```

```
      IYA      = IYR
      DO 79 IT = IYA, NYEARS
C
C     USE THE PREDICTED DISTRESS SCORES
C
      DO 76 ID   = 1, 8
   76 CALDIS(ID) = AGEDIS(ID,IT)
      SII        = SIA(IT)
C
      CALL STUTVL( CALDIS, SII, UV )
C
      DO 78 ID = 1, 9
   78 AGEDUT(ID,IT) = UV(ID)
   79 CONTINUE
C
C     CALCULATE THE UVU FOR THE PREDICTED DISTRESS UTILITY SCORES
C
      BACKSPACE 1
C
C     WRITE THE NEW DISTRESS UTILITY SCORES FOR THE MAINTENENCE APPLIED
C     FOR THE YEAR OF THE MAINTENENCE
C
      AGEUVU = 1.0
      WRITE(1,200) IDIST, ICNTY, DATA1, ISPEED, IPTYPE, DATA2, IADT,
     +             IESAL, DATA3, (AGEDIS(IU,IYR),IU=1,8),
     +             AGEUVU, SIA(IYR), AGEDUT(9,IYR), ISTR1, IFLAG
C
      IYA   = IYR+1
      ISTR2 = 0
C
C     WRITE THE PREDICTED DISTRESS UTILITY SCORES FOR THE MAINTENENCE
C     APPLIED FROM THE YEAR OF MAINTENENCE TO NYEARS
C
      DO 80 IT = IYA, NYEARS
C
C
      AGERUC   = AGEDUT(1,IT)+AGEDUT(2,IT) - 1.
      AGEUVU   = AGERUC*AGEDUT(3,IT)*AGEDUT(4,IT)
     +          *AGEDUT(5,IT)*AGEDUT(6,IT)*AGEDUT(7,IT)*AGEDUT(8,IT)
   80 WRITE(1,202) IDIST, ICNTY, DATA1, ISPEED, IPTYPE, DATA2, IADT,
     +             IESAL, DATA3, (AGEDIS(IU,IT),IU=1,8),
     +             AGEUVU, SIA(IT), AGEDUT(9,IT), ISTR2, FILL
  202 FORMAT( I2,I3, A24, 2I2, A6, I6, I5, A2, 8I5, 3F6.3, I3, A2 )
C
  900 CONTINUE
C
      CLOSE(1)
      CLOSE(3)
C
      RETURN
      END
C
C
      SUBROUTINE STAJST ( FAIL, PAT )
C
C     ADJUST THE FAILURE AND PATCHING DISTRESS SCORES
C
      INTEGER*4 FAIL, PAT
C
      PAT = 0
```

```
C
      IF( FAIL .LE. 2 ) RETURN
C
   10 IF( FAIL .GT. 2 ) THEN
         FAIL = FAIL - 2
         PAT  = PAT + 5
      ENDIF
C
      IF( FAIL .GT. 2 ) GO TO 10
C
      RETURN
      END
C
C
      SUBROUTINE STUTVL( DISTRS, SI, UV )
C
C     USE THE S-SHAPED DISTRESS UTILITY CURVES TO CONVERT THE DISTRESS
C     AND RIDE SCORES INTO DISTRESS UTILITY SCORES IN THE RANGE 0 TO 1
C
      INTEGER*4   DISTRS(9)
C
      COMMON/ADJ/ ESAL, ICNTY, IPTYPE
      COMMON/BRO/ IS, IYA
      COMMON/UTV/ IADT, ICASE, ISPEED
C
      DIMENSION DAL(8), DBT(8), DRO(8), DCAL(8), DCBT(8), DCRO(8)
      DIMENSION UV(9)
C
C     FLEX ALPHA  S.R.   D.R.  BLCK    PTCH  FAIL   ALGR   LONG  TRAN
      DATA DAL/   0.31,  0.69, 0.49,   0.45, 1.00,  0.53,  0.87, 0.69/
C
C     FLEX BETA   S.R.   D.R.  BLCK    PTCH  FAIL   ALGR   LONG  TRAN
      DATA DBT/   1.00,  1.00, 1.00,   1.00, 1.00,  1.00,  1.00, 1.00/
C
C     FLEX RHO    S.R.   D.R.  BLCK    PTCH  FAIL   ALGR   LONG  TRAN
      DATA DRO/  19.72, 16.27, 9.78,  10.15, 4.70,  8.01,  184.0,10.39/
C
C     COMP ALPHA  S.R.   D.R.  BLCK    PTCH  FAIL   ALGR   LONG  TRAN
      DATA DCAL/  0.23,  0.32, 0.31,   0.32, 1.00,  0.42,  0.37, 0.43/
C
C     COMP BETA   S.R.   D.R.  BLCK    PTCH  FAIL   ALGR   LONG  TRAN
      DATA DCBT/  1.00,  1.00, 1.00,   1.00, 1.00,  1.00,  1.00, 1.00/
C
C     COMP RHO    S.R.   D.R.   BLCK   PTCH  FAIL   ALGR   LONG  TRAN
      DATA DCRO/ 17.55,  9.04, 13.79, 17.28, 4.70, 18.77, 136.9, 9.56/
C
C
C     CALCULATE THE DISTRESS UTILITY SCORES
C
      IF( IPTYPE .EQ. 7 .OR. IPTYPE .EQ. 8 ) THEN
         DO  5 I = 1, 8
         IF( DISTRS(I) .EQ. 0 ) THEN
             UV(I) = 1.0
             GO TO 5
      ENDIF
         TRM = (-(DCRO(I)/DISTRS(I))**DCBT(I))
         IF( TRM .GT.  88.0 ) TRM =  88.0
         IF( TRM .LT. -88.0 ) TRM = -88.0
         UV(I)     = 1.0 - DCAL(I)*EXP(TRM)
    5    CONTINUE
```

```
      ELSE
C
          DO 15 I = 1, 8
          IF( DISTRS(I) .EQ. 0 ) THEN
              UV(I) = 1.0
              GO TO 15
      ENDIF
          TRM = (-(DRO(I)/DISTRS(I))**DBT(I))
          IF( TRM .GT.  88.0 ) TRM =  88.0
          IF( TRM .LT. -88.0 ) TRM = -88.0
          UV(I)     = 1.0 - DAL(I)*EXP(TRM)
   15     CONTINUE
      ENDIF
C
C     CALCULATE THE RIDE UTILITY SCORE
C
   25 ICASE = IADT*ISPEED
C
      IF( ICASE .LE. 27500 ) THEN
          IF( SI .GE. 2.5 ) THEN
              SIU = 1.0
              GO TO 35
          ENDIF
          XN  = ABS(100.*((2.5-SI)/2.5))
          RAL = 1.818
          RBT = 1.0
          RRO = 58.5
          GO TO 30
      ENDIF
C
      IF( ICASE .GT. 27500 .AND. ICASE .LE. 165000 ) THEN
          IF( SI .GE. 3.0 ) THEN
              SIU = 1.0
              GO TO 35
          ENDIF
          XN  = ABS(100.*((3.0-SI)/3.0))
          RAL = 1.76
          RBT = 1.0
          RRO = 48.1
          GO TO 30
      ENDIF
C
      IF( ICASE .GT. 165000 ) THEN
          IF( SI .GE. 3.5 ) THEN
              SIU = 1.0
              GO TO 35
          ENDIF
          XN  = ABS(100.*((3.5-SI)/3.5))
          RAL = 1.73
          RBT = 1.0
          RRO = 41.0
      ENDIF
C
   30 TRM   = (-(RRO/XN)**RBT)
      IF( TRM .GT.  88.0 ) TRM =  88.0
      IF( TRM .LT. -88.0 ) TRM = -88.0
      SIU   = 1.0 - RAL*EXP(TRM)
      IF( RAL*EXP(TRM) .GE. 1.0 ) SIU = 1.0
   35 UV(9) = SIU
C
```

```
      RETURN
      END
C
C
      SUBROUTINE STDAGE( ID, DSI, SI, DSA )
C
C     USE THE PAVEMENT PERFORMANCE CURVES FOR THE MAINTENENCE LEVEL
C     APPLIED AND TYPE OF PAVEMENT TO PREDICT THE DISTRESS SCORES AND
C     THE RIDE SCORE FOR THE SPECIFIED NUMBER OF YEARS
C
      COMMON/UTV/ IADT, ICASE, ISPEED
      COMMON/AGE/ SIA(10), PSIMIN
      COMMON/ADJ/ ESAL, ICNTY, IPTYPE
      COMMON/BRO/ IS, IYA
      COMMON/DAG/ DAL(4,9), DBT(4,9), DRO(4,9)
C
      DIMENSION DSA(10)
C
C     SET A DEFAULT SCORE FOR PATCHING
C
      IF( ID .EQ. 4 ) THEN
          DO 10 IT = IYA, 10
   10     DSA(IT)  = DSI
          RETURN
      ENDIF
C
C     ADJUST THE RHO VALUES FOR BLOCK AND ALLIGATOR CRACKING, RUTTING,
C     AND PSI FOR THE SUBGRADE SUPPORT EFFECTS AND THE TRAFFIC EFFECTS
C
      RHOADJ = DRO(IS,ID)
C
      IF(ID.EQ.1 .OR. ID.EQ.2 .OR. ID.EQ.6 .OR. ID.EQ.9 )
     +    CALL STARHO( ID, DRO(IS,ID), RHOADJ )
C
C
C     CALCULATE THE PREDICTED PSI VALUES
C
      IF( ID .EQ. 9 ) THEN
          IF( SI .GE. 4.5 ) THEN
              PIT = 0.1
              GO TO 11
          ENDIF
          PIT = (4.5 - SI)/(4.5 - PSIMIN)
C
   11     IF( PIT .GT. 1.0 ) PIT = 1.0
          IF( PIT .LT. 0.0 ) PIT = 0.0
          IF( PIT .EQ. 1.0 ) THEN
              TO = 0.0
              GO TO 12
      ENDIF
C
          TO  = RHOADJ/((-ALOG(PIT/DAL(IS,ID)))**(1.0/DBT(IS,ID)) )
C
   12 ITC = 0
      DO 15 IT = IYA, 10
C     IF INITIAL PSI < 1.5, SET AGED PSI TO 1.5
      IF( SI .LT. 1.5 ) THEN
          SIA(IT) = 1.5
          GO TO 15
      ENDIF
```

```
         ITC = ITC + 1
            TI        = TO + FLOAT(ITC)
            T4        = (-(RHOADJ/TI)**DBT(IS,ID))
            IF( T4 .GT.  88.0 ) T4 =  88.0
            IF( T4 .LT. -88.0 ) T4 = -88.0
            PT        = DAL(IS,ID)*EXP( T4 )
            SIA(IT)   = 4.5 - (PT * (4.5 - PSIMIN))
            PSI       = SIA(IT)
C
   15 DSA(IT) = SIA(IT)
      RETURN
      ENDIF
C
C     CALCULATE THE PREDICTED DISTRESS SCORES FOR ALL OTHER DISTRESS
C
      IF( DSI .EQ. 0.0 ) THEN
         TO = 0.1
         GO TO 17
      ENDIF
C
      PIT =  DSI
      TO  = RHOADJ/((-ALOG(PIT/DAL(IS,ID))) ** (1.0/DBT(IS,ID)) )
C
   17 ITC = 0
      DO 20 IT = IYA, 10
C     SKIP CALCULATION IF INITIAL DISTRESS > 0.95 OF THE MAXIMUM DISTRESS
      IF( DSI .GT. 0.95*DAL(IS,ID) ) THEN
         DSA(IT) = 0.95*DAL(IS,ID)
         GO TO 20
      ENDIF
      ITC = ITC + 1
      TI        = TO + FLOAT(ITC)
      T4        = (-(RHOADJ/TI)**DBT(IS,ID))
      IF( T4 .GT.  88.0 ) T4 =  88.0
      IF( T4 .LT. -88.0 ) T4 = -88.0
      PT        = DAL(IS,ID)*EXP( T4 )
      DSA(IT)   =  PT
      IF( DSA(IT) .GT. (0.95*DAL(IS,ID)) ) DSA(IT) = 0.95*DAL(IS,ID)
   20 CONTINUE
C
      RETURN
      END
C
C
      SUBROUTINE STARHO( ID, RHO, RHOADJ )
C
C     ADJUST THE RHJO CURVE COEFFICIENT FOR CLIMATE, SUBGRADE, AND TRAFFIC
C     EFFECTS FOR RUTTING, BLOCK AND ALLIGATOR CRACKING, AND RIDE
C
      COMMON/ADJ/ ESAL, ICNTY, IPTYPE
      COMMON/FAC/ CRKFAC, PSIFAC, RUTFAC, TRFFAC(9)
C
      INTEGER*2 SGSUP1(122), SGSUP2(132), SGRSUP(254)
C
      COMMON/SUP/ CRKADJ(5), PSIADJ(5), RUTADJ(5)
C
      DIMENSION CA(10), CB(10), CR(10), RA(10), RB(10), RR(10)
      DIMENSION SA(10), SB(10), SR(10)
C
C     PAVEMENT TYPE    4       5      6       7       8       9       10
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      DATA CA/3*0.0,  1.30,  1.30, 1.30,  1.30,  1.30,  1.30, 1.30 /
      DATA CB/3*0.0,  3.16,  2.34, 2.31,  2.84,  2.43,  2.24, 1.92 /
      DATA CR/3*0.0, 37.35, 15.37, 5.81, 38.53, 27.41, 11.48, 1.87 /
C
      DATA RA/3*0.0,  1.18,  1.18, 1.18,  1.18,  1.18,  1.18, 1.18 /
      DATA RB/3*0.0,  1.48,  1.14, 1.13,  1.34,  1.18,  1.09, 0.96 /
      DATA RR/3*0.0, 33.28, 13.56, 5.13, 33.97, 24.18, 10.13, 1.65 /
C
      DATA SA/3*0.0,  1.12,  1.12, 1.12,  1.12,  1.12,  1.12, 1.12 /
      DATA SB/3*0.0,  0.63,  0.50, 0.50,  0.58,  0.52,  0.49, 0.44 /
      DATA SR/3*0.0, 27.58, 11.20, 4.24, 28.14, 19.99,  8.36, 1.36 /
C
C     SUBGRADE SUPPORT VALUES, BY COUNTY NUMBER
C
      DATA SGSUP1/ 3,2,4,5,4,4,4,4,4,1,4,4,4,1,1,1,4,1,3,5,1,2,4,4,2,4,
     + 1,4,5,1,5,3,4,3,4,5,3,4,3,3,2,2,3,4,3,1,2,3,1,1,4,1,1,4,1,4,2,4,
     + 4,5,1,3,4,4,3,4,1,1,1,4,2,2,4,3,3,4,4,4,5,4,4,4,3,4,4,1,4,3,4,4,
     + 1,3,4,3,4,4,1,4,3,5,4,3,4,4,1,4,4,5,1,4,1,4,4,3,3,1,4,2,1,5,3,3/
      DATA SGSUP2/
     + 5,3,5,3,4,5,5,1,4,4,1,1,3,2,5,4,4,4,1,4,4,4,4,4,4,4,4,1,1,4,4,4,
     + 3,3,1,5,3,1,2,5,2,1,2,4,1,1,1,3,4,3,3,4,4,3,3,5,4,4,5,1,4,1,4,1,
     + 4,4,4,4,4,4,1,4,1,5,5,4,4,3,3,4,4,4,5,1,1,3,2,4,4,3,1,4,2,2,2,1,
     + 4,1,2,1,3,4,4,3,1,5,2,3,3,2,1,4,4,3,4,1,3,4,5,4,4,4,5,1,4,2,2,3,
     + 3,3,4,4 /
C
      DO 10 I   = 1, 122
   10 SGRSUP(I) = SGSUP1(I)
C
      DO 15 I         = 1, 132
   15 SGRSUP(122 + I) = SGSUP2(I)
C
C
C     ADJUST RHO FOR SUBGRADE SUPPORT EFFECTS
C
      IF( ID .EQ. 9 ) THEN
          RHOADJ = RHO * PSIADJ(SGRSUP(ICNTY))
          PSIFAC = PSIADJ(SGRSUP(ICNTY))
      ENDIF
      IF( ID .EQ. 6 ) THEN
          RHOADJ = RHO * CRKADJ(SGRSUP(ICNTY))
          CRKFAC = CRKADJ(SGRSUP(ICNTY))
      ENDIF
      IF( ID .EQ. 1 .OR. ID .EQ. 2 ) THEN
          RHOADJ = RHO * RUTADJ(SGRSUP(ICNTY))
          RUTFAC = RUTADJ(SGRSUP(ICNTY))
      ENDIF
C
C     ADJUST RHO FOR THE TRAFFIC EFFECTS ACCORDING TO THE DISTRESS
C     AND THE PAVEMENT TYPE
C
      BETA   = 1.0
C
C     RUTTING: SHALLOW & DEEP
C
      IF( ID .EQ. 1 .OR. ID .EQ. 2 ) THEN
          TRM = (-(RR(IPTYPE)/ESAL)**BETA)
          IF( TRM .GT.  88.0 ) TRM =  88.0
          IF( TRM .LT. -88.0 ) TRM = -88.0
          TRFADJ = RA(IPTYPE) - RB(IPTYPE)*EXP(TRM)
          IF( TRFADJ .LT. 0.83 ) TRFADJ = 0.83
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      ENDIF
C
C     CRACKING: BLOCK & ALLIGATOR
C
      IF( ID .EQ. 6 ) THEN
          TRM = (-(CR(IPTYPE)/ESAL)**BETA)
          IF( TRM .GT.  88.0 ) TRM =  88.0
          IF( TRM .LT. -88.0 ) TRM = -88.0
          TRFADJ = CA(IPTYPE) - CB(IPTYPE)*EXP(TRM)
          IF( TRFADJ .LT. 0.70 ) TRFADJ = 0.70
      ENDIF
C
C     RIDE QUALITY:
C
      IF( ID .EQ. 9 ) THEN
          TRM = (-(SR(IPTYPE)/ESAL)**BETA)
          IF( TRM .GT.  88.0 ) TRM =  88.0
          IF( TRM .LT. -88.0 ) TRM = -88.0
          TRFADJ = SA(IPTYPE) - SB(IPTYPE)*EXP(TRM)
          IF( TRFADJ .LT. 0.94 ) TRFADJ = 0.94
      ENDIF
   20 RHOADJ      = RHOADJ * TRFADJ
      TRFFAC(ID) = TRFADJ
C
      RETURN
      END
C
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