**Prototype Needs Estimating and Project Ranking Software for the TxDOT PMS**

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Research performed in cooperation with the State of Texas.
Research Study Title "Incorporating District Requirements into MICRO-PES"

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.

**Key Words**
Pavement Management Systems, PMS, Needs Estimating, Decision Trees, Ranking

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PROTOTYPE NEEDS ESTIMATING
AND PROJECT RANKING SOFTWARE
FOR THE TxDOT PMS

by

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C. H. Michalak
R. E. Smith

Submitted by
Texas Transportation Institute
Texas A&M University
College Station, Texas 77843

Sponsored by
Texas Department of Transportation

November, 1992
# METRIC (SI*) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

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<tr>
<td>yd³</td>
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**NOTE:** Volumes greater than 1000 L shall be shown in m³.

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

* SI is the symbol for the International System of Measurements
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.

ACKNOWLEDGEMENTS

The work described has been supported by the Pavement Management section of D-8. The work was conducted under the guidance of the TxDOT Pavement Management Steering Committee. Bryan Stampley of D-8 was the project contact; his support and encouragement are greatly appreciated. Many of the concepts proposed were developed in discussions with Bob Briggs, Rob Harris and Bryan Stampley of D-8.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF FIGURES</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vi</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>DESCRIPTION OF MAJOR SUBROUTINES</td>
<td>5</td>
</tr>
<tr>
<td>a. Subroutine AGER</td>
<td>7</td>
</tr>
<tr>
<td>b. Subroutine NDTREE</td>
<td>20</td>
</tr>
<tr>
<td>c. Subroutine SLPMSC</td>
<td>22</td>
</tr>
<tr>
<td>d. Subroutine STAGE</td>
<td>29</td>
</tr>
<tr>
<td>PROTOTYPE MICROCOMPUTER SOFTWARE</td>
<td>31</td>
</tr>
<tr>
<td>CONCLUSIONS AND RECOMMENDATIONS</td>
<td>52</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>54</td>
</tr>
<tr>
<td>APPENDIX A SOURCE CODE LISTING OF PROTOTYPE PMS SOFTWARE</td>
<td>55</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Suggested Cost Category Treatments for Estimating Costs</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Pavement Performance Coefficient for Equation 1,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Used to Project Condition with no Treatments</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Parameters Used in Equation 2 to Generate the Traffic Adjustment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Factor $\chi$</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>Subgrade Support Factors Used Within Equation 1. Factors are</td>
<td></td>
</tr>
<tr>
<td></td>
<td>by County and Based on Average Falling Weight Deflectometer Results</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>$\alpha$, $\beta$, and $\rho$ Coefficients for Distress Utility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equations. Flexible are Pavements Types 4, 5, 6, 9, 10; Composites</td>
<td></td>
</tr>
<tr>
<td></td>
<td>are Pavement Types 7 and 8</td>
<td>16</td>
</tr>
<tr>
<td>6</td>
<td>Ride Utility Coefficients to be used with Equation 4</td>
<td>17</td>
</tr>
<tr>
<td>7</td>
<td>The Output of AGER for a Single Section Showing Predicting Aged</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Condition for 10 Years</td>
<td>19</td>
</tr>
<tr>
<td>8</td>
<td>Impact of Strategies on PSI</td>
<td>23</td>
</tr>
<tr>
<td>9</td>
<td>Pavement Deterioration Factors Used with Equation 1 to Calculate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Levels of Distress After Treatment</td>
<td>24</td>
</tr>
<tr>
<td>10</td>
<td>Cost Per $/sq$ Yard Currently Used in System</td>
<td>27</td>
</tr>
<tr>
<td>11</td>
<td>User Desired Budget Levels in $</td>
<td>28</td>
</tr>
<tr>
<td>12</td>
<td>Pavement Condition as Predicted by AGER Before Repair</td>
<td>30</td>
</tr>
<tr>
<td>13</td>
<td>Pavement Condition with Medium Rehabilitation in Year 5 as</td>
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<tr>
<td></td>
<td>Predicted by STAGE</td>
<td>30</td>
</tr>
<tr>
<td>14</td>
<td>Input Record Format</td>
<td>32</td>
</tr>
<tr>
<td>15</td>
<td>Maintenance Level of Service Guidelines (TxDOT AC 5-92)</td>
<td>46</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flowchart of the Prototype Need Estimating and Ranking Software</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Typical Alligator Cracking and Ride Prediction Curves</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>Decision Trees Flex Pavements Types 4 thru 10</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>Example Calculation of Area Between Repair and Unrepaired UVU Curves</td>
<td>25</td>
</tr>
<tr>
<td>5</td>
<td>Cases in the Benefit Calculation</td>
<td>26</td>
</tr>
<tr>
<td>6</td>
<td>Introductory Screen in Prototype PMS Software</td>
<td>34</td>
</tr>
<tr>
<td>7</td>
<td>Main Menu Screen</td>
<td>35</td>
</tr>
<tr>
<td>8</td>
<td>Input Available Budget Level in $</td>
<td>36</td>
</tr>
<tr>
<td>9</td>
<td>Set Up Screen for Prioritization Procedure</td>
<td>37</td>
</tr>
<tr>
<td>10</td>
<td>Output Option for Prototype PMS Software</td>
<td>39</td>
</tr>
<tr>
<td>11</td>
<td>Listing of Network Level Report Available</td>
<td>40</td>
</tr>
<tr>
<td>12</td>
<td>Example of Network Level of Service Report (Option 1) for Ride</td>
<td>41</td>
</tr>
<tr>
<td>13</td>
<td>Example of Network Level of Service Report (Option 1) for Alligator Cracking</td>
<td>42</td>
</tr>
<tr>
<td>14</td>
<td>Example of Network Level of Service Report (Option 1) for Rutting</td>
<td>43</td>
</tr>
<tr>
<td>15</td>
<td>Example of Network Level Average Score Report (Option 2)</td>
<td>44</td>
</tr>
<tr>
<td>16</td>
<td>Example of Network Level Backlog Report (Option 3)</td>
<td>45</td>
</tr>
<tr>
<td>17</td>
<td>Example of Network Level Work Program Report (Option 4)</td>
<td>48</td>
</tr>
<tr>
<td>18</td>
<td>Example of Project Specific Report Showing the Effect of &quot;Do Nothing&quot; Scenario on Pavement Score</td>
<td>49</td>
</tr>
<tr>
<td>19</td>
<td>Example of Project Report Showing Recommended Decision Tree Treatment (Do Nothing Scenario)</td>
<td>50</td>
</tr>
<tr>
<td>20</td>
<td>Example Project Level Report Showing Influence of Budget on Pavement Condition Using Optimal Solution</td>
<td>51</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>1</th>
<th>2, 3</th>
<th>4, 5, 9</th>
<th>6</th>
<th>10</th>
<th>7, 8</th>
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<tbody>
<tr>
<td>Preventative Maintenance</td>
<td>Joint Seal</td>
<td>Joint Seal</td>
<td>Crack Seal Surface Seal</td>
<td>Crack Seal Surface Seal</td>
<td>Surface Seal</td>
<td>Crack Seal Surface Seal</td>
</tr>
<tr>
<td>Light Rehabilitation</td>
<td>CPR</td>
<td>CPR</td>
<td>Thin Overlay</td>
<td>Thin Overlay</td>
<td>---</td>
<td>Thin Overlay</td>
</tr>
<tr>
<td>Moderate Rehabilitation</td>
<td>Patch &amp; AC Overlay</td>
<td>Patch &amp; AC Overlay</td>
<td>Thick Overlay</td>
<td>Mill &amp; Overlay</td>
<td>Surface Seal with heavy patching</td>
<td>Mill &amp; Overlay</td>
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<tr>
<td>Heavy Rehabilitation or</td>
<td>PCC Overlay</td>
<td>PCC Overlay</td>
<td>Remove AC &amp; Replace Rework Base</td>
<td>Reconstruct</td>
<td>Rework Base and Surface Seal</td>
<td>Remove AC &amp; Replace PCC Base</td>
</tr>
<tr>
<td>Reconstruction</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
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</table>

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:

$$D_N = \alpha \exp \left( -\frac{x\exp \rho}{N} \right)$$  \hspace{1cm} (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 \( ADT \times SPEED > 165,000 \)  \( P_F = 1.50 \)  
  - \( ADT \times SPEED > 27501 \)  \( P_F = 1.0 \)  
  - \( ADT \times SPEED < 27500 \)  \( P_F = 0.5 \)

\( \alpha \) = 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

$\rho$ and $\beta$ = parameter which defined the curve (see actual values in Table 2)
$\chi$ = traffic adjustment factor (Table 3)
$\epsilon$ = climatic adjustment factor
$\sigma$ = 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 $\alpha$, $\beta$ and $\rho$ coefficients, from Equation 1, used to project condition are shown in Table 2. The traffic adjustment factor $\chi$ 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 $\chi$ and subgrade support factors $\sigma$ 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 $\chi$ (chi) is a function of projected 18-kip Equivalent Single Axle Loads and pavement type. The $\chi$ equation takes the sigmoidal form:

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

(2)

where: $\chi$ is the traffic adjustment factor used in Equation 1
A is maximum value of $\chi$
B and $\rho$ 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 $B$ and $\rho$ 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):

<table>
<thead>
<tr>
<th>Coefficient</th>
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<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<tr>
<td>A</td>
<td>1.1800</td>
<td>1.1800</td>
<td>1.1800</td>
<td>1.1800</td>
<td>1.1800</td>
<td>1.1800</td>
<td>1.1800</td>
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<tr>
<td>B</td>
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<td>1.1400</td>
<td>1.1300</td>
<td>1.3400</td>
<td>1.1800</td>
<td>1.0900</td>
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<td>33.2800</td>
<td>13.5600</td>
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</table>

For Cracking (Alligator, Block):

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.3000</td>
<td>1.3000</td>
<td>1.3000</td>
<td>1.3000</td>
<td>1.3000</td>
<td>1.3000</td>
<td>1.3000</td>
</tr>
<tr>
<td>B</td>
<td>3.1600</td>
<td>2.3400</td>
<td>2.3100</td>
<td>2.8400</td>
<td>2.4300</td>
<td>2.2400</td>
<td>1.9200</td>
</tr>
<tr>
<td>$\rho$</td>
<td>37.3500</td>
<td>15.3700</td>
<td>5.8100</td>
<td>38.5300</td>
<td>27.4100</td>
<td>11.4800</td>
<td>1.8700</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.7000</td>
<td>0.7000</td>
<td>0.7000</td>
<td>0.7000</td>
<td>0.7000</td>
<td>0.7000</td>
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</table>

For Ride Quality:

<table>
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<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
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<td>0.5000</td>
<td>0.5000</td>
<td>0.5800</td>
<td>0.5200</td>
<td>0.4900</td>
<td>0.4400</td>
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<tr>
<td>Minimum</td>
<td>0.9400</td>
<td>0.9400</td>
<td>0.9400</td>
<td>0.9400</td>
<td>0.9400</td>
<td>0.9400</td>
<td>0.9400</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>SUBGRADE SUPPORT FACTORS -- ACP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very Good</td>
<td>Rutting 1.80</td>
</tr>
<tr>
<td>2</td>
<td>Good</td>
<td>Rutting 1.61</td>
</tr>
<tr>
<td>3</td>
<td>Fair</td>
<td>Rutting 1.42</td>
</tr>
<tr>
<td>4</td>
<td>Poor</td>
<td>Rutting 1.21</td>
</tr>
<tr>
<td>5</td>
<td>Very Poor</td>
<td>Rutting 1.00</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>DISTRICT</th>
<th>COUNTY NO.</th>
<th>COUNTY NAME</th>
<th>SUBGRADE SUPPORT</th>
<th>σ</th>
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<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>Delta</td>
<td>5</td>
<td>Rutting 1.00</td>
</tr>
<tr>
<td>1</td>
<td>75</td>
<td>Fannin</td>
<td>3</td>
<td>Rutting 1.42</td>
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<tr>
<td>1</td>
<td>81</td>
<td>Franklin</td>
<td>4</td>
<td>Rutting 1.21</td>
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<tr>
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<td>92</td>
<td>Grayson</td>
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<td>Rutting 1.80</td>
</tr>
<tr>
<td>1</td>
<td>113</td>
<td>Hopkins</td>
<td>4</td>
<td>Rutting 1.21</td>
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<tr>
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<td>Rutting 1.80</td>
</tr>
<tr>
<td>1</td>
<td>139</td>
<td>Lamar</td>
<td>4</td>
<td>Rutting 1.21</td>
</tr>
<tr>
<td>1</td>
<td>190</td>
<td>Rains</td>
<td>4</td>
<td>Rutting 1.21</td>
</tr>
<tr>
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<td>Red River</td>
<td>4</td>
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<tr>
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<td>73</td>
<td>Erath</td>
<td>2</td>
<td>Rutting 1.61</td>
</tr>
<tr>
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<td>112</td>
<td>Hood</td>
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<td>Rutting 1.80</td>
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<td>Jack</td>
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<td>Rutting 1.80</td>
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</tr>
<tr>
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<td>184</td>
<td>Parker</td>
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<td>Rutting 1.80</td>
</tr>
<tr>
<td>2</td>
<td>213</td>
<td>Somervell</td>
<td>1</td>
<td>Rutting 1.80</td>
</tr>
<tr>
<td>2</td>
<td>220</td>
<td>Tarrant</td>
<td>1</td>
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<tr>
<td>2</td>
<td>249</td>
<td>Wise</td>
<td>2</td>
<td>Rutting 1.61</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>Archer</td>
<td>4</td>
<td>Rutting 1.21</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>Baylor</td>
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<tr>
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<td>39</td>
<td>Clay</td>
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</tr>
<tr>
<td>3</td>
<td>49</td>
<td>Cooke</td>
<td>1</td>
<td>Rutting 1.80</td>
</tr>
<tr>
<td>3</td>
<td>169</td>
<td>Montague</td>
<td>1</td>
<td>Rutting 1.80</td>
</tr>
<tr>
<td>3</td>
<td>224</td>
<td>Throckmorton</td>
<td>4</td>
<td>Rutting 1.21</td>
</tr>
<tr>
<td>3</td>
<td>243</td>
<td>Wichita</td>
<td>4</td>
<td>Rutting 1.21</td>
</tr>
<tr>
<td>3</td>
<td>244</td>
<td>Wilbarger</td>
<td>4</td>
<td>Rutting 1.21</td>
</tr>
<tr>
<td>3</td>
<td>252</td>
<td>Young</td>
<td>3</td>
<td>Rutting 1.42</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Armstrong</td>
<td>4</td>
<td>Rutting 1.21</td>
</tr>
<tr>
<td>4</td>
<td>33</td>
<td>Carson</td>
<td>4</td>
<td>Rutting 1.21</td>
</tr>
<tr>
<td>4</td>
<td>56</td>
<td>Dallam</td>
<td>4</td>
<td>Rutting 1.21</td>
</tr>
<tr>
<td>4</td>
<td>59</td>
<td>Deaf Smith</td>
<td>4</td>
<td>Rutting 1.21</td>
</tr>
</tbody>
</table>
Currently the environmental factor \( e \) 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 RH0 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

\[
UVU = [U_\text{r}* U_\text{b}* U_\text{p}* U_\text{a}* U_\text{d}* U_\text{t}]*100
\]

where

- \( U_\text{r} \) is the utility value for rutting
- \( U_\text{b} \) 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.

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

where

- \( U_i \) is the utility value for distress \( i \)
- \( \alpha, \beta \{\text{and}} \rho \{\text{are}} \ CONSTANTS \{\text{obtained \ from \ Table \ 5}}
- \( N \) is the value of distress (e.g. for rutting \( N = \% \) of section with rutting, for failures \( N = \text{number of failures} \))

15
Table 5. $\alpha$, $\beta$, and $\rho$ Coefficients for Distress Utility Equations. Flexible are Pavements Types 4, 5, 6, 9, 10; Composites are Pavement Types 7 and 8.

<table>
<thead>
<tr>
<th>DISTRESS</th>
<th>Flexible</th>
<th>Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\alpha$</td>
<td>$\beta$</td>
</tr>
<tr>
<td>Shallow Rutting</td>
<td>0.3100</td>
<td>1.0000</td>
</tr>
<tr>
<td>Deep Rutting</td>
<td>0.6900</td>
<td>1.0000</td>
</tr>
<tr>
<td>Patching</td>
<td>0.4500</td>
<td>1.0000</td>
</tr>
<tr>
<td>Failures</td>
<td>1.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>Block Crk.</td>
<td>0.4900</td>
<td>1.0000</td>
</tr>
<tr>
<td>Allig. Crk.</td>
<td>0.5300</td>
<td>1.0000</td>
</tr>
<tr>
<td>Long. Crk.</td>
<td>0.8700</td>
<td>1.0000</td>
</tr>
<tr>
<td>Trans Crk.</td>
<td>0.6900</td>
<td>1.0000</td>
</tr>
</tbody>
</table>
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.

\[ U_{RUTTING} = U_{R-\text{SHALLOW}} + U_{R-\text{DEEP}} - 1 \] (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"):

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

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

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

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

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

where the SI is the measured pavement serviceability index (range 0 to 5.0). The α, β 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.

<table>
<thead>
<tr>
<th>ADT*Speed Limit</th>
<th>α</th>
<th>β</th>
<th>ρ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-27,500</td>
<td>1.8180</td>
<td>1.0000</td>
<td>58.5000</td>
</tr>
<tr>
<td>27,501-165,000</td>
<td>1.7600</td>
<td>1.0000</td>
<td>48.1000</td>
</tr>
<tr>
<td>165,001+</td>
<td>1.7300</td>
<td>1.0000</td>
<td>41.0000</td>
</tr>
</tbody>
</table>
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.

<table>
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<th>Section ID</th>
<th>Section Info</th>
<th>Traffic</th>
<th>1</th>
<th>2</th>
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<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>UVU</th>
<th>SI</th>
<th>Ride Utility</th>
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<td>+55505502018</td>
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<td>85</td>
<td>11</td>
<td>0.093</td>
<td>2.154</td>
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</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Functional Class</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low ADT/Lane &lt;</td>
<td>.7500</td>
<td>7500</td>
<td>-7500</td>
<td>3000</td>
<td>2000</td>
<td>2000</td>
<td>2000</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Change in Serviceability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+0.5 (max = 4.2)</td>
</tr>
<tr>
<td>2</td>
<td>+1.0 (max = 4.2)</td>
</tr>
<tr>
<td>3</td>
<td>Set to 4.2</td>
</tr>
<tr>
<td>4</td>
<td>Set to 4.2</td>
</tr>
</tbody>
</table>

2) For each cost category, the pavement is then deteriorated using Equation 1 with the $\alpha$, $\beta$ and $\rho$ 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.

<table>
<thead>
<tr>
<th>Distress</th>
<th>Prev. Maint. (PM)</th>
<th>Light Rehab (LRhb)</th>
<th>Medium Rehab (MRhb)</th>
<th>Heavy Rehab/Reconstruction (HRhb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>α</td>
<td>β</td>
<td>ρ</td>
<td>α</td>
</tr>
<tr>
<td>Rutting, Shallow</td>
<td>100</td>
<td>4.5</td>
<td>5.0</td>
<td>100</td>
</tr>
<tr>
<td>Rutting, Deep</td>
<td>100</td>
<td>2.47</td>
<td>6.78</td>
<td>100</td>
</tr>
<tr>
<td>Failures</td>
<td>20</td>
<td>2.17</td>
<td>5.5</td>
<td>20</td>
</tr>
<tr>
<td>Allig. Crk.</td>
<td>100</td>
<td>3.38</td>
<td>6.5</td>
<td>100</td>
</tr>
<tr>
<td>Block Crk.</td>
<td>100</td>
<td>2.51</td>
<td>7.08</td>
<td>100</td>
</tr>
<tr>
<td>Long Crk.</td>
<td>500</td>
<td>0.81</td>
<td>8.39</td>
<td>500</td>
</tr>
<tr>
<td>Trans. Crk.</td>
<td>20</td>
<td>1.94</td>
<td>5.57</td>
<td>20</td>
</tr>
<tr>
<td>Ride Quality</td>
<td>1.000</td>
<td>2.000</td>
<td>3.2000</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

Note: There are no performance curves for patching.

<table>
<thead>
<tr>
<th>Distress</th>
<th>Medium Rehab (MRhb)</th>
<th>Heavy Rehab/Reconstruction (HRhb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>α</td>
<td>β</td>
</tr>
<tr>
<td>Rutting, Shallow</td>
<td>100</td>
<td>2.67</td>
</tr>
<tr>
<td>Rutting, Deep</td>
<td>100</td>
<td>1.33</td>
</tr>
<tr>
<td>Failures</td>
<td>20</td>
<td>1.34</td>
</tr>
<tr>
<td>Allig. Crk.</td>
<td>100</td>
<td>1.75</td>
</tr>
<tr>
<td>Block Crk.</td>
<td>100</td>
<td>1.45</td>
</tr>
<tr>
<td>Long Crk.</td>
<td>500</td>
<td>1.78</td>
</tr>
<tr>
<td>Trans. Crk.</td>
<td>20</td>
<td>2.36</td>
</tr>
<tr>
<td>Ride Quality</td>
<td>1.000</td>
<td>2.000</td>
</tr>
</tbody>
</table>

Note: There are no performance curves for patching.
Figure 4. Example Calculation of Area Between Repaired and Unrepaired UVU Curves.
CASES IN BENEFIT CALCULATION

I. A Above Minimum

II. A Below Minimum

III. A and B Above Minimum

IV. Utility at 1.0 (No Benefit)

V. A and B Below Minimum (No Benefit)

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.

Cost and Budget Level

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.

<table>
<thead>
<tr>
<th>Pav. Type</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strat 1</td>
<td>0.95</td>
<td>0.95</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
<td>0.90</td>
<td>0.75</td>
</tr>
<tr>
<td>Strat 2</td>
<td>2.00</td>
<td>2.00</td>
<td>1.50</td>
<td>1.75</td>
<td>1.75</td>
<td>1.75</td>
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<tr>
<td>Strat 3</td>
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<td>5.50</td>
<td>4.00</td>
<td>4.50</td>
<td>4.50</td>
<td>4.50</td>
<td>3.20</td>
</tr>
<tr>
<td>Strat 4</td>
<td>11.0</td>
<td>8.00</td>
<td>7.50</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
<td>7.50</td>
</tr>
</tbody>
</table>

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 $.

<table>
<thead>
<tr>
<th>Year</th>
<th>$ Available</th>
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<tbody>
<tr>
<td>1</td>
<td>5,000,000.00</td>
</tr>
<tr>
<td>2</td>
<td>5,000,000.00</td>
</tr>
<tr>
<td>3</td>
<td>2,000,000.00</td>
</tr>
<tr>
<td>4</td>
<td>5,000,000.00</td>
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<tr>
<td>5</td>
<td>10,000,000.00</td>
</tr>
<tr>
<td>6</td>
<td>5,000,000.00</td>
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<tr>
<td>7</td>
<td>7,000,000.00</td>
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<tr>
<td>8</td>
<td>8,000,000.00</td>
</tr>
<tr>
<td>9</td>
<td>3,000,000.00</td>
</tr>
<tr>
<td>10</td>
<td>5,000,000.00</td>
</tr>
</tbody>
</table>

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 $\alpha$, $\beta$, and $\rho$ 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.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>RUT SHLW</th>
<th>RUT CRACK</th>
<th>BLOCK CRACK</th>
<th>PATCH FAILR</th>
<th>ALGR CRACK</th>
<th>LONG CRACK</th>
<th>TRAN CRACK</th>
<th>UVU</th>
<th>RIDE</th>
<th>SIU</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>15</td>
<td>0</td>
<td>1</td>
<td>.594</td>
<td>4.100</td>
</tr>
<tr>
<td>1</td>
<td>18</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>19</td>
<td>0</td>
<td>2</td>
<td>.533</td>
<td>3.718</td>
<td>1.000</td>
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<tr>
<td>2</td>
<td>20</td>
<td>0</td>
<td>5</td>
<td>2</td>
<td>23</td>
<td>0</td>
<td>3</td>
<td>.428</td>
<td>3.332</td>
<td>1.000</td>
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<td>3</td>
<td>37</td>
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<td>10</td>
<td>2</td>
<td>27</td>
<td>2</td>
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<tr>
<td>4</td>
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<td>15</td>
<td>1</td>
<td>31</td>
<td>9</td>
<td>5</td>
<td>.317</td>
<td>2.693</td>
<td>0.984</td>
</tr>
<tr>
<td>5</td>
<td>52</td>
<td>1</td>
<td>15</td>
<td>2</td>
<td>34</td>
<td>18</td>
<td>6</td>
<td>.258</td>
<td>2.449</td>
<td>0.872</td>
</tr>
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<td>6</td>
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<td>20</td>
<td>1</td>
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<td>30</td>
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<td>1.832</td>
<td>0.409</td>
</tr>
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<td>10</td>
<td>76</td>
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<td>30</td>
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<td>85</td>
<td>11</td>
<td>.086</td>
<td>1.737</td>
<td>0.438</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>YEAR</th>
<th>RUT SHLW</th>
<th>RUT CRACK</th>
<th>BLOCK CRACK</th>
<th>PATCH FAILR</th>
<th>ALGR CRACK</th>
<th>LONG CRACK</th>
<th>TRAN CRACK</th>
<th>UVU</th>
<th>RIDE</th>
<th>SIU</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>3.718</td>
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<td>0.635</td>
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<td>10</td>
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<td>85</td>
<td>11</td>
<td>.086</td>
<td>1.737</td>
<td>0.438</td>
</tr>
</tbody>
</table>

**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.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Alpha (N)umeric</th>
<th>Columns</th>
<th>Decimal Places</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
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<td>N</td>
<td>1-2</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>County Number</td>
<td>N</td>
<td>3-5</td>
<td></td>
<td>170</td>
</tr>
<tr>
<td>Highway Prefix</td>
<td>A</td>
<td>6-7</td>
<td></td>
<td>FM</td>
</tr>
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<td>0149</td>
</tr>
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<td></td>
<td>5</td>
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</tr>
<tr>
<td>Lane</td>
<td>A</td>
<td>29</td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>% Shallow Ruts</td>
<td>N</td>
<td>31-33</td>
<td></td>
<td>010</td>
</tr>
<tr>
<td>% Deep Ruts</td>
<td>N</td>
<td>34-36</td>
<td></td>
<td>000</td>
</tr>
<tr>
<td>% Block Cr</td>
<td>N</td>
<td>37-39</td>
<td></td>
<td>025</td>
</tr>
<tr>
<td>% Patching</td>
<td>N</td>
<td>40-42</td>
<td></td>
<td>005</td>
</tr>
<tr>
<td># Failures</td>
<td>N</td>
<td>43-45</td>
<td></td>
<td>000</td>
</tr>
<tr>
<td>% Alligator Cr</td>
<td>N</td>
<td>46-48</td>
<td></td>
<td>000</td>
</tr>
<tr>
<td>Length Longitudinal Cr</td>
<td>N</td>
<td>49-51</td>
<td></td>
<td>200</td>
</tr>
<tr>
<td># Transverse Cr</td>
<td>N</td>
<td>52-54</td>
<td></td>
<td>001</td>
</tr>
<tr>
<td>Ride (SI)</td>
<td>N</td>
<td>55-56</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>Speed (MPH)</td>
<td>N</td>
<td>62-63</td>
<td></td>
<td>55</td>
</tr>
<tr>
<td>Pavement Type</td>
<td>N</td>
<td>64-65</td>
<td></td>
<td>05</td>
</tr>
<tr>
<td>Functional Class</td>
<td>N</td>
<td>66</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Number of Lanes</td>
<td>N</td>
<td>67-68</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Surface Width (ft)</td>
<td>N</td>
<td>69-71</td>
<td></td>
<td>38</td>
</tr>
<tr>
<td>AADT</td>
<td>N</td>
<td>72-77</td>
<td></td>
<td>005920</td>
</tr>
<tr>
<td>20-Year 18kixp ('000)</td>
<td>N</td>
<td>78-82</td>
<td></td>
<td>06721</td>
</tr>
<tr>
<td>Section Length (miles)</td>
<td>N</td>
<td>83-84</td>
<td>1</td>
<td>20</td>
</tr>
</tbody>
</table>
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 (GER, 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 formatted 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

33
Figure 6. Introductory Screen in Prototype PMS Software.
Figure 7. Main Menu Screen.
<table>
<thead>
<tr>
<th>YEAR</th>
<th>$ AVAILABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50000.00</td>
</tr>
<tr>
<td>2</td>
<td>50000.00</td>
</tr>
<tr>
<td>3</td>
<td>50000.00</td>
</tr>
<tr>
<td>4</td>
<td>50000.00</td>
</tr>
<tr>
<td>5</td>
<td>100000.00</td>
</tr>
<tr>
<td>6</td>
<td>50000.00</td>
</tr>
<tr>
<td>7</td>
<td>50000.00</td>
</tr>
<tr>
<td>8</td>
<td>50000.00</td>
</tr>
<tr>
<td>9</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>0.00</td>
</tr>
</tbody>
</table>

PRESS "ENTER" TO CONTINUE

ENTER THE BUDGET AMOUNT FOR THIS BUDGET YEAR

Figure 8. Input Available Budget Level in $. 
MULTI-YEAR COST ESTIMATING
AND
PRIORITIZATION PROCEDURE

ANALYSIS CONTROL VARIABLES

FILEIN - THE NAME OF THE INPUT DATA FILE

NYEARS - NUMBER OF YEARS IN THE ANALYSIS PERIOD-----→16

SDATE - STARTING DATE OF THE ANALYSIS, (MNYR)-----→
(EX: JAN 91; 0191)

USE ▲▼ ARROWS TO MOVE TO THE FIELD AND ENTER YOUR DATA
PRESS "ESC" TO CORRECT AN ERROR

PRESS "ENTER" TO CONTINUE

ENTER THE NAME OF THE INPUT DATA FILE (UP TO 32 ALPHANUMERIC CHARS.)

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.
MULTI-YEAR COST ESTIMATING
AND
PRIORITIZATION PROCEDURE

OUTPUT CONTROL VARIABLES

1. PROJECT REPORTS
2. NETWORK REPORTS
3. RETURN TO MAIN MENU

ENTER 1 OR 2 OR 3 TO
SPECIFY YOUR OPTION

PRESS "ESC" TO CORRECT AN ERROR
PRESS "ENTER" TO CONTINUE

ENTER 1 OR 2 OR 3 FOR YOUR OPTION

Figure 10. Output Option for Prototype PMS Software.
MULTI-YEAR COST ESTIMATING AND PRIORITIZATION PROCEDURE

OUTPUT CONTROL VARIABLES

NETWORK REPORTS

1. LEVEL OF SERVICE
2. AVERAGE SCORES
3. BACKLOG MILES
4. WORK PROGRAM

ENTER 1, 2, 3 OR 4

PRESS "ESC" TO CORRECT AN ERROR

PRESS "ENTER" TO CONTINUE

ENTER 1, 2, 3, OR 4 FOR THE NETWORK REPORT DESIRED

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).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Desirable Level (Highest)</th>
<th>Acceptable Level (Priority 1)</th>
<th>Tolerable Level (Priority 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal Rutting</td>
<td>Maintain as follows:</td>
<td>Maintain as follows:</td>
<td>Maintain as follows:</td>
</tr>
<tr>
<td>0 - 500 ADT</td>
<td>&lt; ³⁄₄&quot; &amp; &lt; 25% per wheel path</td>
<td>&lt; ¹⁄₄&quot; &amp; &lt; 50% per wheel path</td>
<td>&lt; 1&quot; &amp; ≤ 50 % per wheel path</td>
</tr>
<tr>
<td>501-10,000 ADT</td>
<td>&lt; ¹⁄₄&quot; &amp; &lt; 25% per wheel path</td>
<td>&lt; ¹⁄₄&quot; &amp; &lt; 50% per wheel path</td>
<td>&lt; 1&quot; &amp; ≤ 50 % per wheel path</td>
</tr>
<tr>
<td>10,001 &amp; up ADT</td>
<td>&lt; ³⁄₄&quot; &amp; &lt; 25% per wheel path</td>
<td>&lt; 1&quot; &amp; 25% per wheel path</td>
<td>&lt; 1&quot; &amp; ≤ 50 % per wheel path</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>Maintain with no visible cracks</td>
<td>Maintain with visible cracks</td>
<td>Maintain with visible cracks</td>
</tr>
<tr>
<td>For all ADT's</td>
<td>(Priority 1)</td>
<td>≤ 10% per wheel path</td>
<td>≤ 50% per wheel path</td>
</tr>
<tr>
<td>Ride Quality</td>
<td>Maintain as follows:</td>
<td>Maintain as follows:</td>
<td>Maintain as follows:</td>
</tr>
<tr>
<td>0 - 500 ADT</td>
<td>...... &gt; 2.5 SI</td>
<td>...... &gt; 2.0 SI</td>
<td>...... &lt; 1.5 SI</td>
</tr>
<tr>
<td>501-10,000 ADT</td>
<td>...... &gt; 3.0 SI</td>
<td>...... &gt; 2.5 SI</td>
<td>...... &lt; 2.0 SI</td>
</tr>
<tr>
<td>10,001 &amp; up ADT</td>
<td>...... &gt; 3.5 SI</td>
<td>...... &gt; 3.0 SI</td>
<td>...... &lt; 2.5 SI</td>
</tr>
</tbody>
</table>

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 critical level 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.
<table>
<thead>
<tr>
<th>YEAR</th>
<th>DISTRICT</th>
<th>COUNTY</th>
<th>HIGHWAY</th>
<th>REFERENCE MARKERS FROM TO</th>
<th>TREATMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>170</td>
<td>FM0149</td>
<td>0440 +00 0442 +00</td>
<td>PM</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
<td>170</td>
<td>FM0149</td>
<td>0450 +00 0452 +00</td>
<td>PM</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>170</td>
<td>FM0149</td>
<td>0454 +00 0456 +00</td>
<td>LRhb</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>170</td>
<td>FM0149</td>
<td>0446 +00 0448 +00</td>
<td>PM</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>170</td>
<td>FM0149</td>
<td>0442 +00 0444 +00</td>
<td>LRhb</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>170</td>
<td>FM0149</td>
<td>0440 +00 0442 +00</td>
<td>MRhb</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>170</td>
<td>FM0149</td>
<td>0444 +00 0446 +00</td>
<td>LRhb</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>170</td>
<td>FM0149</td>
<td>0448 +00 0450 +00</td>
<td>HRhb</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>170</td>
<td>FM0149</td>
<td>0450 +00 0452 +00</td>
<td>MRhb</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>170</td>
<td>FM0149</td>
<td>0452 +00 0454 +00</td>
<td>LRhb</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>170</td>
<td>FM0149</td>
<td>0446 +00 0448 +00</td>
<td>MRhb</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>170</td>
<td>FM0149</td>
<td>0454 +00 0456 +00</td>
<td>PM</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
<td>170</td>
<td>FM0149</td>
<td>0442 +00 0444 +00</td>
<td>PM</td>
</tr>
</tbody>
</table>

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 $\log_{10} (\text{AADT})$ 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


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

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

PROGRAM TO READ PAVEMENT CONDITION AND RIDE DATA FROM THE PMIS DATABASE
AND USE PAVEMENT PERFORMANCE CURVES TO PREDICT THE DISTRESS AND RIDE
SCORES FOR A SECTION FOR THE NUMBER OF YEARS IN THE ANALYSIS PERIOD
(NYEARS) AND CREATE AN OUTPUT FILE OF THE PREDICTED DISTRESS AND RIDE
SCORES TO BE USED FOR THE MAINTENANCE FUND BUDGET OPTIMIZATION

>>>>>>>> PROGRAM AGER <<<<<<<<

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

CHARACTER DATA1*29, DATA2*23, FILEIN*32, FILLER*5
CHARACTER BEG*3, BEGX(3), ENDH

INTEGER*4 AGEDIS, CALDIS, DISTRS, FAIL, PAT

DIMENSION AGEDIS(9,10), CALDIS(10), DISTRS(9), DSA(10)
DIMENSION AGEDUT(9,10), UV(9)

EQUIVALENCE (BEG, BEGX)

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)

INITIALIZE THE MARKERS

BEGX(1) = CHAR(19)
BEGX(2) = CHAR(255)
BEGX(3) = CHAR(1)
ENDH = CHAR(1)

DISPLAY AGESCRN.AID

WRITE(*,*) BEG,'USE,AGERSCRN.AID',ENDH
WRITE(*,*) BEG,'DISPLAY,NYEARS,=',NYEARS,ENDH

INITIALIZE REHAB ACTION AND FUND REQUIREMENTS

NSEC = 0
FILLER = ',

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')

READ THE ADJUSTMENT FACTORS
SKIP THE TREATMENT COST TABLE, AND RATE OF GAIN TABLE

DO 5 IS = 1, 15
 5 READ(3,102)

READ THE SUBGRADE SUPPORT VALUES

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 )

READ THE PAVEMENT PERFORMANCE CURVE COEFFICIENTS
ALPHA, BETA, AND RHO FOR THE PAVEMENT DISTRESSES

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 )

READ THE PMIS PAVEMENT CONDITION DATABASE FILE

10 READ(1,605,END=990) DATA1, (DISTRSC(I),I=1,8), SI, DATA2, ISPEED,
  ICTYPE, IFC, IADT, ESAL, ICHTY
605 FORMAT( A29, 1X, 8I3, F2.1,5X,A23, T62, 2I2,11,5X,16,F5.3,T3,13)

CHECK FOR FLEXIBLE PAVEMENTS ONLY

IF( ICTYPE .LT. 4 .OR. ICTYPE .GT. 10 ) GO TO 10

NSEC = NSEC + 1

AGE THE INITIAL DISTRESS SCORES AND CALCULATE THE DISTRESS UTILITY
SCORES AND CALCULATE THE UVU SCORE FROM THE DISTRESS AND SI DATA

ADJUST THE INITIAL FAILURE AND SET THE INITIAL PATCHING SCORE

FAIL = DISTRSC(5)

CALL ADJDIS ( FAIL, PAT )

DISTRSC(4) = PAT
DISTRSC(5) = FAIL

SI0 = SI

AGE EACH DISTRESS SCORE FOR THE NUMBER OF YEARS DESIRED

FIND THE SI(min) VALUE TO USE

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
SET IS = 4 TO USE THE STRATEGY 4 BETAS & RHOS FOR INITIAL AGEING
SET IYA = 1 TO AGE THE INITIAL DISTRESS SCORES FOR NYEARS
C
IS
   = 4
IYA
   = 1
DIST R S(9) = SI
C
DO 25 ID = 1, 9
DSI = DIST R S(ID)
C
CALL DISAGE( ID, DSI, SI, DSA )
C
DO 20 IT = 1, NYEARS
20 AGEDIS(ID,IT) = DSA(IT)
25 CONTINUE
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( DISTS, SI, UV )
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
WRITE THE INITIAL DISTRESS SCORES TO THE OUTPUT FILE
C
WRITE(2,610) DATA1, DATA2, (DISTS(I),I=1,8), UVU, SI,
+ UV(9), FILLER
WRITE(4,610) DATA1, DATA2, (DISTS(I),I=1,8), UVU, SI,
+ UV(9), FILLER
610 FORMAT( A29, A23, B15, 3F6.3, A5 )
C
CALCULATE THE PREDICTED UTILITY SCORES FROM THE PREDICTED DISTRESS
SCORES. CALCULATE THE UVU FOR THE PREDICTED UTILITY SCORES AND
WRITE THE PREDICTED DISTRESS AND UTILITY SCORES TO THE OUTPUT FILE
C
DO 39 IT = 1, NYEARS
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), AGERUC,
            + 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
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
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

59
DIMENSION DAL(8), DBT(8), DRO(8), DCAL(8), DCBT(8), DCR(8)
DIMENSION UV(9)

CURVE COEFFICIENTS FOR THE DISTRESS UTILITY CURVES

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/

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/

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/

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/

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/

COMP RHO S.R. D.R. BLCK PTCH FAIL ALGR LONG TRAN
DATA DCR/ 17.55, 9.04, 15.79, 17.28, 4.70, 18.77, 136.9, 9.56/

CALCULATE THE DISTRESS UTILITY VALUES

IF( IPTYPE .EQ. 7 .OR. IPTYPE .EQ. 8 ) THEN
  DO 5 I = 1, 8
    IF( DISTR(I) .EQ. 0 ) THEN
      UV(I) = 1.0
      GO TO 5

    TRM = (-1.0/((DCR(I)/DISTR(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) = -DCR(I)/ALOG((1.-UV(I))/DCAL(I))
    5 CONTINUE

ELSE

  DO 15 I = 1, 8
    IF( DISTR(I) .EQ. 0 ) THEN
      UV(I) = 1.0
      GO TO 15

    TRM = (-1.0/((DRO(I)/DISTR(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

ENDIF

CALCULATE THE RIDE UTILITY VALUE

ICASE = IADT*ISPEED
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  
SUBROUTINE DISAGE( ID, DSI, SI, DSA )  
C  
USE THE PAVEMENT PERFORMANCE CURVES FOR THE HEAVY REHAB/RECON-  
STRUCTION MAINTENANCE LEVEL TO PREDICT THE DISTRESS AND RIDE  
SCORES FOR THE NUMBER OF YEARS IN THE ANALYSIS PERIOD  
C  
COMMON/UTV/ IADT, ICASE, ISPEED  
COMMON/AGE/ SIA(10), PSIMIN  
COMMON/AOJ/ ESAL, ICHMY, ITYPE  
COMMON/BRO/ IS, IYA  
COMMON/DAG/ DAL(4,9), DBT(4,9), DRO(4,9)  
C
DIMENSION DSA(10)

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 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 ADJRHOC( ID, DRO(IS,ID), RHoadj )

C CALCULATE THE PREDICTED PSI VALUES

C IF( ID .EQ. 9 ) THEN
    IF( SI .GE. 4.5 ) THEN
        PIT = 0.1
        GO TO 11
    ENDF
    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
    ENDF

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
    ENDF
    ITC = ITC + 1
    T1 = 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 CALCULATE THE PREDICTED DISTRESS VALUES FOR ALL OTHER DISTRESS

C IF( DSI .EQ. 0.0 ) THEN
    TO = 0.1

62
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
C
IF( DSI .GT. 0.95*DAL(IS,ID) ) THEN
   DSA(IT) = 0.95*DAL(IS,ID)
   GO TO 20
ENDIF

ITC = ITC + 1
T1 = TO + FLOAT(ITC)
T4 = (- (RHOADJ/T1)**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
SUBROUTINE ADJRHO( ID, RHO, RHOADJ )
C
ADJUST THE RHO CURVE COEFFICIENT FOR CLIMATE, SUBGRADE, AND TRAFFIC
EFFECTS FOR RUTTING, BLOCK AND ALLIGATOR CRACKING, AND RIDE
C
COMMON/ADJR/ ESAL, ICTY, 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
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, 26.14, 19.99, 8.36, 1.36 /
C
SUBGRADE SUPPORT VALUES, BY COUNTY NUMBER
C
DATA SGSUP1/ 3,2,4,5,4,4,4,4,1,4,4,1,1,4,1,1,4,1,3,5,1,2,4,4,2,4,
+ 1,4,5,1,5,3,4,3,4,5,3,4,3,2,2,3,4,3,1,2,3,1,1,4,1,4,1,2,4,4,4, + 4,5,1,3,4,4,3,4,1,1,1,4,2,2,4,3,4,4,5,4,4,4,3,4,4,4,1,4,3,4,4, + 1,3,4,6,4,1,4,3,5,4,3,4,1,4,4,4,5,1,4,1,4,3,3,1,4,2,1,5,3,3/ 
DATA SGSUP2/
+ 5,3,5,4,5,5,1,4,4,1,1,3,2,5,4,4,1,4,4,4,4,4,4,1,4,4,4,1,4,4,4, + 3,1,5,3,1,2,5,2,1,2,4,1,1,1,3,4,3,3,4,4,3,5,4,4,3,5,4,5,1,4,1,4,1, + 4,4,6,4,4,4,1,4,1,5,5,4,4,3,4,4,5,1,1,3,2,4,4,3,1,4,2,2,2,1, + 4,1,2,1,3,4,4,3,1,5,2,3,3,2,1,4,3,3,4,1,3,4,5,4,4,5,1,4,2,2,3, + 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
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
ADJUST RHO FOR THE TRAFFIC EFFECTS ACCORDING TO THE DISTRESS
AND THE PAVEMENT TYPE
C
BETA = 1.0
C
RUTTING: SHALLOW & DEEP
C
IF( ID .EQ. 1 .OR. ID .EQ. 2 ) THEN
  TRM = (- (R2(IPTYPE)/ESAL)**BETA)
  IF( TRM .GT. 88.0 ) TRM = 88.0
  IF( TRM .LT. -88.0 ) TRM = -88.0
  TRFADJ = RA(IPTYPE) - RC(IPTYPE)*EXP(TRM)
  IF( TRFADJ .LT. 0.83 ) TRFADJ = 0.83
ENDIF
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
RIDE QUALITY:
C
IF( ID .EQ. 9 ) THEN
  TRM = (- (SR(IPTYPE)/ESAL)**BETA)

64
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
SUBROUTINE NDTREE

***************************************************************************
  DECISION TREE PROGRAM TO ASSIGN THE MAINTENANCE LEVEL FOR A PAVEMENT
  SECTION BASED ON THE CONDITION OF THE PAVEMENT AT A GIVEN TIME. THE
  MAINTENANCE LEVEL ASSIGNED IS ALSO BASED ON THE ADT AND THE
  FUNCTIONAL CLASS OF THE PAVEMENT SECTION. THE DECISION TREES WERE
  DEVELOPED BY TX DOT PERSONNEL.

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

COMMON/CON/ IYR, NSEC, NYEARS

CHARACTER ALPH1*31, ALPH2*3, ALPH3*7, ALPH5*6, ALPH6*6
CHARACTER BEG*3, BEGX(3), ENDH, FILL2*2, FILLER*5
INTEGER ALG, BLK, FAIL, LNG, RUTD, RUTS, PAT, TRN

EQUIVALENCE (BEG, BEGX)

INITIALIZE THE MARKERS

FILLER = ' ', FILL2 = ' '

BEGX(1) = CHAR(19)
BEGX(2) = CHAR(255)
BEGX(3) = CHAR(1)
ENDH = CHAR(1)

DISPLAY NDECSCRN.AID

IYR = 1
NYEARS = 10
NSEC = 1

WRITE(*,*) BEG,'USE,OPTSCRN.AID',ENDH
WRITE(*,*) BEG,'DISPLAY,IYR,=',IYR,ENDH
WRITE(*,*) BEG,'DISPLAY,MYEARS,=',NYEARS,ENDH
WRITE(*,*) BEG,'DISPLAY,NSEC,=',NSEC,ENDH

OPENUNIT=10,FILE='FILE1.OUT',STATUS='UNKNOWN'

START OF THE CALCULATION LOOP

DO 900 IYR=1,NSEC

KNT = 1
WRITE(*,*) BEG,'DISPLAY,KNT,=',KNT,ENDH

ISTR=0

SKIP THE NUMBER OF RECORDS TO GET THE CORRECT RECORD FOR THE YEAR

DO 20 JX = 1, IYR
   READ(10,*)
20   CONTINUE
READ THE RECORD FOR THE YEAR OF INTEREST

READ(10,210)ALPH1,NPVMT,NFUNC,NML,ALPH2,NADT,ALPH3,RUTS,RUTD,
*  BLK,PAT,FAIL,ALG,LNG,TRN,ALPH5,PSI,ALPH6,
+  FILLER

210 FORMAT(A31,12,11,12,A3,16,A7, B15, A6, F6.3, A6, A5)

C

STRATEGY 4 (HEAVY REHAB/RECONSTRUCTION)

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

STRATEGY 3 (MEDIUM REHABILITATION)

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

STRATEGY 2 (LIGHT REHABILITATION)

IF( NFUNC .EQ. 4 ) NHI = 3000
IF( NFUNC .GE. 5 .AND. NFUNC .LE. 10 ) NHI = 2000

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

STRATEGY 1 (PREVENTATIVE MAINTENENCE)

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 )  
101 CONTINUE

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,WPVMT,NFUNC,NML,ALPH2,NADT,ALPH3,RUTS,RUTD,
    *     BLK,PAT,FAIL,ALG,LNG,TRN,ALPH5,PSI,ALPH6,ISTR,
    +     FILL2
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   PROGRAM TO APPLY THE MAINTENANCE TREATMENT TO A PAVEMENT SECTION
C   AT A GIVEN YEAR, COMPUTE THE BENEFIT OF THE TREATMENT, COMPUTE
C   THE COST/BENEFIT RATIO, RANK THE SECTIONS FROM LARGEST TO SMALLEST
C   COST/BENEFIT RATIO, AND OPTIMIZE THE MAINTENANCE FUNDS FOR
C   THE YEAR BY SELECTING THE SECTIONS WITH THE LARGEST COST/BENEFIT RATIOS UNTIL THE FUNDS ARE USED UP
C
C******************************************************************************
C
C   >>>>>>>>> PROGRAM SLPMSC <<<<<<<<
C
C******************************************************************************
C
REAL CR(4,10)
INTEGER*4 CALDIS(9), FAIL, ORGDIS, PAT
C
DIMENSION DSA(10), UV(10)
DIMENSION ORGUVU(10), TRDUT(9,10), TRTUVU(10)
DIMENSION ORGDIS(9,10), SIO(10), SIORUT(10), TRTDIS(9,10)
DIMENSION COST(300), CSR(300), IFLAG(300), INDX(300)
C
COMMON/AGE/ TRSITU(10), PSIMIN
COMMON/ADJ/ ESAL, ICNTY, ICTYPE
COMMON/BEG/ ISTR1, IYA
COMMON/CON/ IYR, NSEC, NYEARS
COMMON/DAG/ DADJ(4,9), DBT(4,9), DRO(4,9)
COMMON/SUP/ CRKADJ(5), PSIAJ(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
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='DISADJFAC.DAT',STATUS='UNKNOWN')
OPEN(UNIT=14,FILE='BUDGET.DAT',STATUS='UNKNOWN')
C
READ THE BUDGET DATA FILE
SKIP THE COLUMN HEADINGS AND THE UNWANTED YEARS
C
DO 8 JX = 1, IYR
  8 READ(14,208)
C
READ THE BUDGET DATA FILE FOR THE YEAR OF INTEREST
READ(14,208) M YEARS, BG T AMT
208 FORMAT( 15, F15.2 )

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)

DO 11 IJ = 1, 6
11 READ(11,205)

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 )

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)

20 CONTINUE

READ THE FILE TO SEE IF MAINTENANCE SHOULD BE APPLIED TO THIS
SECTION FOR THE YEAR BEING CONSIDERED

START OF THE CALCULATION LOOP

DO 900 JS = 1, NSEC
KNT = JS

COST(JS) = 0.0
CBR(JS) = 0.0
IFLAG(JS) = 0
INDX(JS) = 0

WRITE(***,*) BEG, 'DISPLAY,KNT=',KNT,ENDH

SKIP THE RECORDS BEFORE THE RECORD OF INTEREST

DO 22 JX = 1, IYR

70
22 READ(10,*)
C
C READ THE RECORD OF INTEREST
C
C BENFIT = 0.0
C
C READ(10,200) IDIST, ICNTY, DATA1, ISPEED, IPYTYPE, DATA2, L1,
+ IADT, IESAL, L2, (ORGDIS(IU,IYR)),IU=1,8),
+ ORGUUVU(IYR), SIO(IYR), SIORUT(IYR), ISTR1, FILLER
200 FORMAT( 12,15, A24, 212, A3, 13, 16, 15, 12, 815, 3F6.3,
+ 13, A2 )
C
C READ THE ORIGONAL UVU AND SI UTILITY SCORES FROM THE ORIGONAL
C CURVE FOR THE REMAINING YEARS FOR THE SECTION
C
C IF( IYR .EQ. 10 ) GO TO 26
DO 25 JX = IYR+1, NYEARS
25 READ(10,202) ORGUUVU(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
C IF( ISTR1 .EQ. 0 ) GO TO 900
C
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
56 SIM = SIO(IYR)
IF( SIM .GT. 4.2 ) SIM = 4.2
GO TO 59
C
57 SIM = SIO(IYR) + 0.5
IF( SIM .GT. 4.2 ) SIM = 4.2
GO TO 59
C
58 SIM = 4.2
C
59 CONTINUE
C
ICASE = IADT*ISPEED
C
71
CALL DISAGE TO PREDICT THE ORIGINAL DISTRESS SCORES FROM THE YEAR THE
MAINTENANCE WAS APPLIED TO NYEARS TO GET THE TREATED DISTRESS SCORES

DO 61 ID = 1, 9
   DSI   = ORGDIS(ID, IYR)

CALL DISAGE(ID, DSI, SIM, DSA)

DO 60 IT = IYA, NYEARS
   TRTDIS(ID, IT) = DSA(IT)
   CONTINUE

ADJUST THE TREATED FAILURES AND SET THE TREATED PATCHING SCORES

DO 63 IT = IYA, NYEARS
   FAIL = TRTDIS(5, IT)

CALL ADJUST(FAIL, PAT)
   TRTDIS(4, IT) = PAT
   TRTDIS(5, IT) = FAIL

CALCULATE THE TREATED UTILITY SCORES FROM THE TREATED DISTRESS SCORES

CALCULATE THE TREATED UVU FROM THE TREATED UTILITY SCORES

   IYA = IYR
   DO 79 IT = IYA, NYEARS

USE THE TREATED DISTRESS SCORES

   DO 76 ID = 1, 9
   CALDIS(ID) = TRTDIS(ID, IT)
    SII   = SIM
   CALL UTVAL(CALDIS, SII, UV)

DO 78 ID = 1, 9
   TRTDUT(ID, IT) = UV(ID)
   TRTSIU(IT)   = UV(9)
   CONTINUE

CALCULATE THE UVU FOR THE TREATED UTILITY SCORES

   IYA = IYR

   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)
   CONTINUE

CALCULATE THE BENEFIT OF THE TREATMENT, THE COST/BENEFIT RATIO,
AND RANK THE SECTIONS BY SORTING ON COST/BENEFIT RATIO

CALL UTBEN(IYA, NYEARS, ORGlVU, TRTVU, BNFTUT)
CALL SIBEN(IYA, NYEARS, SIGRT, TRTSIU, BNFTSI)

BENEFIT = BNFTUT + BNFTSI
CALCULATE THE COST OF THE PROJECT & COST BENEFIT RATIO

\[
\text{COST}(JS) = L1 \times L2 \times CR(ISTR1, IPTYPE) \times (1760/3.)/10.
\]
\[
\text{CBR}(JS) = \text{BENEFIT/COST}(JS)
\]

900 CONTINUE

END OF THE CALCULATION LOOP FOR THE YEAR OF INTEREST
SORT THE COST BENEFIT RATIOS FROM LARGEST TO SMALLEST

CALL SORTIT( NSEC, CBR, INDX )

SET THE FEASIBILITY FLAG TO ZERO INITIALLY (INFEASIBLE)

DO 85 IF = 1, NSEC

85 IFLAG(IF) = 0

SELECT SECTIONS TO FIX UP STARTING WITH THE LARGEST COST BENEFIT RATIO'S UNTIL THE BUDGET HAS BEEN USED UP

TCOST = 0.0

DO 88 JS = 1, NSEC

TCOST = TCOST + COST(INDX(JS))

IF( TCOST .GE. BGMT ) GO TO 88

IF( COST(INDX(JS)) .EQ. 0.0 ) GO TO 88

SET THE FEASIBILITY FLAG TO 1 IF THE SECTION WAS SELECTED

IFLAG(INDX(JS)) = 1

88 CONTINUE

RE-READ THE FILE AND WRITE THE RANKINGS

REWIND (UNIT=10)

DO 95 I = 1, NSEC

KNT = I

WRITE(*,*) BEG,'DISPLAY,KNT,=',KNT,ENDH

SKIP THE UNWANTED RECORDS

DO 90 JX = 1, IYR

90 READ(10,*)

READ THE RECORD OF INTEREST

READ(10,200) IDIST, ICNTY, DATA1, ISPEED, IPTYPE, DATA2, L1, + IADT, IESAL, L2, (ORQDIS(IU,IYR),IU=1,8), + ORGUV(IYR), SIO(IYR), SIGRUT(IYR), ISTR1, FILLER

BACKSPACE 10

WRITE THE UPDATED RECORD WITH THE MAINTENANCE FEASIBILITY FLAG

WRITE(10,210) IDIST, ICNTY, DATA1, ISPEED, IPTYPE, DATA2, L1, + IADT, IESAL, L2, (ORQDIS(IU,IYR),IU=1,8),
+ ORGUVU(IYR), SIOU(IYR), SICORUT(IYR), ISTR1, IFLAG(I)
210 FORMAT( 12,13, A24, 212, A3, I3, I6, I5, I2, B15, 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, INDEX )
C
C******************************************************************************
C SUBROUTINE SORTS HIGHWAYS IN ACCENDING ORDER ACCORDING TO EFF. BEN.
C Order of ascending benefit saved in index, array order is unchanged
C******************************************************************************
C
   DIMENSION CBR(300), INDEX(300)
C
C
   IF( NSEC .EQ. 1 ) GO TO 40
C
   DO 10 J=1,NSEC
      INDEX(J)=J
   10 CONTINUE
   L=NSEC/2+1
   IR=NSEC
   20 CONTINUE
      IF(L.GT.1)THEN
L=L-1
INDX=INDX(L)
Q=CBR(INDX)
ELSE
   INDX=INDX(IR)
   Q=CBR(INDX)
   INDX(IR)=INDX(1)
   IR=IR+1
IF(IR.EQ.1)THEN
   INDX(1)=INDX
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)=INDX
GO TO 20
C
40 CONTINUE
C
RETURN
END
C
SUBROUTINE UTBEN( IYA, NYEARS, ORGUVU, TRTUVU, BNFTUT )
C
CALCULATE THE ADDED UTILITY BENEFIT OF A MAINTENANCE LEVEL
C
DIMENSION ORGUVU(300), TRTUVU(300)
C
BNFTUT = 0.0
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
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
CONTINUE

NAREAS = I - I

CALCULATE & SUM THE AREAS

SUMA = 0.0
IA = 0
DO 20 IF = 1, NAREAS
IF( TRUVU(I+IA).LT.0.5 ) TRUVU(I+IA) = 0.5
IF( ORGUVU(I+IA).LT.0.5 ) ORGUVU(I+IA) = 0.5
IF( TRUVU(I+IA+1).LT.0.5 ) TRUVU(I+IA+1) = 0.5
IF( ORGUVU(I+IA+1).LT.0.5 ) ORGUVU(I+IA+1) = 0.5

AVGTRT = (TRUVU(I+IA) + TRUVU(I+IA+1))/2.
AVGUVU = (ORGUVU(I+IA) + ORGUVU(I+IA+1))/2.
AREA = (AVGTRT - AVGUVU) * 1.0
SUMA = SUMA + AREA
20 IA = IA + 1

BNFTUT = SUMA

RETURN
END

SUBROUTINE SIBRM( I, NYER, SORUT, TRTSIU, BNFTSI )

CALCULATE THE ADDED SI BENEFIT OF THE MAINTENANCE LEVEL

DIMENSION SORUT(300), TRTSIU(300)

BNFTSI = 0.0

FIND THE CASE. USE 0.5 AS THE MINIMUM SI UTILITY SCORE

IF( SORUT(I) .GT. 0.5 .AND. SORUT(NYER) .LE. 0.5 ) ICASE = 1
IF( SORUT(I) .LE. 0.5 .AND. TRTSIU(I) .GT. 0.5 ) ICASE = 2
IF( SORUT(I) .GT. 0.5 .AND. SORUT(NYER) .GT. 0.5 ) ICASE = 3
IF( SORUT(I) .LE. 0.5 .AND. TRTSIU(I) .LE. 0.5 ) ICASE = 4
IF( SORUT(I) .EQ. 1.0 .AND. SORUT(NYER) .EQ. 1.0 ) ICASE = 5

IF( ICASE .GE. 4 ) RETURN

FIND THE NUMBER OF AREAS UNDER THE SI UTILITY CURVE WITH SI UTILITY > 0.5

DO 10 IA = I, NYER
IF( TRTSIU(I) .LE. 0.5 ) GO TO 15
10 CONTINUE

NAREAS = I - I

CALCULATE & SUM THE AREAS

SUMA = 0.0
IA = 0
DO 20 IF = 1, NAREAS
IF( TRTSIU(I+IA) .LT. 0.5 ) TRTSIU(I+IA) = 0.5
IF( SORUT(I+IA) .LT. 0.5 ) SORUT(I+IA) = 0.5
IF( TRTSIU(I+IA+1) .LT. 0.5 ) TRTSIU(I+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.
AVGUUVU = (SIORUT(IYA+IA) + SIORUT(IYA+IA+1))/2.
AREA = (AVGTRT - AVGUUVU) * 1.0
SUMA = SUMA + AREA
20 IA = IA + 1
C
BNFTSI = SUMA
C
C
RETURN
END
SUBROUTINE STAGE

C*****************************************************************************C
C PROGRAM TO APPLY A MAINTENANCE LEVEL AT A GIVEN YEAR, AND TO
C PREDICT THE PAVEMENT CONDITION ACCORDING TO THE MAINTENANCE
C APPLIED TO THE END OF THE SPECIFIED TIME PERIOD
C
C >>>>>>>>> SUBROUTINE STAGE <<<<<<<<<
C
C*****************************************************************************C
C CHARACTER BEG*3, BEGX(3), ENDH
C CHARACTER DATA1*24, DATA2*6, DATA3*2
C CHARACTER FILL*2
C INTEGER*4 AGEDIS, CALDIS, FAIL, PAT
C
C DIMENSION AGEDIS(9,10), AGEDUT(9,10), UV(9)
C DIMENSION CALDIS(10), DSA(10)
C
C COMMON/CON/ IYR, NSEC, NYEARS
C COMMON/UTV/ IADT, ICASE, ISPEED
C COMMON/AGE/ SIA(10), PSIMIN
C COMMON/ADJ/ ESAL, ICNTY, IPTYPE
C COMMON/FAC/ CRKFAC, PSIIFAC, RUTFAC, TRFFAC(9)
C COMMON/BRO/ ISTR1, IYA
C COMMON/SUP/ CRKADJ(5), PSIADJ(5), RUTADJ(5)
C COMMON/DAG/ DAL(4,9), DBT(4,9), DRO(4,9)
C
C EQUIVALENCE (BEQG, BEGX)
C
C INITIALIZE THE MARKERS
C
C BEGX(1) = CHAR(19)
C BEGX(2) = CHAR(255)
C BEGX(3) = CHAR(1)
C ENDH = CHAR(1)
C
C FILL = ' '
C
C OPEN(UNIT=1,FILE='FILE1.OUT',STATUS='UNKNOWN')
C OPEN(UNIT=3,FILE='DISADIFAC.DAT')
C
C READ THE ADJUSTMENT FACTOR FILE
C
C SKIP THE TREATMENT COST TABLE & RATE OF GAIN TABLE
C
C DO 1 IS = 1, 12
C 1 READ(3,102)
C
C 102 FORMAT( 8X, 9F7.4 )
C
C READ THE SUBGRADE SUPPORT VALUES
C
C READ(3,104) (RUTADJ(I),I=1,5), (CRKADJ(I),I=1,5),
C +(PSIADJ(I),I=1,5)
C 104 FORMAT( /// 8X, 5F7.4/ 8X, 5F7.4/ 8X, 5F7.4 )
C
C READ THE PAVEMENT PERFORMANCE CURVE COEFFICIENTS
C
C
READ(3,*)
READ(3,*)
READ(3,*)
DO 16 K = 1, 4
16 READ(3,102) (DAL(K,1),I=1,9)
READ(3,*)
READ(3,*)
DO 17 K = 1, 4
17 READ(3,102) (OBT(K,1),I=1,9)
READ(3,*)
READ(3,*)
DO 18 K = 1, 4
18 READ(3,102) (DRO(K,1),I=1,9)
C
C
10 CONTINUE
C
START OF THE CALCULATION LOOP
C
DO 900 JS = 1, NSEC
KNT = JS
C
WRITE(*,*) BEG,'DISPLAY',KNT,='',KNT,'END
C
SKIP THE RECORDS PRIOR TO THE YEAR OF INTEREST
C
DO 20 JX = 1, IYR
20 READ(1,*)
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(12,13, A24, 212, A6, 16, 15, A2, B15, 3F6.3,
  + 13, 12 )
C
CHECK TO SEE IF MAINTENANCE IS TO BE APPLIED THIS YEAR
C
IF( ISTR1 .EQ. 0 .OR. IFLAG .EQ. 0 ) THEN
C
DO NOTHING. NO MAINTENANCE WAS APPLIED
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
APPLY THE MAINTENANCE 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 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 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 SET THE INITIAL SI SCORE FOR THE YEAR SELECTED
C SIM = SIA(IYR)
ICASE = IADT*ISPEED
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
50 AGEDIS(ID,IT) = DSA(IT)
60 CONTINUE
C ADJUST THE PREDICTED FAILURES AND SET THE PREDICTED PATCHING SCORES
C DO 63 IT = IYA, NYEARS
C FAIL = AGEDIS(5,IT)
C CALL STAJS( FAIL, PAT )
C AGEDIS(4,IT) = PAT
63 AGEDIS(5,IT) = FAIL
C CALCULATE THE PREDICTED DISTRESS UTILITY SCORES FROM THE PREDICTED
C DISTRESS SCORES. CALCULATE THE UVU FOR THE PREDICTED DISTRESS
C UTILITY SCORES

80
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
WRITE THE NEW DISTRESS UTILITY SCORES FOR THE MAINTENANCE APPLIED
FOR THE YEAR OF THE MAINTENANCE
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
WRITE THE PREDICTED DISTRESS UTILITY SCORES FOR THE MAINTENANCE
APPLIED FROM THE YEAR OF MAINTENENCE TO NYEARS
C
DO 80 IT = IYA, NYEARS
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( I2,13, A24, 212, A6, 16, 19, A2, B13, 3F6.3, 13, 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
IF( FAIL .LE. 2 ) RETURN

10 IF( FAIL .GT. 2 ) THEN
   FAIL = FAIL - 2
   PAT = PAT + 5
ENDIF

IF( FAIL .GT. 2 ) GO TO 10

RETURN
END

SUBROUTINE STUTVL( DISTS, SI, UV )

USE THE S-SHAPED DISTRESS UTILITY CURVES TO CONVERT THE DISTRESS
AND RIDE SCORES INTO DISTRESS UTILITY SCORES IN THE RANGE 0 TO 1

INTEGER*4 DISTS(9)

COMMON/ADJ/ ESAL, ICNTY, IPTYPE
COMMON/BRO/ IS, IYA
COMMON/UTLV/ IADT, ICASE, ISPEED

DIMENSION DAL(8), DBT(8), DRO(8), DCAL(8), DCBT(8), DCRO(8)
DIMENSION UV(9)

FLEX ALPHA S.R. D.R. BLCK PITCH FAIL ALGR LONG TRAN
DATA DAL/ 0.31, 0.69, 0.49, 0.45, 1.00, 0.53, 0.87, 0.69/

FLEX BETA S.R. D.R. BLCK PITCH FAIL ALGR LONG TRAN
DATA DBT/ 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00/

FLEX RHO S.R. D.R. BLCK PITCH FAIL ALGR LONG TRAN
DATA DRO/ 19.72, 16.27, 9.78, 10.15, 4.70, 8.01, 104.0, 10.39/

COMP ALPHA S.R. D.R. BLCK PITCH FAIL ALGR LONG TRAN
DATA DCAL/ 0.23, 0.32, 0.31, 0.32, 1.00, 0.42, 0.37, 0.43/

COMP BETA S.R. D.R. BLCK PITCH FAIL ALGR LONG TRAN
DATA DCBT/ 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00/

COMP RHO S.R. D.R. BLCK PITCH FAIL ALGR LONG TRAN
DATA DCRO/ 17.55, 9.04, 13.79, 17.28, 4.70, 18.77, 136.9, 9.56/

CALCULATE THE DISTRESS UTILITY SCORES

IF( IPTYPE .EQ. 7 .OR. IPTYPE .EQ. 8 ) THEN
   DO 5 I = 1, 8
      IF( DISTS(I) .EQ. 0 ) THEN
         UV(I) = 1.0
      GO TO 5
ENDIF

TRM = (-DCRO(I)/DISTS(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

        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
         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

SUBROUTINE STDAGE( ID, DSI, SI, DSA )

USE THE PAVEMENT PERFORMANCE CURVES FOR THE MAINTENANCE LEVEL
APPLIED AND TYPE OF PAVEMENT TO PREDICT THE DISTRESS SCORES AND
THE RIDE SCORE FOR THE SPECIFIED NUMBER OF YEARS

COMMON/UTV/IADT, ICASE, ISPEED
COMMON/AGE/ SIA(10), PSIMIN
COMMON/ADJ/ ESAL, ICNTY, Iptype
COMMON/BRO/ IS, IYA
COMMON/DADE/ DAL(4,9), DBT(4,9), DRO(4,9)

DIMENSION DSA(10)

SET A DEFAULT SCORE FOR PATCHING

IF( ID .EQ. 4 ) THEN
  DO 10 IT = IYA, 10
    10      DSA(IT) = DSI
  RETURN
ENDIF

ADJUST THE RHO VALUES FOR BLOCK AND ALLIGATOR CRACKING, RUTTING,
AND PSI FOR THE SUBGRADE SUPPORT EFFECTS AND THE TRAFFIC EFFECTS

RHOADJ = DRO(IS,ID)

IF(ID.EQ.1 .OR. ID.EQ.2 .OR. ID.EQ.6 .OR. ID.EQ.9 )
  + CALL STARH0( ID, DRO(IS,ID), RHOADJ )
C
C
CALCULATE THE PREDICTED PSI VALUES

IF( ID .EQ. 9 ) THEN
  IF( SI .GE. 4.5 ) THEN
    PIT = 0.1
    GO TO 11
  ENDFI
  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
  ENDFI

  TO = RHOADJ/((-ALOG(PIT/DAL(IS,ID))))**(1.0/DBT(IS,ID))
C
12 ITC = 0
  DO 15 IT = IYA, 10
    IF INITIAL PSI < 1.5, SET AGED PSI TO 1.5
    IF( SI .LT. 1.5 ) THEN
      SIA(IT) = 1.5
      GO TO 15
  ENDFI
ITC = ITC + 1
T1 = T0 + FLOAT(ITC)
T4 = (-RHOADJ/T1)**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)

15 DSA(IT) = SIA(IT)
RETURN
ENDIF

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
C
ITC = ITC + 1
T1 = T0 + FLOAT(ITC)
T4 = (-RHOADJ/T1)**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)
CONTINUE
C
RETURN
END

C SUBROUTINE STARHO( ID, RHO, RHOADJ )
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/ CRKFAO, PSIADJ, RUTFAO, TRFFAC(9)
C INTEGER*2 SQSUP(122), SSGSUP2(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

85
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, 2.51, 2.84, 2.43, 2.24, 1.92 /
DATA CR/3*0.0, 37.35, 15.97, 5.81, 38.53, 27.41, 11.48, 1.67 /
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, 0.65, 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
SUBGRADE SUPPORT VALUES, BY COUNTY NUMBER
C
DATA SSGSUP/ 3,2,4,5,4,4,4,1,4,4,4,1,1,1,1,4,1,3,5,1,2,4,4,2,4,
+ 1,4,5,1,5,3,4,3,4,5,3,4,3,2,2,3,4,3,1,2,3,1,1,4,1,1,4,1,2,2,4,
+ 4,5,1,3,4,4,3,4,1,1,1,2,4,3,3,4,4,5,4,4,4,3,4,4,1,4,3,4,4,
+ 1,3,4,3,4,4,4,3,5,4,3,4,4,1,4,5,5,1,4,1,4,3,3,1,4,2,1,5,3,3/
DATA SSGSUP2/
+ 5,3,5,3,4,5,5,4,4,1,1,3,2,5,4,4,4,1,4,4,4,4,4,4,4,4,4,4,4,4,
+ 3,5,1,5,3,1,2,5,2,1,2,4,1,1,1,3,4,3,4,3,5,4,4,5,1,4,1,4,4,1,
+ 4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,1,3,2,4,4,3,1,4,4,2,2,4,1,
+ 4,1,2,1,3,4,4,3,1,5,2,3,3,2,1,4,4,3,4,1,3,5,4,4,4,5,1,4,2,2,3,
+ 3,5,3,4,4 /
C
DO 10 I = 1, 122
10 SGRSUP(I) = SSGSUP(I)
C
DO 15 I = 1, 132
15 SGRSUP(122 + I) = SSGSUP2(I)
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
ADJUST RHO FOR THE TRAFFIC EFFECTS ACCORDING TO THE DISTRESS
C AND THE PAVEMENT TYPE
C
BETA = 1.0
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. 0.05 ) TRFADJ = 0.85
86
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