EFFECTS OF TRUCK WEIGHTS ON PAVEMENT DETERIORATION

by

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Texas Transportation Institute

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<td>Calculation of Rigid Pavement Damage Breakdown Illinois Models - Texas Weighting Factors (Pavement Input data in Table F-8)</td>
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<td>Calculation of Rigid Pavement Damage Breakdown Illinois Models - Washington Weighting Factors (Pavement Input data in Table F-8)</td>
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<td>F-14</td>
<td>Predicted Rigid Pavement damage breakdown for the State of Kansas</td>
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<td>F-15</td>
<td>Predicted Rigid Pavement damage breakdown for the State of Washington</td>
<td></td>
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<td>Predicted Rigid Pavement Damage Breakdown for the State of Texas</td>
<td></td>
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<td></td>
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<td>F-18</td>
<td>Calculated Average Weighting Factors</td>
<td></td>
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<td>F-19</td>
<td>Climatic Data used to input to Illinois J.R.C.P. models</td>
<td></td>
</tr>
<tr>
<td>Table</td>
<td>Description</td>
<td>Page</td>
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</tr>
</tbody>
</table>

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CHAPTER I
INTRODUCTION

This report describes the results of a study of damage which occurs to pavements in the United States due to a variety of causes which can be classified into three categories: traffic loads, climate, and a combination of the two. One of the immediate causes of interest in this study is the public debate that is being carried on at present concerning the equitable distribution of the costs of maintenance, repair, and rehabilitation of pavements which have reached the end of their useful service life.

There are several variations of the two major theories of cost allocation that are being considered at present, one of which is termed the incremental cost theory and the other is called the consumption theory. At the risk of oversimplification, a brief outline of these two theories is discussed here.

INCREMENTAL COST THEORY

The incremental cost theory is based upon the pavement design equations that were developed at the AASHO Road Test, and was presented in a paper by Duzan, Oehmann, and Davis in TRB Special Report 61E which is a record of the proceedings of a conference held in 1962 in St. Louis. The pavement design equation is of the form

\[ g = \left( \frac{R W}{\rho} \right)^{\beta} \]  \hspace{1cm} (1)

where \( g \) = the damage function which begins at 0 when the serviceability index is \( P_i \) and approaches 1.0 as the serviceability index approaches 1.5.
or \[ g = \frac{P_1 - P}{P_1 - 1.5} \]  

\( P_1 \) = the initial serviceability index  
\( P \) = the present serviceability index  
\( 1.5 \) = the terminal serviceability index at which test sections were taken out of the Road Test  
\( W \) = the number of 18-kip (80 kN) equivalent single axle loads that have passed when the serviceability index reaches its present value, \( P \).  
\( \rho \) = a constant that depends upon load level and the structural design of the pavement. Numerically, \( \rho \) is equal to the number of 18-kip equivalent single axle loads that reduced the serviceability index to its terminal value at the AASHO Road Test.  
\( R \) = the "regional factor" which was intended to account for the effect of climate factors that are different from those at the AASHO Road Test where, by definition, the "regional factor" was set at 1.0.  
\( \beta \) = a power which also depends upon load level and design but in a different way than does the constant, \( \rho \).  

This form of equation was assumed to apply equally to flexible and rigid pavements and the constants were determined by regression analysis upon the observed results of the AASHO Road Test. The structural design of flexible pavements was characterized by a "structural number" SN, which is given by  
\[ SN = a_1D_1 + a_2D_2 + a_3D_3 + \cdots \]  \( a_1 \), \( a_2 \), and \( a_3 \) are constants determined by regression analysis.
where $a_1$, $a_2$, $a_3$ = the structural coefficients of the surface, base, and subbase layers used at the AASHO Road Test. These numbers were found to be 0.44, 0.14, and 0.11, respectively.

and $D_1$, $D_2$, $D_3$ = the depth of the surface, base, and subbase layers, in inches.

In rigid pavements, the structural number was the depth of the concrete surface layer, $D$, in inches.

The incremental cost theory was applied as follows:

1. First, a pavement was designed to last for 20 years to carry the expected passenger vehicle traffic. This resulted in layer thicknesses $D_1$, $D_2$, and $D_3$. The cost of this new pavement, $C_1$, was to be paid for by the passenger traffic.

2. Secondly, the pavement was re-designed to last for 20 years to carry passenger vehicles plus the lightest category of trucks. This gave new values of layer thicknesses, and a new total cost, $C_2$. The difference in the cost of the two pavements, $C_1-C_2$, was to be paid for by the new increment of truck traffic.

3. Thirdly, a redesign for all previous traffic plus the next heavier category of trucks produced a new cost, $C_3$, the increment of which, $C_3-C_2$, was to be paid by this next heavier category of traffic.

4. All load categories were applied in sequence and the incremental costs were borne by the load category that caused the increase.

In this way, pavement construction costs were associated with the load levels that occasioned the costs. When these pavements reached the end of
their service lives, and were in need of further expenditures for maintenance and rehabilitation, another theory of cost allocation was suggested.

CONSUMPTION COST THEORY

Simply stated, the consumption theory of cost allocation holds that the costs of pavement repair, maintenance, and rehabilitation should be paid by each load category based upon the amount of damage that it does. As simple as it is to state, it is difficult to apply because of the multiple causes of pavement damage.

If it is assumed that all damage is measured by the serviceability index and that the AASHO Road Test design equations completely describe the causes of that damage, then it can be shown that

for flexible pavements,

\[ N = N_0 \left( \frac{2P_0 + L}{2P + L} \right)^{4.79} g \left( \frac{1}{\beta} - \frac{1}{\beta_0} \right) \]  \hspace{1cm} (8)

where

\[ \beta = 0.4 + \frac{0.081 \left( 2P + L \right)^{3.23}}{(SN+1)^{5.19} L^{3.23}} \]  \hspace{1cm} (9)

\( L = 1 \) if single axle, 2 if tandem axle
SN = the structural number of the pavement
\( g = (4.2 - p_t)/(2.7) \)
\( p_t \) = selected terminal serviceability index

and for rigid pavements

\[ N = N_0 \left( \frac{2P_0 + L}{2P + L} \right)^{4.62} g \left( \frac{1}{\beta} - \frac{1}{\beta_0} \right) \]  \hspace{1cm} (10)
where

\[ y = 1.0 + \frac{3.63(2P + L)^{5.20}}{(D + L)L^{5.20}} \]  

\( P_0 \) = standard wheel load
\( N_0 \) = number of passes of \( P_0 \) to reduce the serviceability index to a terminal value, \( p_t \)
\( g = (4.5 - p_t)/(3.0) \)
\( D \) = depth of pavement, inches.

In either pavement, the damage varies roughly as the fourth power of axle load.

If, on the other hand, it is assumed that the costs of repair, maintenance, and rehabilitation are occasioned by distress as well as by riding quality, the way in which costs are allocated must by reconsidered, especially if some types of distress which motivate the decision to maintain a pavement are independent of load, as in the case of thermal cracking.

A study was made of state pavement condition rating systems which are used to compute a pavement rating score which, in turn, is used to rank pavement sections in a priority scale. The sections of pavement with the lower scores receive a higher priority when funding becomes available for maintenance or rehabilitation projects. Because of this fact, and because a number of types of distress and serviceability index are included in the overall rating, it appears that costs are occasioned by a multiplicity of factors. As a consequence, an application of the consumption theory which reflects reality will necessarily be more complicated than the use of the AASHO Road Test design equations. Appendix L documents methods that are
used by various states to determine pavement rating scores. These weighting schemes were studied on a state-by-state basis to determine approximate percentages of the total "damage" that is done to a pavement that may be ascribed to loads. The procedure that was used in this study is described in Chapter III and Appendix C.
REFERENCES


CHAPTER II
CLASSIFICATION OF PAVEMENT DAMAGE

The causes of pavement distress can be classified roughly as due to load, climate, or a combination of the two but this classification does not take into account the actual interaction of load and climatic effects. In an ongoing study of environmental effects for the Federal Highway Administration, a combined team of the University of Illinois and Texas A&M University classified the causes of distress into the following categories:

Load-related distress, (L)
Combined distress with environment passive, (EP)
Combined distress with environment active, (EA)
Combined distress with aging active, (AA)
Environmental distress, (E)

That study pointed out that no pavement distress occurs due to load alone and that the remaining four are what have been called load (EP), combined (EA, AA), and environmental distress (E) in this report. In that project, each of the types of distress that are contained in the FHWA Report, "Highway Pavement Distress Identification Manual" (1), was classified according to the L, EP, EA, AA, and E scheme noted above. They will be repeated below and will be used in the remainder of this report. Distress types which have L and/or EP-causes alone are classified as load related, those which have E-causes are classified as climatically related, and all of the rest are classified as combined distress in this study. Loss of serviceability index is also classified as combined distress.
### TABLE 1. JOINTED CONCRETE PAVEMENT DISTRESS CLASSIFICATION

<table>
<thead>
<tr>
<th>Distress No.</th>
<th>Distress</th>
<th>Causes of Distress (FHWA Project)</th>
<th>Classification in this Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Blow up</td>
<td>E</td>
<td>Climatic</td>
</tr>
<tr>
<td>2</td>
<td>Corner cracking</td>
<td>L, EP, EA</td>
<td>Combined</td>
</tr>
<tr>
<td>3</td>
<td>Corner spalling</td>
<td>L, E</td>
<td>Combined</td>
</tr>
<tr>
<td>4</td>
<td>Depression</td>
<td>L, E</td>
<td>Combined</td>
</tr>
<tr>
<td>5</td>
<td>Durability Cracking</td>
<td>E</td>
<td>Climatic</td>
</tr>
<tr>
<td>6</td>
<td>Faulting</td>
<td>L, EA, E</td>
<td>Combined</td>
</tr>
<tr>
<td>7</td>
<td>Joint Failure</td>
<td>EP, EA, E</td>
<td>Combined</td>
</tr>
<tr>
<td>8</td>
<td>Lane/Shoulder Dropoff</td>
<td>L, E</td>
<td>Combined</td>
</tr>
<tr>
<td>9</td>
<td>Potholes</td>
<td>L, E</td>
<td>Combined</td>
</tr>
<tr>
<td>10</td>
<td>Longitudinal Cracking</td>
<td>L, EP, EA, E</td>
<td>Combined</td>
</tr>
<tr>
<td>11</td>
<td>Joint/Crack Spalling</td>
<td>L, E</td>
<td>Combined</td>
</tr>
<tr>
<td>12</td>
<td>Popouts</td>
<td>L, EA</td>
<td>Combined</td>
</tr>
<tr>
<td>13</td>
<td>Random Cracking</td>
<td>L, E</td>
<td>Combined</td>
</tr>
<tr>
<td>14</td>
<td>Scaling and Crazing</td>
<td>L, E</td>
<td>Combined</td>
</tr>
<tr>
<td>15</td>
<td>Second Stage Cracking</td>
<td>L, EP, EA, E</td>
<td>Combined</td>
</tr>
<tr>
<td>16</td>
<td>Swell</td>
<td>E</td>
<td>Climatic</td>
</tr>
<tr>
<td>17</td>
<td>Transverse and Diagonal Cracking</td>
<td>EP, EA, E</td>
<td>Combined</td>
</tr>
<tr>
<td>18</td>
<td>Shattered Slab</td>
<td>L, EP, EA</td>
<td>Combined</td>
</tr>
</tbody>
</table>

*Note:* no load only
<table>
<thead>
<tr>
<th>Distress No.</th>
<th>Distress</th>
<th>Causes of Distress (FHWA Project)</th>
<th>Classification in this Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Blow-up</td>
<td>E</td>
<td>Climatic</td>
</tr>
<tr>
<td>2</td>
<td>Depression</td>
<td>L, E</td>
<td>Combined</td>
</tr>
<tr>
<td>3</td>
<td>Durability Cracking</td>
<td>E</td>
<td>Climatic</td>
</tr>
<tr>
<td>4</td>
<td>Edge Punchout</td>
<td>L, EP, EA</td>
<td>Combined</td>
</tr>
<tr>
<td>5</td>
<td>Longitudinal Joint Failure</td>
<td>L, EP, EA, E</td>
<td>Combined</td>
</tr>
<tr>
<td>6</td>
<td>Lane/Shoulder Dropoff</td>
<td>L, EP, EA, E</td>
<td>Combined</td>
</tr>
<tr>
<td>7</td>
<td>Longitudinal Cracking</td>
<td>L, EP, EA, E</td>
<td>Combined</td>
</tr>
<tr>
<td>8</td>
<td>Popouts</td>
<td>L, EA</td>
<td>Combined</td>
</tr>
<tr>
<td>9</td>
<td>Localized Distress-Potholes</td>
<td>L, EA, E</td>
<td>Combined</td>
</tr>
<tr>
<td>10</td>
<td>Scaling and Crazing</td>
<td>L, E</td>
<td>Combined</td>
</tr>
<tr>
<td>11</td>
<td>Spalling</td>
<td>L, E</td>
<td>Combined</td>
</tr>
<tr>
<td>12</td>
<td>Swell</td>
<td>E</td>
<td>Climatic</td>
</tr>
<tr>
<td>13</td>
<td>Transverse Cracking</td>
<td>EP, EA, E</td>
<td>Combined</td>
</tr>
</tbody>
</table>

Note: No load only.
### TABLE 3. FLEXIBLE PAVEMENTS DISTRESS CLASSIFICATION

<table>
<thead>
<tr>
<th>Distress No.</th>
<th>Distress</th>
<th>Causes of Distress (FHWA Project)</th>
<th>Classification in this Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alligator Cracking</td>
<td>L, EP, EA, AA</td>
<td>Load*</td>
</tr>
<tr>
<td>2</td>
<td>Bleeding</td>
<td>L, EP, E</td>
<td>Combined</td>
</tr>
<tr>
<td>3</td>
<td>Block Cracking</td>
<td>EP, E, AA</td>
<td>Climatic</td>
</tr>
<tr>
<td>4</td>
<td>Corrugation</td>
<td>L, EP</td>
<td>Load</td>
</tr>
<tr>
<td>5</td>
<td>Contraction/ Shrinkage Fracture</td>
<td>E, AA</td>
<td>Climatic</td>
</tr>
<tr>
<td>6</td>
<td>Depression</td>
<td>L, EP</td>
<td>Load</td>
</tr>
<tr>
<td>7</td>
<td>Joint Reflection Cracking</td>
<td>L, E</td>
<td>Combined</td>
</tr>
<tr>
<td>8</td>
<td>Lane/Shoulder Drop-Off</td>
<td>L, EA, E</td>
<td>Combined</td>
</tr>
<tr>
<td>9</td>
<td>Lane/Shoulder Separation</td>
<td>L, E</td>
<td>Combined</td>
</tr>
<tr>
<td>10</td>
<td>Meandering Cracks</td>
<td>E</td>
<td>Climatic</td>
</tr>
<tr>
<td>11</td>
<td>Non-reflective Transverse and Longitudinal Cracking</td>
<td>L, EP, EA, AA</td>
<td>Climatic*</td>
</tr>
<tr>
<td>12</td>
<td>Pavement Edge Cracking</td>
<td>L, EP, EA</td>
<td>Load</td>
</tr>
<tr>
<td>13</td>
<td>Potholes</td>
<td>L, E</td>
<td>Combined</td>
</tr>
<tr>
<td>14</td>
<td>Raveling and Weathering</td>
<td>EP, EA, E, AA</td>
<td>Climatic*</td>
</tr>
<tr>
<td>15</td>
<td>Rutting</td>
<td>L, EP</td>
<td>Load</td>
</tr>
<tr>
<td>16</td>
<td>Shoving</td>
<td>L, EP</td>
<td>Load</td>
</tr>
<tr>
<td>17</td>
<td>Swelling and Bumps</td>
<td>E</td>
<td>Climatic</td>
</tr>
</tbody>
</table>

*In these cases, the predominant cause was used to classify the distress.*
These classifications of pavement distress are used in all of the computer programs that have been prepared in this project to compute deduct points and damage ratios. It is a fact that no State uses all of the distress types in Tables 1, 2, and 3 in computing a pavement rating score. Some states do not include a serviceability index rating in the determination of a pavement rating score. Obviously, with such a variety of practices from State to State, without a standard list of distresses that make up a pavement rating score, and without a standard weight applied to each distress, it is impossible to say, in general, how much "damage" is done by loads, climate, and combined influences. Instead, the practices that are used in each State must be investigated to see what, in the opinion of each State, is the relative amount of damage that is done by each of these factors.

The weighting that is given to each type of distress and to serviceability loss will be discussed in the next section of this report. Much more detail of the individual States distress weighting schemes and how they were used in this study is given in Appendices C, I, and L.
CHAPTER III
WEIGHTING OF PAVEMENT DAMAGE

This section of this report will describe the methods adopted in this study to assign relative weights on different types of distress in a manner that is consistent with the method of assigning deduct points that is used in a particular State. Deduct points are usually whole numbers that are subtracted from a perfect pavement score (normally 100) to indicate the level of deterioration of specific types of distress that have been observed on a pavement. In this section, the point weighting scheme that is used in each State will be discussed and the way it was represented in the computer programs prepared in this study will be described. A detailed description of each State's deduct point weighting scheme is given in Appendices C, I, and L.

DEDUCT POINTS FOR FLEXIBLE PAVEMENTS

In this section, the deduct point weighting scheme that is used by each State are summarized and the points that were used in computing the load damage ratios are presented. A detailed description of each State's deduct point rating method is given in Appendix L. The computed load damage ratios are in Appendix I. The State's point weighting schemes are described in alphabetical order.

In general, deduct points for a particular kind of distress increase with the area that it covers and the severity of the distress. The total deduct points are usually arranged in tabular form so that the rater can determine at a glance the combined effect of the area and severity of distress. As an example, the hypothetical deduct point table is shown below.

13
<table>
<thead>
<tr>
<th>Percent Area Covered by Distress</th>
<th>Severity Level of Distress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>0 - 1</td>
<td>2</td>
</tr>
<tr>
<td>1 - 15</td>
<td>4</td>
</tr>
<tr>
<td>16 - 30</td>
<td>8</td>
</tr>
<tr>
<td>&gt; 30</td>
<td>10</td>
</tr>
</tbody>
</table>

The maximum deduct points are 30 and decision weights are given to both the area and severity of the distress. The increase in deduct points is not usually linearly related to the level of distress, even though the assumption of linearity is not usually a bad approximation.

The determination of load damage ratios used in this report assumed that the deduct points are linearly related to distress levels below the critical level primarily to reduce the programming and computation efforts that would be required to represent the tabulated deduct points, distress by distress, and State by State.

Out of the maximum of 30 deduct points in the example shown above, the "linear assumption" assigns a maximum of 15 points to the area and 15 points to the severity of distress. The deduct points are then calculated as a percentage of the critical levels of area and severity which, in this case, is 30 percent of the area and a severity level of 3. The "linear assumption" would generate the following table of deduct points.
Deduct Points Computed by the
"Linear Assumption"

<table>
<thead>
<tr>
<th>Percent Area Covered By Distress</th>
<th>Mean Area</th>
<th>Level of Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>0 - 1</td>
<td>0.5</td>
<td>5</td>
</tr>
<tr>
<td>1 - 15</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>16 - 30</td>
<td>23</td>
<td>16</td>
</tr>
<tr>
<td>&gt; 30</td>
<td>30</td>
<td>20</td>
</tr>
</tbody>
</table>

By comparing the two tables, it can be seen that the "linear assumption" assigns a heavier weight to the distress at every level of area and severity. Because of this, the "linear assumption" will usually overestimate the total deduct points until the maximum level is reached and as a result, the calculated load damage ratios will usually be somewhat larger than would actually be computed using the States tabulated deduct point weighting scheme. This fact is mentioned here so that it can be noted that throughout the computed results there is a bias in the estimated load damage ratios that will tend to overestimate them.

In general, the maximum number of deduct points was divided evenly between area and severity, the deduct points were calculated for each using the "linear assumption", and they were added together to get the total deduct points for a particular level of distress.

In the following discussion, the maximum deduct points for each type of distress used by each State will be presented, and any unusual features of the deduct point weighting scheme will be noted.
California Flexible Pavement Deduct Points

California includes both distress and riding quality in their determination of the pavement condition rating. The maximum deduction for riding quality is 100 points. The following table gives the maximum deductions for the types of distress that are considered, along with the maximum deduct points for area and severity.

<table>
<thead>
<tr>
<th>Distress</th>
<th>Maximum Deduct Points</th>
<th>Maximum Deduct Points Used in This Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alligator Cracks</td>
<td>96</td>
<td>48, 48</td>
</tr>
<tr>
<td>Transverse Cracks</td>
<td>24</td>
<td>12, 12</td>
</tr>
<tr>
<td>Longitudinal Cracks</td>
<td>48</td>
<td>24, 24</td>
</tr>
<tr>
<td>Raveling</td>
<td>60</td>
<td>30, 30</td>
</tr>
<tr>
<td>Rutting</td>
<td>48</td>
<td>24, 24</td>
</tr>
<tr>
<td>Patching</td>
<td>24</td>
<td>12, 12</td>
</tr>
</tbody>
</table>

California also includes 10 deduct points for annual rainfall level but these were not included in this study.

Florida Flexible Pavement Deduct Points

Florida also combines a ride rating with a distress, or defect, rating. The maximum deduction for road roughness is 100 points and the deduct points for the various types of distress are given in the table below.
<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
<th>Maximum Deduct Points Used in This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Area</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>Total of 90</td>
<td>30</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Rutting</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Patching</td>
<td>15</td>
<td>8</td>
</tr>
</tbody>
</table>

The cracking categories in Florida included nonconnected and alligator cracks, and crack spalling, for which the maximum deduct points were 20, 30, and 40 points, respectively. Since there was no model for crack spalling in the Texas flexible pavement equations, spalling was treated as a severity category for both longitudinal (nonconnected) and alligator cracks. The 40 points for spalling was allocated to the two crack categories in proportion to the area deduct points.

**Georgia Flexible Pavement Deduct Points**

Georgia includes ride, skid, and a structural rating which is based upon Dynaflect measurements into their pavement rating method. The maximum deduct points for each is 100 points. In order to get a total score, the scores in each of these categories are further weighted by the following factors:

- Roughness - 1.0
- Skid - 1.5
- Structural - 1.5

and then multiplied by a traffic factor to get the final result.
Because there is no model for skid number in the Texas flexible pavement equations, this factor was not included in the calculation of load damage ratios. The structural rating was assumed to be directly related to rutting and the rutting equation was used to calculate the deduct points for that rating.

The Texas serviceability index equation was assumed to be the best predictor of roughness. The following table gives the maximum deduct points that were used in determining load damage ratios for Georgia.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
<th>Maximum Deduct Points Used in This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rutting</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

The deduct points for roughness were allowed to reach a maximum of 100 points. Because rutting is a load-related distress and roughness (i.e. serviceability index) is a combined distress type, the maximum damage ratio will always be 1.00. This is because there are no climatically related distress types that are included in Georgia's pavement rating score.

**Indiana Flexible Pavement Deduct Points**

Indiana has a sufficiency rating system for scoring the condition of its pavements. Out of all of the 100 points, 60 are derived from geometrics and 40 are determined from the current pavement condition. Of these 40 points, 22 points are for "structural adequacy" and 5 points are for "riding quality".

For the purposes of the this study, structural adequacy was considered to be indicated by cracking and rutting, with the deduct points divided
evenly among them. Riding quality was predicted with the serviceability index equation. The distress deduct points used in this study are given in the table below.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
<th>Maximum Deduct Points Used in This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Area</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Longitudical Cracking</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Transverse Cracking</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Rutting</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td></td>
</tr>
</tbody>
</table>

The deduct points are assumed to be somewhat larger for the load-related types of distress.

**Kansas Flexible Pavement Deduct Points**

Kansas has a rating system that includes pavement condition, skid, routine maintenance activities, and structural adequacy. No riding quality rating is included. The maximum deduct points for distress that were used in this study are given in the table below.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
<th>Maximum Deduct Points Used In This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Area</td>
</tr>
<tr>
<td>Longitudinal Cracks</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Transverse Cracks</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>Rutting</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>
No additional rating for "structural adequacy", skid, or maintenance activities were included.

**Louisiana Flexible Pavement Deduct Points**

Louisiana uses a sufficiency rating system involving ratings of condition, volume/capacity ratio, and safety. The only condition rating for which a Texas equation was available was roughness, as measured by a Mays Meter. The serviceability index equation was used to estimate the deduct points for roughness which had a maximum number of 5 deduct points.

Because loss of serviceability index is a combined distress, the load damage ratios will be either 0.0 (for load deduct points alone) or 1.0 (for combined deduct points).

**Maine Flexible Pavement Deduct Points**

Maine has a very detailed method of weighting distress based upon the layer from which the distress originates. The details of this rating system can be found in Appendix L. The deduct Points for distress that were used in this study are given in the table below.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
<th>Maximum Deduct Points Used in This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alligator Cracks</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Longitudinal Cracks</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Transverse Cracks</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Rutting</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>Corrugations (Washboard)</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Raveling (Pitting)</td>
<td>0.70</td>
<td>0.70</td>
</tr>
</tbody>
</table>
There was a "general overall" rating of the pavement that had a maximum weight of 0.45, and this was assumed to be predicted by the serviceability index equation. The load damage ratios that were predicted for Maine with the Texas equations appeared to be reasonably well aligned with other such values in other States. However, the climate in Maine is so different from that in Texas, that the equations are outside of the range of data from which they were originally derived. Thus, the Maine load damage ratios should be regarded as of questionable value.

**Maryland Flexible Pavement Deduct Points**

Maryland has a sufficiency rating system which allocates 40 of the total of 100 points to pavement condition. Because no specific assignment of maximum deduct points is made for this study, the 40 deduct points were divided equally among the distress categories that are observed. The "cracking" distress category was divided equally between longitudinal and transverse cracking. No riding quality rating is included in the Maryland pavement rating score.

The maximum deduct points that were used in this study are given in the table below.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
<th>Maximum Deduct Points Used in This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Area</td>
</tr>
<tr>
<td>Alligator Cracks</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Longitudinal Cracks</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Transverse Cracks</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Rutting</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Patching</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Raveling</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>
Minnesota Flexible Pavement Deduct Points

Minnesota has a detailed procedure involving a structural rating and a present serviceability rating. The structural ratings are different based upon the type of pavement: flexible, concrete, or bituminous overlaid concrete pavements. The structural rating and the serviceability rating are given an equal weight in the overall pavement rating. The maximum deduct points for distress are given in the table below.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flexible Area</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>35</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>2</td>
</tr>
<tr>
<td>Transverse Cracking</td>
<td>2</td>
</tr>
<tr>
<td>Rutting</td>
<td>15</td>
</tr>
<tr>
<td>Patching</td>
<td>30</td>
</tr>
<tr>
<td>Multiple Cracking</td>
<td>15</td>
</tr>
<tr>
<td>Serviceability Index</td>
<td>100</td>
</tr>
</tbody>
</table>

The total serviceability index deduct points were adjusted to equal the total number of distress (or structural) deduct points. A very detailed discussion of the Minnesota data, prediction equations, and load damage ratios is given in Appendixes A, B, C, and E.

North Dakota Flexible Pavement Deduct Points

North Dakota has a very detailed breakdown of surface cracking worth a total of 24 deduct points. Surface distortion categories are allocated a total of 13 points. No riding quality is considered in the rating. The
maximum deduct points for each type of distress is given in the table below.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
<th>Maximum Deduct Points Used In This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alligator Cracking</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Transverse Cracking</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Rutting</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Flushing (Seal Condition)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Corrugations (Shoving)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Patching</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Raveling</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Other types of distress are rated including fatigue cracking (3 points), map cracking (3 points), and crack spalling (4 points) for which no model was available among the Texas equations. The fatigue cracking deduct points could have been added to the alligator cracking points because the two have identical causes. However, this was not done in this study.

**Tennessee Flexible Pavement Deduct Points**

Tennessee rates the pavement cross section geometry as well as its surface condition. A total of 25 deduct points are allotted to profile characteristics such as waves, bumps, dips, and riding quality. A total of 50 points is allotted to distress. In neither case is a specific number of deduct points assigned to a particular type of distress. Because of this,
the maximum deduct point values were divided evenly among the distress types that are observed. The deduct points used in this study are given in the table below.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
<th>Maximum Deduct Points Used In This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Area</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Transverse Cracking</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Rutting</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Flushing</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Corrugations</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Patching</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Raveling</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Failures/Mile</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>73</strong></td>
<td></td>
</tr>
</tbody>
</table>

The maximum serviceability index deduct points were set at 12, so that a total of 85 deduct points out of 100 are represented in this assumed point-weighting scheme. The only items that are used by Tennessee that are not represented here are uniformity of crown, superelevation, raveling and spalling of pavement edge, bumps, dips, blowups, and pumping.

**Texas Flexible Pavement Deduct Points**

The pavement rating method in Texas uses both distress and riding quality. The deduct points for distress were distributed evenly between area and severity, as shown in the table below.
<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
<th>Maximum Deduct Points Used In This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Area</td>
</tr>
<tr>
<td>Alligator cracking</td>
<td>25</td>
<td>13</td>
</tr>
<tr>
<td>Longitudinal cracking</td>
<td>25</td>
<td>13</td>
</tr>
<tr>
<td>Transverse cracking</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Rutting</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Flushing</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Corrugations</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Patching</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Raveling</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Failures/Mile</td>
<td>40</td>
<td>--</td>
</tr>
</tbody>
</table>

The maximum deduct points for loss of serviceability index was 50 points.

**Virginia Flexible Pavement Deduct Points**

Virginia uses distress to rate its flexible pavement. The deduct points were divided evenly between area and severity, as given in the following table.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
<th>Maximum Deduct Points Used In This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Area</td>
</tr>
<tr>
<td>Alligator cracking</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Longitudinal cracking</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Transverse cracking</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Rutting</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Flushing</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Raveling</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
The types of distress that are used by Virginia but are not represented in this study include multiple cracking (10 points), waves and humps (2 points).

**Washington Flexible Pavement Deduct Points**

Washington rates both the riding quality and distress of flexible pavements. The ride rating and the "defect rating" are weighted equally in determining the overall pavement rating. The deduct points for individual distress types were divided evenly between area and severity as shown in the table below.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
<th>Maximum Deduct Points Used In This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Area</td>
</tr>
<tr>
<td>Alligator cracking</td>
<td>25</td>
<td>13</td>
</tr>
<tr>
<td>Longitudinal cracking</td>
<td>25</td>
<td>13</td>
</tr>
<tr>
<td>Transverse cracking</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Rutting</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Corrugations</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Patching</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Failures/mile</td>
<td>10</td>
<td>--</td>
</tr>
</tbody>
</table>

The maximum deduct points for loss of serviceability index was set at 100 points.
DEDUCT POINTS FOR RIGID PAVEMENTS

Appendix F contains a detailed discussion of the deduct points used in estimating load damage ratios for rigid pavements. Only four States were found to have detailed deduct point rating schemes for rigid pavements: Kansas, Texas, Virginia, and Washington. The following discussion describes the deduct point assumptions that were used in estimating load damage ratios.

Kansas Rigid Pavement Deduct Points

Kansas includes roughness, distress, and general structural adequacy ratings. The following maximum deduct points were used in estimating load damage ratios for jointed concrete pavements. No division was made between area and severity in these pavements since the rigid pavement equations from Illinois included only one measure of distress.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint Faulting</td>
<td>4</td>
</tr>
<tr>
<td>Joint Deterioration</td>
<td>4</td>
</tr>
<tr>
<td>D - Cracking</td>
<td>8</td>
</tr>
<tr>
<td>Swells and Depressions</td>
<td>10</td>
</tr>
<tr>
<td>Transverse Cracks</td>
<td>5</td>
</tr>
</tbody>
</table>

The roughness of the pavement is estimated with the equation for loss of serviceability index. The maximum deduct points for roughness is 4 points. The types of distress that are rated by Kansas but are not included in this study include scaling, random and longitudinal cracking, patching, and skid resistance.
Texas Rigid Pavement Deduct Points

Texas includes riding quality and distress in rating rigid pavements. The maximum deduct points used in this study are given in the following table.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint faulting</td>
<td>40</td>
</tr>
<tr>
<td>Pumping</td>
<td>60</td>
</tr>
<tr>
<td>Joint deterioration</td>
<td>60</td>
</tr>
<tr>
<td>D-cracking</td>
<td>40</td>
</tr>
<tr>
<td>Transverse cracking</td>
<td>30</td>
</tr>
</tbody>
</table>

The loss of serviceability index has a maximum deduct value of 50 points. Although D-cracking is not rated by Texas, it does occur in that part of the State that is subject to freeze-thaw cycling and the point weight used is that allotted to failures per mile. Thus, in the Texas study, the D-cracking prediction equation was used to predict the appearance of "failures per mile". The types of distress that Texas rates but were not included in this study are as follows: surface deterioration, longitudinal cracking, and patching.

Virginia Rigid Pavement Deduct Points

Virginia rates distress alone in determining a rigid pavement rating score. The following table gives the maximum deduct points for each type of distress included in this study.
<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint faulting</td>
<td>10</td>
</tr>
<tr>
<td>Pumping</td>
<td>20</td>
</tr>
<tr>
<td>Joint deterioration</td>
<td>25</td>
</tr>
<tr>
<td>D-cracking (Sealing)</td>
<td>5</td>
</tr>
<tr>
<td>Transverse cracking</td>
<td>5</td>
</tr>
</tbody>
</table>

The types of distress that are rated in Virginia but not included in this study are as follows: cracked and broken panels, patching, and longitudinal cracking. Although D-cracking is not rated in Virginia, scaling is and the scaling deduct points are used with the D-cracking equation.

Washington Rigid Pavement Deduct Points

Washington uses both distress and riding quality in determining a pavement rating score. The following table gives the maximum deduct points for each type of distress.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Deduct Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint faulting</td>
<td>30</td>
</tr>
<tr>
<td>Pumping</td>
<td>45</td>
</tr>
<tr>
<td>Joint deterioration</td>
<td>50</td>
</tr>
<tr>
<td>D-cracking (Raveling, sealing)</td>
<td>50</td>
</tr>
<tr>
<td>Transverse cracks</td>
<td>50</td>
</tr>
</tbody>
</table>
The maximum deduct points value for loss of serviceability index is 100 points. The distress types that Washington rates but were not included in this study are patching and blowups.
CALCULATION OF DAMAGE RATIOS

The total damage that occurs to a pavement at any stage of its life is measured by the total deduct points that would be subtracted from a perfect pavement rating score. That total may be broken down into the three distress categories: load, combined, and climatic deduct points. Damage ratios may be calculated from the sums of these deduct points, as follows:

Total deduct points = load + combined + climate deduct points

**Damage Ratio No. 1**

Load damage ratio = \( \frac{\text{Load deduct points}}{\text{Total deduct points}} \)

**Damage Ratio No. 2**

Load associated damage ratio = \( \frac{\text{Load + combined deduct points}}{\text{Total deduct points}} \)

The two damage ratios are estimates of the total amount of pavement damage that is due to traffic loads. Damage Ratio No. 1 is a lower limit and Damage Ratio No. 2 is an upper limit of the percent of damage that is done by these loads.

A sample calculation of the deduct points is given in Table 4. The sums of these deduct points are as follows: load, 22.7; combined, 31.5; and climatic, 8.7. The total of these deduct points is 62.9. The two damage ratios are computed as follows:

**Damage Ratio No. 1**

\[ \frac{\text{Load Deduct Points}}{\text{Total Deduct Points}} = \frac{22.7}{62.9} = 0.36 \]
Damage Ratio No. 2

\[
\frac{\text{Load + Combined Deduct Points}}{\text{Total Deduct Points}} = \frac{22.7 + 31.5}{62.9} = 0.87
\]

Thus, from this example, an inference would be made that loads cause between 36 and 87 percent of all of the damage observed on the pavement. Calculations that are similar to this have been carried out using the deduct point weighting schemes of a number of the states which have them. The calculations have been done for each of the climatic zones that fall within each State using weather data taken from the records of specific cities within those zones.

The deduct point weighting system used by each State is presented in Appendices C, I, and L. The climatic data for each city is given in Appendix D. The equations that were used to represent flexible pavements in Climatic Zones I, II, IV, and V were developed with Texas data and are recorded in Appendix H. Flexible overlaid and composite pavement equations for Climatic Zone III were taken from data gathered in Minnesota and are recorded in Appendix E. Jointed concrete pavement equations were developed at the University of Illinois from Illinois pavement data and these equations are recorded in Appendix F.
TABLE 4. Sample Calculations of Deduct Points

<table>
<thead>
<tr>
<th>Distress</th>
<th>Type of Distress</th>
<th>Total Amount</th>
<th>Maximum Deduct Points</th>
<th>Deduct Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Loads</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Combined</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Climate</td>
</tr>
<tr>
<td>1. Alligator Cracking</td>
<td>Area L</td>
<td>0.2</td>
<td>15</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>Severity L</td>
<td>2*</td>
<td>15</td>
<td>10.0</td>
</tr>
<tr>
<td>2. Rutting</td>
<td>Area L</td>
<td>0.3</td>
<td>10</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>Severity L</td>
<td>2</td>
<td>10</td>
<td>6.7</td>
</tr>
<tr>
<td>3. Transverse Cracking</td>
<td>Area E</td>
<td>0.2</td>
<td>10</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Severity E</td>
<td>0.2</td>
<td>10</td>
<td>--</td>
</tr>
<tr>
<td>4. Present Service-</td>
<td>C</td>
<td>2.5</td>
<td>50</td>
<td>--</td>
</tr>
<tr>
<td>ability Index</td>
<td></td>
<td></td>
<td></td>
<td>31.5*</td>
</tr>
</tbody>
</table>

\[ \text{Severity level} \frac{\text{Maximum Severity Level}}{\text{Total Amount}} \times \text{Deduct Points}. \] The severity scale is 0, none; 1, slight; 2, moderate; 3, severe (or maximum)

* Combined deduct points = \( \frac{4.2 - 2.5}{4.2 - 1.5} \times 50 = \) where the initial serviceability index is 4.2 and the terminal serviceability index is 1.5.
CHAPTER IV

METHODS OF ESTIMATING PAVEMENT DAMAGE

The type of damage that the AASHO Road Test was concerned with was loss of serviceability index. Observations were made over the two year period of the AASHO Road Test and the loss of serviceability index was plotted on a logarithmic scale against the logarithm of the 18-kip equivalence single axle loads that had passed over each section of pavement. The data that were gathered in that period of time seemed to indicate a linear relationship between the logarithm of damage and the logarithm of 18-kip equivalents. This resulted in the form of damage that was adopted at the AASHO Road Test which is as follows:

\[ g = \left( \frac{N}{P} \right)^8 \]

where

\( g \) = the damage function which ranges between 0 and 1 as the serviceability index drops from its initial value to its terminal value

One peculiarity of these equations is that if an extrapolation is carried out to large levels of 18-kip equivalent single axle loads, then one can calculate negative values of serviceability index. This does not make sense physically since the serviceability index scale was originally set up to go only between 0 and 5 with 0 as a bounding lower limit. In addition, physical measurements have shown that the serviceability index is not a linear scale, particularly in the lower ranges of that scale. Below a serviceability index of about 2, the serviceability index scale becomes much less sensitive to large changes in roughness. This is un-
doubtlessly due to the fact that panel ratings were always bounded by a lower limit of 0. Technically, this means that it would take a road that is infinitely rough to cause a rating of 0. Thus, it is seen that because of the way the serviceability index scale was constructed, the serviceability index should approach 0 as a limit, and the curve should be S-shaped.

Another phenomenon can also be noted on stiff, strong pavements in good condition. In the initial period after they have been constructed these pavements become somewhat rougher than they were when constructed, and seem to reach a horizontal plateau in which the serviceability index does not change appreciably over a long period of time. These strong, stiff pavements approach a serviceability index asymptote that is not 0 but is primarily dictated by the strength of the pavement and the level of traffic that it is carrying. Thus, strong stiff pavements also have S-shaped curves.

The S-shaped curve is also observed in pavements which have been protected from deterioration by a program of periodic routine maintenance. In these types of pavements the serviceability index may drop toward a terminal level but once the routine maintenance is applied, the serviceability index level stabilizes. Thus, the relationship between serviceability index and 18-kip ESAL's is an S-shaped curve even for these types of pavements.

With these considerations in mind, it is obvious that the actual curve of serviceability index versus 18-kip equivalent single axle loads should be S-shaped, approaching a lower asymptote at its later stages of service life. These expectations have been borne out in fact by measurements that have been made on the AASHO Road Test sections subsequent to the close of
the road test. In research work done on NCHRP Project 1-19, Darter presented a revised AASHO Road Test equation that was based upon all of the original data as well as subsequent observations after the close of the AASHO Road Test up until 1974. The equation was of the characteristic S-shape as is shown in Figures 1, 2, 3, and 4. Darter's equation, which better represented the long term performance of the AASHO Road Test sections is as follows:

\[
\log_{10} W_{18} = \log_{10} W'_{18} + (3.892 - 0.706 \, P2)
\]

\[
\log \left[ \frac{F28}{690} \right] = 4 \log \left[ \frac{8.75H^{0.75}}{M} + 0.359 \right]
\]

\[
= 4 \log \left[ \frac{z^{0.25} (0.540H^{0.75})}{M} + 0.359 \right]
\]

(EQ. 5)

where:

\[ M = \sqrt{1.6 \, a^{2} + H^{2}} - 0.675H \]

\[ a = \text{radius of applied edge load, inches} \]

\[ F28 = \text{modulus of rupture used in design} \]

\[ P2 = \text{terminal serviceability index} \]

\[ H = \text{PCC slab thickness, inches} \]

\[ F28 = FF - C \left( \frac{F_{cv}}{100} \right) FF \]

\[ FF = \text{mean modulus of rupture at 28 days, 3rd point load, psi} \]

\[ F_{cv} = \text{coefficient of variation of modulus of rupture, \%} \]

\[ C = 1.03, \text{a constant representing a confidence level of 8.5 percent} \]

\[ z = E/k \]

\[ E = \text{PCC slab modulus of elasticity, psi} \]

\[ k = \text{modulus of subgrade reaction, pci} \]
Figure I. Comparison of Original AASHO Performance Equation and New Performance Equation (Eq. 5) for 12.5 in. (318 mm) Thick Slab.

Note: Individual points represent individual test sections.
Figure 2. Comparison of Original AASHO Performance Equation and New Performance Equation (Eq. 5) for 11 in. (279 mm) Thick Slab.

Note: Individual points represent individual test sections.
Figure 4. Comparison of Original AASHO Performance Equation and New Performance Equation (Eq. 5) for 8 in. (203 mm) Thick Slab.

Note: Individual points represent individual test sections.
and

\[ W_{18}^i = \left[ \rho \ln \left( \frac{3}{y} - 1 \right) + \beta \right] 10^6 \]

where:

\[ W_{18}^i \] = total equivalent 18-kip single axle loads to reduce the serviceability index from P1 to P2
\[ \beta = -50.08826 - 3.7748 \, H + 30.64386 \, \sqrt{H} \]
\[ \rho = -6.69703 + 0.13879 \, H^2 \]
\[ y = P2 \left( \frac{3.0}{(e)^{-\beta/\rho+1}} \right) - P1 \]

P1 = initial serviceability index

The equation for \( W_{18}^i \) gives an S-shaped curve.

The next bit of evidence that the performance equation is S-shaped came from the regression analyses made by Lytton and his colleagues at the Texas Transportation Institute. While Darter's curves were developed for jointed concrete pavements, the equations developed by TTI were all for flexible pavements. The form of those equations was somewhat different from that of Darter but they are generally as follows.

Serviceability Index:

\[ \frac{P_i - P}{P_i - P_f} = e^{-k/N} \]

where:

\[ P_i \] = the initial serviceability index
\[ P_f \] = the final (or asymptotic) value of serviceability index
\[ P = \text{the present serviceability index} \]
\[ N = \text{the number of 18-kip equivalent single axle loads} \]
\[ k = \text{the pavement deterioration rate constant.} \]

The performance equations and the distress equations developed for Texas flexible pavements are all given in Appendix H. The significance of these developments is to note that fundamentally the shape of the AASHO Road Test equation damage function is incorrect. It may do an adequate job of expressing the loss of serviceability index during the initial portions of the life of a pavement, but because it expresses only a single curvature and cannot approach an asymptote, the accuracy of predictions of serviceability index as a function of 18-kip equivalent single axle loads becomes more doubtful as the serviceability index level decreases.

In the final report of NCHRP Project 20-7 Task 17 entitled "Evaluation of AASHO Road Test Satellite and Environmental Studies", Lytton and Garcia pointed out three different types of performance and distress equations that may be used to express pavement damage. These equations are listed below:

**Design Equation 1**

\[ g = \frac{P_i - P}{P_i - P_t} = \left( \frac{N}{\rho} \right) \beta \]

where

\[ g = \text{the damage function that begins at 0 and becomes 1 when} \]
\[ P_i = P_t. \]
\[ P_i = \text{the initial serviceability index} \]
\[ P_t = \text{the terminal serviceability index} \]
\[ \rho, \beta = \text{constants which depend upon the pavement structure and the load acting upon it.} \]
**Design Equation 2**

\[
\frac{P - P_f}{P_1 - P_f} = \frac{1}{e^{\beta_N} - 1 + 1}
\]

where

\(P_f\) = the asymptotic value of serviceability index which the performance equation approaches.

and all other quantities are as defined previously.

**Design Equation 3**

\[
\frac{P - P_f}{P_1 - P_f} = 1 - e^{-\frac{N}{\beta_N}}
\]

Design Equation 1 is the AASHO Road Test Design Equation. Because it cannot approach a horizontal asymptote, its use in predicting the long term performance of pavements is limited.

Design Equation 2 is of the form used by Darter in describing the long term performance of jointed concrete pavements at the AASHO Road Test site. The form of that equation allows it to approach a horizontal asymptote and as such it is expected to be very useful in predicting long term performance of pavements.

Design Equation 3 is of the form selected by the Texas Transportation Institute to describe the long term performance of flexible pavements in Texas. That equation also can approach a horizontal asymptote and is expected to be very useful in describing the long term performance of pavements.
Associated with these three design equations are similar forms of distress equations. Two components of distress are normally recorded, that is, area and severity. The area and severity equations corresponding to Design Equation 1, the AASHO Road Test Equation, are as follows:

Area:

\[ \frac{a}{a_f} = \left( \frac{N}{\rho} \right)^\beta \]

Severity:

\[ \frac{s}{s_f} = \left( \frac{N}{\rho} \right)^\beta \]

where \( \rho \) and \( \beta \) are constants for a particular section of pavement, and \( a_f \) and \( s_f \) are the maximum area and severity levels of a particular level of distress.

The forms of distress equation which correspond to Design Equation 2 are as follows:

Area:

\[ \frac{a}{a_f} = e^{\beta \left( \frac{W}{\rho} - 1 \right)} \]

Severity:

\[ \frac{s}{s_f} = e^{\beta \left( \frac{W}{\rho} - 1 \right)} \]
The forms of distress equation corresponding to Design Equation 3 are as follows:

**Area:**

\[ a = e^{-\left(\frac{P}{N}\right)^B} \]

**Severity:**

\[ s = s_f e^{-\left(\frac{P}{N}\right)^B} \]

The damage functions corresponding to Design Equation 1 cannot approach a horizontal asymptote as they should if they are to properly represent the increase of distress over its entire history. Obviously, the area on which a particular type of distress is visible cannot exceed 100 percent. Thus, even though the area of alligator cracking may increase exponentially during the first stages of the life of a pavement, the equation which predicts the increase of area of alligator cracking should never predict an area greater than 100%. A maximum or asymptote value of severity of distress is more difficult to picture mentally, but is nevertheless a real limitation to the level of damage that can be done to a pavement. The severity of distress may also increase exponentially in the early stages of the life of a pavement but there is an upper limit of severity to which the forces of load and climate can reduce a pavement. It is rare that such a limit is ever reached on any pavement that is used constantly by the traveling public. Instead, some form of maintenance will be applied to the pavement before such a drastic level of severity is reached. The shape that a severity curve would take if the pavement were
allowed to deteriorate to its maximum severity condition, would however be an S-shaped curve. There is a maximum rut depth which is roughly equal to the radius of the vehicle tires beyond which there would simply be no traffic on the road. Alligator cracking breaks up into small blocks of pavement which then remain intact even as they are picked out of the pavement structure by passing traffic. These two extreme examples indicate that an asymptote can be reached in a severity of distress curve even though in most cases the severity is never allowed to even approach such an extreme level on roads that are in constant use by the traveling public. Thus, it is seen that the distress equations associated with the AASHO Road Test are themselves erroneous in form even though they may duplicate the behavior of distress in the early stages of the life of a pavement.

The distress equations corresponding to Design Equation 2 are also of such a form that they cannot approach a horizontal asymptote. This constitutes a limitation to the usefulness of distress equations of this form. The distress equations that are associated with Design Equation 3 such as was used in the development of the Texas flexible pavement equations, can approach a horizontal asymptote at the upper limit of both area and severity.

In summary, the S-shaped curve of serviceability index and distress when plotted against the accumulated 18-kip equivalent single axle loads should be expected from the physical boundary conditions imposed by the rating scheme in the case of serviceability index and by physical geometry in the case of distress. The current form of the AASHO Road Test design equation is incapable of expressing this type of relation.
CHAPTER V

DATA COLLECTION FOR PAVEMENT DISTRESS AND PERFORMANCE EQUATIONS

In order to supplement the calculations that could be made with the Texas flexible pavement equations which had been developed from data gathered over a period of seven years in the state of Texas on approximately 400 sections of pavement which had been selected at random across the state, it was desirable to collect data from other states in other climatic regions. We collected additional flexible pavement data from Minnesota, New York, and Utah and we acquired concrete pavement equations from Darter at the University of Illinois which represents the performance of jointed concrete pavements in Illinois. We also collected data in Minnesota on composite pavements, that is, concrete pavements that have been overlayed with asphalt. There were 128 sections of data that were collected in Minnesota, 98 sections in New York, and 121 sections in Utah on which data were collected. It was found that the actual data that showed promise of being useful in model building were all stored in manual files and represent the results of pavement sections that have been part of a research program in the past. The exception to this is Minnesota which, although it stores some of its data in manual files, actually records very detailed information on construction, maintenance, and condition histories for each section of pavement in its 13,000 miles of primary highway. These data are kept in the District offices of which there are nine in the state. Traffic data are accessible from a centralized computer file. In each state, the data had to be assembled from several sources. Some data were in manual files, some were in reports, and others were computerized. The data collection effort in each case required a familiarity with the sources
of data and at least a full day's assistance from state personnel to
acquaint project personnel with the data sources. In the case of Minnesota,
so much detailed data were available that careful selection could be made
to assemble a set of sections with consistent construction and mainte-
nance histories. An extensive designed experiment could possibly be
selected from among the data available in Minnesota.

The New York data were divided into two parts: a general pavement
inventory system and a set of data from flexible pavement performance
research studies. The former is computerized and is maintained for every
section in the State pavement network but only general information about
each section and present rightability index are stored in the inventory.
Detailed data such as are needed for making revisions to the AASHTO design
equations is recorded only on the States pavement performance research
study sections. Although 60 percent of the State's highways are rigid and
40 percent are flexible, the research sections are entirely on flexible
pavement.

The Utah data were divided in a similar way. Very detailed pavement
condition records are kept on all pavement sections in the State in a com-
puterized form. However, construction and maintenance histories are not
maintained so that the layer thicknesses, material properties and ages
cannot be readily associated with the pavement condition without a de-
tailed program of field coring and testing and laboratory testing. A
second set of data are available on pavement research sections which were
studied in detail between 1964 and 1969. Several performance and distress
equations have been developed from these data as described in Appendix E.
Data collection on these sections has been discontinued leaving 121 pavement
sections with data on the first five years of life. The short time span of the data makes its usefulness for long-term projections problematical.

The rigid pavement equations that were used in this study were developed by regression analysis upon the data that were gathered in NCHRP Project 1-19 by Darter and his colleagues at the University of Illinois.

The details of data collection efforts are given in Appendix A. A discussion of the typical types of distress that are found in Minnesota and Utah, both which are in a hard freeze zone, is discussed in some length in Appendix B. It is interesting to note that a large portion of the distress that is visible on the road surface at the time of maintenance or rehabilitation is largely transverse, a distress pattern is caused by thermal, or environmental, stresses. The rigid pavement equations and their sources of data are discussed in detail in Appendix F.
CHAPTER VI
TYPICAL RESULTS OF COMPUTATIONS

In making estimates of load damage ratios, it is necessary to assume a pavement structure on which the loads are applied over a period of time in order to compute the amount of distress and loss of serviceability index that occurs. In order to determine the effect of pavement structure on load damage ratios, two pavements were selected to represent on the one hand, typical stiff, strong pavement sections and on the other hand, typical weak and light pavement sections.

Also, in order to represent the climates in which these pavements must perform, thirty-five cities distributed across the United States were selected to represent the six unique climatic zones in the United States. Detailed climatic data were collected for each of these cities and are summarized in Appendix D. The climatic data representing specific cities were used as input to the computer programs that include the pavement equations from Texas, Minnesota, and Illinois.

This chapter gives an overview of the typical pavements, typical climates, and typical results of calculations in each of the climatic regions.

TYPICAL PAVEMENTS - TEXAS FLEXIBLE PAVEMENT EQUATIONS

The stiff pavement chosen for use in the Texas flexible pavement equations had a Dynaflect maximum deflection of 0.4 mils (0.0004 inches) and a surface curvature index of 0.2 mils. There are numerous arrangements of pavement layers that would provide these deflection characteristics. However, a typical pavement that does this is shown in Figure 5 a. This pave-
FIGURE 5a. Typical Stiff Pavement for Texas Flexible Pavement Equations (Dynaflect maximum deflection = 0.44 mils)

1.5 inch asphaltic concrete
8.0 inch asphalt stabilized base course
8.0 inch crushed limestone subbase course
A6 clay subgrade

FIGURE 5b. Typical Weak Pavement for Texas Flexible Pavement Equations (Dynaflect maximum deflection = 1.57 mils)

Double Surface Treatment
6.0 inch crushed limestone base course
A6 clay subgrade
FIGURE 6 a. Typical Stiff Pavement for Minnesota Pavement
Equations (Dynaflect maximum deflection = 0.27 mils)

3.0 inches Asphalitic concrete
4.0 inches Asphalt stabilized base course
8.0 inches Aggregate subbase course
A-2 Granular subgrade

FIGURE 6 b. Typical Weak Pavement for Minnesota Pavement
Equations (Dynaflect maximum deflection = 1.00 mils)

4.0 inches Asphalt concrete
18.0 inches Aggregate base course
A-5 Silty subgrade
ment has an AASHTO Structural Number of approximately 4.4.

The weak pavement chosen for use in the Texas flexible pavement equations had a Dynaflect maximum deflection of 1.5 mils and a surface curvature index of 1.0 mils. A typical pavement that meets these characteristics is shown in Figure 5 b. This pavement has an AASHTO Structural Number of approximately 1.1.

TYPICAL PAVEMENTS - MINNESOTA FLEXIBLE AND COMPOSITE PAVEMENT EQUATIONS

The stiff pavement sections that were used with the Minnesota equations provided a Dynaflect maximum deflection of 0.3 mils whereas the typical weak pavement provided a Dynaflect maximum deflection of 1.0 mil. Figure 6 a. shows a typical stiff pavement, which has an AASHTO Structural Number of 3.5. Figure 6 b. shows a typical weak pavement, which has an AASHTO Structural Number of 3.5. In this case, the difference between the two pavements is the strength of the subgrade material.

TYPICAL PAVEMENTS - ILLINOIS RIGID PAVEMENT EQUATIONS

Appendix F gives a detailed description of the typical rigid pavements that were used in the analysis of load damage ratios. Several sensitivity analyses were made with 10-inch thick concrete slabs with different joint and drainage conditions, with stabilized and granular subbase courses, and with crushed stone and gravel concrete aggregates.

The basic concrete pavement is 10-inches thick with a 70-foot long slab length, 1.5-inch dowels, and 0.135 sq. in. of steel reinforcing per foot of width.
TYPICAL CLIMATES OF SELECTED CITIES

A total of thirty-five cities were selected to give a broad geographic distribution and a wide variety of climatic data for specific locations. Details of the climatic information collected on each of the cities is given in Appendix D. This section gives an overview of the climatic data that are represented among the 35 selected cities.

The cities are located in 13 States but there are several States which have 2, 3, or 4 different climatic zones within their boundaries. As is expected, the computed damage ratios showed that the climate has a significant effect upon the relative amount of damage that is due to load- and non-load- associated factors.

The dividing line between wet and dry climates is a Thornthwaite Index of 0.0. There are 22 locations in the wet zones and 13 in the dry zones. Table 5 shows that the annual rainfall in the wet zones ranges between 6 and 105 inches per year. The dry zones have between 3 and 25 inches of rainfall each year. Mean temperature drops lower in the climatic zones that are farther to the north. Whereas the no freeze zones have mean temperatures between 49 and 74°F, the hard freeze zones average between 39 and 55°F each year. Freeze thaw cycling takes place in both the hard freeze and the "freeze-thaw-cycling" zones. However, there is usually a larger number of freeze-thaw-cycles each year in the latter zones since their characteristically higher winter temperatures cause the daily temperature excursions to swing above and below the freezing point. One city, Quillayute, Washington which plots in Zone I (wet, no freeze) was moved into Zone II because of its large number of freeze-thaw-cycles (67). The
### TABLE 5. Summary Table of Climatic Data

<table>
<thead>
<tr>
<th>Climatic Zone</th>
<th>Description of Zone</th>
<th>Number of Locations</th>
<th>Range of Annual Rainfall, in.</th>
<th>Range of Thornthwaite Index</th>
<th>Range of Mean Temperatures, °F</th>
<th>Range of Annual Freeze-Thaw Cycles</th>
<th>Range of Annual Wet Freeze-Thaw Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Wet, No Freeze</td>
<td>5</td>
<td>40 - 54</td>
<td>20 - 100</td>
<td>49 - 73</td>
<td>3 - 52</td>
<td>1 - 13</td>
</tr>
<tr>
<td>II</td>
<td>Wet, Freeze-Thaw Cycling</td>
<td>10</td>
<td>6 - 105</td>
<td>30 - 100</td>
<td>50 - 66</td>
<td>38 - 135</td>
<td>9 - 36</td>
</tr>
<tr>
<td>III</td>
<td>Wet, Hard Freeze</td>
<td>7</td>
<td>15 - 41</td>
<td>10 - 80</td>
<td>39 - 55</td>
<td>67 - 115</td>
<td>2 - 69</td>
</tr>
<tr>
<td>IV</td>
<td>Dry, No Freeze</td>
<td>3</td>
<td>3 - 25</td>
<td>-20 - -40</td>
<td>62 - 74</td>
<td>1 - 2</td>
<td>1</td>
</tr>
<tr>
<td>V</td>
<td>Dry, Freeze-Thaw Cycling</td>
<td>6</td>
<td>3 - 24</td>
<td>-20 - -40</td>
<td>46 - 65</td>
<td>55 - 199</td>
<td>13 - 64</td>
</tr>
<tr>
<td>VI</td>
<td>Dry, Hard Freeze</td>
<td>4</td>
<td>16 - 20</td>
<td>0 - -20</td>
<td>41 - 54</td>
<td>39 - 139</td>
<td>17 - 37</td>
</tr>
</tbody>
</table>
number of freeze-thaw-cycles in the "freeze-thaw cycling" zones range between 38 and 199 cycles per year whereas the hard freeze zones cycle between 39 and 139 times per year. The differentiation between the zones is made based upon the normal duration of the period when temperature remains below 32°F each winter.

SUMMARY OF COMPUTED LOAD DAMAGE RATIOS

Numerous sensitivity analyses were made with the equations that have been developed in this project and it is impossible to give a comprehensive summary of all of the results of these calculations. The detailed results of these series of computations is given in Appendices C, F, and I. However, in this section some typical results are presented which will give typical results of the calculations of load damage ratios. Table 6 gives ranges of minimum damage ratios considering the damage due to loads alone after the passage of 10 million 18-kip equivalent single axle loads. Most of the ratios reported for the flexible and overlaid flexible pavements were computed using the Texas flexible pavement equations. The jointed concrete pavement results were computed using the Illinois rigid pavement equations. The results for overlaid jointed concrete pavements were calculated in climatic Zone III using the Minnesota composite pavement equations.

In general, the minimum damage ratios range from 0.01 to 0.68 for flexible pavements, 0.26 to 0.58 for overlaid flexible pavements, 0.10 to 0.16 for 10-inch thick jointed concrete pavements with good drainage and joints on stabilized subbase, and 0.0 for composite pavements in Climatic Zone III.
TABLE 6. Range of Minimum Damage Ratios for 10-Million 18-kip Equivalent Single Axle Loads*

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>Flexible Pavement</th>
<th>Overlaid Flexible Pavement</th>
<th>Jointed Concrete Pavement*</th>
<th>Overlaid Jointed Concrete Pavement+</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.45-0.62</td>
<td>0.35-0.53</td>
<td>0.10</td>
<td>--</td>
</tr>
<tr>
<td>II</td>
<td>0.42-0.60</td>
<td>0.30-0.52</td>
<td>0.10</td>
<td>--</td>
</tr>
<tr>
<td>III</td>
<td>0.01-0.68</td>
<td>0.26-0.58</td>
<td>0.13</td>
<td>0</td>
</tr>
<tr>
<td>IV</td>
<td>0.50-0.51</td>
<td>0.35-0.45</td>
<td>0.13</td>
<td>--</td>
</tr>
<tr>
<td>V</td>
<td>0.45-0.60</td>
<td>0.27-0.49</td>
<td>0.14</td>
<td>--</td>
</tr>
<tr>
<td>VI</td>
<td>0.47-0.59</td>
<td>0.26-0.49</td>
<td>0.16</td>
<td>--</td>
</tr>
</tbody>
</table>

*Exclude results from Louisiana and Georgia.

★Computed for 20-million 18-kip ESAL.

+Computed for Maine, Minnesota, and Washington using the Minnesota composite pavement equation.
Maximum damage ratios include the effects of load and combined load and climate distress types. Ranges of these are summarized in Table 7. For case in which 10 million 18-kip equivalent single axle loads have passed over the pavement. In general, the maximum damage ratios range from 0.42 to 0.84 for flexible pavements, from 0.26 to 0.79 for overlaid flexible pavements, from 0.41 to 0.47 for jointed concrete pavements, and 0.33 for composite pavements in Climatic Zone III.

The variability of these damage ratios is due partly to the influence of the climate where available moisture appears to increase the amount of damage done by loads and partly to the differences of opinion that exist between States on how heavily various types of distress should be weighted. It is certain that climatically related distress is responsible for a large proportion of the damage that is done to pavements and the importance of these types of distress is reflected in the weighting factors that are applied to these distresses.
TABLE 7. Range of Maximum Damage Ratios for 10-Million 18-kip Equivalent Single Axle Loads*

<table>
<thead>
<tr>
<th>Climatic Zone</th>
<th>Flexible Pavement</th>
<th>Overlaid Flexible Pavement</th>
<th>Jointed Concrete Pavement†</th>
<th>Overlaid Jointed Concrete Pavement*</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.69-0.72</td>
<td>0.56-0.67</td>
<td>0.44</td>
<td>--</td>
</tr>
<tr>
<td>II</td>
<td>0.42-0.84</td>
<td>0.30-0.79</td>
<td>0.47</td>
<td>--</td>
</tr>
<tr>
<td>III</td>
<td>0.42-0.81</td>
<td>0.26-0.69</td>
<td>0.44</td>
<td>0.33</td>
</tr>
<tr>
<td>IV</td>
<td>0.69</td>
<td>0.67</td>
<td>0.41</td>
<td>--</td>
</tr>
<tr>
<td>V</td>
<td>0.47-0.72</td>
<td>0.27-0.67</td>
<td>0.41</td>
<td>--</td>
</tr>
<tr>
<td>VI</td>
<td>0.47-0.73</td>
<td>0.26-0.69</td>
<td>0.43</td>
<td>--</td>
</tr>
</tbody>
</table>

*Computed for Minnesota using the Minnesota composite pavement equation.
†Computed for 20-million 18-kip ESAL.
CHAPTER VII
CONCLUSIONS

The subject that is addressed by this report is complex. The use of the consumption theory of cost allocation requires that costs of rehabilitation and maintenance should be allocated to classes of vehicles based upon the amount of damage that they do that occasions the expenditure of funds for repairing or reconstructing roads. As shown in this report, the damage that results in a decision to maintain or rehabilitate a pavement is not ascribable to load alone but in some cases is entirely dependent upon climatic influences and in other cases is the result of the combined effect of these two.

The pavement distress and performance equations presented in Appendices E, F, and H show that the interaction of load and climate is complex and that the consumption theory of cost allocation, in order to be in accord with both equity and physical reality must be prepared to incorporate this complexity into its determinations of cost formulas.

It is also apparent that at the present time there is no consensus among the States about what types of distress should be considered or how heavily each should be weighted in determining a decision criterion for maintenance and rehabilitation activities. But despite the lack of consensus, it is evident that in the estimation of all of the States, climatically - caused distress figures heavily in their decision making in developing a pavement maintenance and rehabilitation program for the State highway networks. Estimates have been made of the proportions of the decision to rehabilitate that can be ascribed to loads, climate, and combined influences.
Presumably, these estimated proportions should be reflected in the apportioning of costs of maintenance and rehabilitation. That proportion that is due to loads should be borne by the load classes in proportion to the relative amounts of damage that they do. That proportion that is due to the climate should be shared among all vehicles in a given traffic stream in such a way that it reflects the fact that the load of the vehicle plays no part in that proportion of the total damage. Presumably, this can be done by treated the climatically- caused proportions of damage as a common cost to be shared equally among all vehicles.

The proportions change with the climate, the traffic level, the specific type of pavement under consideration, and the quality of construction and routine maintenance as is shown most strikingly in the study of rigid pavement damage that is presented in detail in Appendix F.

As stated before, this is a complex topic, and it is one that can be addressed successfully only with a careful consideration of the diverse causes of pavement damage, only one of which is the level of load which passes over the pavement.
APPENDIX A

DATA COLLECTION IN VARIOUS STATES
APPENDIX A

Data Collection in Various State

A.1 Introduction
A.2 Accessibility of data within Minnesota D.O.T.
   A.2.1 Introduction
   A.2.2 Maintenance and Construction Road Logs
   A.2.3 Minnesota's Pavement Inspection Procedure
   A.2.4 Traffic Data
   A.2.5 Coding the Collected Data for computer input
A.3 Accessibility of data within the Utah D.O.T.
   A.3.1 Introduction
   A.3.2 Utah's Pavement Rating System
   A.3.3 Utah's Pavement Performance Studies from 1964-1969
A.4 Accessibility of data within the New York State D.O.T.
   A.4.1 Introduction
   A.4.2 Data Available for Project Needs
   A.4.3 Coding of collected data for computer input - New York
APPENDIX A

Data Collection in Various States

A.1 Introduction

This Appendix describes the visits made by the project staff to the Highway Departments of Minnesota, Utah, and New York. The purpose of these visits was to collect pavement data for model building purposes; the minimum data requirement of any section being:

- Pavement Construction Data (Layer types, thicknesses, etc.),
- Pavement Maintenance Data (Type, Thicknesses),
- Pavement Condition Survey Data (for several years), and
- Climatic Data.

For completeness, a comprehensive description is given of the data availability and pavement rating procedure used in each of these states.

Although the States of Utah and New York have established pavement inspection procedures and have detailed data on several experimental sites, they mostly did not meet this project's minimum data requirement. However, as will be described, the State of Minnesota was found to be an excellent source for the required data. The modelling of this data will be described later in Appendices C and E.
A.2 Accessibility of Data Within the Minnesota D.O.T.

A.2.1 Introduction

The Minnesota Department of Transportation is responsible for the 13,000 miles of trunk route within the state, these being primarily Interstate, U.S. and State highway type roads. For administrative purposes, the state is broken up into 9 districts, each of which controls an approximately equal length of road.

Since 1966, the Department has been using a pavement rating system which is described in (A-1)*. Early, during the visit to Minnesota, it was discovered that the minimum data required for model building purposes could be obtained by combining the data collected in their rating system with the data available from other sources within the department. These sources include:

a) The departments construction and maintenance logs
b) The computerized traffic logs
c) The soils records maintained in each district office.

The sources will be described in detail in the following sections.

The above mentioned data were collected in 2 of Minnesota's nine Districts. These data were returned to TTI where they were coded and stored on computer prior to data processing. In all, data have been collected for 128 pavement sections in Minnesota and the coding and storage of these data is described in a later section.

*References (A-1) to (A-5) are given at the end of this appendix.
A.2.2 Maintenance and Construction Road Logs

Each district's network is divided into a number of control-sections which are typically 2 to 12 miles in length. The department maintains construction logs which contain construction and maintenance history for each control section.

The log record for Trunk Highway 35W, Control Section 0280, is shown in Figure A-1. This control section is shown to have the following three subsections:

1. From the County Line to Trunk Highway 49, was constructed in 1968 with an 8 inch thick concrete surfacing over a 3 inch gravel base.

2. From Trunk Highway 49 to Trunk Highway 35E, a distance of 4.68 miles, this subsection being completed in 1969.

3. A short length (0.54 miles) section over a girder bridge.

From discussions with the Minnesota personnel and by studies of these road logs it became clear that their highway network consists essentially of the following four pavement structures.*

1. New Concrete Interstate Routes. Typically being 8" concrete (± 40 ft. slab length) on top of a 3 - 6" natural gravel base, being constructed after 1960. Up until 1976 these pavements have generally received little or no maintenance. However, some sections have recently received thin overlays and others are showing serious distress which will warrant major rehabilitation in the near future.

*Clearly not every trunk route in Minnesota will fall into this classification, however, it appears that the majority of roads may be thus classified.
2. **Overlaid Concrete Routes.** Constructed between the 1930's and 1950's, these sections, typically received a widening in the late 1950's or early 1960's and have received frequent overlays.

3. **Flexible Pavement (Bituminous Base).** The black-base thickness is 6" to 13" depending on traffic and subgrade conditions. These pavements were constructed after 1969. However, the department has relatively few sections of this pavement type.

4. **Flexible Pavement (Gravel Base).** These are generally older pavements which were generally strengthened as traffic levels grew. A typical structure would be 4" asphalt surfacing on top of a 12 to 18" aggregate base.

**A.2.3 Minnesota's Pavement Inspection Procedure**

The rating system is extensively covered in (A-1). In summary it is composed of two parts, a Present Servicability Rating (PSR) and a Structural Rating (SR). The PSR and SR values are averaged to obtain the final Condition Rating (C.R.).

The PSR was initially determined by a 3 man panel using the equation developed at the AASHO Road Test. However, it was found that this was not an accurate indicator of rideability because it could not be determined uniformly on a state-wide basis. Therefore since 1967 the department has measured PSI using a PCA road meter.

The structural rating is calculated from the visual inspection of pavement distress. During this visual inspection, the following distress types are monitored.
a) Flexible Pavements

- transverse cracking - The number of cracks in a 1/4 mile section is converted to a percentage value as shown below:

<table>
<thead>
<tr>
<th>No. cracks per 1/4 mile</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>150+</td>
<td>100</td>
</tr>
<tr>
<td>100-150</td>
<td>75-100</td>
</tr>
<tr>
<td>50-100</td>
<td>25-75</td>
</tr>
<tr>
<td>0-50</td>
<td>0-25</td>
</tr>
</tbody>
</table>

- longitudinal cracking
- multiple cracking
- alligator cracking
- rutting (greater than 1/2")
- patching

b) Bituminous Overlaid Concrete (Composite) Pavements

- slight transverse
- severe transverse

- slight longitudinal
- severe longitudinal

- multiple
- patching

rated as lineal feet per 1/4 mile then converted to %

convert to %, similar to flexible pavements

c) Concrete Pavements

- spalled joints
- faulted joints
- cracked panels
- broken panels
- faulted panels
- Patches
- Overlay
- Scaling

The appropriate forms are shown in Figure A-2, A-3, and A-4 respectively. The structural rating is calculated by multiplying the average percentage of each distress type present by the relevant weighting factors which are shown below.

### Flexible Pavements

<table>
<thead>
<tr>
<th></th>
<th>Transverse</th>
<th>Longitudinal</th>
<th>Multiple</th>
<th>Alligator</th>
<th>Rutting</th>
<th>Patching</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.02</td>
<td>.02</td>
<td>.15</td>
<td>.35</td>
<td>.15</td>
<td>.30</td>
</tr>
</tbody>
</table>

### Concrete Pavements

<table>
<thead>
<tr>
<th></th>
<th>Joints</th>
<th>Panels</th>
<th>Patches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spalled Faulted</td>
<td>Cracked Broken</td>
<td>Faulted &gt;5 sq.ft. Overlay Scaling</td>
</tr>
<tr>
<td></td>
<td>.25 .10</td>
<td>.10 .10</td>
<td>.10 .20 .10 .05</td>
</tr>
</tbody>
</table>

### Overlaid Pavements

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<tr>
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<th>Transverse Cracking</th>
<th>Longitudinal Cracking</th>
</tr>
</thead>
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<tr>
<td>Slight</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Severe</td>
<td>0.30</td>
<td>0.30</td>
</tr>
</tbody>
</table>

The individual weighted averages are then summed, this summed value is converted into the final Structural Rating value via a table look-up. Extracts from this table are shown below in Table A-1.
Figure A-2. Minnesota's Visual Rating Form of Bituminous Pavements
<table>
<thead>
<tr>
<th>MILE</th>
<th>LANE</th>
<th>JOINTS</th>
<th>PANELS</th>
<th>PATCHING</th>
<th>SCALE</th>
<th>S.R.</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(A)</td>
<td>(B)</td>
<td>(C)</td>
<td>(D)</td>
<td>(E)</td>
<td>(F)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(G)</td>
<td>(H)</td>
<td>(I)</td>
<td>(J)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TOTAL</td>
<td>SPALLED %</td>
<td>FAULTED %</td>
<td>TOTAL</td>
<td>VISIBLE</td>
<td>NUMBER</td>
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<tr>
<td>0-1</td>
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</tr>
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</tr>
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</tr>
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<td></td>
</tr>
<tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td></td>
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<td></td>
</tr>
<tr>
<td>10-11</td>
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<td></td>
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<td></td>
</tr>
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<td></td>
</tr>
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<td></td>
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<td></td>
</tr>
<tr>
<td>13-14</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14-15</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

PSR = Average Structural Rating = Condition Rating =

Figure A-3: Minnesota's Visual Rating Form for Concrete Pavements
<table>
<thead>
<tr>
<th>MILE</th>
<th>LANE</th>
<th>CRACKING</th>
<th>PATCHING</th>
<th>S.R.</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(A)</td>
<td>(B)</td>
<td>(C)</td>
<td>(D)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>slight</td>
<td>severe</td>
<td>slight</td>
<td>severe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>transverse</td>
<td>transverse</td>
<td>longitudinal</td>
<td>longitudinal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No.</td>
<td>%</td>
<td>No.</td>
<td>%</td>
</tr>
<tr>
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<td>2-3</td>
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<td>3-4</td>
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<tr>
<td>14-15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSR =</td>
<td>Average Structural Rating =</td>
<td>Condition Rating =</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure A-4. Minnesota's Visual Rating Form For Bituminous Overlaid Concrete Pavements
TABLE A-1. Conversion of the Weighted Average Distress Value Into a Structural Rating

<table>
<thead>
<tr>
<th>Weighted Average</th>
<th>Structural Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>2.5</td>
</tr>
<tr>
<td>30</td>
<td>1.0</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

The values of PSI, SR, and CR of each length of road in the network are stored on computer at the Head Office in St. Paul. The individual rating forms showing the percentages of each distress type are stored in manual files in the relevant district offices. Because it was desirable to study changes in each distress type, it was necessary to visit some district offices.

The following two district offices were visited.

- District Office 5 at Golden Valley, Minneapolis, which controls the metropolitan highway routes to the west of the Mississippi River.
- District Office 9 in North East St. Paul which controls the metropolitan highway routes to the east of the Mississippi River.

District 5 has kept its complete set of inspection records back to 1966 when the rating system was started. After a preliminary inspection of this district's road logs 55 control sections were found to have construction/maintenance histories suitable for inclusion in the TTI
studies. Complete historical visual rating data were collected for each of these sections, this typically consisting of 3 or 4 visual ratings (i.e., in 1969, 1972, 1974, 1976). This involved xeroxing the original visual inspection form, an example of which is shown in Figure A-5, this being for Trunk Highway 7, Control Section 1003 between West County Line and East County Line, a distance of 11.15 miles. This inspection was conducted on July 7th 1970.

District 9 however has only kept previous inspection records back to 1976. In this district 30 control sections were selected and the available visual rating data were xeroxed and returned to TTI.

A.2.4 Traffic Data - Minnesota

The department has computerized its traffic data for each section of pavement which is inspected. The department produces a computer listing containing the sections:

a) Present Serviceability Index,
b) Structural Rating,
c) Condition Rating,
d) Average Daily Traffic, and
e) % Trucks.

The complete listings for Districts 5 and 9 were made available to TTI; a portion of this listing is shown in Figure A-6, in which the indicated subsection is on Trunk Highway 8, control section 8213 between the junction with Trunk Highway 61 and the north end of the divided highway. The total ADT in both directions is 8000 with 4.7% trucks.

The department undertakes frequent truck classification counts on its network. The counts enable the calculation of 18-K ESAL values for each highway segment. These data are made available upon request.
## Bituminous Pavement Structural Rating Form

**Trunk Highway** 7  
**Control Section** 1003  
**Raters**  
**Date** 7-6-76  
**Begin Survey** W. Co Line  
**End Survey** E. Co Line  
**Total Length** 11.15  
**Shoulder Type:** Bituminous □ , Gravel or Earth □ , None □  
**Divided □ Not Divided □**  
**No. of Lanes (Including parking lanes):** 2 □ , 3 or more □  
**District No.** 5

<table>
<thead>
<tr>
<th>MILE</th>
<th>LANE</th>
<th>CRACKING</th>
<th>RUTTING</th>
<th>PATCHING</th>
<th>S.R.</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(A)</td>
<td>(B)</td>
<td>(C)</td>
<td>(D)</td>
<td>(E)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>transverse</td>
<td>longitudinal</td>
<td>multiple</td>
<td>alligating</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>No. %</td>
<td>Ft. %</td>
<td>Ft. %</td>
<td>Ft. %</td>
<td>Ft. %</td>
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<td></td>
<td>300 100</td>
<td>40 3</td>
<td>270 21</td>
<td>90 7</td>
<td>140 11</td>
</tr>
<tr>
<td>1 - 2</td>
<td></td>
<td>284 100</td>
<td>170 13</td>
<td>390 30</td>
<td>20 2</td>
<td>110 8</td>
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<td>2 - 3</td>
<td></td>
<td>259 100</td>
<td>200 15</td>
<td>400 31</td>
<td>40 3</td>
<td>200 15</td>
</tr>
<tr>
<td>3 - 4</td>
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<td>200 15</td>
<td>400 31</td>
<td>40 3</td>
<td>200 15</td>
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<td>4 - 5</td>
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<td>250 19</td>
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<td>110 8</td>
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<td>5 - 6</td>
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<td>294 100</td>
<td>40 3</td>
<td>90 7</td>
<td>0 0</td>
<td>940 70</td>
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<tr>
<td>6 - 7</td>
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<td>142 96</td>
<td>50 4</td>
<td>0 0</td>
<td>0 0</td>
<td>50 4</td>
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</table>

**PSR = 2.90**  
**Average Structural Rating = 2.17**  
**Condition Rating = 2.53**
<table>
<thead>
<tr>
<th>Section</th>
<th>From</th>
<th>To</th>
<th>Miles</th>
<th>ADT</th>
<th>% Trucks</th>
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<tbody>
<tr>
<td>008 W</td>
<td>1.09</td>
<td>1.74</td>
<td>0.08</td>
<td>6213</td>
<td>J 3.1 3.4 3.1&lt;br&gt;J 3.1 3.4 3.1</td>
</tr>
<tr>
<td></td>
<td>13.33</td>
<td>16.34</td>
<td>3.01</td>
<td>1301</td>
<td>J 3.1 3.5 3.3&lt;br&gt;J 3.1 3.5 3.3</td>
</tr>
<tr>
<td></td>
<td>16.34</td>
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<td>1301</td>
<td>J 3.1 3.5 3.3&lt;br&gt;J 3.1 3.5 3.3</td>
</tr>
<tr>
<td></td>
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<td>0.10</td>
<td>1301</td>
<td>J 3.1 3.5 3.3&lt;br&gt;J 3.1 3.5 3.3</td>
</tr>
<tr>
<td>010 W</td>
<td>237.95</td>
<td>239.35</td>
<td>0.40</td>
<td>6266</td>
<td>J 3.0 3.0 3.0&lt;br&gt;J 3.1 3.1 3.4</td>
</tr>
<tr>
<td></td>
<td>239.24</td>
<td>240.40</td>
<td>1.16</td>
<td>6265</td>
<td>J 3.1 3.1 3.3&lt;br&gt;J 3.1 3.1 3.1</td>
</tr>
</tbody>
</table>

Figure A-6. A Typical Listing From Minnesota's Computerized Pavement Condition And Traffic Data File
A.2.5 Coding the Collected Data for Computer Input

As previously discussed, the Minnesota Department of Transportation made the following data available.

1. A complete set of road logs for Districts 5 and 9.
2. Xerox copies of inspection data from 85 control sections (Each control section has several subsections each of which may have had up to 5 pavement inspections).
3. Computer listings of Traffic and PSR data.

These data were returned to TTI where it was coded onto forms suitable for computer input. The complete data for one section is coded onto one form, as shown in Figure A-7. The data are stored in one of the following 3 records.

1. Section Identification Record
   including - Trunk Highway Number
   - Control Section Number
   - District
   - Pavement Type (Flexible, Concrete, Overlaid Concrete, etc.)
   - If highway is divided or not
   - Start of Section
   - Subgrade Rating (AASHTO Soil Classification)
   - ADT
   - % Trucks
   - 18-Kip ESAL data

2. Construction and Maintenance Records
   including - Year of construction
   - Layer type, thickness for top 4 layers
   - Date, type, thickness of maintenance treatments
     (up to 6 maintenance treatments)
3. Pavement Inspection Records

- Type of Pavement Inspection (Concrete, Overlaid, etc.)
- Date of Inspection
- % of each distress types present
- PSI value measured with P.C.A. road meter

The complete data for Trunk Highway 12, Control-Section 2714 is shown in Figure A-7. This section was constructed in 1952 with a 9 inch concrete pavement on top of a 3 inch granular base. The section received a 3½ inch asphalt overlay in 1974. The concrete surfacing was inspected in 1969 and 1972 and the overlay was inspected in 1975 and 1978.

In all, TTI now has similar data on 128 pavement sections in Minnesota.
Figure A-7. TTI coding sheet for Minnesota Data
A.3 Accessibility of Data Within the Utah D.O.T.

A.3.1 Introduction

The questionnaire* returned from Utah indicated that there were no pavement sections within the state on which data had been kept. However, it was known to the project staff that the State of Utah has assembled a significant amount of pavement condition data over a period of over a decade and a half. Because of this apparent discrepancy between the questionnaire response and the known facts, it was decided to collect data from the State of Utah to see what its accessibility, quality, and quantity were.

The Utah Department of Transportation is responsible for the 5570 miles of Trunk routes within the state, these being broken down as follows.

Interstate 940  
Primary 1405  
Secondary 2800  
Urban 425

The majority of these pavements are flexible, since Utah has very few miles of concrete pavement.

For administrative purposes the D.O.T.'s network is broken up into 6 Districts each of which controls an approximately equal length of road.

Utah has pavement rating data from two sources as follows:
1. the state-wide pavement rating system, and
2. the pavement performance studies conducted between 1964 and 1969.

The suitability of the data available from these sources will be discussed in the next two sections.

---

*In previous studies, questionnaires were sent to every state concerning the availability of pavement inspection data.
A.3.2 Utah's Pavement Rating System

Utah has one of the most advanced pavement inspection and reporting systems for prioritizing rehabilitation projects. The final pavement score is calculated by combining the pavements

a) Present Serviceability Index, measured using the PCA roadmeter,

b) Pavement Structural Strength, measured using the dynaflect,

c) Pavement Surface Distress types, monitored in a visual inspection, and

d) Skid Resistance, measured using a Mumeter.

Typical printouts from the current system are shown in Figures A-8 and A-9.

Figure A-8 shows a typical listing of rating data for one section of the State's network.

Figure A-9 shows a summary of the data collected from District 2. The Final Index is the final pavement score which combines each of the distress types illustrated in Figure A-8. Because the Final Index scores have been sorted, this listing theoretically gives the most distressed sections of pavement in District 2.

However, although Utah has some excellent pavement inspection data, it is doubtful if this can be used without a corresponding program of coring, field deflection measurements, and laboratory tests. This is because, unlike Minnesota, Utah does not maintain any road construction logs. The construction records are maintained in centralized manual files, but it is very difficult to relate these files to the pavement inspection
### Pavement Evaluation for State Route UU6 Section 42 Sub Section 0 Emery County (15) District 4 FAP-28

- From No. to Horse Cyn. Milepost 267.64 to Rest Area Woodside Milepost 278.77
- Material Cover Aggregate Bitum, Surface (CABS)
- Maintenance Shed 435 I.D. No. 100
- Present 1st Loads 93861

#### Dynaflect Test Data

<table>
<thead>
<tr>
<th>No. of Tests</th>
<th>Late 10/11/79 HR Min</th>
<th>Temp.</th>
<th>LANE</th>
<th>Last Revision 08-15-1978</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>13</td>
<td>0</td>
<td>60</td>
<td>72</td>
</tr>
</tbody>
</table>

#### Dynaflect Summary and Average Conditions

<table>
<thead>
<tr>
<th>1st Loads</th>
<th>Spread</th>
<th>DMD</th>
<th>SCI</th>
<th>BCI</th>
<th>To Failure</th>
<th>YITF</th>
</tr>
</thead>
<tbody>
<tr>
<td>38.5</td>
<td>.640</td>
<td>.148</td>
<td>.027</td>
<td>3.3A117+06</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>57.9</td>
<td>1.112</td>
<td>.436</td>
<td>.123</td>
<td>7.0260+05</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>45.9</td>
<td>.899</td>
<td>.340</td>
<td>.054</td>
<td>1.3659+06</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

#### Structural No. Required for 10 Years Additional Life

- Average SCI + NCI Indicate Subgrade Strong, Pavement Weak
- If present trends continue, the structural needs are moderate and the road will probably last from six to ten years.

#### Scireq = .30 RCI REQ = .07 DMDREQ = .84 tDSYRS = 13

#### Serviceability Summary and Average Conditions

<table>
<thead>
<tr>
<th>Average Surface Wear</th>
<th>Average Popouts</th>
<th>Average Weathering</th>
<th>Average Uniformity</th>
<th>Average Rut Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3</td>
<td>5.0</td>
<td>3.3</td>
<td>3.3</td>
<td></td>
</tr>
</tbody>
</table>

#### Average P.S.I. Indicates that the Service Needs are Critical and Will Probably Fall Below the T.S.I. Within a Year.

### Mumlter Test Data

There is no Mumlter data available for this section.

No friction evaluation was made.
<table>
<thead>
<tr>
<th>RANK</th>
<th>CITY</th>
<th>LENGTH</th>
<th>BEGINNING LOCATION</th>
<th>START</th>
<th>ENDING LOCATION</th>
<th>END</th>
<th>FINAL INDEX</th>
</tr>
</thead>
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<td>1</td>
<td>35</td>
<td>171</td>
<td>1.52  I-15 1ST URB</td>
<td>10.10</td>
<td>JCT SR-71 700 E</td>
<td>11.79</td>
<td>1.8</td>
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<tr>
<td>2</td>
<td>35</td>
<td>80</td>
<td>4.27  BEGIN SR-116</td>
<td>115.95</td>
<td>I-80 MERGES W/TH I-15</td>
<td>126.22</td>
<td>2.0</td>
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<tr>
<td>3</td>
<td>35</td>
<td>68</td>
<td>2.25  4800 S 3 RD</td>
<td>52.25</td>
<td>54.50</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>35</td>
<td>171</td>
<td>3.60  I-15 200 W 15</td>
<td>6.60</td>
<td>10.10</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>43</td>
<td>224</td>
<td>5.37  11TH ST  LEFT</td>
<td>15.70</td>
<td>JCT I-137E</td>
<td>21.57</td>
<td>2.3</td>
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<tr>
<td>6</td>
<td>43</td>
<td>340</td>
<td>5.37  JCT. SR-80</td>
<td>0.00</td>
<td>55.76</td>
<td>2.2</td>
<td></td>
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<tr>
<td>7</td>
<td>43</td>
<td>80</td>
<td>4.90  PIRY INT.</td>
<td>179.62</td>
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<td>184.52</td>
<td>2.3</td>
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<tr>
<td>8</td>
<td>43</td>
<td>56</td>
<td>5.16  300 S STATE LINE</td>
<td>198.76</td>
<td>WASHATCH INTERCHANGE</td>
<td>203.60</td>
<td>2.4</td>
</tr>
<tr>
<td>9</td>
<td>35</td>
<td>66</td>
<td>2.30  400 N DOWNTOWN TO I-15</td>
<td>62.60</td>
<td>64.50</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>43</td>
<td>50</td>
<td>5.30  SL-2000 S</td>
<td>135.13</td>
<td>struct over S.C. JCT.</td>
<td>145.36</td>
<td>2.4</td>
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<tr>
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<td>43</td>
<td>80</td>
<td>4.50  CASTLE ROCK INT.</td>
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<td>EMORY JCT.</td>
<td>194.02</td>
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<td>12</td>
<td>35</td>
<td>152</td>
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<td>205E E</td>
<td>205S E</td>
<td>2.5</td>
<td></td>
</tr>
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<td>13</td>
<td>35</td>
<td>709</td>
<td>1.88  5500 S CROSSING</td>
<td>319.77</td>
<td>JCT SR-173 5300 S</td>
<td>321.65</td>
<td>2.5</td>
</tr>
<tr>
<td>14</td>
<td>35</td>
<td>715</td>
<td>2.75  structure over SR-93</td>
<td>317.56</td>
<td>CASTLE ROCK INC</td>
<td>319.56</td>
<td>2.6</td>
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<td>15</td>
<td>35</td>
<td>748</td>
<td>1.86  2000 E</td>
<td>10.32</td>
<td>CENTER ST,たくい</td>
<td>11.29</td>
<td>2.6</td>
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<td>35</td>
<td>66</td>
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<td>328.30</td>
<td>JCT SR-266 400 W</td>
<td>329.04</td>
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</tr>
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<td>17</td>
<td>35</td>
<td>181</td>
<td>5.60  2100 S</td>
<td>4.60</td>
<td>1700 S</td>
<td>2.6</td>
<td></td>
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<td>18</td>
<td>35</td>
<td>181</td>
<td>2.80  JCT SR-152 VAN VINKEL</td>
<td>0.00</td>
<td>JCT SR-171 3300 S</td>
<td>2.80</td>
<td>2.6</td>
</tr>
<tr>
<td>19</td>
<td>35</td>
<td>173</td>
<td>2.63  JCT SR-111</td>
<td>2.63</td>
<td>5600 W</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>45</td>
<td>136</td>
<td>10.42  TCECN-JUAR CO. LTd</td>
<td>6.15</td>
<td>RAILROAD CROSSING</td>
<td>7.00</td>
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</tr>
<tr>
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<td>35</td>
<td>66</td>
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<td>JCT SR 187  TEMPLE</td>
<td>91.36</td>
<td>2.7</td>
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<tr>
<td>22</td>
<td>35</td>
<td>131</td>
<td>1.36  JCT SR-169 AT 5TH EAST</td>
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<td>JCT SR-106 2ND EAST</td>
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<td>508</td>
<td>1.16  JCT SR-173 5300 SO</td>
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<td>JCT SR-256 3000 S</td>
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<td>43</td>
<td>80</td>
<td>9.08  CASTLE ROCK INC</td>
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<td>WASHATCH INTERCHANGE</td>
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<td>25</td>
<td>35</td>
<td>508</td>
<td>5.16  4400 N INTERCHANGE</td>
<td>193.60</td>
<td>2300 W</td>
<td>194.30</td>
<td>2.8</td>
</tr>
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<td>26</td>
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<td>195</td>
<td>9.72  2100 S</td>
<td>3.89</td>
<td>JCT SR-136 FOURTH ST</td>
<td>4.38</td>
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<tr>
<td>27</td>
<td>35</td>
<td>111</td>
<td>7.04  JCT SR-38</td>
<td>7.04</td>
<td>4000 N</td>
<td>7.49</td>
<td>2.9</td>
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<tr>
<td>28</td>
<td>35</td>
<td>105</td>
<td>2.30  struct. OVER SR-93</td>
<td>317.56</td>
<td>4000 N</td>
<td>319.96</td>
<td>2.9</td>
</tr>
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<td>35</td>
<td>151</td>
<td>6.40  JCT SR-111</td>
<td>6.40</td>
<td>3000 W</td>
<td>6.79</td>
<td>2.9</td>
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<tr>
<td>30</td>
<td>35</td>
<td>181</td>
<td>1.76  1800 S</td>
<td>6.90</td>
<td>1700 S</td>
<td>7.29</td>
<td>2.9</td>
</tr>
<tr>
<td>31</td>
<td>35</td>
<td>508</td>
<td>1.93  1400 N</td>
<td>319.86</td>
<td>structure over SR-93</td>
<td>321.82</td>
<td>3.0</td>
</tr>
<tr>
<td>32</td>
<td>35</td>
<td>508</td>
<td>2.24  7700 S</td>
<td>316.93</td>
<td>5000 N</td>
<td>320.79</td>
<td>3.0</td>
</tr>
<tr>
<td>33</td>
<td>35</td>
<td>184</td>
<td>1.26  ENT GAVEL PIT RIGHT</td>
<td>7.57</td>
<td>JCT SR-29 4700 E</td>
<td>7.65</td>
<td>3.0</td>
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<td>34</td>
<td>35</td>
<td>315</td>
<td>1.92  PAGES LANE</td>
<td>320.79</td>
<td>4000 N</td>
<td>322.82</td>
<td>3.0</td>
</tr>
<tr>
<td>35</td>
<td>35</td>
<td>286</td>
<td>1.94  5TH EAST STREET</td>
<td>1.76</td>
<td>JCT. SR-111</td>
<td>2.70</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Figure A-9. Summary of Rating Data for District 2, Utah; Worst Distressed Pavements Have Lowest Final Index Score.
data. Furthermore, the Department does not keep any records of maintenance activities. Details of major maintenance/rehabilitation, i.e., overlays can only be obtained from the Pavement Design Engineer who estimates, from his memory, the year and type of treatment. Routine maintenance, seals, etc., are applied at approximately 5 year intervals, however, no readily accessible information was available. Details of sealing activities are thought to be maintained by the various District offices, but the quality and quantity of information available was uncertain. Therefore, it appears that little of Utah's current pavement inspection data can be used without being supplemented by additional measurements. However, it may be possible to use some of the earlier (A-3) pavement performance data which was collected between 1964 and 1969. This possibility will be discussed in detail in the next section of this report.

A.3.3 Utah's Pavement Performance Studies from 1964-1969

From 1964 to 1969, the Utah D.O.T. performed evaluations on 121 projects situated throughout the state. The projects varied in length from 0.5 mile to 10 mile and each was constructed in the early 1960's. The Utah project notation is equivalent to the Minnesota Control Section. The aim of this study was to monitor changes in each project's serviceability index, as defined by the AASHTO road test equation.

Typical results from this study are shown in Figure A-10a and A-10b. Figure A-10a shows the pavement design and construction data for Project I-15-1(9)22 and Figure A-10b shows the same pavement's inspection data. The pavement inspection data includes the following.

- roughness measurements (profilograph)
- rutting
Project Engineer: Ben Lee  
Contractor: V. C. Mendenhall Const.  
Completion Date: 1961

Pavement Design:
1 1/4" Plant Mix Bituminous Surface, Type "A" (Wearing)  
1 3/4" Plant Mix Bituminous Surface, Type "A" (Leveling)  
  120-150 Penetration Asphalt Cement  
4  " Cement Treated Base Course  
5  " Gravel Base Course: N.B. Station 820 to 836, 867 to 1084+42  
   S.B. Station 822 to 1089+94  
8  " Gravel Base Course: N.B. Station 814+13 to 820, 836 to 867  
   S.B. Station 795 to 822  

Construction Index:  4.73  
Soil Support Value:  5  
Regional Factor:  1.0  
Terminal Serviceability Index:  2.5  
Structural Number of Design:  2.96  
Design 18K Loads:  305

Serviceability Test Sections:  1N, 12N, 14N, 17N, 23N, 25N,  
  1S, 12S, 14S, 17S, 23S, 25S

Comments: Continuous L Cracking outside lane, with some type 2 beginning.  
Final surfacing completed 1967

Figure A-10a. Construction Data Contained in Utah Pavement Performance Study (Ref. G-3)
### Year of Study:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Traffic Volume Data:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADT</td>
<td>2460</td>
<td>2562</td>
<td>2610</td>
<td>2657</td>
<td>2662</td>
<td>2875</td>
</tr>
<tr>
<td>Heavy Trucks</td>
<td>420</td>
<td>496</td>
<td>449</td>
<td>325</td>
<td>426</td>
<td>350</td>
</tr>
<tr>
<td>18k Equiv. Ld</td>
<td>80</td>
<td>127</td>
<td>120</td>
<td>85</td>
<td>116</td>
<td>109</td>
</tr>
<tr>
<td>Cumulative 18k Equiv. Lds. x 10^3</td>
<td>98.2</td>
<td>142.0</td>
<td>173.0</td>
<td>215.4</td>
<td>255.1</td>
<td></td>
</tr>
<tr>
<td><strong>Roughness; Inches per Mile:</strong></td>
<td>Roughometer</td>
<td>Profilograph</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBL Best Mile</td>
<td>--</td>
<td>88</td>
<td>40</td>
<td>27</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Worst Mile</td>
<td>--</td>
<td>93</td>
<td>58</td>
<td>40</td>
<td>45</td>
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</tr>
<tr>
<td>Average Mile</td>
<td>80</td>
<td>90</td>
<td>49</td>
<td>33</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>NBL Best Mile</td>
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<td>85</td>
<td>41</td>
<td>14</td>
<td>23</td>
<td></td>
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<td>96</td>
<td>62</td>
<td>27</td>
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<td>Average Mile</td>
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<td>91</td>
<td>63</td>
<td>20</td>
<td>31</td>
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<tr>
<td><strong>Rutting; Average Depth in Inches</strong></td>
<td>0.00</td>
<td>0.06</td>
<td>0.10</td>
<td>0.01</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td><strong>Cracking; Sq. ft. per 1000 sq. feet</strong></td>
<td>None</td>
<td>None</td>
<td>12</td>
<td>None</td>
<td>None</td>
<td></td>
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<tr>
<td><strong>Patching; Sq. ft. per 1000 sq. feet</strong></td>
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<td>None</td>
<td>None</td>
<td>None</td>
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<tr>
<td><strong>Present Serviceability Index</strong></td>
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<td>3.28</td>
<td>3.85</td>
<td>4.05</td>
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<tr>
<td><strong>Pavement Rating</strong></td>
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<td>Good</td>
<td>Good</td>
<td>Very</td>
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</tbody>
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---

**Figure 10b.** Pavement Inspection Data for The Pavement Section in Figure A-10a
- cracking (all cracking types were combined into a single figure, the comments entry on Figure A-10a was used to indicate if the cracking was longitudinal, transverse or alligator)

- patching

Other data shown in A-10(b) includes.

- ADT
- Number of Heavy trucks
- 18 kip equivalent axles
- Cumulative 18 kip axles

The PSI was then calculated using the AASHTO equation and was plotted against accumulated 18 equivalent loads. However, as shown in Figure A-10b, the relationship did not always follow the expected trends.

In 1970, the system's output was used by the Utah Department of Transportation to evaluate the needs within each District for roadway improvements. However, there were several cases in which the pavement's PSI was determined to be well above minimum but the Districts claimed that the pavements were highly distressed. A further investigation showed that these sections did have a high PSI based primarily on a relatively smooth riding surface but they were distressed with extensive cracking. Therefore, the basic difference was the user's viewpoint of performance as evidenced by a high PSI contrasted with the maintenance engineers concern for distress as shown by extensive cracking.

Peterson (A-2) concluded "it was felt that the full potential was not being obtained from the research study (using PSI)" and "it was possible for a pavement to fail in one area but be in a good condition in others. A failure in any area would be critical and it was therefore essential that they be looked at individually as well as collectively."
The detailed pavement inspection data, an example of which is shown in Figures A-10a and A-10b, has been made available. It appears that these data will be useful in

a) identifying the type of pavement distress found early in the life of Utah's flexible pavements, and in

b) monitoring changes in present serviceability index.

However, it is anticipated that this data will be of limited use for model building purposes. This is mainly because the early inspections did not clearly differentiate between the different types of cracking. The amount of cracking was expressed as a single figure (sq.ft./1000 sq.ft.). It is not sure how the amounts of longitudinal and transverse cracking, which were measured in lineal feet per 1000 sq.ft., were incorporated into this figure.

Utah has recently conducted other studies (A-4) and (A-5) to examine the cause of early pavement distress in Utah's pavements, both studies involved materials characterization and performance prediction. In (A-4), equations were derived using multiple regression techniques, to relate each distress type to the following independent variables.

- asphalt physical properties
- asphalt chemical properties
- accumulative 18-kip axle loads
- percentage asphalt content
- pavement age
A.4 Accessibility of Data Within the New York State D.O.T.

A.4.1 Introduction

The New York pavement system or network consists of approximately sixteen thousand (16,000) miles of pavement. The total pavement miles in the state of New York is approximately 107,000 as per the 1978 highway statistics. The type of pavements in the New York State Highway System consists of approximately sixty percent (60%) rigid pavements and forty percent (40%) flexible pavements. Generally, two types of rigid pavements have been constructed: Jointed Reinforced Concrete Pavements (JRPC) and Jointed Concrete Pavements (JCP). Some of these rigid pavements have been overlaid and are considered as composite pavements. These represent a small number and do not have detailed information concerning material and condition survey information. The flexible pavements generally consist of a dense asphalt concrete with an asphalt stabilized base. As understood, the greatest amount of information is available on the flexible pavement cross-sections, although the rigid pavements comprise a greater majority of pavement miles. In general, the rigid pavements have been performing satisfactorily and have not undergone detailed investigations in relation to their performance, unlike the flexible pavements.

New York State has pavement data from two sources which may be used for revising the AASHTO interim design equations. These sources are:

1. the general pavement inventory system, and
2. the pavement performance research studies on flexible pavements which were mostly completed in 1971.

The general pavement inventory system is computerized and lists basic
construction and general information about each pavement section in the State's network. However, no condition survey data (cracking, rutting) are provided in this inventory. Only present rightability index values are given, these being a function of roughness. Therefore, it is doubtful whether the data stored in this inventory system will be of any use in revising the AASHTO design equations.

However, the type of information that is required can be obtained from the data collected in the state's pavement performance research studies. These data include traffic data, deflection measurements, environmental data, condition survey information, roughness measurements, PSI calculations, materials and soils data and PRI information. These data were collected and returned to TTI where they were coded for computer input.

The types of data available are discussed in detail in the following section and the coding of this data into a form suitable for computer input is described subsequently.

A.4.2 Data Available for Project Needs - New York

The type of information that would be beneficial to project needs has only been included in research studies. This type of information includes traffic data, deflection measurements, environmental data, condition survey information, roughness measurements, PSI calculations, material and soils data and PRI information. There are numerous other data available on almost all state highway pavements in the state of New York; except for these sections condition survey information, deflection, and material and soils data do not exist. Only traffic data, environmental data, and PRI data exist on other sections.
1) **Traffic Data - New York**

Traffic data on each section consists of average annual daily traffic, percent trucks, and an equation to calculate equivalent 18-kip axles. Generally, AADT and percent trucks are taken annually. Comprehensive truck weight studies are not completed annually. At the present, New York State uses an equation developed from previous findings to determine the number of 18-kip equivalences. This truck weight study was completed on 175 pavements in 1961, 1962, and 1963. These studies were conducted at 26 stations, 10 on rural and urban interstate highways and 16 on primary rural roads. The basic assumption was that all pavements studied had the same distribution of axles and axle loadings as the 26 in the weighing study. This assumption was considered valid because these factors did not vary to any great extent at the 26 stations. Therefore, using these truck weight studies a procedure was developed to determine the average number of axles per truck and the average weight of each axle load to determine the 18-kip equivalencies using the AASHTO equivalency factors. The resulting equation is:

\[
\text{18-kip EAL's} = 507(\text{Total Truck Traffic}) + 1.46(\text{Total Traffic-Truck Traffic});
\]

which has been used for all New York pavement research studies.

2) **Environmental Data**

The environmental data collected on each pavement section includes maximum and minimum air temperatures by day, the amount of precipitation and snow by day, and the freezing index for
each year. This type of data exists for a 30-year period for 42 stations across the state.

3) **Deflection Measurements**
   
   On resurfaced asphalt concrete pavements, Benkelman Deflections have been collected on the research sections. Generally, these measurements have been taken on selected sections and at no certain time interval. These measurements are collected purely for research needs. On portland cement concrete pavements, differential vertical joint movements are measured using the Benkelman beam. Theses are collected semi-annually for research studies.

4) **Condition Survey**
   
   The physical measurements of cracking and rutting are only taken for research studies on selected sections of highways. For asphalt concrete pavements the distress recorded is both cracking and rutting. Cracking is recorded in terms of length of cracks in feet, for both transverse and longitudinal cracking and area of cracking for alligator cracking Rut depths are measured both in the inner wheel path and outer wheel paths. For the highway sections under study during the research period this information is collected annually. Other types of distress are rated subjectively as low, moderate, or severe distress. The other types of distress recorded include ravelling, distortion, pitting, and pot holes. Patching is also recorded along with cracking. It is recorded in area measurements. For portland cement concrete pavements faulting, cracking, joint deterioration, and sealant condition are measured. As with
flexible pavements, a condition survey is only completed for the rigid pavements which are included in research studies. Condition surveys along with other physical conditions of the pavement are not measured or recorded for sections not included in research studies.

5) **Roughness**

Prior to 1971 BPR roughometer measurements were taken on all asphalt concrete sections included in research studies, and the California profilograph was used on rigid pavements. After 1971, the PCA roadometer is used to record roughness. This information is collected annually on all sections included in the New York State inventory system. At the present, these roughness readings (PCA roadometer) are used to compute the PRI index values.

6) **Skid Resistance**

Skid resistance measurements have not been recorded or reported on any of the research sections or other sections included in the inventory system.

7) **Present Serviceability Index (PSI)**

Using the same measurements as at the road test, New York has developed an equation for performance. The background of its development and the procedure were based on a survey of flexible pavements similar to the one used at the AASHO Road Test. The developed equation is presented below.

\[
\log_e \text{PSI} = 1.73 - 0.0053R - 2.67 \sqrt{RD} - 0.022(C + P)^{\frac{1}{3}}
\]
where

\[ R = \text{roughness index}, \]
\[ RD = \text{rut depth}, \]
\[ C = \text{amount of cracking}, \]
\[ P = \text{area of patching}. \]

Generally, the New York State performance equation is more sensitive to changes in rut depth and cracking and patching in relation to PSI values than the AASHO Road Test Performance Equation.

8) Material and Soils Data

Detailed material and soils informations are available on pavements included in research studies only. Such information includes gradation, strength values (CBR value, flexible strength), penetration of asphalt, asphalt contents, densities, volume change characteristics, and other mix properties of portland cement concrete. This type of data is not available on all sections included in the inventory system.

9) PRI Data and Photo Log Information

As stated previously, in the New York State System both present rightability index values and photo log information are available on all sections of pavements in New York State. The PRI value is determined from roughness measurements only using the PCA roadmeter. This value has not been related to condition survey information or physical features of the pavements surface. From discussions with state personnel, it is believed not to be related to cracking or rutting. Photo log information of each pavement section included in the pavement
inventory system is available from 1975 to the present time. This information is mainly used for safety studies, although it would be possible to use this photo log process to develop condition survey information.

A.4.3 Coding of Collected Data for Computer Input - New York

The data items discussed in the previous section were collected and returned to TTI for coding. The complete data for one section is coded onto one coding form as shown in Figure A-11. As with the Minnesota data the New York State data has been coded into one of the following 3 records.

1. Sectional Identification Record

Including

- Site number
- Pavement Type (flexible, etc.)
- Section length
- If the highway is divided
- Start of Section
- Freezing Index
- Mean Temps in January and June
- Rainfall
- Snowfall
- ADT
- % Trucks
- Construction Year
- Subgrade CBR, PI, Frost susceptibility
2. **Construction Record**

Including

- Layer type, thickness for top 4 layers
- Penetration of binder in surface layer + year of test

3. **Pavement Inspection Record**

Including

- Date of inspection
- Rut depths
- Length of Transverse, longitudinal, Multiple cracking
- Area of alligator cracking
- Area of patching
- Pavement roughness
- PSI
- Pavement deflection

The complete data for Site Number 94022 is shown in Figure A-11. This section was constructed in 1959 with a 1 inch AC layer, 4" inch Asphalt Stabilized Base on top of a 17 inch Flexible Base. The subgrade CBR was 2 and the PI was 10. The penetration of the surfacing binder was measured to be 77 in 1959. Pavement inspections were performed in 08/66, 07/67 and 07/69.

In all, TTI now has similar data on 98 pavement section in New York State.
**Figure A-11. TTI Coding Sheet For New York State Data**

<table>
<thead>
<tr>
<th>TTI No</th>
<th>DATE</th>
<th>RUT.</th>
<th>TRANS.</th>
<th>LONG.</th>
<th>MULT.</th>
<th>AREA</th>
<th>PATCH.</th>
<th>ROUGH</th>
<th>PSI</th>
<th>DEFN</th>
</tr>
</thead>
<tbody>
<tr>
<td>2261</td>
<td>08/36,115</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>27</td>
<td>0</td>
<td>106</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2261</td>
<td>07/67,192</td>
<td>0</td>
<td>41</td>
<td>0</td>
<td>22</td>
<td>0</td>
<td>108</td>
<td>9.031</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2261</td>
<td>07/69,186</td>
<td>0</td>
<td>49</td>
<td>0</td>
<td>190</td>
<td>0</td>
<td>1012</td>
<td>8.032</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

1. Since 1966, Minnesota has been performing detailed inspections of every pavement in its highway network. These inspection records are maintained in decentralized manual files in the various district offices. These records can be linked to the centralized road log and traffic files.

2. Data from 128 pavement sections in Minnesota have been coded and stored on computer. It is anticipated that they will be extremely useful for model building.

3. Utah does not maintain any easily accessible construction or maintenance logs, it must therefore be concluded that Utah's current pavement inspection data will be of limited use for model building purposes.

4. Utah has performed several well documented studies on samples of their road network. An extensive study (A-3) "Evaluation of Pavement Serviceability on Utah Pavements" was performed between 1964 and 1969. This study gives detailed pavement performance data on 121 projects throughout the state. Other studies (A-4) and (A-5) examine causes of early pavement distress in Utah's pavements. Although these data will be useful in identifying the types of early pavement distress in Utah, it is thought that they will not be of sufficient quantity or accuracy to permit model building.

5. New York State has a computerized inventory system which includes construction and maintenance data about every pavement in the states network. However, no condition survey data is stored, only present rideability index values are given, these being a function of roughness. Because some condition survey data are essential to quantify the amount of each distress type that is present, it is doubtful whether these inventory data will be of any use for model building.
6. New York State performed several detailed research studies of flexible pavement performance. The raw data collected during the studies was returned to TTI where it was coded for computer input. In all, detailed data on 98 sections has been stored on computer.
APPENDIX A - References


APPENDIX B

TYPICAL DISTRESS TYPES FOUND
IN MINNESOTA AND UTAH
APPENDIX B

Discussion of the typical distress types found in Minnesota and Utah

B.1 Introduction

B.2 Deterioration Cycle for Flexible Pavements

B.3 Preliminary Analysis of Pavement Inspection Data Collected in Minnesota

B.4 Implications of Results

B-2
APPENDIX B

Discussion of the Typical Distress Types Found in Minnesota and Utah

B.1 Introduction

The collection of pavement performance data in Minnesota and Utah has been described previously in Appendix A. The data returned from Minnesota was found to be the most complete and most suitable for model building purposes. TTI has constructed a data base of these data on 128 sections of pavement in Minnesota, the detailed data analysis will be discussed in depth in Appendix E.

During visits to these states discussions were held with senior engineers concerning the typical deterioration cycles commonly found in that states flexible pavements. (A typical flexible pavement being a 4" bituminous surfacing on top of a thick 12" - 18" gravel base course.) Both states are located in hard freeze environmental zones and their pavements should be most prone to traffic associated distress according to AASHTO or similar models. However the discussions and pavement inspection data indicate that thermal cracking is the major distress type found in each state.

A summary of these discussions and an initial simple analysis of the inspection data is presented below.
B.2 Deterioration Cycle for Flexible Pavements

From the discussions with these states' engineers and inspectors it was concluded that the typical flexible pavements in each state have similar deterioration cycles, which are described as follows:

Step 1. Transverse Cracks with large spacing.

These transverse cracks are thermal cracks which are induced by the freeze-thaw environmental forces. The crack spacing is commonly in the order of forty feet. A typical transverse crack is shown in Photograph B-1.
It was commented that in some pavements it is sufficient to seal these cracks and the pavement would then give satisfactory performance. However, in many other cases rapid pavement deterioration occurs once these initial cracks are observed.

**Step 2. Closer Spaced Transverse Cracks**

Cracks form either between the initial cracks or close to the initial crack.

These cracks are again thought to be due to the environmental forces.

**Step 3. Longitudinal Cracks**

Longitudinal cracks then form at the edge of the pavement.

These cracks may be caused by either

- Environmental forces (thermal cracks)
- Construction joints between passes of the lay down machine or
- Traffic-associated when they occur in the wheelpaths.

Thermal cracking was thought to be the main cause of longitudinal cracking in Utah. The thermal longitudinal cracks shown in Photograph B-2 have formed along the white lane-marking.

These longitudinal and transverse cracks join up to form block cracks typically 8 to 12 feet square.
Step 4. Map cracking

The large block crack initiated in Step 3 then start breaking down into smaller blocks,

\[ \ldots \text{typical crack pattern}\ldots \]

This cracking pattern is thought to be due to the action of both environment and traffic. Water penetrates the pavement, via the large block cracks, weakens the structure, this combined with the action of traffic initiates map cracking.
The departments felt that the rate of crack deterioration into multiple cracking was dependent on the quality of the subgrade soils, the traffic loading and environmental conditions. They stated that multiple cracking usually deteriorates to alligatoring if left untreated. Therefore the departments would prefer to usually overlay once multiple cracking has occurred rather than risk a greater expenditure at a later date.

The initial stages of map cracking are shown in Photograph B-3. The departments thought that the optimum time to apply preventative maintenance was just prior to the appearance of this type of cracking, this maintenance being commonly a seal coat or thin overlay.

Photograph B-3

Large block cracks have formed and these are starting down into smaller blocks (onset of map cracking)
Step 5. Serious Traffic Associated Distress

Once map cracking is evident this usually rapidly deteriorates into alligator type cracking. Load associated rutting greatly increases and potholes start to form. Once these distress types are evident only costly rehabilitation strategies are feasible.

Both departments stated that alligator cracking is not common in their pavement because: a) the departments prefer to maintain their pavement before alligatoring occurs; b) localized areas of alligator cracking are usually patched by routine maintenance forces. Typical localized areas are shown below:

![Diagram of localized alligator cracking and patched areas]

They occur because of localized base failures or poor control over earlier maintenance activities.

Both departments thought that rutting was not a serious problem in their flexible pavements. For example, of the 212 sections inspected annually between 1964 and 1969 in Utah, the maximum rut depth was measured at .53", the vast majority of the sections exhibited no significant rutting (i.e. ruts less than .10").
B.3 Preliminary Analysis of the Pavement Inspection Data Collected in Minnesota

As described in Appendix A the Minnesota Department of Transportation has been performing annual pavement inspections since the mid 1960's. During these inspections the amounts of pavement distress evident in each pavement is recorded and a riding quality survey is made using the P.C.A. roadmeter. These data are converted into a pavement score, the pavements with the lowest score being those in most need of maintenance.

For flexible pavements the following distress types are recorded (in terms of % distress per section).

a. Transverse Cracking. The number of transverse cracks being counted and converted into a % value as shown below:

<table>
<thead>
<tr>
<th>Number of Cracks per 1/4 mile</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 +</td>
<td>100</td>
</tr>
<tr>
<td>100 - 150</td>
<td>75 - 100</td>
</tr>
<tr>
<td>50 - 100</td>
<td>25 - 75</td>
</tr>
<tr>
<td>0 - 50</td>
<td>0 - 25</td>
</tr>
</tbody>
</table>

b. Longitudinal Cracking

c. Multiple Cracking

d. Alligator Cracking

e. Rutting (greater than 1/2")

f. Patching

} rated as lineal feet per 1/4 mile then converted to %.
In order to illustrate the distress types commonly found in Minnesota's pavements, twenty sections were chosen for an initial analysis. These sections were chosen because they:

a. All are flexible pavements of similar structure;
b. All are located in District 5, west of Minneapolis;
c. All had received an asphalt overlay in the mid 1970's; and
d. All were inspected 1 or 2 years before and after the application of the overlay.

A statistical analysis was performed to:

1) calculate what percentage of each distress type was present just prior to the maintenance treatment; and
2) calculate what percentage of each distress type was present one year after the application of the maintenance treatment.

These results are shown in Table B-1 and in Figure B-1.

Table B-1. Summary of Results from 20 Flexible Pavements in Minnesota

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Just Prior to Maintenance</th>
<th>One Year After Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Cracking</td>
<td>87.95</td>
<td>34.89</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>16.48</td>
<td>6.48</td>
</tr>
<tr>
<td>Multiple Cracking</td>
<td>11.92</td>
<td>0.73</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>1.61</td>
<td>0.15</td>
</tr>
<tr>
<td>Rutting</td>
<td>3.97</td>
<td>0.00</td>
</tr>
<tr>
<td>Patching</td>
<td>11.29</td>
<td>0.07</td>
</tr>
</tbody>
</table>
Table B-1 and the histogram shown in Figure B-1 illustrate that the major distress type found in Minnesota flexible pavements is thermally induced Transverse Cracking. Furthermore, very little load associated distress is present when the decision is made to overlay the pavements. Therefore the overlays being applied are essentially preventative, which indicates that the pavements are sufficiently distressed to warrant maintenance and that if this maintenance is delayed, the load associated distress types will rapidly develop.
FIGURE B-1.
MEAN PERCENTAGES OF THE DISTRESS TYPES PRESENT IN MINNESOTA'S FLEXIBLE PAVEMENTS

1. Just Prior to Maintenance
2. One Year After Maintenance

LOAD ASSOCIATED DISTRESS TYPES

PERCENTAGE PRESENT

TRANSVERSE CRACKING
LONGITUDINAL CRACKING
MULTIPLE CRACKING
ALLIGATOR CRACKING
RUTTING
PATCHING
Implications of Results

1. Minnesota's pavements because of the states hard freeze/spring thaw environmental cycle's should be most prone to traffic associated distress according to AASHTO or similar models. However, in Minnesota thermal cracking is the major cause of the expenditure of pavement maintenance and rehabilitation funds.

2. Minnesota has a similar climate to the AASHTO Road Test Site, yet the pavement distress types commonly occurring in Minnesota are different from those observed during the AASHTO Road Test. This is undoubtedly due to the accelerated pace of load applications at the AASHTO Road Test relative to environmentally applied stresses. On other pavements in the same climatic zone, under more normal loading conditions, the distress caused by climatic influences initiates the damage and weakens the pavement to the point where loads can begin to cause their damage. Under these normal circumstances, pavements will be repaired or maintained before load-associated distress begins to occur. From this point of view, the experimental observations at the AASHTO Road Test run counter to normal experience in the same climatic region.
APPENDIX C

CALCULATION OF DEDUCT POINTS AND

PAVEMENT DAMAGE BREAKDOWN
APPENDIX C

Calculation of Deduct Points and Pavement Damage Breakdown

C.1 Introduction

C.2 Detailed Deduct point calculation for each state
   C.2.1 State of Minnesota
   C.2.2 State of Maine
   C.2.3 State of Washington

C.3 Summary
APPENDIX C
Calculation of Deduct Points and Pavement Damage Breakdown

C.1 Introduction
In Appendix E regression models are derived from the pavement inspection data collected in Minnesota. These models relate growth in each of the following distress types.*

- transverse cracking
- longitudinal cracking
- multiple cracking
- Alligator cracking
- Rutting
- Patching

to parameters such as

- Number of heavy loads carried ($N_{18} = 18 \text{ kip ESAL}$)
- Number of months in service (TIME)
- Most recent overlay thickness (OVT)
- Average Daily Traffic (ADT)
- Pavement Structural Strength, via a calculated Dynaflect Mean Deflection (DMD) or surface curvature value (SCI)

As described earlier the assumed equation for growth in area of distress is as shown in equation 1:

$$D = e^{-K/n}, \quad (1)$$

where, $D$ is the normalized area of distress (range 0 to 1, indicating 0%

*as defined in Appendix A
To 100% of area),

N is the number of months in service (or 18 kips for some distress types), and

\( K = f(18 \text{ kips}, \text{Time}, \text{Overlay Thickness (OVT)}, \text{Dynaflect Mean Deflection (DMD)}, \ldots \ldots \). 

A typical example is the K value for transverse cracking as shown below in equation 2.

\[
K_{\text{Tran.Cr.}} = \exp \left[ - \frac{14.82}{N^{0.2552}} \frac{\text{OVT}^{0.0706} \times \text{TIME}^{0.60}}{\text{DMD}^{0.701}} \right] 
\]

(2)

The proposed equation which described the reduction in PSI is shown below:

\[
\ln(P_i - P) - \ln(P_i - P_f) = -\frac{K}{N}, 
\]

(3)

where \( P_i \) and \( P_f \) are the initial and final PSI values,

N is the accumulative 18 kip ESAL,

P is the current PSI value, and

K = deterioration constant.

Once the equations of the K values have been determined, it is then possible to predict pavement performance under varying values of pavement strength and traffic loading. Such a prediction is shown below in Table C-1.
<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Predicted Distress Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Cracking</td>
<td>93.76</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>40.17</td>
</tr>
<tr>
<td>Multiple Cracking</td>
<td>20.51</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>0.35</td>
</tr>
<tr>
<td>Rutting</td>
<td>0.74</td>
</tr>
<tr>
<td>Patching</td>
<td>3.92</td>
</tr>
<tr>
<td>PSI (initially 3.75)</td>
<td>2.63</td>
</tr>
</tbody>
</table>

Table C-1 Distress level predictions for a weak flexible pavement (DMD=1.5 mils) with a 1.5" Overlay, after 10 years in service with 1 million 18 kips.

In order to calculate a pavement score, each state would typically multiply each one of the distress levels in Table C-1 by its corresponding weighting factor. The percentage distress x weighting factor is defined as the deduct points for that particular distress type. The total pavement damage is defined as the summation of the deduct points for all distress types plus the deduct points associated with the reduction or PSI.

The main objective of this study is to determine what percentage of total pavement damage is

a) directly attributable to load,

b) directly attributable to climate, or

c) attributable to the interaction of load and climate.

For the Minnesota models, the total deduct points (total damage) is defined as follows

\[
\text{Total Deducts} = \text{Distress Deducts} + \text{PSI deducts}; \quad (4)
\]
the distress deducts being defined as

\[ \text{Distress Deducts} = f(\text{Area of Transverse Cracking} \times \text{Weighting Factor} + \text{Area of Longitudinal Cracking} \times \text{Weighting Factor} + \ldots) \], and \ (5)

the PSI deducts being defined as

\[ \text{PSI Deducts} = f(\text{Original PSI} - \text{Current PSI}) \]. \ (6)

The distress types which are directly attributable to load are assumed to be
a) Alligator Cracking, and
b) Rutting.

The distress types which are directly attributable to climate (environment) are
a) Transverse Cracking, and
b) Longitudinal Cracking.

The distress types which are attributable to a combination of climate and load are
a) Multiple cracking,
b) Patching, and
c) Changes in PSI.

In order to calculate total pavement damage and the damage breakdown it is necessary to determine each state's
a) Pavement distress weighting factors and
b) Pavement score calculation procedure.

Both a) and b) have been described in detail elsewhere.*

---


C-6
In the following sections of this Appendix, the pavement damage breakdown calculation is presented for the pavement performance data shown in Table C-1. This calculation is performed with the distress weighting factors currently used by the states of Minnesota, Maine, and Washington.
C.2 Detailed Deduct Point Calculations for Each State

C.2.1 State of Minnesota

A) Flexible Pavements

For flexible pavement in Minnesota, the following weighting factors are used:

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Weighting Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Cracking</td>
<td>0.02</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>0.02</td>
</tr>
<tr>
<td>Multiple Cracking</td>
<td>0.15</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>0.35</td>
</tr>
<tr>
<td>Rutting</td>
<td>0.15</td>
</tr>
<tr>
<td>Patching</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Table C-2 Minnesota's Distress Weighting Factors.

A structural rating is calculated by

a) Summing the % occurrence of each distress type x weighting factor and

b) Converting this sum into a number between 0 and 4 by a table look up; a portion of this table is shown below

<table>
<thead>
<tr>
<th>Sum (% distress x weighting factor)</th>
<th>Structural Structural Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>2.5</td>
</tr>
<tr>
<td>20</td>
<td>1.7</td>
</tr>
<tr>
<td>50</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Table C-3 Portion of the Table used in Minnesota to calculate Structural Rating
The ride value is measured on a scale of 0 to 5, using a P.C.A. roadmeter. However, a typical value for a newly resurfaced pavement in Minnesota is 3.7 to 3.8.

The final pavement score calculation is shown below:

\[
Pavement \, Score = \frac{1}{2} (Structural \, Rating + \, PSI).
\]

(7)

The calculation of the load associated, climate associated, and combined associated deduct points is shown below for the distress levels shown in Table C-1.

<table>
<thead>
<tr>
<th>Distress Types</th>
<th>Predicted Distress Level</th>
<th>Weighting Factors</th>
<th>LOAD</th>
<th>CLIMATE</th>
<th>COMBINED</th>
<th>ACC. TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Cracking</td>
<td>93.75</td>
<td>0.02</td>
<td>1.875</td>
<td></td>
<td></td>
<td>1.875</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>40.17</td>
<td>0.02</td>
<td>.80</td>
<td></td>
<td></td>
<td>2.675</td>
</tr>
<tr>
<td>Multiple Cracking</td>
<td>20.51</td>
<td>0.15</td>
<td></td>
<td></td>
<td>3.076</td>
<td>5.751</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>0.35</td>
<td>0.35</td>
<td>0.123</td>
<td></td>
<td></td>
<td>5.874</td>
</tr>
<tr>
<td>Rutting</td>
<td>0.74</td>
<td>0.15</td>
<td>0.111</td>
<td></td>
<td></td>
<td>5.985</td>
</tr>
<tr>
<td>Patching</td>
<td>3.92</td>
<td>0.30</td>
<td></td>
<td></td>
<td>1.175</td>
<td>7.16</td>
</tr>
</tbody>
</table>

TOTALS 0.234 2.575 4.251 7.16

TABLE C-4 Calculation of Deduct Points for Minnesota

The accumulated total of % distress x weighting factor is 7.16. This converts* to a structural rating value of 2.784 on a scale 0 to 4 where 4 represents a perfect pavement with no distress. Therefore, the total visual distress deduction from a perfect score of 4.0 is 1.216.

The next step is to calculate what fraction of this total visual

*Via Table B1, pg. 89 of "Development of a rating system to determine the needs for resurfacing pavements," Investigation No. 189, by P.C. Hughes, Minnesota, D.O.T., 1971
distress deduction is attributable to a) load, b) climate, or c) the combination of load and climatic forces. This calculation is shown below:

**Fraction of the Visual Distress Deduction which is attributable to Load**

\[
\frac{\text{Summation of Load Deduct Points}}{\text{Summation of Total Deduct Points}} \times 1.216
\]

from Table C-4, gives

\[
\frac{0.234}{7.160} \times 1.216 = 0.040.
\]

**Fraction of the Visual Distress Deduction which is attributable to Climate**

\[
\frac{\text{Summation of Climate Deduct Points}}{\text{Summation of Total Deduct Points}} \times 1.216
\]

from Table C-4, gives

\[
\frac{2.675}{7.160} \times 1.216 = 0.454.
\]

**Fraction of the Visual Distress Deduction which is attributable to Combined Climate/Load**

\[
\frac{\text{Summation of Combined Deduct Points}}{\text{Summation of Total Deduct Points}} \times 1.216
\]

from Table C-4, gives

\[
\frac{4.251}{7.16} \times 1.216 = 0.722.
\]

Therefore, the total visual distress deduction of 1.216 is broken down as shown in Table C-5.
<table>
<thead>
<tr>
<th>Attributable To</th>
<th>Distress Deduction</th>
<th>% of Total Visual Distress Deduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>0.040</td>
<td>3.3%</td>
</tr>
<tr>
<td>Climate</td>
<td>0.454</td>
<td>37.3%</td>
</tr>
<tr>
<td>Combined</td>
<td>0.722</td>
<td>59.4%</td>
</tr>
</tbody>
</table>

Table C-5 Breakdown of total visual distress deduction

In Minnesota, the final pavement score is obtained by averaging the structural rating and PSI, as shown in Equation 7. The total PSI deduct is therefore, simply the initial minus the current PSI, which from Table C-1 is 1.119. This reduction in riding quality is attributable to both load and climatic forces hence it is classified as combined.

From Equation 4, the total deducts may be calculated

\[
\text{Total Deducts} = \text{Distress Deducts} + \text{PSI deducts} \\
= 1.216 + 1.119 \\
= 2.335.
\]

The final step is therefore to calculate what percentage of the total deducts may be attributed to a) load, b) climate, or c) combined forces. This calculation is shown below.

\[
\% \text{ of Total Deducts directly attributable to Load} = \left( \frac{\text{Visual Distress Deductions attributable to load}}{\text{Total Deducts}} \right) \times 100
\]

\[
= \frac{0.04}{2.335} \times 100 = 1.7\% .
\]

C-11
% of Total Deducts directly attributable to climate

\[
\text{Visual Distress Deductions attributable to climate} \times 100 = \frac{0.454}{2.335} \times 100 = 19.4\%.
\]

% of Total Deducts directly attributable to combined forces

\[
\text{Visual Distress Deduction attributable to combined + PSI deduction} \times 100 \quad \text{Total Deducts}
\]

\[
= \frac{.722 + 1.119}{2.335} \times 100 = 78.8\%.
\]

Thus using Minnesota's weighting factors and pavement score calculation procedure, the damage induced into the pavement can be broken down as shown in Table C-6,

<table>
<thead>
<tr>
<th>Directly Attributable to</th>
<th>As measured by</th>
<th>% of total damage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Load</strong></td>
<td>Alligator Cracking Rutting</td>
<td>1.7%</td>
</tr>
<tr>
<td><strong>Climate</strong></td>
<td>Longitudinal Cracking Transverse Cracking</td>
<td>19.4%</td>
</tr>
<tr>
<td><strong>Combined Load/Climate</strong></td>
<td>PSI Reduction Patching Multiple Cracking</td>
<td>78.8%</td>
</tr>
</tbody>
</table>

TABLE C-6 Breakdown of Pavement Damage from Table 1, into Load, Climate and Combined associated damages

The results reported in Table C-6 indicate that the majority of the pavement damage is due to the combines forces of load/climate. Almost 20% of the damage can be attributed to climatic forces alone, but only a very small percentage is directly attributable to load alone.
Clearly, the reason why little load associated damage is predicted is that the models (discussed in detail in Appendix E) only predict very small occurrences of the two load associated distress types, alligator cracking and rutting. Table C-1 shows only 0.35% of the section length having alligator cracking and 0.74% with rutting. However, it must be emphasized that the inspection staff in Minnesota commented that these two distress types were not common in the state's pavements, alligator cracking being replaced by a patch before any potholing can occur. These opinions of the inspection staff were substantiated by their pavement inspection data. Of the 266 inspections of flexible pavements which are in the TTI data base, only

- 42 (25%) recorded any rutting, the maximum value being 14%.
- All the other observation recorded zero rutting.
- 38 (23%) recorded any alligator cracking. All the other observations recorded zero alligator cracking.

Hence, the models derived from these data will predict only small levels of these distress types, which is a true reflection of average levels of these distress types in Minnesota's flexible pavements.

B) Composite Pavements

For composite pavements in Minnesota, the following distress types are rated, (the relevant weighting factors are given in brackets):

a) slight transverse cracking (0.05)
b) severe transverse cracking (0.30)
c) slight longitudinal cracking (0.05)
d) severe longitudinal cracking (0.30)

e) multiple cracking (0.10)

f) patching (0.20)

g) P.S.I.

In total, complete data were obtained on 128 pavement sections in Minnesota, of these, 37 were composite pavements. Therefore, using regression techniques it was possible to determine performance equations (e.g. Eqs. 1, 2, and 3) for these composite pavements. In order to perform this analysis and to obtain reasonable growth rates (K values) for transverse and longitudinal cracking, it was necessary to combine the slight and severe ratings into a single figure. This was because it was common to find that transverse cracking could be rated as slight in an initial inspection then rated as severe in a subsequent inspection. Therefore, the amount of slight transverse cracking could decrease from inspection to inspection while clearly the amount of total transverse cracking would increase. Therefore the combined transverse (and longitudinal) distress type was defined as simply the sum of the slight and severe components, with a maximum value of 100%. The relative weighting of the combined distress types was defined as the average of the slight and severe weighting factors.

For composite pavements in Minnesota, the following weighting factors were used in this analysis.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Cracking</td>
<td>0.17</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>0.17</td>
</tr>
<tr>
<td>Multiple Cracking</td>
<td>0.10</td>
</tr>
<tr>
<td>Patching</td>
<td>0.20</td>
</tr>
</tbody>
</table>

TABLE C-7 Distress types and Weighting Factors used in the composite pavements data analysis
The pavement score is calculated in a similar manner to that used for flexible pavements.

The various deterioration slopes and $P_f$ values have to be calculated from regression analysis. The pavement performance models are discussed extensively in Appendix E. Typical distress level predictions and the calculation of the load, climatic and combined deduct points are shown below in Table C-8.

<table>
<thead>
<tr>
<th>Distress Types</th>
<th>Predicted Distress Level</th>
<th>Weighting Factors</th>
<th>DEDUCT POINTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Cracking</td>
<td>75.79</td>
<td>0.17</td>
<td>12.884</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>82.43</td>
<td>0.17</td>
<td>14.012</td>
</tr>
<tr>
<td>Multiple Cracking</td>
<td>1.11</td>
<td>0.10</td>
<td>0.111</td>
</tr>
<tr>
<td>Patching</td>
<td>0.21</td>
<td>0.20</td>
<td>0.042</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>LOAD</th>
<th>CLIMATE</th>
<th>COMBINED</th>
<th>ACC. TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Totals</td>
<td>0.000</td>
<td>26.896</td>
<td>0.153</td>
<td>27.049</td>
</tr>
</tbody>
</table>

TABLE C-8 Distress level predictions and deduct point calculations for a composite pavement (DMD=0.4 mils) with a 1.5" Overlay, after 10 years in service with 1 million 18 Kips.

The accumulated total of % distress x weighting factor is 27.049. This converts to a structural rating of 1.195 on a scale 0 to 4 where 4 represents a perfect pavement with no distress. Therefore, the total visual distress deduction from a perfect score of 4.0 is 2.805.

The predicted level of PSI for the pavement described in Table C-8 is 2.36. The calculation of what percentage of the total damage is associated to load, etc. is identical to that performed for flexible pavements,
which has previously been described. Repeating this calculation for this
composite pavements yields the following damage breakdown.

<table>
<thead>
<tr>
<th>Directly Attributable to</th>
<th>As Measured by</th>
<th>% of total damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>No distress types directly attributable</td>
<td>0</td>
</tr>
<tr>
<td>Climate</td>
<td>Longitudinal Cracking</td>
<td>66.6</td>
</tr>
<tr>
<td></td>
<td>Transverse Cracking</td>
<td></td>
</tr>
<tr>
<td>Combined Load/Climate</td>
<td>PSI reduction</td>
<td>33.4</td>
</tr>
<tr>
<td></td>
<td>Patching</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multiple Cracking</td>
<td></td>
</tr>
</tbody>
</table>

TABLE C-9. Breakdown of Composite Pavement Damage from Table C-8, into load, climate and Combined associated damages.

Thus as shown in Table C-9, the majority of the pavement damage in Minnesota's composite pavements is due to climatic forces. This is manifested in transverse and longitudinal reflection cracking which are clearly non-load associated.
C.2.2 State of Maine

In section C.2.1, the following were discussed

a) the form of the pavement performance models derived from Minnesota data,

b) predictions of pavement distress using these models,
   (see Table C-1), and

c) the calculation of what percentage of pavement damage is attributable to load, climate and combined load/climate forces (this calculation being performed with the weighting factors and pavement score calculation procedure currently used by the Minnesota D.O.T.).

It may be argued that the distress types observed in Minnesota's flexible pavements will be similar to the distress types found in other flexible pavements which are in a similar environmental zones. Therefore, it is beneficial to examine the weighting factors, etc. used in other states and to recalculate the pavement damage breakdown using these new weighting factors.

In this section, the flexible pavement damage calculation will be repeated with the predicted pavement distress levels in Table C-1 and the weighting factors used in the State of Maine. A full description of these factors is given elsewhere (*), and a summary is presented below.

---

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Maximum Overall Weighting Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Cracks</td>
<td>.40</td>
</tr>
<tr>
<td>Centerline Cracks</td>
<td>.25</td>
</tr>
<tr>
<td>Random Cracks</td>
<td>.70</td>
</tr>
<tr>
<td>Alligator Cracks</td>
<td>.75</td>
</tr>
<tr>
<td>Rutting</td>
<td>.70</td>
</tr>
<tr>
<td>Patching</td>
<td>0 (Not Rated)</td>
</tr>
</tbody>
</table>

**TABLE C-10. Weighting Factors used in Maine**

To use these weighting factors with the distress types predicted by the Minnesota models (Table C-1) the following assumptions must be made,

- The weighting of Temperature Cracks is equivalent to the weighting of Transverse Cracks.
- The weighting of Centerline Cracks is equivalent to the weighting of longitudinal cracks.
- Maine does not rate riding quality (PSI) but it does give a weighting to General Overall Appearance (max. 0.45). For this analysis it is assumed General Overall Appearance is equivalent to a rating of riding quality.

In Maine, the pavement score is simply the summation of distress point score x weighting factor. The distress point score is a measure of extent of observed distress (% present).

Therefore, using the distress levels in Table C-1 and the weighting factors in Table C-10, it is possible to calculate the following deduct points for Maine.
<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Predicted Distress Levels</th>
<th>Weighting Factors</th>
<th>DEDUCT POINTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Load</td>
</tr>
<tr>
<td>Transverse</td>
<td>93.75</td>
<td>.40</td>
<td>37.50</td>
</tr>
<tr>
<td>Longitudinal</td>
<td>40.17</td>
<td>.25</td>
<td>10.04</td>
</tr>
<tr>
<td>Multiple</td>
<td>20.51</td>
<td>.70</td>
<td>14.357</td>
</tr>
<tr>
<td>Alligator</td>
<td>0.35</td>
<td>.75</td>
<td>.263</td>
</tr>
<tr>
<td>Rutting</td>
<td>0.74</td>
<td>.70</td>
<td>.518</td>
</tr>
<tr>
<td>Patching</td>
<td>3.92</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
*PSI(initial 3.75) | 2.63                     | .45               | 22.37 |         | 85.05    |             |
| TOTAL        |                          |                   | .781  | 47.54   | 36.727   | 85.05      |

TABLE C-11 Calculation of deduct points using the weighting factors currently in use in Maine.

The total deduct points from Table C-11 are 85.05. These deduct points represent the total damage which the pavement has sustained. This total damage value can be broken down as follows:

<table>
<thead>
<tr>
<th>Attributable to</th>
<th>As Measured by</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>Alligator Cracking Rutting</td>
<td>0.9%</td>
</tr>
<tr>
<td>Climate</td>
<td>Transverse Cracking Longitudinal Cracking</td>
<td>55.9%</td>
</tr>
<tr>
<td>Combined (Load/Climate)</td>
<td>Multiple Cracking Patching Loss of PSI</td>
<td>43.2%</td>
</tr>
</tbody>
</table>

TABLE C-12 Breakdown of total pavement damage into load, climate, and combined attributes.

*For Maine, the General Overall Appearance deducts are simply summed with other distress types. Calculation of PSI deduct points is therefore: \[ \left( \frac{P_i - P}{P_i - P_f} \right) * 0.45 \]

where \( P_i = 3.75, \ P_f = 1.5 \) and \( P \) is the predicted value of PSR.
C.2.3 State of Washington

In this section, the calculation performed in section C.2.2 will be repeated using the weighting factors which are currently used in the State of Washington, these being as shown below.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Weighting Factors (assumed from maximum deducts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Cracking</td>
<td>.15</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>.25</td>
</tr>
<tr>
<td>Multiple Cracking*</td>
<td>.20</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>.25</td>
</tr>
<tr>
<td>Rutting</td>
<td>.40</td>
</tr>
<tr>
<td>Patching</td>
<td>.15</td>
</tr>
</tbody>
</table>

TABLE C-13 Weighting Factors assumed for the State of Washington

In Washington, riding quality is measured by the PCA roadmeter and the PSI value is converted into the range 0 to 10, where 0 represents a perfect pavement. For the purpose of this analysis a perfect pavement is assumed to have a PSI of 3.75 or above, and a failed pavement to have a PSI of 1.50. Therefore, a PSI value of 2.63 is converted into the range 0 to 10 as shown below.

\[
\frac{P_i - P}{P_i - P_f} \times 10 = \frac{3.75 - 2.63}{3.75 - 1.50} \times 10 = 4.97,
\]

Ride Range Value = 4.97.

In Washington, the total ride deduct points are defined as

\[
\text{Ride Deducts} = 10 \times \text{Ride Range Value}. \quad (8)
\]

*Multiple cracking is not defined in this state's rating system, it is therefore presumably rated as Transverse or Alligator. Therefore, for this analysis an average weighting factor is assumed.
Therefore a PSI value of 2.63 is calculated to be equal to 49.7 deduct points.

Using the distress levels shown in Table C-1 and the weighting factors in Table C-13, it is possible to calculate the following deduct points for Washington.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Predicted Distress Levels</th>
<th>Weighting Factors</th>
<th>DEDUCT POINTS</th>
<th>Acc. Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse</td>
<td>93.75</td>
<td>.15</td>
<td>14.06</td>
<td>14.06</td>
</tr>
<tr>
<td>Longitudinal</td>
<td>40.17</td>
<td>.25</td>
<td>10.04</td>
<td>24.10</td>
</tr>
<tr>
<td>Multiple</td>
<td>20.51</td>
<td>.20</td>
<td>.088</td>
<td>4.102</td>
</tr>
<tr>
<td>Alligator</td>
<td>0.35</td>
<td>.25</td>
<td>.296</td>
<td>28.30</td>
</tr>
<tr>
<td>Rutting</td>
<td>0.74</td>
<td>.40</td>
<td>.587</td>
<td>28.59</td>
</tr>
<tr>
<td>Patching</td>
<td>3.92</td>
<td>.15</td>
<td></td>
<td>29.18</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>.384</strong></td>
<td><strong>24.10</strong></td>
<td><strong>4.689</strong></td>
<td><strong>29.18</strong></td>
</tr>
</tbody>
</table>

TABLE C-14 Calculation of deduct points using weighting factors currently in use in Washington

Thus the total deduct points for this pavement are the sum of ride and visual deduct points.

\[
\text{Total Deduct} = \text{Ride Deducts} + \text{Visual Deducts}, \\
= 49.7 + 29.18, \\
= 78.88.
\]

The total deduct points associated with the combined load and climate forces are therefore,

\[
\text{Combined Deducts} = \text{Multiple Cracking Deducts} + \text{Patching} \\
\text{Deducts} + \text{Ride Deducts}, \\
= 4.102 + 0.587 + 49.7, \\
= 54.389.
\]
The total deducts of 78.88 represent the total damage which the pavement has sustained. This total damage value can be broken down as follows:

<table>
<thead>
<tr>
<th>Attributable to</th>
<th>As Measured by</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>Alligator Cracking</td>
<td>0.5%</td>
</tr>
<tr>
<td>Climate</td>
<td>Rutting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transverse Cracking</td>
<td>30.5%</td>
</tr>
<tr>
<td></td>
<td>Longitudinal Cracking</td>
<td></td>
</tr>
<tr>
<td>Combined (Load/Climate)</td>
<td>Multiple Cracking</td>
<td>69.0%</td>
</tr>
<tr>
<td></td>
<td>Patching</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Loss of PSI</td>
<td></td>
</tr>
</tbody>
</table>

TABLE C-15 Breakdown of total pavement damage into load, climate, and combined attributes.
C.3 Summary

In Appendix E, a description is given of the pavement performance models developed from inspection data collected in Minnesota. Using these models it is possible to predict the variation of distress levels and PSI with 18 kips loads, time in service, etc. A typical prediction is shown in Table C-1, this being for a weak flexible pavement which had received a 1.5 inch overlay and had then carried 1 million 18 kips after 10 years in service.

Using the predictions and the weighting factors currently defined by the Minnesota D.O.T., it is possible to calculate the total damage, in terms of deduct points, which the pavement has sustained. This total damage can then be broken down into the following attributes.

1. **Load Associated**
   
   The distress types which are considered load associated are alligator cracking and rutting.

2. **Climate Associated**

   The distress types which are considered climate (or environment) associated are transverse and longitudinal cracking.

3. **Combined (Load/Climate) Associated**

   Certain distress types are clearly the result of the combined forces of load and climate. These are assumed to be multiple cracking and patching. Deduct points resulting from a loss in PSI also falls into this category.
In this section, the total damage breakdown has been calculated for

1. Flexible pavements in the states of Minnesota, Maine, and Washington using the Minnesota pavement performance prediction models and each state's own individual weighting factors.

2. Composite pavements in the state of Minnesota using that state's weighting factors.

The summary of the flexible pavement damage breakdown calculated for the distress levels shown in Table C-1 is tabulated below:

<table>
<thead>
<tr>
<th>Attributable to</th>
<th>% of Total Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minnesota</td>
</tr>
<tr>
<td>Load</td>
<td>1.7%</td>
</tr>
<tr>
<td>Climate</td>
<td>19.4%</td>
</tr>
<tr>
<td>Combined</td>
<td>78.8%</td>
</tr>
</tbody>
</table>

**TABLE C-16** Summary of pavement damage breakdown for flexible pavements
APPENDIX D

CLIMATIC DATA
CLIMATIC DATA

Climatic data for each of thirty-five locations was collected or developed for input into Program PAVDEDUC. That input data is shown in Table 4-1. Except for the Thornthwaite Index and the Climatic Zone, the data in Table 4-1 comes from publications of the National Oceanic and Atmospheric Administration, Environmental Data and Information Service, National Climatic Center, Asheville, North Carolina.

As a general environmental indicator of regional climatic conditions, C. W. Thornthwaite introduced the concept of potential evapo-transpiration. This quantity is defined as that amount of ground water which would reenter the atmosphere as a result of evaporation from the surface and transpiration by plants assuming an unlimited water supply. Based on this potential evapo-transpiration measure, which is independent of local soil and vegetation conditions, a rational classification of climate is possible. The "Thornthwaite Moisture Index" or "Thornthwaite Index" is described by the equation,

$$\text{Im} = \frac{100S - 60d}{E_p},$$

where \( \text{Im} \) = moisture index,
\( S \) = water surplus in inches,
\( d \) = water deficit in inches, and
\( E_p \) = potential evapo-transpiration in inches.

This equation, by considering separately moisture surpluses and deficits that may occur in different seasons, allows for the storage of water in subsoil regions where it is available to deep rooted plants. A surplus
of water in one season can counteract a considerably larger deficit in another season; however, the soil is only able to store a certain amount of rainfall (usually 4 to 6 inches) and any excess will be "runoff" which is not available for a later deficit. Such data can be accumulated and converted to surplus or deficit moisture and then to the Thornthwaite Moisture Index. The variation of the Thornthwaite Index, measured over a short period, from the average value of the Thornthwaite Index gives an indication of the changing soil water content. This measurement has been shown to be an effective tool in studying climatic effects on highway pavements. Average values of the Thornthwaite Index, found in Table D-1, were interpolated from a map such as that shown in Figure D.1.

The "climatic zones" found Table D-1 are shown on the map in Figure D-2. It can be expected that variation in the amount of damage done as a result of climatic factors and the interaction of climatic factors with traffic loads will be significant. Briefly the zones are described as follows:

<table>
<thead>
<tr>
<th>Climatic Zone</th>
<th>Characteristics of Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>wet, no freeze</td>
</tr>
<tr>
<td>II</td>
<td>wet, freeze-thaw cycling</td>
</tr>
<tr>
<td>III</td>
<td>wet, hard freeze</td>
</tr>
<tr>
<td>IV</td>
<td>dry, no freeze</td>
</tr>
<tr>
<td>V</td>
<td>dry, freeze-thaw cycling</td>
</tr>
<tr>
<td>VI</td>
<td>dry, hard freeze</td>
</tr>
</tbody>
</table>

To determine the climatic zones more precisely "wet", "dry", "no freeze", "freeze-thaw cycling", and "hard freeze" areas are defined as follows. The boundary between "wet" and "dry" zones is the contour where the Thornthwaite
Index is zero. A "hard freeze" area is one in which there will be at least 60 consecutive days during which the temperature will drop below freezing. A "freeze-thaw cycling" area is one in which maximum frost penetration of the soil can be expected to be five inches or more each year. A "no freeze" area is one in which frost penetration during the year is expected to be less than five inches. Information on frost depth can be found in reference [D-2].

The "normal annual precipitation" and the "average mean annual temperature" can be read directly from "Local Climatological Data, Annual Summary with Comparative Data" for the thirty-five locations, published by the National Oceanic and Atmospheric Administration, Environmental Data and Information Service, National Climatic Center, Asheville, North Carolina. Those same publications also contain average monthly mean temperatures from which the yearly "harmonic mean temperature above 32°F" can be generated. The data for those entries in Table D.1 was from the 1979 Annual Summaries. The "yearly harmonic mean temperature" above 32°F is given by

$$H = \frac{12}{\sum_{i=1}^{12} \frac{1}{T_i - 32}}$$

where $T_i$ is the average mean monthly temperature in degrees-Fahrenheit.

The entries in Table D-1 for "freeze-thaw cycles" and "wet freeze-thaw cycles" were developed from "Climatological Data, National Oceanic and Atmospheric Administration, Environmental Data and Information Service, National Climatic Center, Asheville, North Carolina."

The method used to develop those entries is as follows. For each day in the period January 1, 1974 to December 1, 1977, three pieces of data were
recorded:

(1) an indication of the temperature variation with respect to 32°F,

(2) precipitation recorded as greater than a trace (0.01 inches or more), and

(3) snowfall and snow or ice cover on the ground recorded as more than a trace (0.1 inches or more).

The data used for "indication of the temperature variation about 32°F" was the recorded daily maximum and minimum temperature. A daily maximum temperature above 32°F with a minimum at or below 32°F was taken to be a movement from above freezing to a freezing temperature or from freezing to above freezing according to what the temperature had been the previous day; if both the maximum and minimum temperature were above 32°F or were at or below 32°F, then the temperature may or may not vary about 32°F. For example, suppose for some location the temperature maxima and minima over a six day period are recorded as follows.

<table>
<thead>
<tr>
<th>day</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45</td>
<td>35</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>32</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>32</td>
<td>26</td>
</tr>
<tr>
<td>5</td>
<td>33</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>45</td>
<td>33</td>
</tr>
</tbody>
</table>

If on the day before day 1, a minimum of 32°F or less had been recorded, since both the maximum and minimum for day one are above 32°F this would have been recorded as a movement from freezing to above freezing. However, for the sake of demonstration, assume that on the day previous to day 1,
the minimum temperature was above freezing; then for day 1, no movement of temperature about 32°F is recorded. For day 2, since the previous day had no movement of temperature about 32°F, a movement from above freezing to freezing is recorded. Day three is recorded as a movement from freezing to above freezing (which gives a freeze thaw cycle) and then a movement of temperature from above freezing to below freezing. On day 4, both the maximum and the minimum are at or below 32°F, so no movement of temperature about 32°F is recorded. Day 5 has a maximum above freezing, for a movement from freezing to above freezing, (giving a freeze-thaw cycle starting on day 3 and ending on day 5) and a minimum below 32°F, for a movement from above freezing to freezing. On day 6, the maximum is above freezing giving a movement from at or below 32°F to above freezing (and determining a freeze-thaw cycle with the freeze on day 5 and the thaw on day 6).

Whenever a freeze-thaw cycle had been determined by the method described above, if on the day of freezing or during the time before the next thaw, a measurable amount of rain, snow, or ice had fallen or, if a measurable amount of snow or ice was recorded as ground cover, then that freeze-thaw cycle is considered to be a "wet freeze thaw cycle".

The total number of "freeze-thaw cycles" during the period January 1, 1974 to December 31, 1977 was divided by four to determine the "average freeze-thaw cycles" per year; the "average wet freeze-thaw cycles" per year were found similarly.
<table>
<thead>
<tr>
<th>Location</th>
<th>Harmonic Mean Temperature Above 32°F</th>
<th>Thornthwaite Index</th>
<th>Average Freeze-Thaw Cycles/yr. *</th>
<th>Average Wet Freeze-Thaw Cycles/yr.</th>
<th>Normal Annual Precipitation</th>
<th>Average Mean Annual Temperature</th>
<th>Climatic Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flagstaff, Arizona (1)</td>
<td>-18.3966</td>
<td>-20</td>
<td>199</td>
<td>64</td>
<td>19.31</td>
<td>45.5</td>
<td>V</td>
</tr>
<tr>
<td>Yuma, Arizona (2)</td>
<td>36.4853</td>
<td>-40</td>
<td>1</td>
<td>1</td>
<td>2.67</td>
<td>72.8</td>
<td>IV</td>
</tr>
<tr>
<td>Bishop, California (3)</td>
<td>9.5110</td>
<td>40</td>
<td>135</td>
<td>18</td>
<td>5.72</td>
<td>55.4</td>
<td>II</td>
</tr>
<tr>
<td>Eureka, California (4)</td>
<td>21.4324</td>
<td>60</td>
<td>3</td>
<td>1</td>
<td>39.76</td>
<td>51.9</td>
<td>I</td>
</tr>
<tr>
<td>Los Angeles, California (5)</td>
<td>29.1333</td>
<td>-20</td>
<td>1</td>
<td>1</td>
<td>11.59</td>
<td>62.0</td>
<td>IV</td>
</tr>
<tr>
<td>Orlando, Florida (6)</td>
<td>38.7722</td>
<td>20</td>
<td>3</td>
<td>1</td>
<td>51.21</td>
<td>72.5</td>
<td>I</td>
</tr>
<tr>
<td>Athens, Georgia (7)</td>
<td>24.0481</td>
<td>80</td>
<td>49</td>
<td>11</td>
<td>50.60</td>
<td>61.4</td>
<td>II</td>
</tr>
<tr>
<td>Augusta, Georgia (8)</td>
<td>27.0758</td>
<td>30</td>
<td>52</td>
<td>13</td>
<td>42.63</td>
<td>64.4</td>
<td>I</td>
</tr>
<tr>
<td>Cairo, Illinois (9)</td>
<td>13.9082</td>
<td>40</td>
<td>51</td>
<td>14</td>
<td>47.12</td>
<td>58.7</td>
<td>II</td>
</tr>
<tr>
<td>Chicago, Illinois (10)</td>
<td>65.2809</td>
<td>20</td>
<td>82</td>
<td>34</td>
<td>31.72</td>
<td>49.0</td>
<td>III</td>
</tr>
<tr>
<td>Evansville, Indiana (11)</td>
<td>20.2260</td>
<td>50</td>
<td>75</td>
<td>24</td>
<td>41.88</td>
<td>56.6</td>
<td>II</td>
</tr>
<tr>
<td>Ft. Wayne, Indiana (12)</td>
<td>-97.7995</td>
<td>40</td>
<td>90</td>
<td>47</td>
<td>35.80</td>
<td>50.1</td>
<td>III</td>
</tr>
<tr>
<td>Dodge City, Kansas (13)</td>
<td>10.2734</td>
<td>-20</td>
<td>106</td>
<td>19</td>
<td>20.58</td>
<td>54.7</td>
<td>V</td>
</tr>
<tr>
<td>Goodland, Kansas (14)</td>
<td>7.5316</td>
<td>-20</td>
<td>136</td>
<td>36</td>
<td>16.65</td>
<td>51.4</td>
<td>VI</td>
</tr>
<tr>
<td>Topeka, Kansas (15)</td>
<td>2.7917</td>
<td>10</td>
<td>101</td>
<td>2</td>
<td>34.66</td>
<td>54.7</td>
<td>III</td>
</tr>
<tr>
<td>Baton Rouge, Louisiana (16)</td>
<td>31.7600</td>
<td>40</td>
<td>24</td>
<td>5</td>
<td>54.05</td>
<td>67.5</td>
<td>I</td>
</tr>
</tbody>
</table>

* a minimum of at least 1/yr. is assumed.
<table>
<thead>
<tr>
<th>City</th>
<th>Harmonic Mean Temperature Above 32°F</th>
<th>Thornthwaite Index</th>
<th>Average Freeze-Thaw cycles/yr.</th>
<th>Average Wet Freeze-Thaw cycles/yr.</th>
<th>Normal Annual Precipitation</th>
<th>Average Mean Annual Temperature</th>
<th>Climatic Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shreveport, Louisiana</td>
<td>28.4515</td>
<td>30</td>
<td>38</td>
<td>9</td>
<td>44.72</td>
<td>65.9</td>
<td>II</td>
</tr>
<tr>
<td>Portland, Maine</td>
<td>3.5344</td>
<td>80</td>
<td>115</td>
<td>69</td>
<td>40.80</td>
<td>45.5</td>
<td>III</td>
</tr>
<tr>
<td>Baltimore, Maryland</td>
<td>5.0479</td>
<td>40</td>
<td>81</td>
<td>25</td>
<td>40.46</td>
<td>55.0</td>
<td>II</td>
</tr>
<tr>
<td>Duluth, Minnesota</td>
<td>-83.7889</td>
<td>20</td>
<td>67</td>
<td>41</td>
<td>30.18</td>
<td>38.5</td>
<td>III</td>
</tr>
<tr>
<td>Lincoln, Nebraska</td>
<td>-102.3891</td>
<td>10</td>
<td>103</td>
<td>35</td>
<td>28.61</td>
<td>51.7</td>
<td>III</td>
</tr>
<tr>
<td>North Platte, Nebraska</td>
<td>78.0006</td>
<td>-15</td>
<td>139</td>
<td>31</td>
<td>19.90</td>
<td>49.1</td>
<td>VI</td>
</tr>
<tr>
<td>Albuquerque, New Mexico</td>
<td>9.7712</td>
<td>-40</td>
<td>123</td>
<td>15</td>
<td>7.77</td>
<td>55.8</td>
<td>V</td>
</tr>
<tr>
<td>Bismarck, North Dakota</td>
<td>-34.3999</td>
<td>-20</td>
<td>102</td>
<td>37</td>
<td>16.16</td>
<td>41.2</td>
<td>VI</td>
</tr>
<tr>
<td>Knoxville, Tennessee</td>
<td>17.8768</td>
<td>60</td>
<td>59</td>
<td>13</td>
<td>46.18</td>
<td>58.8</td>
<td>V</td>
</tr>
<tr>
<td>Abilene, Texas</td>
<td>25.5090</td>
<td>-20</td>
<td>55</td>
<td>11</td>
<td>23.59</td>
<td>64.5</td>
<td>V</td>
</tr>
<tr>
<td>Brownsville, Texas</td>
<td>39.6292</td>
<td>-20</td>
<td>2</td>
<td>1</td>
<td>25.09</td>
<td>73.5</td>
<td>IV</td>
</tr>
<tr>
<td>Houston, Texas</td>
<td>31.6147</td>
<td>20</td>
<td>26</td>
<td>6</td>
<td>48.19</td>
<td>67.6</td>
<td>I</td>
</tr>
<tr>
<td>Milford, Utah</td>
<td>1.1742</td>
<td>-20</td>
<td>175</td>
<td>49</td>
<td>8.40</td>
<td>49.1</td>
<td>V</td>
</tr>
<tr>
<td>Salt Lake City, Utah</td>
<td>-17.9662</td>
<td>20</td>
<td>105</td>
<td>49</td>
<td>15.17</td>
<td>51.7</td>
<td>III</td>
</tr>
<tr>
<td>Richmond, Virginia</td>
<td>15.4989</td>
<td>40</td>
<td>89</td>
<td>24</td>
<td>42.59</td>
<td>57.7</td>
<td>II</td>
</tr>
<tr>
<td>Olympia, Washington</td>
<td>12.7485</td>
<td>100</td>
<td>90</td>
<td>36</td>
<td>57.74</td>
<td>49.7</td>
<td>II</td>
</tr>
<tr>
<td>Quintayate, Washington</td>
<td>13.6155</td>
<td>100</td>
<td>67</td>
<td>32</td>
<td>104.99</td>
<td>48.7</td>
<td>II</td>
</tr>
<tr>
<td>Walla Walla, Washington</td>
<td>-35.0848</td>
<td>0</td>
<td>39</td>
<td>17</td>
<td>16.01</td>
<td>53.8</td>
<td>VI</td>
</tr>
<tr>
<td>Yakima, Washington</td>
<td>-8.0783</td>
<td>-40</td>
<td>134</td>
<td>33</td>
<td>8.00</td>
<td>50.8</td>
<td>V</td>
</tr>
</tbody>
</table>
APPENDIX D - References


APPENDIX E

PAVEMENT PERFORMANCE MODELS
APPENDIX E

Pavement Performance Models

E.1 Introduction
E.2 Overview of Procedure Used to Develop Performance Models
E.3 Derivation of Models
E.4 Pavement Modelling Using Flexible Pavement Models
E.5 Calculation of Pavement Damage Breakdown
APPENDIX E

Pavement Performance Models

E.1 Introduction

In the following sections of this Appendix the following will be described.

a) The form of the proposed pavement performance models and an overview of the procedure used to derive them.

b) A detailed analysis of data from one section of the TTI Minnesota data base. This analysis describes the calculation of the deterioration slopes and other inputs into the final regression analysis. A description of the models generated is given in Tables E-6, E-7, and E-8.

c) The use of the derived models to predict pavement performance.

d) The calculation of percentage pavement damage which may be attributed to load, climate and combined forces.

E.2 Overview of the Procedure Used to Develope the Performance Models

The data TTI has assembled on 128 sections of pavement in Minnesota have been extensively discussed earlier in Appendix A. In this section an overview is given of the procedure used to develop the proposed pavement performance models from these data. This procedure has been broken down into the following 5 steps.

Step 1 For each inspection date calculate the number of months and number of 18 kips carried since last maintenance date.

The following data items are stored for each pavement section in the TTI data base:
a) the date of each pavement inspection,
b) the date of each maintenance activity, and
c) the number of 18 kip ESAL carried by the design lane daily.

It is therefore fairly straightforward to calculate for each inspection date:

a) the number of months since last maintenance and
b) the approximate number of 18 kip ESAL carried since last maintenance.

**Step 2** Determine K values for growth of each distress type for each pavement section

As described earlier the assumed equation for growth in area of distress is

\[ D = e^{-K/N} \]  \hspace{1cm} (1)

where

D is the normalized area of distress (range 0 to 1),
N is the number of months since maintenance (or 18 kip ESAL for some distress types), and
K = f (18 kips, time, dynaflect mean deflection (DMD), . . . )

this relationship is illustrated in Figure E-1.
FIGURE E-1. Proposed form of the growth in area of distress curve

Step 3 Determine K and Pf Values for Loss in Riding Quality (PSI)

The assumed equation for change in PSI is

\[
\frac{P_i - P}{P_i - P_f} = e^{-K/N},
\]

(2)

where \( P_i \) and \( P_f \) are the asymptotic initial and final PSI values,

\( N \) is the accumulative 18 kip ESAL,

\( P \) is the current PSI value, and

\( K \) is the deterioration constant.

Equation 2 therefore has two unknowns of \( P_f \) and \( K \), these can be calculated from simple linear regression as shown below:

Equation (2) can be rewritten

\[
(P_i - P) = (P_i - P_f) e^{-K/N}, \quad \text{or}
\]

\[
\ln (P_i - P) = \ln (P_i - P_f) e^{-K/N}
\]

(3)
This is similar to

\[ y = mx + c, \]  

where \( y = \ln(P_i - P), \)
\( m = -K, \)
\( x = (1/N), \) and
\( b = \ln(P_i - P_f). \)

**Step 4** Determine the Deflection Bowl Characteristics (DMD, SCI, etc.) for each Pavement Section

This determination is accomplished using the Russian Equations which have been fully described and documented elsewhere*. Inputted to these equations are each layer's thickness and estimated modulus. The estimated moduli used in this analysis are shown in Table E-1.

<table>
<thead>
<tr>
<th>AASHTO Class</th>
<th>1-a</th>
<th>1-b</th>
<th>2-4</th>
<th>2-5</th>
<th>2-6</th>
<th>2-7</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7-5</th>
<th>7-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus kpsi</td>
<td>90</td>
<td>72</td>
<td>45</td>
<td>45</td>
<td>22.5</td>
<td>22.5</td>
<td>30</td>
<td>15</td>
<td>15</td>
<td>9</td>
<td>9</td>
<td>6</td>
</tr>
</tbody>
</table>

**Estimated Base Course Modulus**

<table>
<thead>
<tr>
<th>Type</th>
<th>Modulus, kpsi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushed Aggregate</td>
<td>150</td>
</tr>
<tr>
<td>Granular Base</td>
<td>150</td>
</tr>
<tr>
<td>Bituminous ASB</td>
<td>500</td>
</tr>
<tr>
<td>Lightly Stabilized</td>
<td>250</td>
</tr>
</tbody>
</table>

Table E-1 - Estimated Moduli used to Calculate Deflection Bowl Characteristics

The output from the Russian Equations are estimates of the pavement's.

- Dynaflect Mean Deflection (DMD) in mils,
- Surface Curvature Index (SCI), and
- Volume of Dynaflect Deflection Basin (VOL).

**Step 5  Generation of Performance Models**

The performance equations are generated via regression analysis using TTI's select regression program*.

The dependent variable inputted into this program are

a) the individual K values which describe growth in each distress type (transverse, longitudinal, etc. ....), and

b) the K and P_f values determined for loss in serviceability index.

Each of these dependent variables is regressed against the following independent variables.

a) Number of months since maintenance (TIME).

b) Numbers of 18 kip ESAL carried in the number months specified in
   a) (N18).

c) Average Daily Traffic (ADT).

d) Dynaflect Mean Deflection (DMD).

e) Surface Curvature Index (SCI).

f) Volume of Dynaflect Basin (VOL).

g) Thickness of asphalt overlay applied at last maintenance (OVT).

*Description of Select Regression.
The form of the proposed regression equation is

\[ K = (N_{18}) X_1(\text{TIME}) X_2(\text{ADT}) X_3(\text{DMD}) X_4(\text{SCI}) X_5(\text{VOL}) X_6(\text{OVT}) X_7 \]  \hspace{1cm} (5)

The values \( X_1 \) to \( X_7 \) being determined by the regression analysis, one or more values of \( X_i \) may be zero. In order to obtain this form of regression equation it is necessary to take the natural logarithm of each variable prior to input into the select regression program.

In order to demonstrate the method of developing the pavement performance models the complete calculation will be described for one section of pavement. This is shown in the following section.
E.3 Derivation of Performance Models

This analysis is to be performed on the following section which is one of the flexible pavement sections stored in TTI's Minnesota Data Base.

- Trunk Highway 5
- Control Section 2701
- District 5
- Start of Section .2M East of West County Line

The construction data is as follows.

- Year of Construction 1951
- Surfacing 1.5 inch Asphalt Concrete
- Base 13.0 inch Granular Base
- Subgrade AASHTO Classification 6

The maintenance data is as follows.

<table>
<thead>
<tr>
<th>Year of Maintenance</th>
<th>Type</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1954</td>
<td>Seal Coat</td>
<td>0.5 inch</td>
</tr>
<tr>
<td>1966</td>
<td>Seal Coat</td>
<td>0.5 inch</td>
</tr>
<tr>
<td>1970</td>
<td>Asphalt Concrete</td>
<td>2.5 inch</td>
</tr>
<tr>
<td>1976</td>
<td>Asphalt Concrete</td>
<td>2.7 inch</td>
</tr>
</tbody>
</table>

The inspection data is as follows (for transverse cracking and PSI only).

<table>
<thead>
<tr>
<th>Month/Year of Inspection</th>
<th>Extent of Transverse Cracking</th>
<th>PSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/71</td>
<td>7</td>
<td>3.2</td>
</tr>
<tr>
<td>06/75</td>
<td>88</td>
<td>2.7</td>
</tr>
</tbody>
</table>
The steps in the calculation are as follows.

**Step 1  Number of Months and 18 kip ESAL's Carried Since Last Maintenance**

The section received a 2.5 inch overlay in 1970 and was inspected in 06/1971 and 06/1975. In Minnesota major maintenance treatments are commonly undertaken in the months of July, August, and September. Therefore it may be assumed that 10 months passed between the laying of the overlay and the first inspection in 06/1971. The next inspection occurred in 06/1975 which is 58 months after the overlay was applied.

Using these figures and the number of 18 kip ESAL carried by the design lane each day it is possible to estimate number of 18 kip ESAL carried at each inspection date. The figures for this section are shown below.

<table>
<thead>
<tr>
<th>Inspection Date</th>
<th>No. Months Since Maintenance</th>
<th>18 kip ESAL Carried Since Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/71</td>
<td>10</td>
<td>52500</td>
</tr>
<tr>
<td>06/75</td>
<td>58</td>
<td>304500</td>
</tr>
</tbody>
</table>

**Number of Months and 18 kips Carried Since Maintenance**

**Step 2  Determination of K Values for Transverse Cracking**

The transverse cracking distress for this section is shown in Table E-2.

It has been proposed that this data fits the exponential type equation shown in Equation 1. The method used to determine the K value in Equation 1 is as follows.
1. Solve equation 1 using the first normalized area of transverse cracking and number of months since maintenance i.e., \(0.07, 10\)\(^+\), and equation 1,
\[ D = e^{-K/N} \]
becomes
\[ 0.07 = e^{-K/10} \]
so that
\[ K = -10 \ln (0.07) = 26.59. \]

<table>
<thead>
<tr>
<th>Inspection Date</th>
<th>Area of Transverse Cracking* (Normalized)</th>
<th>Number of Months Since Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/71</td>
<td>7% (0.07)</td>
<td>10</td>
</tr>
<tr>
<td>06/75</td>
<td>88% (0.88)</td>
<td>58</td>
</tr>
</tbody>
</table>

Table E-2 Transverse Cracking Data Used to Determine K Value

2. Solve equation 1 using the second normalized area of transverse cracking and number of months since maintenance, i.e., \((0.88, 58)\), in which case
\[ 0.88 = e^{-K/58} \]
and
\[ K = -58 \ln (0.88) = 7.414. \]

\[+\] If zero distress is present at any inspection then a very small value (0.01\%) is used for D to permit the logarithmic calculation.

*As described earlier in Appendix A the inspector counts the number of transverse cracks in a 1/4 mile section, then using a Table look-up he converts this into a percentage value i.e. 0-50 cracks per 1/4 mile is equivalent to 0-25\% cracked, 7\% represents a transverse crack count of 14 in the 1/4 mile section.
3. Average the determined K values.

Average K = 17.00

Therefore the equation which describes the growth of transverse cracking for this pavement section is

\[ D = e^{-\frac{17}{N}} \]  

(7)

where D is the normalized area of distress (range 0 to 1.0), and N is the number of months since maintenance.

This K value calculated for this pavement will be inputted as the dependent variable into the select regression program.

Step 3 Determination of K and Pf Values for Loss in PSI

The PSI data for this section is shown below:

<table>
<thead>
<tr>
<th>Inspection Date</th>
<th>PSI Value</th>
<th>No. 18 kip ESAL Since Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/71</td>
<td>3.2</td>
<td>52500</td>
</tr>
<tr>
<td>06/75</td>
<td>2.7</td>
<td>304500</td>
</tr>
</tbody>
</table>

Table E-3 PSI Data Used to Determine K and Pf Value

It has been proposed that this data fits an exponential type equation as follows:

\[ \frac{P_i - P}{P_i - Pf} = e^{-K/N} \]  

(8)

where \( P_i, Pf \) are the initial and final PSI values,

N is the accumulated 18 kips ESAL,

P is the current PSI value, and
K is the deterioration constant.

The value of $P_i = 3.75$ was chosen after discussion with the highway rating staff in Minnesota. Therefore, the two unknowns are $P_f$ and $K$. As mentioned earlier in this appendix, these unknowns are determined using simple linear regression in Equation 4.

$$y = m + c,$$

where $y = \ln(P_i - P)$,

$m = -K$,

$x = 1/N$, and

$b = \ln(P_i - P_f)$.

With the values in Table E-3 we get the following.

<table>
<thead>
<tr>
<th>$P_i - P$</th>
<th>N</th>
<th>y</th>
<th>x</th>
</tr>
</thead>
<tbody>
<tr>
<td>.0001*</td>
<td>5240</td>
<td>-4.605</td>
<td>$1.9 \times 10^{-4}$</td>
</tr>
<tr>
<td>.55</td>
<td>52500</td>
<td>-0.597</td>
<td>$1.9 \times 10^{-5}$</td>
</tr>
<tr>
<td>1.05</td>
<td>304500</td>
<td>0.048</td>
<td>$3.3 \times 10^{-6}$</td>
</tr>
</tbody>
</table>

Table E-3a Value inputted to linear regression to calculate $K$ and $P_f$

This regression produces the following values:

$$K = 49784 \text{ and}$$

$$P_f = 2.42$$

Therefore Equation (2) reduces to

$$\frac{3.75 - P}{3.75 - 2.42} = e^{-49784/N},$$

(9)

*The first data point is obtained by assuming that during the first month in service only a small reduction in PSI occurs. Thus N is the first months 18KIP ESAL Value.
which further reduces to

$$P = 3.75 - 1.33 \ e^{-49784/N}$$ (10)

The $K_{PSI}$ and $P_F$ values calculated for this pavement are each inputted as the dependent variable into the select regression program.

**Step 4 Determination of Deflection Bowl Characteristics**

Prior to the 2.5 inch overlay in 1970, the pavement had the following structure.

![Figure E-2 Pavement Structure prior to the 1970 overlay](image)

Therefore, the following layer thickness and layer moduli were inputted into the Russian Equations.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness (inches)</th>
<th>Estimated Modulus p.s.i.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surfacing (a.c.)</td>
<td>2.5</td>
<td>500000</td>
</tr>
<tr>
<td>Base (Granular)</td>
<td>13.0</td>
<td>150000</td>
</tr>
<tr>
<td>Subgrade (ASSTHO CL. 6)</td>
<td>---</td>
<td>15000</td>
</tr>
</tbody>
</table>

Table E-4 Input into Russian Equations to permit dynaffect basin predictions
The predicted dynaflect deflections (in mils) from this structure are as follows.

Dynaflect Mean deflection = 0.57 mils
Dynaflect Surface Curvature Index = .031
Volume of Dynaflect Basin = 10.46

These predicted values are inputted as independent variables into the select regression program.

Step 5 Select Regression

As shown earlier in step 2, the K value calculated for Transverse cracking is 17.00. This value is inputted, as the dependent variable, for one pavement section into the select regression program. The independent variables for this section are tabulated below.

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Value for this section</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME (in months)</td>
<td>58</td>
</tr>
<tr>
<td>18 KIP ESAL</td>
<td>305400</td>
</tr>
<tr>
<td>ADT (per day)</td>
<td>18000</td>
</tr>
<tr>
<td>DMD</td>
<td>.57</td>
</tr>
<tr>
<td>SCI</td>
<td>.031</td>
</tr>
<tr>
<td>VOL</td>
<td>10.46</td>
</tr>
<tr>
<td>OVT (overlay thickness)</td>
<td>2.5</td>
</tr>
</tbody>
</table>

TABLE E-5 Independent variables for section under consideration

The above described dependent and independent variables represent one input into the select regression program. In total, 87 sets of dependent and independent variables were inputted.
The select regression program, described earlier, is a step-down program in which at first all seven independent variables are considered. Then one of the variables is dropped and the best 6-variable model is computed. Another variable is dropped and the best 5-variable model is computed. This process continues until the best 1-variable model is found.

For transverse cracking, the best correlation coefficient was obtained with the equation

\[ K = e^{2.696 N_{18}^{-0.2552} \ DMD^{-0.701} \ TIME^{0.60} \ OVT^{0.706}}. \text{ (11)} \]

This value of \( K \) is inputted into equation 1;

\[ D = e^{-K/N}, \text{ (1)} \]

where \( D \) is the normalized area of distress (range 0 to 1), and \( N \) is the number of months since Maintenance (TIME). Therefore, equation 1 reduces to

\[ D = \exp \left[ -\frac{14.82}{N_{18}^{0.2552} \ DMD^{0.701} \ TIME^{0.40}} \right], \text{ (12)} \]

which gives, equation 12 as the model which describes growth of Transverse Cracking in Minnesota's flexible pavement.

Similar models have been derived for these distresses.

Flexible Pavements
- longitudinal cracking
- multiple cracking
- alligator cracking
- rutting
- patching
- PSI K value
- PSI $P_f$ value

Composite Pavements
- transverse cracking
- longitudinal cracking
- multiple cracking
- patching
- PSI K value
- PSI $P_f$ value

The flexible and composite distress models are shown in Tables E-6 and E-7. The PSI models are shown in Table E-8.
<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Model for $D$, the Normalized area of distress ($D = e^{-k/N}$)</th>
<th>Correlation Coefficient $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Cracking</td>
<td>$\exp - \frac{14.82}{N_{18}^{0.2552}} \frac{\text{OVT}^{0.706}}{\text{DMD}^{0.701} \text{TIME}^{0.40}}$</td>
<td>0.23</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>$\exp - \frac{10.85}{\text{ADT}^{0.151} \text{TIME}^{0.285} \text{SCI}^{0.278}} \text{OVT}^{0.0886}$</td>
<td>0.59</td>
</tr>
<tr>
<td>Multiple Cracking</td>
<td>$\exp - \frac{19.47}{N_{18}^{0.003}} \frac{\text{OVT}^{0.348}}{\text{DMD}^{0.270} \text{TIME}^{0.522}}$</td>
<td>0.77</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>$\exp - \frac{19.65}{N_{18}^{0.0354}} \frac{\text{OVT}^{0.144}}{\text{DMD}^{0.145} \text{TIME}^{0.158}}$</td>
<td>0.92</td>
</tr>
<tr>
<td>Rutting</td>
<td>$\exp - \frac{18.80}{N_{18}^{0.0151}} \frac{\text{OVT}^{0.114}}{\text{DMD}^{0.199} \text{TIME}^{0.23}}$</td>
<td>0.91</td>
</tr>
<tr>
<td>Patching</td>
<td>$\exp - \frac{32.69}{N_{18}^{0.0760}} \frac{\text{DMD}^{0.360}}{\text{TIME}^{0.233}}$</td>
<td>0.84</td>
</tr>
</tbody>
</table>

**TABLE E-6.** Distress models for Minnesota's flexible pavements

**Key:**
- $N_{18}$ = 18 kip ESAL since last maintenance
- TIME = time in months since last maintenance
- OVT = Overlay thickness
- ADT = Average daily traffic
- DMD = Dynaflect mean deflection
- SCI = Surface curvature Index
<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Model for D, the Normalized area of distress (D=e^{-k/N})</th>
<th>Correlation Coefficient (R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Cracking</td>
<td>(\exp\left(-\frac{1.361 \times \text{OVT}^{1.350} \times N_{18}^{0.1537}}{\text{VOL}^{0.103} \times \text{TIME}^{0.895}}\right))</td>
<td>0.56</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>(\exp\left(-\frac{0.750 \times \text{OVT}^{0.337} \times \text{VOL}^{0.189} \times N_{18}^{0.2759}}{\text{TIME}^{0.741}}\right))</td>
<td>0.31</td>
</tr>
<tr>
<td>Multiple Cracking</td>
<td>(\exp\left(-\frac{82.1 \times \text{OVT}^{0.566}}{N_{18}^{0.0888} \times \text{TIME}^{0.405} \times \text{VOL}^{0.144}}\right))</td>
<td>0.94</td>
</tr>
<tr>
<td>Patching</td>
<td>(\exp\left(-\frac{148.71 \times \text{OVT}^{0.180}}{N_{18}^{0.1612} \times \text{TIME}^{0.222} \times \text{VOL}^{0.169}}\right))</td>
<td>0.78</td>
</tr>
</tbody>
</table>

**TABLE E-7** Distress models for Minnesota's composite pavements

**KEY:**
- \(N_{18}\) = 18 kip ESAL since last maintenance
- \(\text{TIME}\) = time in months since last maintenance
- \(\text{OVT}\) = Overlay thickness
- \(\text{ADT}\) = Average daily traffic
- \(\text{DMD}\) = Dynaflect mean deflection
- \(\text{SCI}\) = Surface curvature index
<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>Model for PSI $P_i-P = e^{-k/N}$</th>
<th>Correlation Coefficient $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLEXIBLE</td>
<td>$\exp\left(-\frac{9.757}{N_{18}^{0.0027 \times \text{TIME}^{1.007 \times \text{OVT}^{0.0068}}}}\right)$</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>$P_f = 1.111 \frac{N_{18}^{0.0449 \times \text{TIME}^{0.0504 \times \text{DMD}^{0.0796 \times \text{OVT}^{0.00281}}}}}{N_{18}^{1.01162 \times \text{OVT}^{0.0351 \times \text{VOL}^{0.0114}}}}$</td>
<td>0.41</td>
</tr>
<tr>
<td>COMPOSITE</td>
<td>$\exp\left(-\frac{1141.2 \times \text{TIME}^{0.0427 \times \text{N}<em>{18}^{1.01162 \times \text{OVT}^{0.0351 \times \text{VOL}^{0.0114}}}}}{N</em>{18}^{1.01162 \times \text{OVT}^{0.0351 \times \text{VOL}^{0.0114}}}}\right)$</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>$P_f = 1.576 \frac{\text{ADT}^{0.0319 \times \text{TIME}^{0.0397 \times \text{VOL}^{0.0444 \times \text{OVT}^{0.00406}}}}}{\text{OVT}^{0.00406}}$</td>
<td>0.34</td>
</tr>
</tbody>
</table>

**TABLE E-8** PSI models for Minnesota's flexible and composite pavements

**KEY:**

- $N_{18}$ = 18 kip ESAL since last maintenance
- TIME = time in months since last maintenance
- OVT = Overlay thickness
- ADT = Average daily traffic
- DMD = Dynaflect mean deflection
- SCI = Surface curvature index

E-20
E.4 Pavement Performance Modeling using the flexible pavement models

Using the models shown in Table E-6 it is possible to predict flexible pavement performance in Minnesota. The results shown in the table below assume a structurally strong pavement (DMD 0.2), which received a 1.5 inch overlay prior to trafficking and then carries 10,000 N\textsubscript{18}/month.

<table>
<thead>
<tr>
<th>Time</th>
<th>16 months</th>
<th>64 months</th>
<th>128 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Cracking</td>
<td>56</td>
<td>79</td>
<td>86</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>11</td>
<td>23</td>
<td>29</td>
</tr>
<tr>
<td>Multiple Cracking</td>
<td>0</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Patching</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Rutting</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Predicted levels of Pavement distress for a flexible pavement in Minnesota

These results are shown graphically in Figure E-3. The models predict the early appearance of a large number of transverse cracks. Longitudinal cracks are less extensive but also appear early in the pavements life. After 5 years in service, the first multiple cracks appear. The models predict very little alligator cracking, patching or rutting., which is in agreement with the inspection data. It is worth repeating that these low (near zero) values of alligatoring and rutting are a true reflection of the extent of these distress types in the sections under investigation. Of the 166 inspections of flexible pavements which are in the TTI data base, only

• 42 (25%) recorded any rutting, the maximum value being 14%.
All other observations recorded zero rutting.

- 38 (23%) recorded any alligatoring. All other observations recorded zero alligator cracking.

Therefore, the models derived from these data will correctly predict only very small levels of these distress types.
E.5 Calculation of Pavement Damage Breakdown

As explained in Appendix C, the calculation of pavement damage requires

a) A measurement (or prediction) of pavement distress levels
b) A measurement (or prediction) of the pavement riding quality (PSI)
c) A knowledge of the individual states distress weighting factors and methods of calculating pavement score.

In Appendix C, example calculations were performed on the same distress and PSI data, using the weighting factors currently employed in the states of Minnesota, Maine, and Washington.

Therefore using the pavement performance models derived in this Appendix, shown in Tables E-6, E-7, and E-8, it is possible to predict pavement performance with pavements of different structural strength under varying traffic loadings. Then using the procedure described in Appendix C, it is possible to calculate the total pavement damage and also the damage breakdown into

a) Load associated damage
b) Climate associated damage
c) Combined (Load/Climate) associate damage.

This calculation has been performed for flexible pavements in the states of Minnesota, Maine, and Washington and composite pavements in the state of Minnesota. The results of these calculations are shown in Tables E-9, E-10, E-11 and E-12 respectively. Each calculation is performed for

a strong pavement (low deflection, DMD=0.2),
- a weak pavement (high deflection, DMD=1.5),
- a thin overlay (1.5 inch) applied prior to trafficking,
- a medium to thick overlay (3.5 inch) applied prior to trafficking, and
- assuming 60 months in service at which time the pavement has carried either $1 \times 10^6$, $3 \times 10^6$, or $10 \times 10^6$ 18-kip ESAL's.

Reported in these tables are two damage ratios, for example 0.011-0.759 in Table E-9. The 0.011 value is the calculated percentage (1.10%) of pavement damage which is directly attributable to load. The 0.759 value is the calculated percentage (75.9%) of pavement damage which is attributable to load PLUS combined load/climate forces. Clearly, the percentage of damage which is attributable to climate is 24.1% (ie 100-75.9). Therefore, for this pavement the majority of the damage is attributable to the combined load/climate forces.

The results in Tables E-9 through E-12 will now be discussed. For a detailed description of how these values were obtained, refer to Appendix C.

Table E-9

This table shows the load damage ratios for flexible pavement in Minnesota. The main conclusion from this table is that using the weighting factors pavement score calculation, etc., which are currently used in Minnesota, the majority of pavement damage is attributable to combined forces. Typically, over 70% of the damage is attributable to these forces. Furthermore, very little damage can be directly attributable to load, as measured by extent of rutting and alligating. The load associated damage was typically around 1%. From Table E-9, the typical flexible pavement
damage breakdown for Minnesota is as follows.

- Load associated damage: 2 to 2%
- Climate associated damage: 24 to 37%
- Combined associated damage: 63 to 76%

It is noted that, as expected, the amount of damage which is attributable to load and combined forces decreases as the pavement strength increases. Consider the results after $3 \times 10^6$ 18kips ESAL's and a 1.5 inch overlay; the load plus combined associated damage is 74.6% for a weak pavement (DMD=1.5) and only 67.9% for a strong pavement (DMD=0.2). Therefore the stronger the pavement the less load related damage can be expected. If the climatic damage is independent of pavement strength, it is clear that the percentage of climatic damage to total damage will increase for stronger pavements.

**Table E-10**

The distress levels predicted by the Minnesota pavement performance equations have been analysed using the weighting factors currently used by the State of Maine's Department of Transportation. Maine is in the same climatic zone as Minnesota, i.e., Zone 3-wet, hard freeze.

Table E-10 therefore illustrates the calculated load damage ratios for flexible pavements in the state of Maine. From this Table, the typical pavement damage breakdown is as follows.

- Load associated damage: .1 to 1%
- Climate associated damage: 60 to 75%
- Combined associated damage: 25 to 40%
Clearly Maine's weighting of the climatic distress types, transverse and longitudinal cracking is higher than the weighting used in Minnesota.

**Table E-11**

The distress levels predicted by the Minnesota pavement performance equations have been analysed using the weighting factors currently used by the State of Washington's Department of Transportation.

Table E-11 therefore illustrates the calculated load damage ratios for flexible pavements in the state of Washington. From this Table the typical pavement damage breakdown is as follows.

- Load associated damage: 0.1 to 1%
- Climate associated damage: 26 to 40%
- Combined associated damage: 59 to 74%

The final damage breakdown using the state of Washington's weighting factors is very similar to that calculated using the state of Minnesota's weighting factors.

**Table E-12**

The damage breakdown in this table has been calculated using the composite pavement performance equations shown in Tables E-7 and E-8 and Minnesota's distress weighting factors discussed earlier in Appendix C.

In Minnesota the following distress types are rated for composite pavements.

- Longitudinal cracking
- Transverse cracking
- Multiple cracking
- Patching
The longitudinal and transverse cracking are assumed to be climatic associated distress types. The multiple cracking, patching and loss in PSI are assumed to be associated to combined load/climate forces. Therefore for Minnesota's composite pavements none of the distress types are directly attributable to load. Hence, from Table E-11, the damage in the typical composite pavement in Minnesota can be broken down as follows.

<table>
<thead>
<tr>
<th>Damage Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load associated damage</td>
<td>0%</td>
</tr>
<tr>
<td>Climate associated damage</td>
<td>53 to 65%</td>
</tr>
<tr>
<td>Combined associated damage</td>
<td>35 to 47%</td>
</tr>
</tbody>
</table>

Thus, the majority of the damage in Minnesota's composite pavements can be directly attributed to climatic forces. This damage takes the form of longitudinal and transverse cracks which are commonly thermally induced reflection cracks.
### TABLE E-9 LOAD DAMAGE RATIOS FOR OVERLAID FLEXIBLE PAVEMENTS-STATE OF MINNESOTA
(Minnesota Models and Weighting Factors)

<table>
<thead>
<tr>
<th>Pavement Properties</th>
<th>Traffic ((18\text{-Kip Equiv.}))</th>
<th>Climatic Zones* ((1.5'' \text{ overlay}))</th>
<th>Climatic Zones* ((3.5'' \text{ Overlay}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>(1 \times 10^6)</td>
<td>0.011 - 0.759</td>
<td>0.006 - 0.752</td>
</tr>
<tr>
<td>Low</td>
<td>(1 \times 10^6)</td>
<td>0.004 - 0.720</td>
<td>0.002 - 0.738</td>
</tr>
<tr>
<td>High</td>
<td>(3 \times 10^6)</td>
<td>0.013 - 0.746</td>
<td>0.007 - 0.731</td>
</tr>
<tr>
<td>Low</td>
<td>(3 \times 10^6)</td>
<td>0.005 - 0.679</td>
<td>0.002 - 0.688</td>
</tr>
<tr>
<td>High</td>
<td>(10 \times 10^6)</td>
<td>0.016 - 0.736</td>
<td>0.009 - 0.721</td>
</tr>
<tr>
<td>Low</td>
<td>(10 \times 10^6)</td>
<td>0.007 - 0.632</td>
<td>0.003 - 0.631</td>
</tr>
</tbody>
</table>

*Climatic Zones: III - Wet, Hard freeze

+Deflections: High - Dynaflect maximum deflection = 1.5 mils; Surface curvature index = 1.0 mils

Low - Dynaflect maximum deflection = 0.4 mils; Surface curvature index = 0.2 mils
TABLE E-10 LOAD DAMAGE RATIOS FOR OVERLAID FLEXIBLE PAVEMENTS - STATE OF MAINE
(Minnesota Models, Maine Weighting Factors)

<table>
<thead>
<tr>
<th>Pavement Properties</th>
<th>Traffic (18-Kip Equiv.)</th>
<th>Climatic Zones*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>III (1.5&quot; Overlay)</td>
</tr>
<tr>
<td>High</td>
<td>$1 \times 10^6$</td>
<td>0.005 - 0.399</td>
</tr>
<tr>
<td>Low</td>
<td>$1 \times 10^6$</td>
<td>0.001 - 0.357</td>
</tr>
<tr>
<td>High</td>
<td>$3 \times 10^6$</td>
<td>0.006 - 0.371</td>
</tr>
<tr>
<td>Low</td>
<td>$3 \times 10^6$</td>
<td>0.002 - 0.313</td>
</tr>
<tr>
<td>High</td>
<td>$10 \times 10^6$</td>
<td>0.007 - 0.344</td>
</tr>
<tr>
<td>Low</td>
<td>$10 \times 10^6$</td>
<td>0.002 - 0.268</td>
</tr>
</tbody>
</table>

*Climatic Zones: III - Wet, Hard Freeze

+Deflections: High - Dynaflect maximum deflection = 1.5 mils;
  Surface curvature index = 1.0 mils

  Low - Dynaflect maximum deflection = 0.4 mils;
  Surface curvature index = 0.2 mils
TABLE E-11 LOAD DAMAGE RATIOS FOR OVERLAID FLEXIBLE PAVEMENTS - STATE OF WASHINGTON
(Minnesota Models, Washington Weighting Factors)

<table>
<thead>
<tr>
<th>Pavement Properties</th>
<th>Traffic (18-Kip Equiv.)</th>
<th>V (1.5&quot; Overlay)</th>
<th>V (3.5&quot; Overlay)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection+</td>
<td>1 X 10^6</td>
<td>0.002 - 0.703</td>
<td>0.001 - 0.714</td>
</tr>
<tr>
<td>High</td>
<td>1 X 10^6</td>
<td>0.001 - 0.707</td>
<td>0.000 - 0.739</td>
</tr>
<tr>
<td>Low</td>
<td>3 X 10^6</td>
<td>0.003 - 0.668</td>
<td>0.002 - 0.677</td>
</tr>
<tr>
<td>High</td>
<td>3 X 10^6</td>
<td>0.001 - 0.655</td>
<td>0.000 - 0.682</td>
</tr>
<tr>
<td>Low</td>
<td>10 X 10^6</td>
<td>0.003 - 0.630</td>
<td>0.002 - 0.637</td>
</tr>
<tr>
<td>Low</td>
<td>10 X 10^6</td>
<td>0.001 - 0.592</td>
<td>0.000 - 0.614</td>
</tr>
</tbody>
</table>

*Climatic Zones: V - Dry, Freeze thaw cycling.

+Deflections: High - Dynaflect maximum deflection = 1.5 mils;
Surface curvature index = 1.0 mils

Low - Dynaflect maximum deflection - 0.4 mils;
Surface curvature index = 0.2 mils
TABLE E-12 LOAD DAMAGE RATIOS FOR COMPOSITE PAVEMENTS - STATE OF MINNESOTA

<table>
<thead>
<tr>
<th>Pavement Properties</th>
<th>Traffic (18-Kip Equiv.)</th>
<th>Climatic Zones*</th>
<th>Climatic Zones*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>III (1.5&quot; Overlay)</td>
<td>III (3.5&quot; Overlay)</td>
</tr>
<tr>
<td>High</td>
<td>$1 \times 10^6$</td>
<td>0.000 - 0.351</td>
<td>0.000 - 0.414</td>
</tr>
<tr>
<td>Low</td>
<td>$1 \times 10^6$</td>
<td>0.000 - 0.367</td>
<td>0.000 - 0.427</td>
</tr>
<tr>
<td>High</td>
<td>$3 \times 10^6$</td>
<td>0.000 - 0.358</td>
<td>0.000 - 0.434</td>
</tr>
<tr>
<td>Low</td>
<td>$3 \times 10^6$</td>
<td>0.000 - 0.371</td>
<td>0.000 - 0.445</td>
</tr>
<tr>
<td>High</td>
<td>$10 \times 10^6$</td>
<td>0.000 - 0.366</td>
<td>0.000 - 0.460</td>
</tr>
<tr>
<td>Low</td>
<td>$10 \times 10^6$</td>
<td>0.000 - 0.376</td>
<td>0.000 - 0.466</td>
</tr>
</tbody>
</table>

*Climatic Zones: III - Wet, Hard Freeze

*Deflections: High - Dynaflect maximum deflection = 1.5 mils
Surface curvature index = 1.0 mils

Low - Dynaflect maximum deflection = 0.5 mils;
Surface curvature index = 0.2 mils
APPENDIX F

RIGID PAVEMENT PERFORMANCE

AND DISTRESS MODELS

F-1
APPENDIX F
Rigid Pavement Performance and Distress Models

F.1 Introduction
F.2 Development of Rigid pavement predictive models
F.3 Rigid pavement performance modelling
F.4 Calculation of Rigid Pavement Damage breakdown
F.5 Calculation of Rigid Pavement Damage Breakdown in each Environmental Zone
APPENDIX F

Rigid Pavement Performance and Distress Models

F.1 Introduction

This appendix describes

a) the development of rigid pavement performance models and
b) the calculation of what percentage of the predicted pavement
damage is load associated, climate associated, etc..

These predictive models were developed for this project by Dr. M. Darter
under agreement L100007, they are described fully in the next section of
this Appendix.

These models were computerized at TTI and several runs have been
made to predict performance of rigid pavements under varying numbers of
18 kip ESALs, time in service, etc. A description of this work is given
in section F.3 of this Appendix.

As described for flexible pavements in Appendix C, it is possible
to calculate the pavement damage breakdown once predictive models and
distress weighting factors are available. In section F.4, the calcula-
tion of pavement damage breakdown is performed using the Illinois per-
formance models with weighting factors from the states of Kansas, Texas
and Washington.
F.2 Development of Rigid Pavement Predictive Models

Note: The following section of this appendix, pages F-5 through F-36, is a reproduction of the report furnished to TTI under agreement L100007. That report is reproduced herein as it was received, except that numbering of pages, tables, figures, and references, have been changed so that they do not conflict with numbering throughout other sections of this report. Where in the text on these pages (pages F-5 through F-36) a reference to Figure 1 is made, see Figure F-1; for Figure 2, see Figure F-2; and so forth. Page numbers, table numbers, and reference numbers have been similarly changed.
1. Several predictive models were developed utilizing the Illinois data base from NCHRP Project 1-19. All pavements were located on the Interstate highway system and were jointed reinforced concrete pavement (JRCP). The following models were developed:

- Present Serviceability Index
- Deterioration of transverse cracks
- Joint faulting
- Pumping
- Joint deterioration (including spalling, blowups, and permanent patches placed at the joints)
- "D" Cracking
- Swells and depressions

All distress types and severity levels are defined in the Federal Highway Administration's "Highway Pavement Distress Identification Manual" (Ref. 1).

2. The data used to develop the models consisted of three different sources and are referred to as A, B, and C.

A-- 123 regular construction projects which represent nearly all of the JRCP constructed on the Interstate system between 1957 and 1973. These sections have a 10 in. slab, 100 ft. joint
spacing, range in age between 6 and 22 years, and have carried between 1 and 16 million 18-kip equivalent single axle loads (ESAL).

B-- 20 sections constructed on I-80 in 1962. These pavements had slab thickness between 8 and 10 inches, stabilized and non-stabilized subbases, 40 and 100 ft. joint spacing and carried about 10 million ESAL.

C-- 22 Sections of the original AASHO Road Test that were left in service on I-80 between 1958 and 1974. These pavements range in thickness from 8 to 12.5 in., joint spacing 40 ft., granular subbases, and have carried up to 18 million ESAL.

Additional data on these sections is found in References 2 and 3. Table 1 summarizes some of the data for data sets B and C, and Table 2 gives some data for data set A.

3. All models were developed using the stepwise regression technique. The SPSS statistical package was used for all data analyses (Ref. 4).

4. Transverse Joint Faulting.

Data sets A, B, and C were utilized. JRCP exhibits no faulting when newly constructed. Faulting occurs with time and traffic as the transverse joints lose their load transfer efficiency through pumping and deterioration of the concrete around the dowel bars. The following variables were tried: slab thickness, dowel diameter, subbase type, joint spacing, freeze-thaw cycles, annual precipitation, Thornthwaite moisture index, and ESALs. None of the climatic variables entered the model, probably because of the limited range of climate in Illinois. The following equation was developed:
\[ \ln(F + 1) = 2.342(\ln(\text{ESAL} \cdot \text{AGE} + 1)/(D \cdot T)) - 0.1116(\ln(\text{ESAL} \cdot \text{AGE} + 1)) + 0.0168 \]

where:

\( F \) = Mean transverse joint faulting, ins. (one foot in from slab edge).

\( \text{ESAL} \) = Equivalent single 18-kip axle loads accumulated over the life of the pavement in the lane, millions

\( \text{AGE} \) = time since pavement construction, years

\( D \) = Diameter of dowel used in joint, ins.

\( T \) = Thickness of slab, ins.

Statistics:

\[ R^2 = 0.45 \quad \text{Standard Error} = 0.09 \]

\[ \text{COV} = 61 \text{ percent} \quad n = 283 \text{ cases} \]

Range of variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>0 - 0.7 ins</td>
</tr>
<tr>
<td>\text{ESAL}</td>
<td>1 - 18 million</td>
</tr>
<tr>
<td>\text{AGE}</td>
<td>4 - 22 years</td>
</tr>
<tr>
<td>D</td>
<td>1.000 - 1.625 ins.</td>
</tr>
<tr>
<td>T</td>
<td>8 - 12.5 ins.</td>
</tr>
</tbody>
</table>

A sensitivity analysis of the model is shown in Figures 1 and 2.
5. **Pumping**

Pumping is caused by a combination of heavy repeated traffic loadings, free water beneath the slab and/or subbase, and erodable materials beneath the slab. Pumping was rated according to three severity levels: 0 - no pumping; 1 - low severity; 2 - medium severity; and 3 - high severity as defined in Reference 1. The following equation was rescaled by dividing the pumping index by three so that it now ranges between 0 and 1. Many variables were tried, particularly climatic variables, but the range of climate within the state of Illinois is not wide enough to really show their effect. Data Set A was utilized in this model development.

\[
\ln (P + 1) = AGE \times ESAL \times 0.0105 \times JTSEAL + 0.0136/(DRAIN + 1) + 0.0003 \times IMOIST + 0.0142
\]

where:

- \( P \) = pumping severity (0 = no pumping, 1 = high severity)
- \( AGE \) = time since construction, years
- \( ESAL \) = accumulated 18-kip single axle load applications divided by the \( AGE \) of the pavement, millions/year
- \( JTSEAL \) = 1, if sealant is in medium to high severity condition (Ref. 1) = 0, if sealant is in low or better condition
- \( DRAIN \) = 1, if underdrains exist along the slab edge = 0, if underdrains do not exist along the slab edge
- \( IMOIST \) = Thornthwaite moisture index.
Statistics:
\[ R^2 = 0.32 \]
\[ COV = 149 \text{ percent} \]
\[ \text{Standard Error} = 0.17 \]
\[ n = 274 \text{ cases} \]

Range of variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>0 - 1</td>
</tr>
<tr>
<td>AGE</td>
<td>0 - 22 years</td>
</tr>
<tr>
<td>ESAL</td>
<td>0 - 1.1 million/yr.</td>
</tr>
<tr>
<td>IMOIST</td>
<td>20 - 44</td>
</tr>
<tr>
<td>DRAIN</td>
<td>0 - 1</td>
</tr>
<tr>
<td>JTSEAL</td>
<td>0 - 1</td>
</tr>
</tbody>
</table>

There were many variables that were considered which did not enter the equation, such as the amount of fines passing the #200 sieve. Figures 3 and 4 show the general sensitivity of the model.

6. **Patching**

The permanent patching of JRCP consists of placing concrete or full depth asphalt at deteriorated joints. Over 2000 patches were placed at joints on the Illinois JRCP. Efforts were made to develop predictive models for the amount of patching (in ft²) and a function of many variables such as AGE, ESAL, slab thickness, and climatic variables. Despite considerable efforts, it was impossible to obtain even an approximate model. The main reason being that the placing of permanent patches also depends greatly upon available funds and crews. It was possible to obtain reasonable models for overall joint deterioration which includes patching, joint spalling and blowups. Thus, the overall joint deterioration model should be used to predict the approximate amount of patching.
7. **Present Serviceability Index**

The initial PSI of Illinois JRCP at the time of construction is between 4 and 5. It then gradually decreases over time and traffic until it reaches an untolerable level and the pavement is rehabilitated. Many different variables were regressed with PSI, including a number of climatic variables such as average annual precipitation, average temperature difference, freeze thaw cycles, the Thornthwaite moisture index. Unfortunately, none of the climatic variables entered into the model due to the small range of climatic conditions in Illinois. Data sets A, B, and C were used in the development of the model.

\[
\text{PSI} = 4.46 + \text{AGE} \times \ln (\text{ESAL} + 1) - 0.07825 + 0.03969 \times T \times \text{AS} + 0.02563 \times \text{STAB} - 0.0002392 \times L
\]

where:

- **PSI** = present serviceability index
- **AGE** = time since construction, years
- **ESAL** = total accumulated 18-kip equivalent single axle load applications since construction, millions
- **T** = concrete slab thickness, ins.
- **AS** = area of steel reinforcement longitudinally in slab, \(\text{ins.}^2/\text{ft. width of slab}\)
- **STAB** = 1, if subbase is stabilized with cement or asphalt
  0, if subbase is unstabilized granular dense graded
- **L** = slab length, ft.

Statistics:

\[
R^2 = 0.72 \quad \text{Standard Error} = 0.37
\]

\[
\text{COV} = 10 \text{ percent} \quad n = 345 \text{ cases}
\]
Range of variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSI</td>
<td>1.5 - 4.5</td>
</tr>
<tr>
<td>AGE</td>
<td>0 - 22 years</td>
</tr>
<tr>
<td>ESAL</td>
<td>0 - 18 million</td>
</tr>
<tr>
<td>T</td>
<td>8 - 12.5</td>
</tr>
<tr>
<td>AS</td>
<td>0.093 - 0.172 ins²/ft. width</td>
</tr>
<tr>
<td>STAB</td>
<td>0 - 1</td>
</tr>
</tbody>
</table>

A sensitivity analysis of the model is shown in Figures 5 and 6.
8. Joint Deterioration

A deteriorated joint is defined herein as a joint exhibiting blowups, corner breaks, permanent patches, and medium to high severity spalling. The total number of deteriorated joints are converted to a total percent joints. This figure could be converted to joints/mile by knowing that joint spacing on all Illinois pavement in Data Set A was 100 ft. Data Set A was used to develop the following predictive model.

\[
\ln(\text{DETER} + 1) = \ln(\text{ESAL} + 1) \times \text{AGE} \left[ 0.0011 \times \text{FTCYCLE} \\
+ 0.000013 \times \text{TEMPDIF} \times \text{PPTN} \times \text{DX} \\
\frac{1}{\text{DRAIN} + 1} \right] \\
+ 0.0019 \times \text{INCOMP} \times \text{FTCYCLE} \times \text{JTSEAL} \\
\frac{1}{\text{DX} + 1} \right] + 0.0429
\]

Where:
- DETER = Percent deteriorated joints
- ESAL = Cumulative 18-kip single axle load applications over AGE of slab in lane, millions
- AGE = time since construction, years
- FTCYCLE = Average number of annual freeze thaw cycles within the concrete slab
- TEMPDIF = Difference between highest average monthly temperature and lowest average monthly temperature, °C
- PPTN = Total average annual precipitation at the pavement site, cm
- DX = 1.0, if "D" cracking exists
  0.0, if no "D" cracking exists
DRAIN = 1.0, if longitudinal underdrains exist along the slab edge (these drains were placed during the previous 2 to 7 years).

0.0, if no underdrains exist

INCOMP = 1.0, if incompressibles are visible in the joints

0.0, if no incompressibles are visible

JTSEAL = 1.0, if the sealant is in medium to high severity

0.0, if the sealant is in low or better condition

Statistics:

\[ R^2 = 0.54 \]

Standard Error = 1.00

C.O.V. = 119%

No. of cases = 268

Ranges of variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>DETER</td>
<td>0 - 100 percent</td>
</tr>
<tr>
<td>ESAL</td>
<td>0 - 15 million</td>
</tr>
<tr>
<td>AGE</td>
<td>0 - 22 years</td>
</tr>
<tr>
<td>FTCYCLE</td>
<td>5 - 15/ year</td>
</tr>
<tr>
<td>TMPDIF</td>
<td>32 - 40 °</td>
</tr>
<tr>
<td>PPTN</td>
<td>84 - 114 cm</td>
</tr>
</tbody>
</table>

A sensitivity analysis of the model is shown in Figures 7, 8 and 9.
Swells and Depressions

A depression or swell was detected by a rider in medium-sized car on a 55 mph pass over the uniform section as described in Ref. 1. The total number of depressions and swells at all levels of severity (L,M,H) were added together and then divided by the length of the uniform section. This variable was named WAVES. There are many variables that may be directly related to the number of waves which were unavailable, such as compaction data or number of culverts. A model was developed utilizing Data set A and three variables.

The final stepwise regression analysis resulted in the following equation:

\[ \text{WAVES} = 0.145 \times \text{AGE} + 0.0620 \times \text{IMODIST} + 0.0298 \times \text{ESAL} - 1.83 \]

If WAVES is less than zero, then waves equals zero.

where

\[ \text{WAVES} = \text{total no. of depressions and swells per mile} \]
\[ \text{AGE} = \text{age in years of pavement (0-22)} \]
\[ \text{IMODIST} = \text{the WOODHAITE Moisture index (20-40)} \]
\[ \text{ESAL} = \text{cumulative 18-kip (80KN) equivalent single axle load, (0-16)(r_n)} \]

Statistics:

\[ R^2 = 0.56 \quad \text{Standard error } = 1.25 \]
\[ n = 274 \quad \text{C.O.V. } = 93\% \]

Figures 13 and 14 are provided showing the effect of IMDIST and traffic.
Transverse Crack Deterioration

Transverse cracking of JTCP is a normal occurrence due to a combination of drying shrinkage, temperature gradient curling, and moisture gradient warping. When these cracks initially occur they are held tightly together with the reinforcing mesh. After time and traffic some of these cracks begin to spall and deteriorate until the steel ruptures. They eventually can become severely spalled and faulted.

Many attempts were made to improve the original model developed under NCHRP Project 1-19 by adding several climate variables for temperature, moisture, and freeze-thaw. These attempts were unsuccessful in that there was not enough of a climatic range in Illinois to affect the amount of crack deterioration.

Therefore, the following model is submitted which is the same as the original 1-19 development:

\[
TC = AGE \times ESAL \left[ -1.500 + \frac{1.113}{H \times ASTEEL} + \frac{4.584}{L} + \frac{1.129}{STAB+1} \right]
\]

where

TC: Transverse cracks of medium or high severity, no./mi.

AGE: Age of the pavement, years

ESAL: Equivalent 18-kip single-axle loads, millions

ASTEEL: Area of longitudinal reinforcing steel, in.\(^2\)/ft. width of lane

L: Joint spacing, ft.

STAB: 1, if stabilized subbase (asphalt or cement) or
      0, if granular subbase

H: Slab thickness, ins.

Statistics: \( R^2 = 0.52 \)

Std. Error = 39 cks/mi.

\( n = 622 \) data points
Range of Variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td>0-200 cks/ml</td>
</tr>
<tr>
<td>AGE</td>
<td>0-22 yrs</td>
</tr>
<tr>
<td>ESAL</td>
<td>0-18 million</td>
</tr>
<tr>
<td>ASTEEL</td>
<td>0.09 - 0.17 in²/ft. width</td>
</tr>
<tr>
<td>L</td>
<td>40-100 ft.</td>
</tr>
<tr>
<td>H</td>
<td>8-12.5 ins.</td>
</tr>
</tbody>
</table>

A sensitivity analysis is shown in Figure 15.
<table>
<thead>
<tr>
<th>Slab Thickness (in.)</th>
<th>Type Subbase</th>
<th>Transverse Joint Dowels (at 12&quot; ctrs) Diam. (in.)</th>
<th>Length (in.)</th>
<th>Joint Spacing (ft.)</th>
<th>Reinforcement Fabric Style</th>
<th>Fabric Weight (lb/100 sf)</th>
<th>Depth in Pvmnt. (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Gran.</td>
<td>1</td>
<td>18</td>
<td>40</td>
<td>612-33</td>
<td>51</td>
<td>2</td>
</tr>
<tr>
<td>9 1/2</td>
<td>Gran.</td>
<td>1 1/4</td>
<td>18</td>
<td>40</td>
<td>612-22</td>
<td>59</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>Gran.</td>
<td>1 3/8</td>
<td>18</td>
<td>40</td>
<td>612-11</td>
<td>69</td>
<td>2</td>
</tr>
<tr>
<td>12 1/2</td>
<td>Gran.</td>
<td>1 5/8</td>
<td>18</td>
<td>40</td>
<td>612-00</td>
<td>81</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Stab.</td>
<td>1</td>
<td>18</td>
<td>40</td>
<td>612-33</td>
<td>51</td>
<td>2</td>
</tr>
<tr>
<td>9 1/2</td>
<td>Gran.</td>
<td>1 1/4</td>
<td>18</td>
<td>40</td>
<td>612-22</td>
<td>59</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>Gran.</td>
<td>1</td>
<td>18</td>
<td>100</td>
<td>612-004</td>
<td>72</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>Stab.</td>
<td>1</td>
<td>18</td>
<td>100</td>
<td>612-004</td>
<td>72</td>
<td>2</td>
</tr>
<tr>
<td>DIMENSIONS</td>
<td>BAR</td>
<td>JOINT</td>
<td>LANE</td>
<td>WIRE FABRIC*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-----</td>
<td>-------</td>
<td>------</td>
<td>--------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DOWEL BAR (in.)</td>
<td>TIE BAR (in.)</td>
<td>TRANSVERSE BAR (in.)</td>
<td>LONGITUDINAL BAR (in.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
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<td>0.63</td>
<td>0.23</td>
<td>0.33</td>
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<td></td>
</tr>
<tr>
<td>Spacing</td>
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<td>30</td>
<td>12.0</td>
<td>6.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>18</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Welded wire fabric style 612-004 Yield Strength 65 ksi min. place 2.5 ins (6.4 cm) below surface.
Figure F-1. Illustration of transverse joint faulting prediction for different traffic loadings.
Figure F-2. Illustration of transverse joint faulting prediction for different dowel diameters.
Figure F-3. Illustration of the pumping of JRCP and the influence of traffic level.
Figure F-4. Illustration of the influence of underdrains on pumping.
Figure F-6. Illustration of the sensitivity of PSI to truck traffic.
Figure F-7. Effect of Age and Underdrains on the Percent of Deteriorated Joints for PCC pavements exhibiting "D" cracking.
Figure F-8. Effect of Age and Equivalent Single Axle Loads (18-kip) on Percent Joints Deteriorated. ("D" cracked pavements)
Figure F-9. Effect of Age and joint seal/incompressibles on Percent Joint Deterioration (for both with and without "D" cracking).
Figure F-10. Effect of AGE and Aggregate type on "D" cracking.
Figure F-12. Effect of AGE and traffic on "P" cracking
Figure F-14. Effect of AGE and traffic on WAVES.
Figure F-15. Effect of AGE and slab thickness on transverse crack deterioration.
REFERENCES


F.3 Rigid Pavement performance modeling

The predictive models described in Section F.2 have been computerized at the Texas Transportation Institute. The program containing these models is listed in Appendix G.

Several runs have been made with this program to study the effect of variations of 18 kip ESAL's, time in service, slab thickness, etc. on the predicted pavement performance. For each run, it is necessary to specify the following input data which is defined in Section F.2.

- structural design data
  - dowel diameter
  - area of steel reinforcement
  - slab length
  - slab thickness
  - type of aggregate used
  - if base is stabilized
  - if underdrains exist

- environmental data
  - average annual precipitation
  - temperature difference
  - average freeze-thaw cycles
  - Thornthwaite index

- data on observed pavement condition
  - condition of joints
  - initial PSI
  - if "D" cracking already exists

- data with regard to prediction period
  - length of period (in years)
  - accumulated 18 kip ESAL's carried
An example of typical input data is shown below in Table F.3.

**INPUT DATA**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>INITIAL SERV. INDEX</td>
<td>4.46</td>
</tr>
<tr>
<td>DOWEL DIAMETER, IN.</td>
<td>1.500</td>
</tr>
<tr>
<td>AREA STEEL REINFORCE</td>
<td>0.135</td>
</tr>
<tr>
<td>AVG ANN PRECIPITATION</td>
<td>99.0</td>
</tr>
<tr>
<td>SLAB LENGTH, FT</td>
<td>70.0</td>
</tr>
<tr>
<td>TEMP. DIFFERENCE, CEN</td>
<td>36.0</td>
</tr>
<tr>
<td>TIME SINCE CONST, YRS</td>
<td>5.0</td>
</tr>
<tr>
<td>SLAB THICKNESS, IN.</td>
<td>10.0</td>
</tr>
<tr>
<td>EQ SMGL 18-KIP AXLE LD</td>
<td>1000000, 1000000, 2000000</td>
</tr>
<tr>
<td>CR STONE, 1 GRAVEL, Ø</td>
<td>1</td>
</tr>
<tr>
<td>UNDERDRN, YES, 1 NO, Ø</td>
<td>1</td>
</tr>
<tr>
<td>D CRACK, YES, 1 NO, Ø</td>
<td>0</td>
</tr>
<tr>
<td>AVG FREEZE/THAW CYCLES</td>
<td>10</td>
</tr>
<tr>
<td>INCMP IN JNT Y, 1 N, Ø</td>
<td>0</td>
</tr>
<tr>
<td>JT SEAL HI SV, 1 LO, Ø</td>
<td>0</td>
</tr>
<tr>
<td>STAB SBB, 1 GRAN SBB, Ø</td>
<td>0</td>
</tr>
<tr>
<td>THORNTHWAITE NOIST IND</td>
<td>32</td>
</tr>
</tbody>
</table>

**TABLE F.3** Input data for rigid pavement models

From Table F.3, the prediction period is 5 years, three runs are to be made for accumulative 18 kip ESAL's of 1, 10, and 20 million. The predicted performance of this pavement is shown below in Table F.4.
<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Range*</th>
<th>1</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Joint Faulting (ins)</td>
<td>0 - 0.7</td>
<td>0.101</td>
<td>0.211</td>
<td>0.249</td>
</tr>
<tr>
<td>Pumping Index</td>
<td>0 - 1</td>
<td>0.031</td>
<td>0.195</td>
<td>0.408</td>
</tr>
<tr>
<td>(1=high)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSI</td>
<td>1.50-4.46</td>
<td>4.32</td>
<td>3.963</td>
<td>3.829</td>
</tr>
<tr>
<td>Percentage Deteriorated Joints</td>
<td>0 - 100</td>
<td>0.13</td>
<td>0.407</td>
<td>0.525</td>
</tr>
<tr>
<td>D Cracking Index</td>
<td>0 - 100</td>
<td>2.23</td>
<td>19.13</td>
<td>100.0</td>
</tr>
<tr>
<td>Swells and Depressions (no./mile)</td>
<td>0 - 4.3</td>
<td>0.91</td>
<td>1.18</td>
<td>1.47</td>
</tr>
<tr>
<td>Transverse Cracks (no./mile)</td>
<td>0 - 200</td>
<td>3</td>
<td>26</td>
<td>52</td>
</tr>
</tbody>
</table>

TABLE F-4  Predicted performance of the J.R.C.P. described in Table F-3.

*Range of variables in Illinois data base, or minimum/maximum values obtained using Illinois models.
F.4 Calculation of Rigid pavement damage breakdown

As described earlier in Appendix C, deduct points can be defined for each pavement distress type as

distress deduct point = percentage distress present ×

distress weighting factor.

The total pavement damage can therefore be defined as the summation of deduct points for each distress type.

Furthermore, it was shown that this total damage value can then be broken up into the contributing factors of

- load associated damage
- climate associated damage
- combined (load/climate) damage.

In order to perform this calculation, it is necessary to have

a) Models which predict pavement performance,
b) The relative weighting factor for each distress type, and
c) The categorizing of the individual distress types as
   1) chiefly load associated 2) chiefly climate associated
      or 3) neither chiefly load nor climate but a combination of
      the two.

This calculation for flexible and composite pavements was described earlier in Appendix C. The calculation of damage breakdown for rigid pavements is described in the remainder of this Appendix. The prediction models, weighting factors, and distress categorization used in this calculation are as follows.
a) prediction models

The Illinois models, which predict the performance of jointed reinforced concrete pavements, have been described in sections F.2 and F.3.

b) relative weighting factors

The relative weighting factor for each distress type was found by reference to "Pavement Evaluation, FHWA-RD-75-78" by Lytton, Moore and Mahoney. As described in this report only four states have adequate rigid pavement rating systems which rate similar distress types to those predicted using the Illinois models. These states are Kansas, Washington, Texas, and Virginia. The relative weighting factors used by each of these states is shown below in Table F.5.

<table>
<thead>
<tr>
<th>Transverse Joint Faulting (ins)</th>
<th>Range*</th>
<th>Kansas</th>
<th>Texas</th>
<th>Washington</th>
<th>Virginia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumping</td>
<td>0-1</td>
<td>0°</td>
<td>0-60</td>
<td>0-45</td>
<td>0-20</td>
</tr>
<tr>
<td>P.S.I.</td>
<td>4.46-1.50</td>
<td>1-4</td>
<td>0-50</td>
<td>0-100</td>
<td>0X</td>
</tr>
<tr>
<td>Joint Deterioration</td>
<td>0-100</td>
<td>1-4</td>
<td>0-60</td>
<td>0-50</td>
<td>0-25</td>
</tr>
<tr>
<td>D Cracking</td>
<td>0-100</td>
<td>2-8</td>
<td>0-40</td>
<td>0-50</td>
<td>0-5</td>
</tr>
<tr>
<td>Swells and Depressions (no/mile)</td>
<td>0-4.3</td>
<td>1-10</td>
<td>0+</td>
<td>0+</td>
<td>0X</td>
</tr>
<tr>
<td>Transverse Cracks (no/mile)</td>
<td>0-200</td>
<td>1-5</td>
<td>0-30</td>
<td>0-50</td>
<td>0-5</td>
</tr>
</tbody>
</table>

**TABLE F.5 Rigid pavement distress weighting factors**

Using the weighting factors in Table F.5, it is possible to calculate the deduct points for each distress type. For instance, if transverse joint faulting of 0.5 inches is predicted, with a maximum range of

* Maximum range of variable in Illinois data base.
° Kansas does not rate pumping.
△ Assumed weighting for failure/mile
+ Texas and Washington do not rate Swells and Depressions.
X Virginia does not give any weightings for PSI or Swells and Depressions.
0 to 0.7 inches the deduct point calculation for each state would be as follows.

**Kansas**

faulting rating range 1-4: if faulting = 0.5 inches

\[
deduct \ points = \frac{0.5}{0.7} \times (4-1) + 1
\]

= 3.14

**Texas**

faulting rating range 0-50: if faulting = 0.5 inches

\[
deduct \ points = \frac{0.5}{0.7} \times 50
\]

= 35.7

**Washington**

faulting rating range 0-30: if faulting = 0.5 inches

\[
deduct \ points = \frac{0.5}{0.7} \times 30
\]

= 21.4

**Virginia**

faulting rating range 0-10: if faulting = 0.5 inches

\[
deduct \ points = \frac{0.5}{0.7} \times 10
\]

= 7.1

The total pavement damage is therefore the summation of each distress type's deduct points as shown below.

Damage = Transverse Joint faulting deduct points
+ Pumping deduct points
+ Loss in PSI deduct points
+ Transverse Cracking deduct points
c) Categorizing each distress type

Finally it is necessary to categorize the individual distress types as chiefly load, climate or combined associated. To assist with this task, reference has been made to the Federal report "Highway Pavement Distress Identification Manual", FHWA-RD-79-66. This report describes each distress in text and photographically. It also discussed the main causes of each distress type. A summary of these discussion is presented below for each distress type predicted by the Illinois models.

Transverse Joint Faulting

"Faulting is the difference of elevation across a joint or crack. Faulting is caused in part by a build up of loose material under the approach slab.... This buildup is caused by pumping due to heavy loads.... Lack of load transfer contributes greatly to faulting". It can be inferred from the above that load is a major contributing factor to transverse joint faulting.

Pumping

"Pumping is the ejection of material by water through joints or cracks, caused by deflection of the slab under moving loads". This implies that both the presence of water and heavy loads are required for pumping to occur. Thus pumping is a result of a combination of load and climatic forces.

Present Serviceability Index

PSI is a function of many parameters, the main ones being load and climate. Throughout this study, a reduction of PSI has been attributed to combined forces.
Joint Deterioration

A deteriorated joint is defined herein as a joint exhibiting blowups, corner breaks, permanent patches, and medium to high severity spalling. Spalling usually results from "excessive stresses at the joint of crack caused by infiltration of incompressible materials and subsequent traffic loading weak concrete at the joint combined with traffic...poorly designed and constructed load transfer devices". Corner breaks are attributed to "Load repetitions combined with loss of support, poor load transfer across joint...". Clearly load is a major contributing factor to joint deterioration.

"D" Cracking

"D" cracking is a "series of closely spaced crescent-shaped hairline cracks that appear at a PCC pavement slab surface and run roughly parallel to transverse and longitudinal joints...". "D" cracking is caused by freeze-thaw expansive pressure of certain types of coarse aggregates". "D" cracking is therefore primarily caused by environmental forces.

Swells and Depressions

"Swell is characterized by an upward bulge in the pavement's surface. ...A swell is usually caused by frost action in the sub-grade or by swelling soil". From this definition, it is clear that swells are environment associated distress types.

Transverse Cracks

"Thermal and moisture gradient stresses, and drying shrinkage stress" are stated as common causes of Transverse cracks. This would imply that these cracks are mainly caused by environmental forces.
Summarizing the above discussion, the various distress types can be categorized as shown below in Table F.6.

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Chiefly attributed to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Joint Faulting</td>
<td>Load</td>
</tr>
<tr>
<td>Pumping</td>
<td>Combined</td>
</tr>
<tr>
<td>PSI</td>
<td>Combined</td>
</tr>
<tr>
<td>Joint Deterioration</td>
<td>Load</td>
</tr>
<tr>
<td>D cracking</td>
<td>Climate</td>
</tr>
<tr>
<td>Swells and Depressions</td>
<td>Climate</td>
</tr>
<tr>
<td>Transverse Cracks</td>
<td>Climate</td>
</tr>
</tbody>
</table>

TABLE F.6 Categorizing each distress type as load, climate or combined associated.

Using the information in Table F.6, it is possible to determine what percentage of the total pavement damage is attributable to load, climate and combined forces.

An example of this calculation is shown in Table F.7, this being for the pavement described in Table F.3 with the weighting factors used in Kansas.

From Table F.7, the total damage (summation of deduct points) is calculated to be 13.761. Of this figure 4.128 is load associated, 8.130 is climate associated and 1.503 is combined associated. The calculated damage breakdown is therefore as follows.

- load associated 30%
- climate associated 59%
- combined associated 11%
<table>
<thead>
<tr>
<th>DISTRESS NAME</th>
<th>DISTRESS UNITS</th>
<th>LEVEL PRED.</th>
<th>LOAD</th>
<th>LEVEL LOAD</th>
<th>CLIMATE TOTAL DEDUCT POINTS</th>
<th>ILLINOIS RIGID</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANS. FAULT</td>
<td>1000000.00</td>
<td>0.0115</td>
<td>0.01</td>
<td>0.01</td>
<td>1.907</td>
<td>0.400</td>
</tr>
<tr>
<td>PUMPING</td>
<td>2000000.00</td>
<td>0.0151</td>
<td>0.02</td>
<td>0.02</td>
<td>1.948</td>
<td>0.403</td>
</tr>
<tr>
<td>J. DETERMINED</td>
<td>1000000.00</td>
<td>0.0044</td>
<td>0.00</td>
<td>0.00</td>
<td>1.907</td>
<td>0.400</td>
</tr>
<tr>
<td>CRACKING</td>
<td>5000000.00</td>
<td>0.0138</td>
<td>0.02</td>
<td>0.02</td>
<td>1.948</td>
<td>0.403</td>
</tr>
<tr>
<td>TOTALS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.761</td>
</tr>
</tbody>
</table>

**TABLE F.7 Calculation of Pavement Damage breakdown using the Illinois models with the Kansas weighting factors. Pavement age = 5 years. 18 Kips = 10,000,000.**
Calculation of typical damage breakdowns

The calculation of pavement damage breakdown, just described, was repeated using the weighting factors used in Kansas, Texas and Washington, which were shown earlier in Table F.5. The input data for these calculations are shown below in Table F.8.

<table>
<thead>
<tr>
<th>Input Data</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Serv. Ind.</td>
<td>4.46</td>
</tr>
<tr>
<td>Dowel Diameter, in</td>
<td>1.50</td>
</tr>
<tr>
<td>Area Steel Reinforce</td>
<td>6.135</td>
</tr>
<tr>
<td>Avg Ann Precipitation</td>
<td>99.0</td>
</tr>
<tr>
<td>Slab Length, ft</td>
<td>70.0</td>
</tr>
<tr>
<td>Temp. Difference, CEN</td>
<td>30.0</td>
</tr>
<tr>
<td>Time Since Const., YRS</td>
<td>5.0</td>
</tr>
<tr>
<td>Slab Thickness, in</td>
<td>10.0</td>
</tr>
<tr>
<td>Cn Sgld 18-Kip Axle LD</td>
<td>1000000</td>
</tr>
</tbody>
</table>

| CR Stone | 0 |
| #GCB | 1 |
| #GCB | 1 |
| #GCB | 0 |
| Avg Freeze/Thaw Cycles | 10 |
| Incap in Jnt Y, IA, 0 | 0 |
| JT Seal Hi Sv, 1 ; Low, 0 | 0 |
| STA3 SBB, 1 ; Gran SBB, 0 | 0 |
| Thorithwaite Moist Ind. | 32 |

TABLE F.8 Input data for pavement damage breakdown calculation.

For each set of weighting factors, nine damage breakdown calculations were performed, these being for three levels of loading 1, 10, and 20 million 18-kip ESAL's and three time periods in service 5, 10, and 20 years. Typical results from this analysis are shown below in the following tables.

Table F.9 illustrates the damage breakdown calculation for a 5 year old pavement which has carried 1 and 10 million 18 kip ESAL's using the Kansas weighting factors.

Table F.10 illustrates the damage breakdown calculation for a 10 year old pavement which has carried 1 and 10 million 18 kip ESAL's using the
Texas weighting factors.

Table F.11 illustrates the damage breakdown calculation for a 20 year old pavement which has carried 1 and 10 million 18 kip ESAL's using the Washington weighting factors.

Typical results from the analysis are summarized in Table F.12.
<table>
<thead>
<tr>
<th>DISTRESS</th>
<th>LOAD LEVEL</th>
<th>LOAD</th>
<th>AGE</th>
<th>DISTRESS NAME</th>
<th>DISTRESS UNITS</th>
<th>LEVEL</th>
<th>LOAD</th>
<th>CLIMATE</th>
<th>COMBINED</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAVEMENT TYPE</td>
<td>NO</td>
<td>DISTRESS NAME</td>
<td>DISTRESS UNITS</td>
<td>LEVEL</td>
<td>LOAD</td>
<td>CLIMATE</td>
<td>COMBINED</td>
<td>TOTAL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table F.9** Calculation of Rigid Pavement Damage Breakdown Illinois Models – Kansas weighting factors.
(Pavement Input data in Table F.8)
TABLE F.10 Calculation of Rigid Pavement Damage Breakdown  
Illinois Models - Texas weighting factors  
(Pavement Input data in Table F.8)
<table>
<thead>
<tr>
<th>PAVEMENT TYPE</th>
<th>NO</th>
<th>DISTRESS NAME</th>
<th>DISTRESS UNITS</th>
<th>LEVEL</th>
<th>LOAD</th>
<th>CLIMATE</th>
<th>COMBINED</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILLINOIS RIGID</td>
<td>1</td>
<td>TRNS JOINT FAULT</td>
<td>AV T JNT FLT, IN</td>
<td>0.164</td>
<td>7.055</td>
<td>7.055</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILLINOIS RIGID</td>
<td>2</td>
<td>PUMPING</td>
<td>PUMPING SEVERITY</td>
<td>0.311</td>
<td>1.398</td>
<td>8.453</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILLINOIS RIGID</td>
<td>3</td>
<td>PSI</td>
<td>PRESENT SER IND</td>
<td>3.8859</td>
<td>19.395</td>
<td>27.848</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILLINOIS RIGID</td>
<td>4</td>
<td>JOINT DETERATION</td>
<td>PCT DETERED JNTS</td>
<td>0.4742</td>
<td>0.237</td>
<td>32.726</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILLINOIS RIGID</td>
<td>5</td>
<td>D CRACKING</td>
<td>D CRACKING INDEX</td>
<td>9.2821</td>
<td>4.641</td>
<td>32.726</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILLINOIS RIGID</td>
<td>6</td>
<td>SWELLS + DEPRESS</td>
<td>TOT NO SW+DEP/MI</td>
<td>3.0383</td>
<td>0.000</td>
<td>32.726</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILLINOIS RIGID</td>
<td>7</td>
<td>TRNS CRACK DETER</td>
<td>MD/Hi SEV, NO.MI</td>
<td>10.3786</td>
<td>2.595</td>
<td>35.321</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TOTALS = 7.292 7.236 20.794 35.321

<table>
<thead>
<tr>
<th>PAVEMENT TYPE</th>
<th>LEVEL</th>
<th>18-K EQUIV</th>
<th>LOAD RATIO</th>
<th>CLIMATE RATIO</th>
<th>COMB. RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILLINOIS RIGID</td>
<td>1</td>
<td>1000000.0</td>
<td>0.206</td>
<td>0.205</td>
<td>0.589</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PAVEMENT TYPE</th>
<th>NO</th>
<th>DISTRESS NAME</th>
<th>DISTRESS UNITS</th>
<th>LEVEL</th>
<th>LOAD</th>
<th>CLIMATE</th>
<th>COMBINED</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILLINOIS RIGID</td>
<td>1</td>
<td>TRNS JOINT FAULT</td>
<td>AV T JNT FLT, IN</td>
<td>0.2078</td>
<td>12.336</td>
<td>12.336</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILLINOIS RIGID</td>
<td>2</td>
<td>PUMPING</td>
<td>PUMPING SEVERITY</td>
<td>0.1951</td>
<td>8.778</td>
<td>21.114</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILLINOIS RIGID</td>
<td>3</td>
<td>PSI</td>
<td>PRESENT SER IND</td>
<td>2.4739</td>
<td>67.896</td>
<td>88.211</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILLINOIS RIGID</td>
<td>4</td>
<td>JOINT DETERATION</td>
<td>PCT DETERED JNTS</td>
<td>2.4454</td>
<td>1.223</td>
<td>89.434</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILLINOIS RIGID</td>
<td>5</td>
<td>D CRACKING</td>
<td>D CRACKING INDEX</td>
<td>62.9652</td>
<td>31.453</td>
<td>120.886</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILLINOIS RIGID</td>
<td>6</td>
<td>SWELLS + DEPRESS</td>
<td>TOT NO SW+DEP/MI</td>
<td>3.3520</td>
<td>0.000</td>
<td>120.886</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILLINOIS RIGID</td>
<td>7</td>
<td>TRNS CRACK DETER</td>
<td>MD/Hi SEV, NO.MI</td>
<td>103.786</td>
<td>25.946</td>
<td>146.833</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TOTALS = 13.559 57.399 75.874 146.833

<table>
<thead>
<tr>
<th>PAVEMENT TYPE</th>
<th>LEVEL</th>
<th>18-K EQUIV</th>
<th>LOAD RATIO</th>
<th>CLIMATE RATIO</th>
<th>COMB. RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILLINOIS RIGID</td>
<td>2</td>
<td>1000000.0</td>
<td>0.092</td>
<td>0.391</td>
<td>0.517</td>
</tr>
</tbody>
</table>

**TABLE F.11 Calculation of Rigid Pavement Damage Breakdown Illinois Models - Washington weighting factors**
(Pavement Input data in Table F.8)
Typical results from the analysis are summarized below in Table F.12.

<table>
<thead>
<tr>
<th>Weighting Factors For</th>
<th>Damage Breakdown (%)</th>
<th>Accumulative $N_{18} = 1 \times 10^6$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Load</td>
<td>Climate</td>
</tr>
<tr>
<td>Kansas</td>
<td>25</td>
<td>63</td>
</tr>
<tr>
<td>Texas</td>
<td>51</td>
<td>11</td>
</tr>
<tr>
<td>Washington</td>
<td>36</td>
<td>14</td>
</tr>
<tr>
<td>Mean</td>
<td>37.3</td>
<td>29.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weighting Factors For</th>
<th>Damage Breakdown (%)</th>
<th>Accumulative $N_{18} = 10 \times 10^6$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Load</td>
<td>Climate</td>
</tr>
<tr>
<td>Kansas</td>
<td>19</td>
<td>68</td>
</tr>
<tr>
<td>Texas</td>
<td>23</td>
<td>31</td>
</tr>
<tr>
<td>Washington</td>
<td>14</td>
<td>34</td>
</tr>
<tr>
<td>Mean</td>
<td>18.7</td>
<td>44.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weighting Factors For</th>
<th>Damage Breakdown (%)</th>
<th>Accumulative $N_{18} = 20 \times 10^6$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Load</td>
<td>Climate</td>
</tr>
<tr>
<td>Kansas</td>
<td>12</td>
<td>75</td>
</tr>
<tr>
<td>Texas</td>
<td>13</td>
<td>44</td>
</tr>
<tr>
<td>Washington</td>
<td>7</td>
<td>46</td>
</tr>
<tr>
<td>Mean</td>
<td>10.7</td>
<td>55.0</td>
</tr>
</tbody>
</table>

TABLE F.12 Summarized Pavement Damage Breakdown Results Calculated from Illinois Rigid Pavement Models.
F.5 Calculation of Rigid pavement damage breakdown in each environmental zone

The method of calculating the pavement damage breakdown for rigid pavements has previously been described in Section F.4. In order to calculate this damage breakdown for the different climatic zones within the United States it is necessary to

a) locate States with adequate JRCP rating schemes;

b) for major cities* within each of these states, obtain the required climatic data; and

c) run the Illinois models with each states climatic data and weighting factors to predict pavement performance and the damage breakdown.

As shown in Table F.5, only 4 States have adequate rigid pavement rating systems, these being Kansas, Washington, Texas, and Virginia. The climatic data required as input for the Illinois models is as follows.

PERCIPITATION - The total average annual percipitation at the pavement site (cm).

TEMPDIF - The difference between the highest average monthly temperature and the lowest average monthly temperature (°C).

FTCYCLE - Average annual freeze thaw cycles in the slab.

IMOIST - the Thornthwaite Moisture index.

These data, except for the freeze-thaw cycles, are readily obtained by reference to the National Climatic Center's Local Climatological Data summary sheets.

*The highest density of rigid pavements within a state is commonly found near the major cities.
For the purpose of this analysis, climatic data was obtained for the following localities.

- Topeka - Kansas City (State of Kansas)
- Olympia - Seattle (State of Washington)
- Houston (State of Texas)
- Richmond (State of Virginia)

The required climatic data for each of these localities is shown below in Table F.13

<table>
<thead>
<tr>
<th>Locality</th>
<th>Percipitation (cm)</th>
<th>TEMPDIF* (°C)</th>
<th>FTCYCLES*</th>
<th>THORNTHWAITE INDEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topeka-Kansas City</td>
<td>88.0</td>
<td>15.6</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Olympia-Seattle</td>
<td>146.5</td>
<td>14.6</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Houston</td>
<td>122.4</td>
<td>18.6</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Richmond</td>
<td>108.1</td>
<td>20.7</td>
<td>10</td>
<td>40</td>
</tr>
</tbody>
</table>

*Average of data from 1940 to 1979.
*The range of this variable in Illinois is reported to be 5-15 cycles per year. As Kansas, Washington, Virginia, and Illinois have been classified in the Freeze-Thaw Cycling Regions (Regions 2 and 5) it is reasonable to assume that FTCYCLES will have a similar range in each state.

TABLE F.13 Climatic data used as input to Illinois J.R.C.P. models

Each States climatic data and distress weighting factors were inputted into the Illinois Models along with the following pavement design data.

- pavement type - Jointed Reinforced Concrete Pavement (slab length 70 ft.)
- slab thickness - 10 inches
- dowel diameter - 1.5 inches
- area of steel - 0.135 in²/ft.
Aggregate in slab - Crushed Stone

Base type - Granular, unstabilized

Underdrains - Yes

Joint Seals - Good condition (initially)

The pavement distress and damage breakdown was calculated for the following.

- years in service (5, 10, 20)
- 18-kip ESAL's carried during
  years in service (million) (1, 10, 20)

The predicted pavement damage breakdown (% of Load, Climate, and Combined damage) for each State is shown in Tables F.14, F.15, F.16, and F.17.
<table>
<thead>
<tr>
<th>Age (Years)</th>
<th>Traffic (Millions) 18 kips</th>
<th>1</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Load</td>
<td>31</td>
<td>29</td>
<td>19</td>
</tr>
<tr>
<td>5</td>
<td>Climate</td>
<td>54</td>
<td>56</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>15</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>Load</td>
<td>29</td>
<td>24</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Climate</td>
<td>56</td>
<td>61</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>15</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>20</td>
<td>Load</td>
<td>22</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Climate</td>
<td>66</td>
<td>69</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>12</td>
<td>15</td>
<td>14</td>
</tr>
</tbody>
</table>

**TABLE F.14** Predicted Rigid pavement damage breakdown for the State of Kansas

**model inputs**

- climatic data from Topeka-Kansas City Locality
- weighting factors from the State of Kansas
<table>
<thead>
<tr>
<th>Age (Years)</th>
<th>Traffic (Millions) 18 kips</th>
<th>1</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Load</td>
<td>33</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Climate</td>
<td>13</td>
<td>25</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>54</td>
<td>60</td>
<td>47</td>
</tr>
<tr>
<td>10</td>
<td>Load</td>
<td>27</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Climate</td>
<td>15</td>
<td>29</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>57</td>
<td>59</td>
<td>50</td>
</tr>
<tr>
<td>20</td>
<td>Load</td>
<td>20</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Climate</td>
<td>20</td>
<td>36</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>60</td>
<td>56</td>
<td>53</td>
</tr>
</tbody>
</table>

TABLE F.15 Predicted rigid pavement damage breakdown for the State of Washington

*model inputs*

- climatic data from Olympia-Seattle Locality
- weighting factors from the State of Washington
<table>
<thead>
<tr>
<th>Age (Years)</th>
<th>Traffic ( Millions) 18 kips</th>
<th>1</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Load</td>
<td>54</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Climate</td>
<td>8</td>
<td>23</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>38</td>
<td>45</td>
<td>32</td>
</tr>
<tr>
<td>10</td>
<td>Load</td>
<td>50</td>
<td>27</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Climate</td>
<td>8</td>
<td>24</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>42</td>
<td>49</td>
<td>36</td>
</tr>
<tr>
<td>20</td>
<td>Load</td>
<td>42</td>
<td>21</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Climate</td>
<td>9</td>
<td>26</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>49</td>
<td>53</td>
<td>41</td>
</tr>
</tbody>
</table>

TABLE F.16 Predicted rigid pavement damage breakdown for the State of Texas

model inputs
- climatic data from the Houston locality
- weighting factors from the State of Texas
<table>
<thead>
<tr>
<th>Age (Years)</th>
<th></th>
<th>Traffic (Millions) 18 kips</th>
<th>1</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Load</td>
<td>64</td>
<td>34</td>
<td>19</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Climate</td>
<td>8</td>
<td>17</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combined</td>
<td>28</td>
<td>49</td>
<td>49</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Load</td>
<td>66</td>
<td>34</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Climate</td>
<td>11</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combined</td>
<td>23</td>
<td>41</td>
<td>44</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>Load</td>
<td>64</td>
<td>32</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Climate</td>
<td>19</td>
<td>38</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combined</td>
<td>17</td>
<td>30</td>
<td>38</td>
</tr>
</tbody>
</table>

TABLE F.17 Predicted rigid pavement damage breakdown for the State of Virginia

*model inputs*

- climatic data from Richmond locality
- weighting factors from the State of Virginia
- damage breakdown for each environmental zone

As described in the main body of this report, the United States has been broken up into the following 6 environmental zones.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wet/No Freeze</td>
</tr>
<tr>
<td>2</td>
<td>Wet/Freeze-Thaw Cycling</td>
</tr>
<tr>
<td>3</td>
<td>Wet/Hard Freeze</td>
</tr>
<tr>
<td>4</td>
<td>Dry/No Freeze</td>
</tr>
<tr>
<td>5</td>
<td>Dry/Freeze-Thaw Cycling</td>
</tr>
<tr>
<td>6</td>
<td>Dry/Hard Freeze</td>
</tr>
</tbody>
</table>

One of the main objectives of this report has been to predict the pavement damage breakdown in each one of the zones. This calculation for flexible pavements has been described in detail earlier. Several states have distress weighting factors for flexible pavements. Hence it has been possible to combine each States environmental data and individual weighting scheme to calculate the pavement damage breakdown.

However, for jointed reinforced concrete pavements, only 4 States have adequate distress weighting factors, these are shown in Table F.5. Therefore, in an attempt to calculate the damage breakdown for rigid pavements the following approach has been taken;

a) From the 4 sets of weighting factors in Table F.5, calculate an average weighting factor for each distress type.

b) Using the average weighting factor in each zone with the zones typical climatic data, calculate that zone's pavement damage breakdown.

By averaging the percent weighting factors for each of the 4 States, the following weighting factors were obtained.

F-60
TABLE F.18. Calculated Average Weighting Factors

<table>
<thead>
<tr>
<th>Distress</th>
<th>Average Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Joint Faulting</td>
<td>12.6</td>
</tr>
<tr>
<td>Pumping</td>
<td>16.5</td>
</tr>
<tr>
<td>PSI</td>
<td>15.0</td>
</tr>
<tr>
<td>Joint Deterioration</td>
<td>21.7</td>
</tr>
<tr>
<td>D-cracking</td>
<td>15.1</td>
</tr>
<tr>
<td>Swells and Depressions</td>
<td>7.1</td>
</tr>
<tr>
<td>Transverse Cracking</td>
<td>12.0</td>
</tr>
</tbody>
</table>

The next step is to establish typical climatic data for localities within each of the six zones. For the purpose of this analysis, the following were chosen.

TABLE F.19. Climatic Data used as input to Illinois J.R.C.P. models

<table>
<thead>
<tr>
<th>Zone</th>
<th>Locality</th>
<th>Percipitation (cm)</th>
<th>TEMPDIF °C</th>
<th>FTCYCLES</th>
<th>Thornthwaite Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Baton Rouge (Louisiana)</td>
<td>137.2</td>
<td>21.1</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>Knoxville (Tennessee)</td>
<td>117.3</td>
<td>21.4</td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>Duluth (Minnesota)</td>
<td>76.6</td>
<td>31.6</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>Brownsville (Texas)</td>
<td>63.7</td>
<td>13.2</td>
<td>0</td>
<td>-20</td>
</tr>
<tr>
<td>5</td>
<td>Albuquerque (New Mexico)</td>
<td>19.7</td>
<td>22.7</td>
<td>10</td>
<td>-40</td>
</tr>
<tr>
<td>6</td>
<td>Bismarck (North Dakota)</td>
<td>42.2</td>
<td>34.8</td>
<td>20</td>
<td>-20</td>
</tr>
</tbody>
</table>
The Illinois models were then run with a) each States individual climatic data, b) the average distress weighting factors, and c) the pavement design data identical to that described earlier in this section. The time period was fixed at 20 years and the number of 18-kip ESAL carried was fixed at 20 million. The results of this analysis are shown below in Table F.20.

<table>
<thead>
<tr>
<th>Zone</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>10</td>
<td>10</td>
<td>13</td>
<td>13</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Climate</td>
<td>56</td>
<td>53</td>
<td>55</td>
<td>59</td>
<td>58</td>
<td>57</td>
</tr>
<tr>
<td>Combined</td>
<td>34</td>
<td>37</td>
<td>31</td>
<td>28</td>
<td>27</td>
<td>27</td>
</tr>
</tbody>
</table>

TABLE F.20. Predicted pavement damage breakdown using average distress weighting factors.
APPENDIX G

COMPUTER PROGRAM TO COMPUTE RIGID

PAVEMENT DAMAGE RATIOS
1. // ILLRIGID JOB (W207, 55-B, S2, 2, CM), C H

2. // *MAIN USER=W207\CM
3. // *TAMU HOLDOUT
4. // *PASSWORD ******************************************************
5. // *XBM WATFIV
6. C
7. C
8. C PAVEMENT DAMAGE BREAKDOWN PROGRAM
9. C RIGID PAVEMENT -- ILLINOIS JRCP MODELS
10. C
11. C AUTHOR: C. H. MICHALAK AND T. SCULLION
12. C
13. C TEXAS TRANSPORTATION INSTITUTE
14. C
15. C TEXAS A & M UNIVERSITY
16. C
17. C COLLEGE STATION, TEXAS 77843
18. C
19. C PHONE: (713) 845 7126/845 3735
20. C
21. C ******************************************************
22. C
23. IMPLICIT REAL*8 (A-H, 0-Z)
24. INTEGER FTC, DX, DRAIN, TMI, CRUSH, STAB
25. C
26. DIMENSION DISTRS(10,2), DESCR(10,2), READ(10), PNAME(10,2)
27. DIMENSION ESAL(5), SLK(5), DD(10), AG(5)
28. C
29. COMMON AGE, AS, DIA, PR, SLEN, STK, TDIF, CRUSH, DRAIN, DX,
30. + FTC, INCOMP, JTSEAL, STAB, TMI
31. C
32. COMMON /DUC/ DLO(10), DHI(10), RLO(10), RHI(10)
33. C
34. NTR = 3
35. NAG = 3
36. C
37. READ(5,106) (PNAME(1,J), J = 1, 2)
38. READ(5,106) ((DISTRS(I,J), J = 1, 2), I = 1, 10)
39. 106 FORMAT (5(2A8))
40. 12 READ(5,106) ((DESCR(I,J), J = 1, 2), I = 1, 10)
41. C
42. READ(5,107) PI, AS, DIA, PR, SLEN, TDIF
43. 107 FORMAT (8F10.2)
44. READ(5,103) CRUSH, DRAIN, DX, FTC, INCOMP, JTSEAL, STAB, TMI
45. 103 FORMAT (16I5)
46. C
47. READ(5,107) (AG(I), I = 1, NAG)
48. READ(5,107) (ESAL(I), I = 1, 5)
19 READ(5,107) (SLTK(I), I = 1, 5)
20 109 FORMAT( 14F5.0 )
21 C
22 10 CONTINUE
23 C
24 READ(5,108,END=50) (HEA(I), I = , 10)
25 108 FORMAT( 10A8 )
26 C
27 READ(5,109) (DLO(I), DHI(I), I = 1, 7)
28 C
29 READ(5,109) (RLO(I), RHI(I), I = 1, 7)
30 C
31 WRITE(6,202) (HEA(I), I = 1, 10)
32 202 FORMAT(' ', T6, 10A8 )
33 C
34 WRITE(6,208)
35 208 FORMAT( / 5X, 'INPUT DATA' )
36 C
37 WRITE(6,201) PTI, DIA, AS, PR, SLEN, TDIF, (AG(I), I=1,NAG),
38 + SLTK(I), (ESAL(I), I = 1, NTR )
39 C
40 201 FORMAT( /5X, 'INITIAL SURV. INDEX', T35, '= ', F9.2/ 5X,
41 ' DOWEL DIAMETER, IN.', T35, '= ', F9.3/ 5X, ' AREA STEEL REINFORCE-
43 5X, 'SLAB LENGTH, FT', T35, '= ', F9.1/ 5X, ' TEMP. DIFFERENCE, CEN
44 4', T35, '= ', F9.1/ 5X, ' TIME SINCE CONST, YRS', T35, '= ',3F9.1/5X,
45 5 'SLAB THICKNESS, IN.', T35, '= ', F9.1/5X, 'EQ SNGL 18-KIP AXLE LD
46 6', T35, '= ', F9.0, 2F10.0 / )
47 C
48 WRITE(6,203) CRUSH, DRAIN, DX, FTC, INCOMPR, JTSEAL, STAB, THI
49 C
50 203 FORMAT( /5X,'CR STONE, 1 GRAVEL, ø', T35, '= ', I9/ 5X, ' UNDERDRN, Y
51 1ES, 1 NO, ø', T35, '= ', I9 /5X, ' D CRACK, YES, 1 NO, ø', T35,
52 2 ' = ', I9 /5X, ' AVG FREEZE/THAW CYCLES', T35, '= ', I9 / 5X, ' INCHP
53 JIN JNT Y, 1 N, ø', T35, '= ', I9 / 5X, ' JT SEAL HI SV, 1 LD, ø',
54 5 T35, '= ', I9 / 5X, ' STAB SBB, 1 GRAN SBB, ø', T35, '= ', I9 / 5X,
55 6 'THORNTHWAITE MOIST IND', T35, '= ', I9 / )
56 C
57 WRITE(6,206)
58 206 FORMAT( 'Deduct Points' // 5X, 'Range Predicted Deduct Poi
59 INT RANGE' // 5X, 'LOW HIGH LOW HIGH' )
60 C
61 WRITE(6,207) (RLD(I), RHI(I), DLO(I), DHI(I),I=1,7)
62 C
63 STK = SLTK(1)
64 C
65 DO 31 L = 1, NAG
66 31 L = AG(L)
67 C
68 WRITE(6,202) (HEA(I), I = 1, 10)
69 C
70 DO 30 I = 1, NTR
71 30 K = 0
72 C
73 SUML = 0.0
SMCL = 0.0
SUNC = 0.0
SUM = 0.0
W = ESAL(I)/100000.

C
WRITE(6,214)
WRITE(6,205) I, ESAL(I), AGE
205 FORMAT( T40, 'LOAD LEVEL', I4, 5X, 'LOAD = ',', F16.4, 5X,
) 'AGE = ',', F10.1// T23
= , 'DISTRESS', T76, 'PRED. ', I0('**'), 'DEDUCT POINTS ',
+ I0('**') / T6, 'PAVEMENT TYPE
+ 'NO DISTRESS NAME DISTRESS UNITS LEVEL',
* 'LOAD CLIMATE COMBINED TOTAL'

C DISTRESS SUBROUTINES

CALL TFAULT( W, AR )
K = K + 1
CALL DEDUCT ( K, AR, DD )
SUM = SUM + DD(1)
SUML = SUML + DD(1)
WRITE(6,215) (PNAME(I,J), J = 1, 2), K, (DISTRS(K,J), J = 1, 2),
+ (DESCR(K,J), J = 1, 2), AR, DD(1), SUM
215 FORMAT( 5X, 2A8, 16, 5X, 2A8, 2X, 2A8, F14.4, F11.3, 18X, F9.3 )

14 CONTINUE

CALL PUMP( W, AR )
K = K + 1
CALL DEDUCT ( K, AR, DD )
SUM = SUM + DD(2)
SUMC = SUMC + DD(2)
WRITE(6,214) (PNAME(I,J), J = 1, 2), K, (DISTRS(K,J), J = 1, 2),
+ (DESCR(K,J), J = 1, 2), AR, DD(2), SUM
214 FORMAT( 5X, 2A8, 16, 5X, 2A8, 2X, 2A8, F14.4, 20X, 2F9.3)

CALL PSI( W, AR )
K = K + 1
CALL DEDUCT ( K, AR, DD )
SUM = SUM + DD(3)
SUMC = SUMC + DD(3)
WRITE(6,214) (PNAME(I,J), J = 1, 2), K, (DISTRS(K,J), J = 1, 2),
+ (DESCR(K,J), J = 1, 2), AR, DD(3), SUM

CALL JNETER( W, AR )
K = K + 1
CALL DEDUCT ( K, AR, DD )
SUM = SUM + DD(4)
SUML = SUML + DD(4)
WRITE(6,215) (PNAME(I,J), J = 1, 2), K, (DISTRS(K,J), J = 1, 2),
+ (DESCR(K,J), J = 1, 2), AR, DD(4), SUM
154. C
155. 80 CALL DCRACK( W, AR )
156. 81 K = K + 1
157. 82 CALL DEDUCT ( K, AR, DD )
158. 83 SUM = SUM + DD(5)
159. 84 SMCL = SMCL + DD(5)
160. 85 WRITE(6,216) (PNAME(1,J), J = 1, 2), K, (DISTR(K,J), J = 1, 2),
161. + (DESCR(K,J), J = 1, 2), AR, DD(6), SUM
162. C
163. 86 CALL SELLW( W, AR )
164. 87 K = K + 1
165. 88 CALL DEDUCT ( K, AR, DD )
166. 89 SUM = SUM + DD(6)
167. 90 SMCL = SMCL + DD(6)
168. 91 WRITE(6,216) (PNAME(1,J), J = 1, 2), K, (DISTR(K,J), J = 1, 2),
169. + (DESCR(K,J), J = 1, 2), AR, DD(6), SUM
170. C
171. 92 216 FORMAT( 5X, 2AK, I6, 5X, 2AK, 2X, 2AK, F14.4,11X,F9.3,F9.3)
172. C
173. 93 CALL CDDETR( W, AR )
174. 94 K = K + 1
175. 95 CALL DEDUCT ( K, AR, DD )
176. 96 SUM = SUM + DD(7)
177. 97 SMCL = SMCL + DD(7)
178. 98 WRITE(6,216) (PNAME(1,J), J = 1, 2), K, (DISTR(K,J), J = 1, 2),
179. + (DESCR(K,J), J = 1, 2), AR, DD(7), SUM
180. C
181. 99 WRITE(6,222) SUML, SMCL, SUMC, SUM
182. I 100 222 FORMAT( / T74, 'TOTALS = ', 4F9.3 / )
183. C
184. 101 RATIO1 = SUML/SUM
185. 102 RATIO2 = SMCL/SUM
186. 103 RATIO3 = SUMC/SUM
187. C
188. 104 WRITE(6,218)
189. 105 218 FORMAT( 'T23, 'LOAD NO. DF' / T6, 'PAVEMENT TYPE',
190. + T23, 'LEVEL 18-K EQUIV LOAD RATIO CLIMATE RATIO COMB. RATIO')
191. C
192. 106 WRITE(6,220) (PNAME(1,J), J = 1, 2), I, ESAL(I), RATIO1,
193. = RATIO2, RATIO3
194. 107 220 FORMAT( 5X, 2AK, I4, F14.1, 3F14.3 / )
195. I 108 30 CONTINUE
196. 109 31 CONTINUE
197. C
198. 110 GO TO 10
199. C
200. 111 50 WRITE(6,250)
201. C
202. 112 250 FORMAT( '1' )
203. 113 STOP
204. 114 END
205. C
206. 115 SUBROUTINE TFALST ( W, F )
207. }

G-5
IMPLICIT REAL*8 (A-H, O-Z)

INTEGER FTC, DX, DRAIN, TMI, CRUSH, STAB
COMMON AGE, AS, DIA, PR, SLEN, STK, TDIF, CRUSH, DRAIN, DX,
+ FTC, INCOMP, JTSEAL, STAB, TMI

FLN = 2.342 * (DLOG(W * AGE + 1.0)/(DIA * STK)) - 0.1116 *
= (DLOG(W * AGE + 1.0)) + 0.0168

F = DEXP(FLN) - 1.0

IF (F .LE. 0.0) F = 0.0
IF (F .GE. 0.7) F = 0.7
RETURN
END

SUBROUTINE PUMP (W, P)
IMPLICIT REAL*8 (A-H, O-Z)
INTEGER FTC, DX, DRAIN, TMI, CRUSH, STAB
COMMON AGE, AS, DIA, PR, SLEN, STK, TDIF, CRUSH, DRAIN, DX,
+ FTC, INCOMP, JTSEAL, STAB, TMI
FLN = W * (0.0105 * JTSEAL + 0.0136/(DRAIN + 1) +
+ 0.0003 * TMI) + 0.0142
P = DEXP(FLN) - 1.0

IF (P .LE. 0.0) P = 0.0
IF (P .GE. 1.0) P = 1.0
RETURN
END

SUBROUTINE PSI (W, PN)
IMPLICIT REAL*8 (A-H, O-Z)
INTEGER FTC, DX, DRAIN, TMI, CRUSH, STAB
COMMON AGE, AS, DIA, PR, SLEN, STK, TDIF, CRUSH, DRAIN, DX,
+ FTC, INCOMP, JTSEAL, STAB, TMI
PN = 4.46 + AGE * DLOG(W + 1.0) * (-0.7325 + 0.23969 *
+ STK * AS + 0.02563 * STAB - 0.0002392 * SLEN)

IF (PN .LE. 1.5) PN = 1.5
IF (PN .GE. 4.5) PN = 4.5
RETURN
END

SUBROUTINE JDeterminant (W, DET)
IMPLICIT REAL*8 (A-H, O-Z)
INTEGER FTC, DX, DRAIN, TMI, CRUSH, STAB
COMMON AGE, AS, DIA, PR, SLEN, STK, TDIF, CRUSH, DRAIN, DX,
+ FTC, INCOMP, JTSEAL, STAB, TMI
DILN = DLOG(W + 1.0) * AGE * (0.0016 * FTC + (0.000013 *
+ TDIF * PR * DX)/(DRAIN + 1) + (0.0019 * INCOMP * FTC * JTSEAL)
+ / (DX + 1) + 0.0139) + 0.0429
DET = DEXP(DILN) - 1.0

IF (DET .LE. 0.0) DET = 0.0

G-6
IF ( DEI .GE. 100.0 ) DEI = 100.0
RETURN
END

SUBROUTINE DCRACK ( W, DC )
IMPLICIT REAL*8 (A-H, O-Z)
INTEGER FTC, DX, DRAIN, THI, CRUSH, STAB
COMMON AGE, AS, DIA, PR, SLEN, STK, Tdif, CRUSH, DRAIN, DX,

+ FTC, INCOMP, JTSEAL, STAB, THI

D1LN = 0.0734 + 0.203 * W + 0.0077 * (AGE * FTC) + 0.514*CRUSH
DC = DEXP( D1LN ) - 1.0
RETURN
END

SUBROUTINE SWELL ( W, WV )
IMPLICIT REAL*8 (A-H, O-Z)
INTEGER FTC, DX, DRAIN, THI, CRUSH, STAB
COMMON AGE, AS, DIA, PR, SLEN, STK, TDIF, CRUSH, DRAIN, DX,

+ FTC, INCOMP, JTSEAL, STAB, THI

WV = 0.145 * AGE + 0.062 * THI + 0.0298 * W - 1.83
IF ( WV .LT. 0.0 ) WV = 0.0
RETURN
END

SUBROUTINE CDETER ( W, TC )
IMPLICIT REAL*8 (A-H, O-Z)
INTEGER FTC, DX, DRAIN, THI, CRUSH, STAB
COMMON AGE, AS, DIA, PR, SLEN, STK, TDIF, CRUSH, DRAIN, DX,

+ FTC, INCOMP, JTSEAL, STAB, THI

TC = AGE * W * (-1.5 + 1.113/(STK * AS)) + (4.584/SLEN) +
1.129/(STAB + 1))
RETURN
END

IF ( TC .LE. 0.0 ) TC = 0.0
IF ( TC .GE. 200.0 ) TC = 200.0
RETURN
END

SUBROUTINE DEDUCT ( K, AR, DD )
IMPLICIT REAL*8 (A-H, O-Z)
COMMON / DUC / DLO(10), DHI(10), RLO(10), RHI(10)
DIMENSION DD(10)

\[ DD(K) = DLO(K) + (RLO(K) - AR)/(RLO(K) - RHI(K)) \times \\
& (DHI(K) - DLO(K)) \]

RETURN
END
Appendix H

TEXAS PERFORMANCE AND DISTRESS EQUATIONS
TEXAS PERFORMANCE AND DISTRESS EQUATIONS

This appendix lists all of the Texas flexible pavement equations that were used in the determination of damage ratios. There were five types of flexible pavements for which equations were available: (1) hot mix asphaltic concrete on flexible base course; (2) hot mix asphaltic concrete on bituminous stabilized base course; (3) double bituminous surface treated pavements; (4) flexible pavements overlaid with hot mix asphaltic concrete; and (5) thick hot mix asphaltic concrete pavements.

The equations representing the performance and distress of these pavements were S-shaped as described by the forms of equation given below.

SERVICEABILITY INDEX EQUATIONS

The S-shaped equations for Present Serviceability Index were of the form:

\[
\frac{P_i - P}{P_i - P_f} = e^{-K/W},
\]

where \( P_i \) = the initial serviceability index,

\( P_f \) = the asymptote serviceability index,

\( P \) = the present serviceability index,

\( K \) = the deterioration rate constant, and

\( W \) = cumulative number of 18-kip equivalent single axle loads.

The equations used for each type of pavement are given below. Thereafter is a listing of variables used in the equations.
TYPE OF PAVEMENT

Hot Mix Pavement

\[ K = -89.1 - 0.0037 \cdot 39 \cdot (T)^{2.83} \cdot (TTC)^{2.10} \cdot (SCI)^{0.85} \]

\[ PF = 3.66 + 1236 \cdot (SLL)^{-0.08} \cdot (TM)^{3} \cdot (FTC)^{12} \cdot (WFTC)^{-0.21} \cdot (TI)^{-0.22} \cdot (AS)^{0.25} \cdot (ALF)^{-3.13} \]

Initial Serviceability = 4.70

Hot Mix on Black Base

\[ K = 92.8 - 0.27 \cdot 10^{-12} \cdot (SLL)^{1.64} \cdot (DMD)^{-0.46} \cdot (ALF)^{7.97} \cdot (AS)^{-1.43} \cdot (PR)^{-3.38} \cdot (W)^{-0.25} \cdot (T)^{1.03} \]

\[ PF = 3.67 + 117.4 \cdot (SLL)^{-0.08} \cdot (SCI)^{-0.034} \cdot (ALF)^{-0.167} \cdot (WFTC)^{-0.08} \cdot (AS)^{0.48} \cdot (T)^{-0.059} \]

Initial Serviceability = 4.73
Surface Treated Pavement

\[ K = 91.5 - 0.684 \left[ (DMO)^{.23} (TI + 50)^{.38} (WFC)^{-.18} \right. \\
\left. (W)^{-.15} (T)^{1.45} \right] \]

\[ PF = 2.433 + 14.17 \left[ (SPI)^{0.018} (ALF)^{-0.55} (FTC)^{-0.24} \right. \\
\left. (TTC)^{-0.17} (T)^{-0.085} (W)^{0.03} \right] \]

Initial Serviceability = 4.41

---

Overlay

\[ K = -81.8 - 5.052XK \]

\[ PF = 4.109 - .036XK \]

\[ XK = (SCI)^{-0.32} (DMD)^{1.4} (TI + 50)^{0.89} (T)^{0.25} (TTC)^{-1.74} \]

Initial Serviceability = 4.81
Thick Hot Mix

\[ K = 0.074 - 231.6 \left[ (T)^{1.76} \ (SPP)^{3} \ (W)^{-0.47} \right] \]

\[ PF = 0.008 + 7.613 \left[ (SCL)^{-0.15} \ (T)^{-0.021} \ (PR)^{-0.137} \right] \]

Initial Serviceability = 4.60
IDENTIFICATION OF VARIABLES

The variables in the equations are identified as follows.

Traffic Variables
Average daily traffic (ADT)
Cumulative 18-kip equivalent single axle loads (W)

Climatic Variables
Harmonic mean temperature above 32°F (ALF)
Annual average freeze-thaw cycles (FTC)
Mean monthly temperature (TM)
Annual average rainfall (PR)
Thornthwaite index (TI)

Pavement Stiffness Variables
Dynaflect maximum deflection (DMD)
Surface curvature index (SCI)
Volume of Dynaflect basin (VOL)

Pavement Subgrade Properties
Subgrade liquid limit (SLL)
Subgrade plasticity index (SPI)
Percent passing #200 Sieve (SPP)
Texas Traxial Class (TTC)

Surface Course Material Property
Asphalt stiffness coefficient (AS)
Age

Time in years since last major rehabilitation or reconstruction (T)

The same variables are used in the equations for distress.
PAVEMENT DISTRESS EQUATIONS

The S-shaped equations for various types of distress were somewhat different for area and severity of distress. The area equation is simpler:

\[ a = e^{-a_0/N}, \]

where \( a \) = the percent of the total surface area that is covered by a particular type of distress, expressed in decimal form,

\( a_0 \) = a deterioration rate constant, and

\( N \) = the "primary cause" of distress which will be identified later.

The equation for distress severity is:

\[ s = s_f e^{-a_1-a_2/N}, \]

where \( s \) = the level of severity,

\( s_f \) = the asymptote which the severity approaches,

\( a_1 \) = a constant which indicates a base level of distress severity which is not dependent upon the level of 18-kip equivalent single axle loads,

\( a_2 \) = a deterioration rate constant, and

\( N \) = the "primary cause" of distress.

The severity of distress is expressed as a number between 0 and 1. The numerical scales used to represent area and severity of distress is given in the following Tables (Tables H-1 and H-2).
TABLE H-1. NUMERICAL SCALE FOR AREA OF DISTRESS

<table>
<thead>
<tr>
<th>Range of Total Area, %</th>
<th>Numerical Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1</td>
<td>0.0005</td>
</tr>
<tr>
<td>1 - 15 (one wheel path)</td>
<td>0.08</td>
</tr>
<tr>
<td>16 - 30 (two wheel path)</td>
<td>0.23</td>
</tr>
<tr>
<td>Greater than 30</td>
<td>0.50</td>
</tr>
</tbody>
</table>
TABLE H-2. NUMERICAL SCALE FOR SEVERITY OF DISTRESS

<table>
<thead>
<tr>
<th>Severity of Distress</th>
<th>Numerical Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0.005</td>
</tr>
<tr>
<td>Slight</td>
<td>0.167</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.333</td>
</tr>
<tr>
<td>Severe</td>
<td>0.500</td>
</tr>
</tbody>
</table>
Each type of distress has its own primary cause which enters into the equations for area or severity. The "primary causes" used in the Texas flexible pavement distress equations are as follows:

<table>
<thead>
<tr>
<th>Distress</th>
<th>Primary Cause</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rutting</td>
<td>18-kip ESAL*</td>
<td>W</td>
</tr>
<tr>
<td>Raveling</td>
<td>Average daily traffic</td>
<td>ADT</td>
</tr>
<tr>
<td>Flushing</td>
<td>Average daily traffic</td>
<td>ADT</td>
</tr>
<tr>
<td>Corrugations</td>
<td>18-kip ESAL</td>
<td>W</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>18-kip ESAL</td>
<td>W</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>Age (Time)</td>
<td>T</td>
</tr>
<tr>
<td>Transverse Cracking</td>
<td>Age (Time)</td>
<td>T</td>
</tr>
<tr>
<td>Patching</td>
<td>18-kip ESAL</td>
<td>W</td>
</tr>
<tr>
<td>Failures per mile</td>
<td>18-kip ESAL</td>
<td>W</td>
</tr>
</tbody>
</table>

*ESAL is "equivalent single axle load"

The variable time, T, is used as a substitute for climatic variables which are assumed to cause an accumulation of distress with time.

The equations for severity and area of distress for each type of pavement are given below. Variables used in these equations are the same as those used with the serviceability index equations and were listed previously.
TYPE OF PAVEMENT: HOT MIX

Rutting Severity

\[ A_1 = 10^{1.98} \ (SPI)^{-0.82} \ (ALF)^{0.47} \ (DMD)^{0.54} \ (W)^{-0.31} \]

\[ A_2 = 10^{6.3} \]

\[ SF = 10^{9.42} \ (DMD)^{3.45} \ (W)^{-1.91} \ (SPI)^{-5.82} \ (ALF)^{2.80} \]

Ravelling Severity

\[ A_1 = 10^{9.21} \ (ALF)^{-2.99} \ (DMD)^{0.80} \ (VOL)^{-0.88} \ (T)^{-1.17} \]
\[ \quad \text{mun} \ (18-KIP)^{-0.33} \ (FTC)^{-0.89} \]

\[ A_2 = 10^{6.961} \]

\[ SF = 10^{2.4} \]

Flushing Severity

\[ A_1 = 10^{1.441} \]

\[ A_2 = 10^{5.34} \ (AS)^{4.89} \ (ALF)^{-5.24} \ (SPI)^{-5.70} \ (WFTC)^{-1.72} \ (SLL)^{10.98} \]

\[ SF = 10^{0.27} \]
HOT MIX (con't)

Corrugations Severity

$$A_1 = 10^{-1.77} \ (ALF)^{1.18} \ (FTC)^{0.57} \ (TTC)^{0.67} \ (TIME\_YRS)^{0.91} \ (ADT)^{-0.86} \ (18\_KIP)^{0.90}$$

$$A_2 = 0.00$$

$$SF = 10^{-5.96} \ (ALF)^{2.37} \ (FTC)^{1.03} \ (TTC)^{1.37} \ (TIME\_YRS)^{1.91} \ (ADT)^{-1.74} \ (18\_KIP)^{1.83}$$

Alligator Cracking Severity

$$A_1 = 10^{1.233}$$

$$A_2 = 10^{6.570}$$

$$SF = 10^{-1.09} \ (TIME\_YRS)^{-5.84} \ (TTC)^{17.30} \ (SPI)^{-9.82} \ (ADT)^{6.78} \ (18\_KIP)^{-9.07}$$

Longitudinal Cracking Severity

$$A_1 = 10^{1.089}$$

$$A_2 = 10^{2.501}$$

$$SF = 10^{-44.85} \ (TTC)^{14.61} \ (AS)^{-12.75} \ (TI)^{8.46} \ (FTC)^{1.71} \ (SLL)^{24.62} \ (SPI)^{-22.61}$$
HOT MIX (con't)

Transverse Cracking Severity

\[ A_1 = 10^{1.132} \]
\[ A_2 = 10^{-14.64} (AS)^{5.74} (VOL)^{1.34} (SPP)^{17.44} (FTC)^{-0.25} (TIME-YRS)^{-2.35} \]
\[ SF = 10^{-0.754} \]

Patching Severity

\[ A_1 = 10^{1.077} \]
\[ A_2 = 10^{6.165} \]
\[ SF = 10^{7.90} (ADT)^{-0.62} (SCI)^{1.0} (PR)^{2.21} (SLL)^{-8.97} (SPI)^{6.34} \]

Failures/Mile Severity

\[ A_1 = 10^{-1.37} (FTC)^{0.59} (TTC)^{2.13} (ALF)^{2.03} (ADT)^{-0.59} (SLL)^{-1.35} (18-KIP)^{0.60} \]
\[ A_2 = 0.00 \]
\[ SF = 10^{-1.281} \]
HOT MIX (cont')

Rutting Area

\[ A_0 = 10^{6.56} \]

Ravelling Area

\[ A_0 = 10^{6.96} \]

Flushing Area

\[ A_0 = 10^{4.82} \]

Corrugations Area

\[ A_0 = 0.000 \]

Alligator Cracking Area

\[ A_0 = 10^{6.81} \]
HOT MIX (con't)

Longitudinal Cracking Area

\[ A_0 = 10^{2.5} \]

Transverse Cracking Area

\[ A_0 = 10^{2.49} \]

Patching Area

\[ A_0 = 10^{6.351} \]
TYPE OF PAVEMENT: HOT MIX ON BLACK BASE

Rutting Severity

\[ A_1 = 10^{0.360} (TTC)^{-0.88} (VOL)^{0.36} (WFTC)^{0.23} (ADT)^{0.38} (18-KIP)^{-0.45} \]

\[ A_2 = 10^{-7.35} (VOL)^{-1.34} (WFTC)^{1.81} (TTC)^{7.11} (ADT)^{-0.58} (ALF)^{11.23} (PR)^{-8.22} \]

\[ SF = 10^{-1.13} (VOL)^{2.44} (WFTC)^{0.90} (TTC)^{-5.25} (18-KIP)^{-2.32} (ADT)^{1.84} \]

Ravelling Severity

\[ A_1 = 10^{0.97} \]

\[ A_2 = 10^{3.74} (AS)^{3.73} (PR)^{-1.20} (SPI)^{1.93} (18-KIP)^{-1.41} (ADT)^{1.11} \]

\[ SF = 10^{1.57} \]

Flushing Severity

\[ A_1 = 10^{-9.57} (WFTC)^{0.37} (ADT)^{0.19} (SPP)^{6.17} (AS)^{4.56} (SPI)^{-1.83} (SLL)^{4.28} \]

\[ A_2 = 10^{22.02} (AS)^{-3.15} (ALF)^{-7.40} (FTC)^{-2.90} (TTC)^{-3.54} (TIME-YRS)^{2.07} (ADT)^{-0.76} \]

\[ SF = 10^{0.84} \]
HOT MIX ON BLACK BASE (con't)

Corrugations Severity

\[ A_1 = 10^{-0.04} \]
\[ A_2 = 0.0 \]
\[ SF = 10^{-2.2} \]

Alligator Cracking Severity

\[ A_1 = 10^{26.46} \cdot (SCI)^{0.24} \cdot (ALF)^{-1.17} \cdot (TTC)^{1.25} \cdot (TI)^{-15.41} \cdot (TIME-YRS)^{1.24} \]
\[ A_2 = 10^{6.88} \]
\[ SF = 10^{-1.07} \cdot (SCI)^{1.05} \cdot (ALF)^{-4.64} \cdot (SPI)^{1.97} \cdot (TIME-YRS)^{5.22} \]

Longitudinal Cracking Severity

\[ A_1 = 10^{20.68} \cdot (TI)^{-11.70} \cdot (TIME-YRS)^{0.54} \cdot (TTC)^{0.83} \cdot (SPI)^{-0.27} \cdot (18-KIP)^{-0.17} \]
\[ A_2 = 10^{1.74} \]
\[ SF = 10^{1.26} \cdot (18-KIP)^{-1.35} \cdot (SPI)^{-1.29} \cdot (TIME-YRS)^{4.49} \]
HOT MIX ON BLACK BASE (con't)

Transverse Cracking Severity

\[ \begin{align*}
A_1 &= 10^{0.473} \ (FTC)^{-0.26} \ (PR)^{-1.21} \ (18-KIP)^{-0.41} \ (SCI)^{-0.26} \\
      & \quad \times (\text{TIME-YRS})^{2.12} \\
A_2 &= 10^{-1.70} \ (\text{TIME-YRS})^{-0.70} \ (PR)^{1.57} \ (FTC)^{0.83} \ (AS)^{-4.03} \\
SF &= 10^{11.79} \ (PR)^{-6.25} \ (18-KIP)^{-1.41} \ (FTC)^{-0.269} \ (\text{TIME-YRS})^{7.20} \\
      & \quad \times (AS)^{12.76}
\end{align*} \]

Patching Severity

\[ \begin{align*}
A_1 &= 10^{0.65} \\
A_2 &= 10^{6.66} \\
SF &= 10^{-1.68}
\end{align*} \]

Failure/Mile Severity

\[ \begin{align*}
A_1 &= 10^{0.10} \\
A_2 &= 0.00 \\
SF &= 10^{-1.68}
\end{align*} \]
HOT MIX ON BLACK BASE (con't)

Rutting Area

\[ A_0 = 10^{6.97} \times (SCI)^{0.0054} \times (SPI)^{0.0033} \times (FTC)^{-0.0029} \times (18-KIP)^{-0.0098} \times (TIME-YRS)^{0.022} \times (ADT)^{-0.018} \]

Ravelling Area

\[ A_0 = 10^{5.20} \times (FTC)^{0.00076} \times (WFTC)^{-0.0011} \times (SPI)^{0.0012} \times (SPP)^{-0.010} \times (VOL)^{0.00040} \times (TIME-YRS)^{0.0017} \]

Flushing Area

\[ A_0 = 10^{4.98} \times (SPP)^{-0.013} \times (DMD)^{0.0034} \times (VOL)^{-0.0061} \times (18-KIP)^{-0.0012} \times (AS)^{-0.019} \]

Corrugations Area

\[ A_0 = 0.0 \]

Alligator Cracking Area

\[ A_0 = 10^{7.01} \]
HOT MIX ON BLACK BASE (cont)

Longitudinal Cracking Area

$A_0 = 10^{1.84}$

Transverse Cracking Area

$A_0 = 10^{2.13}$

Patching Area

$A_0 = 10^{6.78}$
TYPE OF PAVEMENT: SURFACE TREATED PAVEMENT

Rutting Severity

\[ A_1 = 10^{1.01} \]
\[ A_2 = 10^{7.32} (ADT)^{-0.15} (TIME-YRS)^{-0.25} (SPI)^{-0.97} (PR)^{0.55} (SLL)^{1.83} (TTC)^{-1.75} \]
\[ SF = 10^{1.58} \]

Ravelling Severity

\[ A_1 = 10^{-0.35} \left( VOL \right)^{-0.57} (AS)^{-2.42} (FTC)^{0.56} (PR)^{0.40} (WFTC)^{-0.39} (18-KIP)^{-0.064} \]
\[ A_2 = 10^{1.05} \left( TI \right)^{0.67} (ALF)^{0.78} (VOL)^{0.23} (18-KIP)^{-0.24} (SPI)^{-1.46} (SLL)^{2.44} \]
\[ SF = 10^{-0.01} \]

Flushing Severity

\[ A_1 = 10^{1.80} \]
\[ A_2 = 10^{5.06} (WFTC)^{-0.15} (AS)^{-1.16} (SPI)^{0.38} (ADT)^{-0.30} (DMD)^{-0.36} \]
\[ SF = 10^{3.45} (ALF)^{-9.33} (TTC)^{14.63} (AS)^{19.30} (W)^{5.22} \]
SURFACE TREATED PAVEMENT (con't)

Corrugations Severity

\[ A1 = 10^{0.98} \]
\[ A2 = 10^{6.18} \]
\[ SF = 10^{-1.91} \]

Alligator Cracking Severity

\[ A1 = 10^{1.49} \]
\[ A2 = 10^{7.43} \]
\[ SF = 10^{-0.25} \]

Longitudinal Cracking Severity

\[ A1 = 10^{-0.36} \ (SLL)^{0.33} \ (TI)^{0.39} \ (VOL)^{-0.076} \ (PR)^{-0.49} \ (TTC)^{1.28} \]
\[ A2 = 10^{-3.0} \]
\[ SF = 10^{-11.07} \ (TIME-YRS)^{2.11} \ (PR)^{-5.10} \ (ALF)^{-6.78} \ (SPI)^{7.18} \]
\[ \ (TTC)^{14.39} \]
SURFACE TREATED PAVEMENT (con't)

Transverse Cracking Severity

A1 = 10^{1.46}
A2 = 10^{2.81}
SF = 10^{-1.97}

Patching Severity

A1 = 10^{1.60}
A2 = 10^{6.86}
SF = 10^{-1.31}

Failures/Mile Severity

A1 = 10^{1.68}
A2 = 10^{0.24}
SF = 10^{-1.86}
SURFACE TREATED PAVEMENTS (cont'd)

**Rutting Area**

\[ A_0 = 10^{7.05} \]

**Ravelling Area**

\[ A_0 = 10^{4.86} \left( PR \right)^{-0.31} \times 10^{-3} \left( TI \right)^{0.52} \times 10^{-3} \]

**Flushing Area**

\[ A_0 = 10^{4.96} \left( VOL \right)^{0.24} \times 10^{-3} \left( TI \right)^{0.40} \times 10^{-3} \left( W \right)^{-0.11} \times 10^{-3} \]

**Corrugations Area**

\[ A_0 = 10^{6.23} \]

**Alligator Cracking Area**

\[ A_0 = 10^{7.47} \left( TI \right)^{-0.16} \times 10^{-3} \left( DMD \right)^{-0.17} \times 10^{-3} \]

**Longitudinal Cracking Area**

\[ A_0 = 10^{3.05} \left( AS \right)^{-0.55} \times 10^{-3} \left( PR \right)^{0.26} \times 10^{-3} \]
SURFACE TREATED PAVEMENTS (con't)

Transverse Cracking Area

\[ A_0 = 10^{2.84} \]

Patching Area

\[ A_0 = 10^{6.92} (DMD)^{0.14} \times 10^{-2} (VOL)^{-0.20} \times 10^{-2} (TI)^{-0.15} \times 10^{-2} (SPP)^{-0.17} \times 10^{-2} \]
TYPE OF PAVEMENT: OVERLAYS

Rutting Severity

\[ A_1 = 10^{-1.86} \times (TI)^{0.84} \times (PR)^{-0.69} \times (SPI)^{0.40} \times (ADT)^{0.25} \times (TIME-YRS)^{0.38} \times (18-KIP)^{-0.27} \]

\[ A_2 = 10^{7.01} \]

\[ SF = 10^{-12.95} \times (TI)^{3.55} \times (PR)^{-3.25} \times (SPI)^{1.85} \times (ADT)^{1.73} \times (18-KIP)^{-2.15} \times (TIME-YRS)^{3.27} \]

Ravelling Severity

\[ A_1 = 10^{1.20} \]

\[ A_2 = 10^{5.13} \]

\[ SF = 10^{1.25} \]

Flushing Severity

\[ A_1 = 10^{1.33} \]

\[ A_2 = 10^{5.03} \]

\[ SF = 10^{0.71} \]
OVERLAYS (con't)

Corrugations Severity

\[ A_1 = 10^{-4.95} \ (FTC)^{-0.063} \ (PR)^{-0.22} \ (SPP)^{4.58} \]
\[ A_2 = 10^{0.191} \]
\[ SF = 10^{-17.11} \ (WFTC)^{-0.69} \ (18-KIP)^{0.11} \ (ALF)^{-0.98} \ (TTC)^{-2.34} \]
\[ (SPP)^{13.73} \]

Alligator Cracking Severity

\[ A_1 = 10^{0.48} \]
\[ A_2 = 10^{6.74} \]
\[ SF = 10^{-0.73} \]

Longitudinal Cracking Severity

\[ A_1 = 10^{1.41} \]
\[ A_2 = 10^{4.21} \ (FTC)^{-0.17} \ (SCI)^{0.16} \ (TTC)^{-0.86} \ (ADT)^{0.18} \ (TI)^{-1.23} \]
\[ SF = 10^{-15.37} \ (SLL)^{-3.79} \ (ADT)^{-0.70} \ (TI)^{7.00} \ (FTC)^{1.88} \ (TTC)^{16.74} \]
\[ (TIME-YRS)^{-2.00} \]
OVERLAYS (con't)

Transverse Cracking Severity

$A_1 = 10^{1.43}$

$A_2 = 10^{2.53}$

$SF = 10^{-0.94}$

Patching Severity

$A_1 = 10^{1.17}$

$A_2 = 10^{6.78}$

$SF = 10^{-1.47}$

Failure/Mile Severity

$A_1 = 10^{1.30}$

$A_2 = 10^{0.11}$

$SF = 10^{-1.50}$
OVERLAYS (con't)

Rutting Area

\[ A_0 = 10^{7.17} \times (PR)^{0.011} \times (SPI)^{0.017} \times (SLL)^{-0.030} \]

Ravelling Area

\[ A_0 = 10^{5.246} \]

Flushing Area

\[ A_0 = 10^{5.14} \]

Corrugations Area

\[ A_0 = 10^{0.14} \]

Alligator Cracking Area

\[ A_0 = 10^{6.88} \]

Longitudinal Cracking Area

\[ A_0 = 10^{3.16} \]
OVERLAYS (con't)

Transverse Cracking Area

\[ A_0 = 10^{2.58} \]

Patching Area

\[ A_0 = 10^{6.88} \]
TYPE OF PAVEMENT: THICK HOT MIX

Rutting Severity

\[ A_1 = 10^{0.561} \]
\[ A_2 = 10^{5.619} \]
\[ SF = 10^{1.852} \]

Ravelling Severity

\[ A_1 = 10^{0.510} \]
\[ A_2 = 10^{3.430} \]
\[ SF = 10^{04.50} \]

Flushing Severity

\[ A_1 = 10^{0.736} \]
\[ A_2 = 10^{3.23} \]
\[ SF = 10^{3.048} \]

Corrugations Severity

None

H-32
THICK HOT MIX (con't)

Alligator Cracking Severity

$A_1 = 10^{0.82}$
$A_2 = 10^{5.88}$
$SF = 10^{3.52}$

Longitudinal Cracking Severity

$A_1 = 10^{0.88}$
$A_2 = 10^{1.60}$
$SF = 10^{-1.06}$

Transverse Cracking Severity

$A_1 = 10^{0.728}$
$A_2 = 10^{0.887}$
$SF = 10^{-1.294}$
THICK HOT MIX (con't)

Patching Severity

\[ A_1 = 10^{0.92} \]
\[ A_2 = 10^{5.33} \]
\[ SF = 10^{-0.89} \]

Failures/Mile Severity

\[ A_1 = 10^{0.601} \]
\[ Ad = 0.00 \]
\[ SF = 10^{-0.891} \]

Rutting Area

\[ A_0 = 10^{6.95} \]

Ravelling Area

\[ A_0 = 10^{4.58} \]
THICK HOT MIX (con't)

Flush Area

\[ A_0 = 10^{4.408} \]

Corrugations Area

\[ A_0 = 0.0 \]

Alligator Cracking Area

\[ A_0 = 10^{7.03} \]

Longitudinal Cracking Area

\[ A_0 = 10^{2.00} \]

Transverse Cracking Area

\[ A_0 = 10^{0.88} \]

Patching Area

\[ A_0 = 10^{6.65} \]
APPENDIX I
DEDUCT POINT CALCULATIONS USING THE TEXAS
PERFORMANCE AND DISTRESS EQUATIONS
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<th>Area Alligator Cracking</th>
<th>Area Longitudinal Cracking</th>
<th>Area Transverse Cracking</th>
<th>Area Rutting</th>
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Minnesota

SEE NEXT SHEETS

Nebraska*

New Mexico*

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Climatic Zone: V - dry, freeze-thaw cycling.

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### Augusta, Georgia

**Climatic Zone**

I - wet, no freeze

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*Deflections: High - Dynaflect maximum deflection = 1.5 mils; Surface curvature index = 1.0 mils
Low - Dynaflect maximum deflection = 0.4 mils;

**Ratio 1 = Load Deduct Points/Total Deduct Points
Ratio 2 = Load + Combined Deduct Points/Total Deduct Points**
### Climatic Zone II - Wet, Freeze-Thaw Cycling

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*Deflections: High - Dynaflect maximum deflection = 1.5 mils; Surface curvature index = 1.0 mils
Low - Dynaflect maximum deflection = 0.4 mils; Surface curvature index = 0.2 mils

**Ratio 1 = Load Deduct Points/Total Deduct Points
Ratio 2 = Load + Combined Deduct Points/Total Deduct Points
Ft. Wayne, Indiana

Climatic Zone III - wet, hard freeze

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*Deflections: High - Dynaflect maximum deflection = 1.5 mils; Surface curvature index = 1.0 mils

**Ratio 1 = Load Deduct Points/Total Deduct Points
Ratio 2 = Load + Combined Deduct Points/
## Climatic Zone V - dry, freeze-thaw cycling

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<th>Surface Treatment</th>
<th>Overlays</th>
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*Deflections: High - Dynaflect maximum deflection = 1.5 mils; Surface curvature index = 1.0 mils
Low - Dynaflect maximum deflection = 0.4 mils; Surface curvature index = 0.2 mils

**Ratio 1 = Load Deduct Points/Total Deduct Points
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*Deflections: High - Dynaflect maximum deflection = 1.5 mils; Surface curvature index = 1.0 mils
Low - Dynaflect maximum deflection = 0.4 mils

**Ratio 1 = Load Deduct Points/Total Deduct Points
Ratio 2 = Load + Combined Deduct Points/

Goodland, Kansas
Climatic Zone VI - dry, hard freeze
### Pavement Properties

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*Deflections:* High - Dynaflect maximum deflection = 1.5 mils; Surface curvature index = 1.0 mils
Low - Dynaflect maximum deflection = 0.4 mils; Surface curvature index = 0.2 mils

**Ratio 1 = Load Deduct Points/Total Deduct Points**
**Ratio 2 = Load + Combined Deduct Points/Total Deduct Points**

***Deduct Points for Serviceability Index not Included***
### Climactic Zone

**I - no freeze**

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*Deflections: High - Dynaflect maximum deflection = 1.5 mils; Surface curvature index = 1.0 mils
Low - Dynaflect maximum deflection = 0.4 mils;

**Ratio 1 = Load Deduct Points/Total Deduct Points
Ratio 2 = Load + Combined Deduct Points/Total Deduct Points
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*Deflections: High - Dynaflect maximum deflection = 1.5 mils; Surface curvature index = 1.0 mils
Low - Dynaflect maximum deflection = 0.4 mils; Surface curvature index = 0.2 mils

**Ratio 1 = Load Deduct Points/Total Deduct Points
Ratio 2 = Load + Combined Deduct Points/Total Deduct Points
Portland, Maine

Climatic Zone III - wet, hard freeze

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*Deflections: High - Dynaflect maximum deflection = 1.5 mils; Surface curvature index = 1.0 mils
Low - Dynaflect maximum deflection = 0.4 mils;

**Ratio 1 = Load Deduct Points/Total Deduct Points
Ratio 2 = Load + Combined Deduct Points/Total Deduct Points
### Pavement Properties

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**Ratio 1 = Load Deduct Points/Total Deduct Points**

**Ratio 2 = Load + Combined Deduct Points/Total Deduct Points**

***Deduct Points for Serviceability Index not Included
### Bismarck, North Dakota

**Climatic Zone**: VI - dry, hard freeze

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**Ratio 1 = Load Deduct Points/Total Deduct Points  
Ratio 2 = Load + Combined Deduct Points/Total Deduct Points
Abilene, Texas

Climatic Zone
V - dry, freeze-thaw cycling.

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*Deflections: High - Dynaflect maximum deflection = 1.5 mils; Surface curvature index = 1.0 mils
Low - Dynaflect maximum deflection = 0.4 mils;

**Ratio 1 = Load Deduct Points/Total Deduct Points
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**Deflections:**
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**Ratio 1** = Load Deduct Points/Total Deduct Points
**Ratio 2** = Load + Combined Deduct Points/Total Deduct Points
Houston, Texas

Climatic Zone  
I - wet, no freeze

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**Ratio 1 = Load Deduct Points/Total Deduct Points
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### Climatic Zone
**II - wet, freeze-thaw cycling**

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### Climatic Zone

- **I - wet, no freeze**

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<td>0.266</td>
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<tr>
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</tbody>
</table>

*Deflections: High - Dynaflect maximum deflection = 1.5 mils; Surface curvature index = 1.0 mils
Low - Dynaflect maximum deflection = 0.4 mils;

**Ratio 1 = Load Deduct Points/Total Deduct Points
Ratio 2 = Load + Combined Deduct Points/
Climatic Zone: V - dry, freeze-thaw cycling

<table>
<thead>
<tr>
<th>Pavement Properties</th>
<th>Traffic (18-kip Equiv.)</th>
<th>Ratio**</th>
<th>Hot Mix Asphaltic Concrete</th>
<th>Hot Mix Asphaltic Concrete on Black Base</th>
<th>Surface Treatment</th>
<th>Overlays</th>
<th>Thick Hot Mix Asphaltic Concrete</th>
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</table>

*Deflections: High - Dynafect maximum deflection = 1.5 mils; Surface curvature index = 1.0 mils
Low - Dynafect maximum deflection = 0.4 mils; Surface curvature index = 0.2 mils

**Ratio 1 = Load Deduct Points/Total Deduct Points
Ratio 2 = Load + Combined Deduct Points/Total Deduct Points
APPENDIX J

COMPUTER PROGRAM TO COMPUTE TEXAS FLEXIBLE PAVEMENT DAMAGE RATIOS
C
C
C
PAVEMENT DAMAGE BREAKDOWN PROGRAM
C
TEXAS FLEXIBLE DISTRESS EQUATIONS
C
AUTHOR: C. H. MICHALAK AND T. SCULLION
C
TEXAS TRANSPORTATION INSTITUTE
C
TEXAS A & M UNIVERSITY
C
COLLEGE STATION, TEXAS  77843
C
PHONE: (713) 845 7126 OR 845 3735
C
C
C
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION DI0RS(10,2), PHANE(5,2)
DIMENSION HEAD(10)
DIMENSION DFDATA(6,10), TRDATA(6,10)
COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
     = TR(10)
COMMON /PVAL/ PI(5), PF
C
CALL ERRSET(207,256, -1, 1, 1, 229)
CALL ERRSET(231,256, -1, 1, 1, 239)
CALL ERRSET(241,256, -1, 1, 1, 283)
C
NOP = 5
NW = 10
NLD = 6
C
READ(5,106) ((PHANE(I,J), J = 1, 2), I = 1, NOP )
106 FORMAT( 5( 2A8 ) )
READ(5,106) (( DI0RS(I,J), J = 1, 2), I = 1, 10 )
C
READ(5,107) ( PI(I), I = 1, NOP )
107 FORMAT( 8F10.2 )
READ(5,105) ( D(I), I = 1, 10 )
105 FORMAT( 10F8.0 )
56. READ(5,105) ( T(I), I = 1, 10 )
57. READ(5,105) ( S(I), I = 1, 10 )
58. C
59. DO 2 I = 1, NLD
60. READ(5,105) ( TRDATA(I,J), J = 1, 10 )
61. 2 READ(5,105) ( DFDATA(I,J), J = 1, 10 )
62. C
63. C READ THE CLIMATIC DATA AND DEDUCT POINTS
64. C
65. 10 CONTINUE
66. READ(5,108,END=50) ( HEAD(I), I = 1, 5 )
67. 108 FORMAT( 10A8 )
68. READ(5,105) ( C(I), I = 1, 10 )
69. C(2) = C(2) + 50.0
70. READ(5,105) ( A(I), I = 1, 10 )
71. READ(5,105) ( B(I), I = 1, 10 )
72. C
73. WRITE(6,202) ( HEAD(I), I = 1, 5 )
74. C
75. C
76. 202 FORMAT( ' ', T6, 5A8 )
77. C
78. WRITE(6,400) ((PNAME(I,J),J=1,2), PI(I), I=1, NDP )
79. 400 FORMAT( ' ', T6, 'INITIAL SERV. INDEX' / 5( 5X, 2A8, T46, F7.2 / ) )
80. WRITE(6,401) (D(I), T(I), S(I), I=1, 4 )
81. 401 FORMAT( T6, 'D(I) AS - SBGR STIFF COEF', T46, F7.2 / T6, 
82. + 'T(I) TIME - YEARS', T46, F7.2 / T6, 'S(I) ITC - TEXAS TRIAX', 
83. ) < CLASS', T46, F7.2 / T6, 'S(2) SLL - SBGR LIG LIMIT', T46,F7.2 
84. - / T6, 'S(3) SPI - SBGR PLAS. INDEX', T46, F7.2 / T6, 'S(4) ', 
85. * 'SPP - SBGR PCI PASS 200', T46, F7.2 / )
86. C
87. WRITE(6,402) (C(I), I = 1, 6 )
88. 402 FORMAT( T6, 'C(I) ALF - DIST. TEMP CONST', T46, F9.4 / T6, 
89. & 'C(2) T1 - THORNHAUWE INDEX', T46, F7.2 / T6, 'C(3) FTC - ' 
90. + ', FEZEZ/THAW CYCLES', 
91. #', T46, F7.2 / T6, 'C(4) WFTC - WET F/T CYCLES', T46, F7.2 / T6, 
92. @ 'C(5) PR - ANN MEAN PRECIPITATION', T46, F7.2 / T6, 'C(6) TM', 
93. X', ' - AVG MEAN TEMP', T46, F7.2 / T6, 'NOTE C(2) = C(2) + 50', 
94. + ' IN THE PROGRAM' )
95. C
96. WRITE(6,403) ((DISTRI(I,J),J=1,2), I, A(I), I, B(I), I=1, 9 )
97. 403 FORMAT( T6, 'DEDUCT POINTS' / T6, 'DISTRESS TYPE', T34, 'AREA', 
98. 1 T46, 'SEVERITY' / 9( T6, 2A8, T25, 'A( , I, ', )', F9.2, 'B(', 
99. 2 I2, ')'), F8.2 / )
100. C
101. WRITE(6,404) ( DISTRI(I,J), J = 1, 2 ), B(10)
102. 404 FORMAT( ' ', T6, 2A8, T41, 'B(10)', F8.2 / )
103. C
104. WRITE(6,405) (( TRDATA(I,J),J=1,2), (DFDATA(I,J),J=1,3),I=1,NLD)
105. 405 FORMAT( T6, 'TRAFFIC DATA', T31, 'DEPLETION DATA' / T10, 'ABD', 

J-3
106.    1 T22, 'N-18  DMD  SCI  VOL' / 6( F12.1, F13.1, F8.1, F6.1, 
107.    2 F6.2 )
108.    C
109.    C
110.    DO 45 NRN = 1, NLD
111.    DO 12 I = 1, 10
112.    TR(I) = TRDATA(NRN,I)
113.    12 DF(I) = DFDATA(NRN,I)
114.    C
115.    DO 40 NP = 1, NOP
116.    C
117.    WRITE(6,406) (HEAD(I), I = 1, 5), TR(1), TR(2), (DF(I),I=1, 3)
118.    406 FORMAT(' ', T6, 5A8, 3X, 'ADT = ', FB1.5, 2X, 'N10 = ', F11.1, 2X,
119.    1 'DMD = ', F5.1, 2X, 'SCI = ', F5.1, 2X, 'VOL = ', F6.2 )
120.    W = 8.0
121.    LINE = 0
122.    C
123.    DO 30 I = 1, NW
124.    K = 0
125.    SULM = 0.0
126.    SUNC = 0.0
127.    SUM = 0.0
128.    W = W + TR(2) * 0.1D0
129.    C
130.    WRITE(6,205) I, W
131.    205 FORMAT( T40, 'LOAD LEVEL', I4, 5X, 'LOAD = ', F16.4/T23,
132.    = 'DISTRESS', T77, 'DEDUCT ----------- POINTS' / T6,
133.    1 'PAVEMENT TYPE', T26,
134.    1 'NO  DISTRESS NAME   AREA   SEVERITY   LOAD
135.    2 , 'COMB TOTAL' )
136.    C
137.    C DISTRESS SUBROUTINES
138.    C
139.    CALL ALGRCA( W, NP, AR)
140.    SUM = SUM + AR * A(1)
141.    SULM = SULM + AR * A(1)
142.    C
143.    CALL ALGRCS( W, NP, SE)
144.    SUM = SUM + SE * B(1)
145.    SULM = SULM + SE * B(1)
146.    K = K + 1
147.    WRITE(6,215) (FNAME(NP,J), J = 1, 2), K, (DISTR(K,J), J = 1, 2),
148.    = AR, SE, SULM, SUM
149.    C
150.    CALL LOCRA( W, NP, AR)
151.    SUM = SUM + AR * A(2)
152.    C
153.    CALL LOCRS( W, NP, SE)
154.    SUM = SUM + SE * B(2)
155.    K = K + 1
156.    WRITE(6,214) (FNAME(NP,J), J = 1, 2), K, (DISTR(K,J), J = 1, 2),
157.    = AR, SE, SUM
214 FORMAT(5X, 2A8, I6, 5X, 2A8, F12.4, F13.4, 18X, F9.3)
C
CALL TRCRA( W, NP, AR)
SUM = SUM + AR * A(3)
CALL TRCRS( W, NP, SE)
SUM = SUM + SE * B(3)
K = K + 1
WRITE(6,214) (PNAME(NP,J), J = 1, 2), K, (DISTRS(K,J), J = 1, 2),
       = AR, SE, SUM
C
CALL RUTA( W, NP, AR)
SUM = SUM + AR * A(4)
SUML = SUML + AR * A(4)
C
CALL RUTS( W, NP, SE)
SUM = SUM + SE * B(4)
SUML = SUML + SE * B(4)
K = K + 1
WRITE(6,215) (PNAME(NP,J), J = 1, 2), K, (DISTRS(K,J), J = 1, 2),
       = AR, SE, SUML, SUM
215 FORMAT(5X, 2A8, I6, 5X, 2A8, F12.4, F13.4, F9.3, 9X, F9.3)
C
CALL FLSHA( W, NP, AR)
SUM = SUM + AR * A(5)
SUML = SUML + AR * A(5)
C
CALL FLSHS( W, NP, SE)
SUM = SUM + SE * B(5)
SUML = SUML + SE * B(5)
K = K + 1
WRITE(6,215) (PNAME(NP,J), J = 1, 2), K, (DISTRS(K,J), J = 1, 2),
       = AR, SE, SUML, SUM
C
CALL CORA( W, NP, AR)
SUM = SUM + AR * A(6)
SUML = SUML + AR * A(6)
C
CALL CORS( W, NP, SE)
SUM = SUM + SE * B(6)
SUML = SUML + SE * B(6)
K = K + 1
WRITE(6,215) (PNAME(NP,J), J = 1, 2), K, (DISTRS(K,J), J = 1, 2),
       = AR, SE, SUML, SUM
C
CALL PATA( W, NP, AR)
SUM = SUM + AR * A(7)
SUMC = SUMC + AR * A(7)
C
CALL PATS( W, NP, SE)
SUM = SUM + SE * B(7)
```c
209. if (sumc < sumc1) then
210.   k = k + 1
211.      write(6,210) (pname(np,j), j = 1, 2), k, (dists(k,j), j = 1, 2),
212.      = ar, se, sumc, sum
213.      210 format( 5x, 2a8, i6, 5x, 2a8, f12.4, f13.4, 9x, 2f9.3 )
214.  c
215.      call rava( w, np, ar)
216.      sum = sum + ar * a(0)
217.      sumc = sumc + ar * a(0)
218.  c
219.      call ravs( w, np, se)
220.      sum = sum + se * b(0)
221.      sumc = sumc + se * b(0)
222.      k = k + 1
223.      write(6,210) (pname(np,j), j = 1, 2), k, (dists(k,j), j = 1, 2),
224.      = ar, se, sumc, sum
225.  c
226.      call fapm( w, np, se)
227.      sum = sum + se * b(9)
228.      suml = suml + se * b(9)
229.      k = k + 1
230.      write(6,210) (pname(np,j), j = 1, 2), k, (dists(k,j), j = 1, 2),
231.      = se, suml, sum
232.      216 format( 5x, 2a8, i6, 5x, 2a8, 12x, f13.4, f9.3, 9x, 2f9.3 )
233.  c
234.      call psi( w, np, p)
235.      pn = ((pi(np) - p)/(pi(np) - 1.5))
236.  c
237.      if( (pi(np) - p) .le. 0.0 ) pn = 0.0
238.  c
239.      sum = sum + pn* b(10)
240.      sumc = sumc + pn* b(10)
241.      k = k + 1
242.      write(6,219) (pname(np,j), j = 1, 2), k, (dists(k,j), j = 1, 2),
243.      = p, sumc, sum
244.      219 format( 5x, 2a8, i6, 5x, 2a8, f12.4, 22x, 2f9.3 )
245.  c
246.      if( pn .ne. 0.0 ) write(6,217) pf
247.      if( pn .eq. 0.0 ) write(6,221) pf
248.      221 format( '***', t105, 'pf = ', g14.6, 3x, '***' )
249.  c
250.      217 format( '***', t105, 'pf = ', g14.6 )
251.      ratio1 = suml/sum
252.      ratio2 = (suml + sumc)/sum
253.      ratio3 = sumc/sum
254.  c
255.      write(6,216)
256.      245 format( '0' )
257.      write(6,218)
258.      218 format( t23, 'load no. of' / t6, 'pavement type',
259.      = t23, 'level 10-k equiv
```
= 'RATIO 1 RATIO 2 RATIO 3'

WRITE(6,220) (PHAME(NP,J), J = 1, 2), I, W, RATIO1, RATIO2, RATIO3
220 FORMAT( 5X, 2A8, I4, 4F14.3 )

LINE = LINE + 1
IF( LINE .EQ. 3 ) WRITE(6,406) (HEAD(L), L = 1, 5), TR(1), TR(2),
+ (DF(L), L = 1, 3 )

C IF( LINE .EQ. 3 ) LINE = 0
IF( LINE .EQ. 0 ) GO TO 30

WRITE(6,245)
30 CONTINUE
40 CONTINUE
45 CONTINUE

GO TO 10
50 WRITE(6,250)

250 FORMAT( '1' )

STOP
END

C

SUBROUTINE ALGCRS( W, NP, AR)

IMPLICIT REAL*8 (A-H, O-Z)
COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
= TR(10)

AR = 0.0
GO TO (10, 20, 30, 40, 50 ), NP
GO TO 70

10 A1 = 10.0**6.81
GO TO 60

20 A1 = 10.0**3.701
GO TO 60

30 A1 = 10.0**1.47*C(2)***(-0.0016)*DF(1)***(-0.0017)*C(4)***(-0.00011
=)**T(1)**0.00013**TR(1)**(-0.00012)
GO TO 60

40 A1 = 10.0**6.877
GO TO 60

50 A1 = 10.0**3.029

60 PWR = -A1/W
IF( DBS( PWR ) .GE. 1640 ) RETURN
AR = DEXP( -A1/W )

70 RETURN

END

C

SUBROUTINE ALGCRS( W, NP, SE)

IMPLICIT REAL*8 (A-H, O-Z)
COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
= TR(10)

C
311. \( SE = 0.0 \)
312. \( GO TO (10, 20, 30, 40, 50), NP \)
313. \( GO TO 30 \)
314. \( 10 A0 = 10.0**1.233 \)
315. \( A1 = 10.0**6.57 \)
316. \( SF = 10.0**(-1.09)*T(1)**(-5.84)*S(1)**17.3*S(3)**(-9.82)*TR(1)**(1)*T(1)**(1.24) \)
317. \( = 6.78*TR(2)**(-9.04) \)
318. \( GO TO 60 \)
319. \( 20 A0 = 10.0**26.46*DF(2)**0.24*C(1)**(-1.17)*S(1)**1.25*C(2)**(-15.4) \)
320. \( =1)*T(1)**(1.24) \)
321. \( A1 = 10.0**6.886 \)
322. \( SF = 10.0**(-1.07)*DF(2)**1.95*C(1)**(-4.64)*S(3)**1.97*T(1)**5.22 \)
323. \( GO TO 60 \)
324. \( 30 A0 = 10.0**1.491 \)
325. \( A1 = 10.0**7.43 \)
326. \( SF = 10.0**(-0.247) \)
327. \( GO TO 60 \)
328. \( 40 A0 = 10.0**0.407 \)
329. \( A1 = 10.0**6.74 \)
330. \( SF = 10.0**(-0.726) \)
331. \( GO TO 60 \)
332. \( 50 A0 = 10.0**0.819 \)
333. \( A1 = 10.0**5.077 \)
334. \( SF = 10.0**3.524 \)
335. \( 60 PWR = -A0 -A1/\mu \)
336. \( IF(DABS(PWR) .GE. 164.0 ) RETURN \)
337. \( SE = DEXP( -A0 -A1/\mu ) \)
338. \( IF(SF .GT. 1.000 ) SE = SF * DEXP( -A0 - A1/\mu ) \)
339. \( IF( SE .GT. 1.000 ) SE = 1.0 \)
340. \( 70 RETURN \)
341. \( END \)
342. \( \) SUBROUTINE LOCRA (W, NP, AR)
343. \( IMPLICIT REAL*8 (A-H,0-2) \)
344. \( COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10), \)
345. \( = TR(10) \)
346. \( \) AR = 0.0
347. \( GO TO (10, 20, 30, 40, 50), NP \)
348. \( GO TO 70 \)
349. \( 10 A1 = 10.0**2.597 \)
350. \( GO TO 60 \)
351. \( 20 A1 = 10.0**1.845 \)
352. \( GO TO 60 \)
353. \( 30 A1 = 10.0**3.05*D(1)**(-0.9005)*C(5)**0.0026*S(3)**(-0.90049)* \)
354. \( = S(1)**(-0.9013) \)
355. \( GO TO 60 \)
356. \( 40 A1 = 10.0**2.161 \)
357. \( GO TO 60 \)
358. \( 50 A1 = 10.0**2.66 \)
359. \( GO TO 60 \)
360. \( 60 PWR = -A1/\mu \)
361. \( J-8 \)
SUBROUTINE LOCRS ( W, NP, SE )
IMPLICIT REAL*8 (A-H,O-Z)
COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
            = TR(10)
C
SE = 0.0
GO TO ( 10, 20, 30, 40, 50 ), NP
GO TO 70
10 A0 = 10.0**1.089
    A1 = 10.0**2.501
    SF = 10.0**(-44.05)***S(1)**14.61***D(1)**(-12.75)**C(2)**8.46**C(3)**
        = 1.71**S(2)**24.62**S(3)**(-22.61)
    GO TO 60
20 A0 = 10.0**20.68**C(2)**(-11.7)**T(1)**0.54**S(1)**0.83**S(3)**(-0.27)
    = *TR(2)**(-0.17)
    A1 = 10.0**1.741
    SF = 10.0**1.26**TR(2)**(-1.35)**S(3)**(-1.29)**T(1)**4.49
    GO TO 60
30 A0 = 10.0**(-0.36)**S(2)**0.39**D(3)**(-0.076)**C(5)**
    = (-0.49)**S(1)**1.28
    A1 = 10.0**3.0
    SF = 10.0**(-11.07)**T(1)**2.11**C(5)**(-5.1)**C(1)**(-6.78)**S(3)**
    = 7.18**S(1)**14.39
    GO TO 60
40 A0 = 10.0**1.413
    A1 = 10.0**4.21**C(3)**(-0.17)**DF(2)**0.16**S(1)**(-0.86)**TR(1)**
        = 0.18**C(2)**(-1.23)
    SF = 10.0**(-15.37)**S(2)**(-3.79)**TR(1)**(-0.7)**C(2)**7.0**C(3)**
    = 1.88**S(1)**16.74**T(1)**(-2.0)
    GO TO 60
50 A0 = 10.0**0.879
    A1 = 10.0**-1.602
    SF = 10.0**(-1.06)
60 PWR = -A0 -A1/W
   IF ( DABS( PWR ) .GE. 164.0 ) RETURN
   SF = DEXP( -A0 -A1/W )
63. IF ( SF .GT. 1.000 ) SE = SF * DEXP( -A0 - A1/W )
64. IF ( SE .GT. 1.000 ) SE = 1.0
70 RETURN
END
SUBROUTINE TRCRA ( W, NP, AR )
IMPLICIT REAL*8 (A-H,O-Z)
COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
            = TR(10)
C
J-9
AR = 0.0
GO TO ( 10, 20, 30, 40, 50 ), NP
GO TO 70
10 A1 = 10.0**2.496
GO TO 60
20 A1 = 10.0**2.126
GO TO 60
30 A1 = 10.0**2.843
GO TO 60
40 A1 = 10.0**2.581
GO TO 60
50 A1 = 10.0** 0.88
60 PWR = -A1/W
IF( DBABS( PWR ) .GE. 164.0 ) RETURN
AR = DBEXP( -A1/W )
70 RETURN
END
C
SUBROUTINE TRCRS ( W, NP, SE )
IMPLICIT REAL*8 (A-H,O-Z)
COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
= TR(10)
C
SE = 0.0
GO TO ( 10, 20, 30, 40, 50 ), NP
GO TO 70
10 A0 = 10.0**1.132
A1 = 10.0**(-14.64)*B(1)**5.74*DF(3)**1.34*S(4)**17.44*C(3)**
= (-0.26)*T(1)**(-2.36)
SF = 10.0**(-0.754)
GO TO 60
20 A0 = 10.0**0.473*C(3)**(-0.26)*C(5)**(-1.21)*TR(2)**(-0.41)*DF(2)
= **(-0.26)*T(1)**2.12
A1 = 10.0**(-1.7)*T(1)**(-0.7)*C(5)**1.57*C(3)**0.03*D(1)**(-4.03)
SF = 10.0**11.79*C(5)**(-6.23)*TR(2)**(-1.41)*C(3)**(-2.69)*T(1)**
= 7.2**9(1)**2.76
GO TO 60
30 A0 = 10.0**1.464
A1 = 10.0**2.812
SF = 10.0**(-1.965)
GO TO 60
40 A0 = 10.0**1.431
A1 = 10.0**2.533
SF = 10.0**(-0.936)
GO TO 60
50 A0 = 10.0** 0.728
A1 = 10.0** 0.887
SF = 10.0** (-1.294)
60 PWR = -A0 -A1/W
IF( DBABS( PWR ) .GE. 164.0 ) RETURN
SE = DBEXP( -A0 -A1/W )
IF(SF .GT. 1.0D0) SE = SF * DEXP(-A9 - A1/W)
IF(SE .GT. 1.0D0) SE = 1.0
70 RETURN
END

C

SUBROUTINE RTA(W, NP, AR)
IMPLICIT REAL*(A-H,O-Z)
COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
= TR(10)
C
AR = 0.0
GO TO (10, 20, 30, 40, 50), NP
GO TO 70
10 A1 = 10.0*6.636
GO TO 60
20 A1 = 10.0*6.7*DF(2)**0.0054*S(3)**0.0033*C(3)**(-0.0029)*TR(2)**
= 0.0090*T(1)**0.0122*TR(1)**(-0.018)
GO TO 69
30 A1 = 10.0*7.05*C(3)**0.0006*T(1)**0.0035*C(4)**(-0.0067)*TR(1)
= ** (-0.00041)
GO TO 60
40 A1 = 10.0*7.17*C(1)**(-0.0053)*TR(1)**(-0.0041)*C(5)**0.011*S(3)
= **0.017*S(2)**(-0.03)
GO TO 69
50 A1 = 10.0**6.951
60 PUR = -A1/W
IF(DABS(PUR) .GE. 1.64.0) RETURN
AR = DEXP(-A1/W)
GO TO 70
RETURN
END
C

SUBROUTINE RUTS(W, NP, SE)
IMPLICIT REAL*(A-H,O-Z)
COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
= TR(10)
C
SE = 0.0
GO TO (10, 20, 30, 40, 50), NP
GO TO 70
10 A0 = 10.0*1.98*S(3)**(-0.82)*C(1)**0.47*DF(1)**0.54*W**(0.31)
A1 = 10.0*6.294
SF = 10.0*9.42*DF(1)**3.45*W**(-1.91)*S(3)**(-5.82)*C(1)**2.8
GO TO 60
20 A0 = 10.0*0.36*S(1)**(-0.88)*DF(3)**0.36*C(4)**0.23*TR(1)**0.38*
= TR(2)**(-0.45)
50 A1 = 10.0*(-7.35)*DF(3)**(-1.34)*C(4)**1.81*S(1)**7.11*TR(1)**
= (-0.58)*C(1)**11.23*C(5)**(-0.22)
51 SF = 10.0*(-1.13)*DF(3)**2.44*C(4)**0.9*S(1)**(-5.25)*TR(2)**
= (-2.32)*TR(1)**1.84
GO TO 69
30 A0 = 10.0**1.099
J-11
A1 = 10.8**7.32*TR(1)**(-0.15)*T(1)**(-0.25)*S(3)**(-0.97)*C(5)**
   = 0.55*8(2)**1.83*S(1)**(-1.75)
   SF = 10.0**1.586
   GO TO 60

40 A0 = 10.0*(1.86)*C(2)**0.84*C(5)**(-0.69)*S(3)**0.4*TR(1)**0.25*
   = T(1)**0.38*TR(2)**(-0.27)
   A1 = 10.0**7.014
   SF = 10.0**(-12.95)*C(2)**3.55*C(5)**(-0.35)*S(3)**1.85*TR(1)**
   = 1.73*TR(2)**(-2.15)*T(1)**3.27
   GO TO 60

50 A0 = 10.0**0.561
   A1 = 10.0**5.619
   SF = 10.0**1.852

60 PWR = -A0 -A1/W
   IF( DABS( PWR ) .GE. 164.0 ) RETURN
   SE = DEXP( -A0 -A1/W )
   IF( SF .GT. 1.0D0 ) SE = SF * DEXP( -A0 - A1/W )
   IF( SE .GT. 1.0D0 ) SE = 1.0
70 RETURN
   END

C
SUBROUTINE FLSHA ( W, NP, AR )
IMPLICIT REAL*8 (A-H,O-Z)
COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
C
= TR(10)
540.
C
AR = 0.0
GO TO (10, 20, 30, 40, 50), NP
GO TO 70
10 A1 = 10.0**4.814
GO TO 60
20 A1 = 10.0**4.98*S(4)**(-0.913)*DF(1)**0.0034*DF(3)**(-0.0061)*
   = TR(2)**(-0.0012)*T(1)**(-0.019)
GO TO 60
30 A1 = 10.0**4.96*DF(3)**0.00024*C(2)**0.0004*TR(2)**(-0.00011)*
   = C(6)**(-0.976)*C(1)**0.0015*C(4)**(-0.00024)
GO TO 60
40 A1 = 10.0**5.142
GO TO 60
50 A1 = 10.0**4.408
60 PWR = -A1/W
IF( DABS( PWR ) .GE. 164.0 ) RETURN
AR = DEXP( -A1/W )
70 RETURN
END
C
SUBROUTINE FLSSH ( W, NP, SE )
IMPLICIT REAL*8 (A-H,O-Z)
COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
C
= TR(10)
545.
SE = 0.0
GO TO (10, 20, 30, 40, 50), NP
GO TO 70
10 A0 = 10.0**1.439
A1 = 10.0**5.34*D(1)**4.09*C(1)**(-5.24)*S(3)**(-5.7)*C(4)**
= (-1.72)*S(2)**10.98
SF = 10.0**0.267
GO TO 60
20 A0 = 10.0**(-9.57)*C(4)**0.37*TR(1)**0.19*S(4)**6.17*D(1)**4.56*
= S(3)**(-1.83)*S(2)**4.28
A1 = 10.0**22.02*D(1)**(93.15)*C(1)**(-7.4)*C(3)**(-2.9)*S(1)**
= (-3.54)*T(1)**2.07*TR(1)**(-0.76)
SF = 10.0**0.014
GO TO 60
30 A0 = 10.0**1.18
A1 = 10.0**5.06*C(4)**(-0.15)*D(1)**(-1.16)*S(3)**0.38*TR(1)**
= (-0.3)*D(1)**(-0.36)
SF = 10.0**3.45*C(1)**(-9.33)*S(1)**14.63*D(1)**19.3*TR(2)**5.22
GO TO 60
40 A0 = 10.0**1.326
A1 = 10.0**5.028
SF = 10.0**0.713
GO TO 60
50 A0 = 10.0**0.746
A1 = 10.0**3.225
SF = 10.0**3.668
60 PWR = -A0 -A1/W
IF( DABS( PWR ) .GE. 164.0 ) RETURN
SE = DEXP( -A0 -A1/W )
IF( SF .GT. 1.000 ) SE = SF * DEXP( -A0 - A1/W )
IF( SE .GT. 1.000 ) SE = 1.0
70 RETURN
END

C
SUBROUTINE CORA( W, NP, AR )
IMPLICIT REAL*8 (A-H,O-Z)
COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
= TR(10)
C
AR = 0.0
GO TO (10, 20, 30, 40, 50), NP
GO TO 70
10 A1 = 0.0
GO TO 60
20 A1 = 0.0
GO TO 60
30 A1 = 10.0**6.225
GO TO 60
40 A1 = 10.0**0.143
GO TO 60
50 A1 = 0.0
GO TO 60
60 PWR = -A1/W

J-13
IF ( DABS( PWR ) .GE. 164.0 ) RETURN
AR = DEXP( -A1/W )
70 RETURN
END

C
SUBROUTINE CORS ( W, NP, SE )

Implicit REAL*8 (A-H,O-Z)

COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),

= TR(10)

C
SE = 0.0
GO TO ( 10, 20, 30, 40, 50 ), NP
GO TO 70

10 A0 = 10.0**( -1.77 )*C(1)**1.18*C(3)**0.51*S(1)**0.67*T(1)**0.91*

= TR(1)**(-0.86)*W**0.9
A1 = 0.0
SF = 10.0**(-5.96)*C(1)**2.37*C(3)**1.03*S(1)**1.37*T(1)**1.91*

= TR(1)**(-1.74)*TR(2)**1.83
GO TO 60

20 A0 = 10.0**( -0.0434 )
A1 = 0.0
SF = 10.0**(-2.22)
GO TO 60

30 A0 = 10.0**0.977
A1 = 10.0**0.178
SF = 10.0**(-1.908)
GO TO 60

40 A0 = 10.0**(-4.95)*C(3)**(-0.063)*C(5)**(-0.22)*S(4)**4.58
A1 = 10.0**0.189
SF = 10.0**(-17.11)*C(4)**(-0.69)*TR(2)**0.11*C(1)**(-0.98)*S(1)**

= (-2.34)*S(4)**13.73
GO TO 60

50 A0 = 0.0
A1 = 0.0
SF = 0.0

60 PWR = -A0 -A1/W
IF ( DABS( PWR ) .GE. 164.0 ) RETURN
SE = DEXP( -A0 -A1/W )
IF( SF .GT. 1.000 ) SE = SF * DEXP( -A0 - A1/W )
IF( SE .GT. 1.000 ) SE = 1.0

70 RETURN
END

C
SUBROUTINE PATA ( W, NP, AR )

Implicit REAL*8 (A-H,O-Z)

COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),

= TR(10)

C
AR = 0.0
GO TO ( 10, 20, 30, 40, 50 ), NP
GO TO 70

J-14
10 A1 = 10.0**6.55
670. GO TO 60
671. 20 A1 = 10.0**6.779
672. GO TO 60
673. 30 A1 = 10.0**6.92*DF(1)**0.0014*DF(3)**(-0.092)*C(5)**0.0085*C(2)**
674. = (-0.0015)*S(4)**(-0.0017)
675. GO TO 60
676. 40 A1 = 10.0**6.879
677. GO TO 60
678. 50 A1 = 10.0** A .A51
680. IF ( DABS( PWR ) .GE. 164.0 ) RETURN
681. AR = DEXP( -A1/U )
682. 70 RETURN
683. END
684. C
685. SUBROUTINE PATS ( U, NP, SE )
686. IMPLICIT REAL*8 (A-H,O-Z)
687. COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
688. = TR(10)
689. C
690. SE = 0.0
691. GO TO ( 10, 20, 30, 40, 50 ), NP
692. GO TO 70
693. 10 A0 = 10.0**1.077
694. A1 = 10.0**6.165
695. SF = 10.0**(-1.275)
696. GO TO 60
697. 20 A0 = 10.0**0.65
698. A1 = 10.0**6.666
699. SF = 10.0**(-1.688)
700. GO TO 60
701. 30 A0 = 10.0**1.682
702. A1 = 10.0**6.864
703. SF = 10.0**(-1.389)
704. GO TO 60
705. 40 A0 = 10.0**1.172
706. A1 = 10.0**6.781
707. SF = 10.0**(-1.471)
708. GO TO 60
709. 50 A0 = 10.0** 0.925
710. A1 = 10.0**5.327
711. SF = 10.0**(-0.891)
712. GO PWR = -A0 -A1/U
713. IF ( DABS( PWR ) .GE. 164.0 ) RETURN
714. SE = DEXP( -A0 -A1/U )
715. IF ( SF .GT. 1.000 ) SE = SF * DEXP( -A0 -A1/U )
716. IF ( SE .GT. 1.000 ) SE = 1.0
717. 70 RETURN
718. END
719. C
720. SUBROUTINE RAVA ( W, NP, AR )
IMPLICIT REAL*8 (A-H,O-Z)
COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
= TR(10)
C
AR = 0.0
GO TO (10, 20, 30, 40, 50 ), NP
GO TO 70
10 A1 = 10.0**6.96*DF(1)**0.000038*C(6)**(-0.0015)*T(1)**0.000036
= *C(5)**0.000082
GO TO 60
20 A1 = 10.0**5.52*C(3)**0.00076*C(4)**(-0.0011)*S(3)**0.0012*S(4)**
= (-0.01)*DF(3)**0.0014*T(1)**0.0017
GO TO 60
30 A1 = 10.0**4.36*C(3)**(-0.00006)*C(5)**(-0.00031)*T(1)**(-0.00063)
= *T(1)**0.00016*C(2)**0.00052
40 A1 = 10.0** 4.576
GO TO 60
50 A1 = 10.0** 4.576
GO TO 60
60 PWR = -A1/W
IF ( DABS( PWR ) .GE. 164.0 ) RETURN
AR = DEXP( -A1/W )
70 RETURN
END
C
SUBROUTINE RAUS ( W, NP, SE )
IMPLICIT REAL*8 (A-H,O-Z)
COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
= TR(10)
C
SE = 0.0
GO TO (10, 20, 30, 40, 50 ), NP
GO TO 70
10 A0 = 10.0**9.21*C(1)**(-2.99)*DF(1)**0.8*DF(3)**(-0.99)*T(1)**
= (-1.17)*W**(-0.33)*C(3)**(-0.89)
A1 = 10.0** 6.753
SF = 10.0** 2.397
70 GO TO 60
20 A0 = 10.0** 9.668
A1 = 10.0**3.74*DF(1)**3.73*C(5)**(-1.2)*S(3)**1.93*T(2)**(-1.41)
SF = 10.0**1.572
GO TO 60
30 A0 = 10.0**(-0.35)*DF(3)**(-0.57)*DF(1)**(-2.42)*C(3)**0.56*C(5)**
= 0.4*C(4)**(-0.39)*T(2)**(-0.964)
A1 = 10.0**1.95*C(2)**0.67*C(1)**0.78*DF(3)**0.23*T(2)**(-0.24)
SF = 10.0**(-0.0921)
GO TO 60
40 A0 = 10.0**1.197
A1 = 10.0** 5.132
SF = 10.0** 1.248
J-16
SUBROUTINE FAMP ( W, NP, SE )

IMPLICIT REAL*8 (A-H, O-Z)

COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10).

SE = 0.0

GO TO (10, 20, 30, 40, 50), NP

GO TO 70

10 A0 = 10.0**(-1.37)**D(3)**0.59**S(1)**2.13*C(1)**2.03*TR(1)**(-0.59)

= *S(2)**(-1.35)*TR(2)**0.6

A1 = 0.0

SF = 10.0**(-1.275)

GO TO 60

20 A0 = 10.0**0.184

A1 = 0.0

SF = 10.0**(-1.688)

GO TO 60

30 A0 = 10.0**1.684

A1 = 10.0**0.24

SF = 10.0**(-1.857)

GO TO 60

40 A0 = 10.0**1.4945

A1 = 10.0**0.114

SF = 10.0**(-1.595)

GO TO 60

50 A0 = 10.0**0.601

A1 = 0.0

SF = 10.0**(-0.891)

60 PWR = -A0 -A1/W

IF ( DABS( PWR ) .GE. 164.0 ) RETURN

SE = DEXP(-A0 -A1/W )

IF ( SF .GT. 1.0D0 ) SE = SF * DEXP(-A0 -A1/W )

IF ( SE .GT. 1.0D0 ) SE = 1.0

GO TO 70

RETURN

END

SUBROUTINE PSI ( W, NP, P )

IMPLICIT REAL*8 (A-H, O-Z)

COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10), TR(10)

= TR(10)
COMMON /PVAL/ PI(5), PF

C

P = PI(NP)

GO TO (10, 20, 30, 40, 50), NP

GO TO 70

10 XK = 89.15+0.0036*T(1)**0.99*D(1)**(-2.83)*S(1)**2.1*DF(2)**0.85

PF = -0.961+1236.1*S(2)**(-0.006)*C(1)**0.3*G(3)**0.12*C(4)**(-0.21)

=)C(2)**(-0.22)*D(1)**0.25*C(1)**(-3.13)*C(5)**0.31

GO TO 60

20 XK = 92.83+0.2710.0**(-12.0)*S(2)**1.64*DF(1)**(-0.46)*C(1)**7.97

=)D(1)**(-1.45)*C(5)**(-3.38)*TR(2)**(-0.25)*T(1)**1.09

PF = -0.198+17.44*S(2)**(-0.90)*DF(2)**(-0.94)*C(1)**(-1.67)*C(4)

=*-0.005*D(1)**0.49*T(1)**(-0.059)*C(5)**0.25

GO TO 60

30 XK = 91.51+0.6837*DF(1)**0.23*C(2)**0.38*C(4)**(-0.18)*TR(2)**

=)0.15*T(1)**1.45

PF = 0.117+15.578*S(3)**(0.018)*C(1)**(-0.55)*C(3)**(-0.24)*S(1)

=*(-0.17)*T(1)**(-0.065)*TR(2)**0.03

GO TO 60

40 XK = 81.84+5.052*DF(2)**(-0.32)*DF(1)**1.4*C(2)**0.89*T(1)**0.25*

=)S(1)**(-1.74)

PF = -0.167+3.327*C(1)**(-0.38)*C(4)**0.033*S(3)**(-0.09)*C(3)**

=*(-0.061)*S(4)**0.071*S(2)**0.16*S(1)**(-0.017)*T(1)**(-0.075)

GO TO 60

50 XK = -0.0737+23.63*T(1)**(-1.28)*S(4)**0.3*TR(2)**(-0.47)

PF = 0.00304+7.6131*DF(2)**(-0.15)*T(1)**0.021*C(5)**(-1.37)

IF( DABS( PWR ) .GE. 164.0 ) RETURN

P = FF + (PI(NP) - FF) * DEXP( -XK/W )

70 RETURN

END

//GO.SYSIN DD *

HMAC HMAC ON BLK BASESURF TREATMENT OVERLAYS THICK HOT MIX

ALLISTR CRACKING LONGIT CRACKING TRANSYS CRACKING RUTTING FLUSHING

CORRUGATIONS PATCHING RAVELLED FAILURES/LANE NP PRESENT SERV IND

4.7 4.73 4.41 4.81 4.69
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L 489/475
APPENDIX K

COMPUTER PROGRAM TO COMPUTE

MINNESOTA DAMAGE RATIOS
L //MINDEDUC JOB (W207,55-B,52,3,CM), NICHALAK, C H
//*PASSWORD RAMS
//*XRM WATFIV
C
C
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C
C
SPANIMENT DAMAGE BREAKDOWN PROGRAM
C
C MINNESOTA FLEXIBLE AND COMPOSITE PAVEMENTS
C
C AUTHOR: C. H. NICHALAK AND T. SCULLION
C
C TEXAS TRANSPORTATION INSTITUTE
C
C TEXAS A & M UNIVERSITY
C
C COLLEGE STATION, TEXAS 77843
C
C PHONE: (713) 845-7126/845-3735
C
C
C
C IMPLICIT REAL*8 (A-H,O-Z)
C
REAL*4 RATING
C
DIMENSION DISTR(18,2), PNAME(5,2)
C
DIMENSION HEAD(10), RATING(50)
C
DIMENSION DATA(6,10), TRDATA(6,10)
C
C COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
C
= TR(10), DV(10)
C
COMMON /PVAL/ PI(5), PF
C
C DATA RATING / 4.0, 3.8, 3.6, 3.4, 3.2, 3.0, 2.9, 2.8, 2.7, 2.6,
C
1  2.5, 2.4, 2.3, 2.2, 2.1, 2.0, 1.9, 1.9, 1.8, 1.7,
C
2  1.7, 1.6, 1.5, 1.4, 1.3, 1.3, 1.2, 1.1, 1.1,
C
3  4*1.0, 7*0.9, 7*0.8, 2*0.7/
C
C
C NOP = 2
C
C NW = 3
C
C NLD = 6
C
C READ(5,106) ( (PNAME(I,J), J = 1, 2), I = 1, NOP )
C
106 FORMAT( 5( 2A8 ) )
C
READ(5,106) ( (DISTR(I,J), J = 1, 2), I = 1, 10 )
C
C READ(5,107) ( PI(I), I = 1, NOP )
C
107 FORMAT( BF10.2 )
READ(5,105) (D(I), I = 1, 10)
105 FORMAT(10F8.0)

C
READ(5,105) (T(I), I = 1, 10)
READ(5,105) (S(I), I = 1, 10)

C
DO 2 I = 1, NLD
READ(5,105) (TRDATA(I,J), J = 1, 10)
2 READ(5,105) (DFDATA(I,J), J = 1, 10)

C
READ(5,105) (OV(I), I = 1, 10)

C
NWP = 0
NOP = 0

10 CONTINUE

C
NWP = NWP + 1
NOP = NOP + 1

C
READ(5,108,END=50) (HEAD(I), I = 1, 10)
108 FORMAT(10AB)

C
READ CLIMATIC DATA AND REDUCT POINTS

C
READ(5,105) (C(I), I = 1, 10)
C(2) = C(2) + 50.0
READ(5,105) (A(I), I = 1, 10)
READ(5,105) (B(I), I = 1, 10)

C
DO 45 NRN = 1, NLD
45 DO I = 1, 10

C
TR(I) = TRDATA(NRN,I)
12 DF(I) = DFDATA(NRN,I)

C
DO 40 NP = NWP, NOP
WRITE(6,202) (HEAD(I), I = 1, 7), OV(1), T(1)
202 FORMAT(’1’, T24, 7AB, 10X, ’0T = ’, F6.1, ’MONTHS = ’, F6.1 )

C
W = 0,0
LINE = 0

C
DO 59 I = 1, NW
59 K = 0
SUML = 0,0
SUNC = 0,0
PLOAD = 0,0
PCLIN = 0,0
SUN = 0,0
W = W + TR(2) * 0.5D0

C
WRITE(6,205) I, W
DISTRESS SUBRoutines

CALL ALGCRA(W, NP, AR)
PL = PLOAD + AR*A(1)*B(1)
PCL = PCLIM + AR*A(1)*(100.0 - B(1))
SUM = SUM + AR*A(1)
SUL = SUL + AR*A(1)
SE = SE + B(1)
K = K + 1
IF(NP.NE.2) GO TO 14
WRITE(6,215)(PH(NP,J), J = 1, 2), K, (DISTR(K,J), J = 1, 2),
= AR, SE, SUL, SUM

14 CONTINUE

CALL LOCRA(W, NP, AR)
PL = PLOAD + AR*A(2)*B(2)
PCL = PCLIM + AR*A(2)*(100.0 - B(2))
SUM = SUM + AR*A(2)
K = K + 1
WRITE(6,214)(PH(NP,J), J = 1, 2), K, (DISTR(K,J), J = 1, 2),
= AR, SE, SUL

214 FORMAT(5X, 2A8, I6, 5X, 2A8, F12.4, F13.4, 18X, F9.3 )

CALL TRCRA(W, NP, AR)
PL = PLOAD + AR*A(3)*B(3)
PCL = PCLIM + AR*A(3)*(100.0 - B(3))
SUM = SUM + AR*A(3)
K = K + 1
WRITE(6,214)(PH(NP,J), J = 1, 2), K, (DISTR(K,J), J = 1, 2),
= AR, SE, SUL

CALL RUTA(W, NP, AR)
PL = PLOAD + AR*A(4)*B(4)
PCL = PCLIM + AR*A(4)*(100.0 - B(4))
SUM = SUM + AR*A(4)
SUL = SUL + AR*A(4)
K = K + 1
IF(NP.NE.2) GO TO 16
WRITE(6,215)(PH(NP,J), J = 1, 2), K, (DISTR(K,J), J = 1, 2),
= AR, SE, SUL, SUM

213 FORMAT(5X, 2A8, I6, 5X, 2A8, F12.4, F13.4, 9X, F9.3, F9.3 )

215 FORMAT(5X, 2A8, I6, 5X, 2A8, F12.4, F13.4, F9.3, 9X, F9.3 )

16 CONTINUE

CALL PATA(W, NP, AR)
154. PLOAD = PLOAD + AR*A(7)*B(7)
155. PCLIM = PCLIM + AR*A(7)*(100.0 - B(7))
156. SUM = SUM + AR * A(7)
157. SUMC = SUMC + AR * A(7)
158. K = K + 1
159. WRITE(6,213) (PNAME(NP,J), J = 1, 2), K, (DISTRS(K,J), J = 1, 2),
160. = AR, SE, SUMC, SUM
161. C
162. CALL MULT( W, NP, AR)
163. PLOAD = PLOAD + AR*A(8)*B(8)
164. PCLIM = PCLIM + AR*A(8)*(100.0 - B(8))
165. SUM = SUM + AR * A(8)
166. SUMC = SUMC + AR * A(8)
167. K = K + 1
168. WRITE(6,213) (PNAME(NP,J), J = 1, 2), K, (DISTRS(K,J), J = 1, 2),
169. = AR, SE, SUMC, SUM
170. 216 FORMAT( 5X, 2AI8, 16, 5X, 2AI8, 12X, FI3.4, 2F9.3 )
171. C
172. CALL PSI( W, NP, P)
173. PN = PI(NP) - P
174. K = K + 1
175. WRITE(6,216) (PNAME(NP,J), J = 1, 2), K, (DISTRS(K,J), J = 1, 2),
176. = P
177. WRITE(6,217) PF
178. 217 FORMAT( "+", Ti05, "PF = ", G8.2 )
179. C
180. ISUM = IINT(SUM)
181. RSUM = SUM - ISUM
182. ISUM = ISUM + 1
183. CURSCR = RATING(ISUM) - RSUM*(RATING(ISUM) - RATING(ISUM + 1))
184. DISDED = 4.0 - CURSCR
185. TOTDED = DISDED + PN
186. SLOAD = SML*DISDED / SUM
187. SCONB = ( SUMC * DISDED / SUM ) + PN
188. C
189. RATIO1 = SLOAD / TOTDED
190. RATIO2 = ( SCONB + SLOAD ) / TOTDED
191. C
192. WRITE(6,216)
193. 245 FORMAT( "0" )
194. WRITE(6,210)
195. 210 FORMAT( T23, "LOAD NO. OF" / T6, "PAVEMENT TYPE",
196. = T23, "LEVEL 10-K EQUIV"
197. = "RATIO 1 RATIO 2 PSRDED VIS DED" )
198. C
199. WRITE(6,220) (PNAME(NP,J), J = 1, 2), I, W, RATIO1, RATIO2,
200. 1 PN, DISDED
201. 220 FORMAT( 5X, 2AI8, 14, 5F14.3 )
202. C
203. LINE = LINE + 1
204. IF( LINE .EQ. 3 ) WRITE(6,202) (HEAD(L), L = 1, 7), OV(1), I(1)

K-5
285. IF( LINE .EQ. 3 ) LINE = 0
286. IF( LINE .EQ. 0 ) GO TO 30
287. WRITE(6,245)
288. C
289. 30 CONTINUE
290. 40 CONTINUE
291. 45 CONTINUE
292. C
293. GO TO 10
294. 50 WRITE(6,250)
295. 250 FORMAT( '1' )
296. STOP
297. END
298. C
299. SUBROUTINE ALGOA ( W, NP, AR )
300. IMPLICIT REAL*8 (A-H,O-Z)
301. COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
302. = TR(10), OV(10)
303. C
304. AR = 0.0
305. GO TO ( 10, 20 ), NP
306. GO TO 70
307. 10 A1 = DEXP( - ( 19.65 *OV(1)**0.144)/(W **0.0354*DF(1)**0.145
308. = *T(1)**0.150) )
309. GO TO 60
310. 20 A1 = 0.0
311. GO TO 60
312. 60 AR = A1
313. 70 RETURN
314. END
315. C
316. SUBROUTINE LOCRA ( W, NP, AR )
317. IMPLICIT REAL*8 (A-H,O-Z)
318. COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
319. = TR(10), OV(10)
320. C
321. AR = 0.0
322. GO TO ( 10, 20 ), NP
323. GO TO 70
324. 10 A1 = DEXP( - ( 10.85 *OV(1)**0.0886)/(TR(1)**0.151*T(1)**0.285*
325. = DF(2)**0.278 ))
326. GO TO 60
327. 20 A1 = DEXP( - ( 9.75*OV(1)**0.337*DF(3)**0.189*T(1)**0.2759)/
328. = (T(1)**0.741 ))
329. 60 AR = A1
330. 70 RETURN
331. END
332. C
333. SUBROUTINE TRCRA ( W, NP, AR )
334. IMPLICIT REAL*8 (A-H,O-Z)
335. COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
256. = TR(10), OV(10)
257. C
258. AR = 0.0
259. GO TO (10, 20), NP
260. GO TO 70
261. 10 A1 = DEXP( - ( 1.82*D(1)**0.706)/(W) **0.2552*D(1)**0.701* 
262. = T(1)**0.4 )
263. GO TO 60
264. 20 A1 = DEXP( - ( 1.361*D(1)**1.35*W **0.7537)/(D(3)**0.103* 
265. = T(1)**0.895 )
266. 60 AR = A1
267. 70 RETURN
268. END
269. C
270. SUBROUTINE RATA ( W, NP, AR )
271. IMPLICIT REAL*8 (A-H,O-Z)
272. COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10), 
273. = TR(10), OV(10)
274. C
275. AR = 0.0
276. GO TO (10, 20), NP
277. GO TO 70
278. 10 A1 = DEXP( - ( 18.8*D(1)**0.114)/(W) **0.0151*D(1)**0.199* 
279. = T(1)**0.23 )
280. GO TO 60
281. 20 A1 = 0.0
282. 60 AR = A1
283. 70 RETURN
284. END
285. C
286. SUBROUTINE PATA ( W, NP, AR )
287. IMPLICIT REAL*8 (A-H,O-Z)
288. COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10), 
289. = TR(10), OV(10)
290. C
291. AR = 0.0
292. GO TO (10, 20), NP
293. GO TO 70
294. 10 A1 = DEXP( - ( 32.69)/(W) **0.076*D(1)**0.36*T(1)**0.233 )
295. GO TO 60
296. 20 A1 = DEXP( - ( 148.71*V(1)**0.18)/(W) **0.1612*T(1)**0.222* 
297. = DF(3)**0.169 )
298. 60 AR = A1
299. 70 RETURN
300. END
301. C
302. SUBROUTINE MULT ( W, NP, AR )
303. IMPLICIT REAL*8 (A-H,O-Z)
304. COMMON /VAL/ A(10), B(10), C(10), D(10), DF(10), S(10), T(10), 
305. = TR(10), OV(10)
306. C
AR = 0.0
GO TO (10, 20), NP
GO TO 70

10 A1 = DEXP( - ( 19.47*OV(1)**0.348)/(W **0.003*DF(1)**0.27*T(1)
        = **0.522 )))
GO TO 60

20 A1 = DEXP( - ( 82.1*OV(1)**0.566)/(W **0.0889*T(1)**0.405*
        = DF(3)**0.144 ))
60 AR = A1
70 RETURN
END

C
SUBROUTINE PSI ( W, NP, P )
IMPLICIT REAL*8 (A-H,O-Z)
COMMON /VAL/, A(10), B(10), C(10), D(10), DF(10), S(10), T(10),
        = TR(10), OV(10)
COMMON /IVAL/, PI(5), PF
C
P = PI(NP)
GO TO (10, 20), NP
GO TO 70
10 XK = DEXP( - ( 9.757)/(W **0.0027*T(1)**1.087*OV(1)**0.0068 ))
        PF = 1.111*(W **0.0449*T(1)**0.0504)/(DF(1)**0.0796*OV(1)**
        = **0.00281 )
60 GO TO 60
20 XK = DEXP( - ( 1141.2*T(1)**0.0427)/(W **1.01162*OV(1)**0.0351
        = *DF(3)**0.0114 ))
40 PF = 1.576*(TR(1)**0.0319*T(1)**0.0367*DF(3)**0.0444)/(OV(1)**
        = 0.03406 )
60 P = PI(NP) - (PI(NP) -PF) * XK
70 RETURN
END

//DATA
OVERLAID FLEXIBLE OVERLAID CONCRETE
ALLIGTR CRACKING LONGIT CRACKING TRANSVS CRACKING RUTTING PATCHING
MULTIPLE CRACKING PRESENT SERV IND
3.75 3.75
0.50
60.0
5.0 50.0 30.0 40.0
2000.0 1000000.
1.5 1.0 2.25
2000.0 1000000.
0.4 0.2 0.8
5000.0 3000000.
1.5 1.0 2.25
5000.0 3000000.
0.4 0.2 0.8
10000.0 10000000.
1.5 1.0 2.25
10000.0 10000000
<table>
<thead>
<tr>
<th>358.</th>
<th>0.4</th>
<th>0.2</th>
<th>0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>359.</td>
<td>3.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>360.</td>
<td>MINNESOTA III (MINNEAPOLIS) OVERLAID FLEXIBLE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>361.</td>
<td>-83.789</td>
<td>20.0</td>
<td>67.0</td>
</tr>
<tr>
<td>362.</td>
<td>35.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>363.</td>
<td>100.0</td>
<td>10.0</td>
<td>0.0</td>
</tr>
<tr>
<td>364.</td>
<td>MINNESOTA III (MINNEAPOLIS) OVERLAID CONCRETE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>365.</td>
<td>-83.789</td>
<td>20.0</td>
<td>67.0</td>
</tr>
<tr>
<td>366.</td>
<td>0.0</td>
<td>17.0</td>
<td>17.0</td>
</tr>
<tr>
<td>367.</td>
<td>0.0</td>
<td>20.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>
APPENDIX L

PAVEMENT RATING SYSTEM SUMMARIES USED WITH TEXAS
FLEXIBLE AND ILLINOIS RIGID PAVEMENT EQUATIONS

L-1
PAVEMENT RATING SYSTEM SUMMARIES

ALASKA

General: Alaska uses a sufficiency rating report based on a collective count of all surface failures per mile. The rating system applies only to flexible pavements. Alaska has no rigid pavements in its highway system.

ARIZONA

I. General

1. Basic Composition: A sufficiency rating system is used for both flexible and rigid pavement systems. Ratings are derived primarily from visual observations.

2. Measuring Equipment Used: Unknown

3. Rating Team Composition: Unknown

4. Rating Frequency: Every two years.

5. Other: Arizona is currently in the process of modifying existing rating system to include Mays Meter, Dynaflect and Mu Meter measurements. Additionally, features such as cracking, rutting, shoving will be measured on a 1,000 sq. ft. area at each mile post. Wear, weathering, popouts and other surface deficiencies will be rated on a scale from 1 to 5.

II. Brief Outline of System

1. Condition

<table>
<thead>
<tr>
<th></th>
<th>Max Available Points</th>
<th>Point Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>A. Structural adequacy</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>B. Anticipated remaining life</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>C. Maintenance economy</td>
<td>35</td>
<td>0</td>
</tr>
</tbody>
</table>

L-2
2. **Safety**

Max Available Points **30**

<table>
<thead>
<tr>
<th>Point Range</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Roadway width</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>B. Surface width</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>C. Sight distance</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>D. Consistency</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

3. **Service**

Max Available Points **35**

<table>
<thead>
<tr>
<th>Point Range</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Alignment</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>B. Passing opportunity</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>C. Surface width</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>D. Ride quality</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

III. **Summation**

1. Can a resulting numerical rating be defined? __Yes__

2. If yes, define range: __Better Pavements__

    ![Rating Scale]

    __Poorer Pavements__

3. Numerical rating adjusted for traffic? __Yes__

4. Is assistance of rating system used in determining maintenance priorities at this time? __Yes__

**ARKANSAS**

**General:** Arkansas does not use a numerical weighting system for evaluating pavements at the present time. The Planning and Research Division has conducted inspection ratings for a few sections of pavement. These inspection ratings were conducted for both flexible and rigid pavements. The following are considered on each rating form:
1. Flexible Pavements
   A. Cracking
   B. Texture
   C. Patching
   D. Rut Depth

2. Rigid Pavements
   A. Corner cracking
   B. Edge cracking
   C. Longitudinal cracking
   D. Transverse cracking
   E. Scaling
   F. Spalling
   G. Faulting joints
   H. Concrete disintegration
   I. Pumping
   J. Loss of joint filling
   K. Slab settlement
   L. Slab heaving
   M. Patching
   N. Local reconstruction
   O. Surface roughness
   P. Surface drainage (ponding)
   Q. Shoulder condition
   R. General condition

CALIFORNIA

I. General

1. Basic Composition: California uses a condition rating number to rate flexible pavements and partially rates rigid pavements with a ride rating. The condition rating is derived from both mechanical and visual measurements.


3. Rating Team Composition: Five to six teams, two men each team.

4. Rating Frequency: Every two years.

5. Other: The rating of flexible pavements considers both a ride and defect score. Rigid pavements are currently rated by a ride score only.
II. Brief Outline of System

1. **Ride Score**
   Max Available Negative Points 100
   Score obtained from Cox Ride Meter with 100 points representing the roughest conditions.

2. **Defect Score**
   Max Available Negative Points 310
   \[
   \text{Point Range} \quad \text{Min} \quad \text{Max}
   \]
   
<table>
<thead>
<tr>
<th>Description</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Alligating block cracks</td>
<td>0</td>
<td>96</td>
</tr>
<tr>
<td>B. Transverse cracks</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>C. Longitudinal cracks</td>
<td>0</td>
<td>48</td>
</tr>
<tr>
<td>D. Raveling</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>E. Rutting</td>
<td>0</td>
<td>48</td>
</tr>
<tr>
<td>F. Patching</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>G. Rainfall</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

3. Condition Rating = $\sqrt{\text{Ride Rating} \times \sum \text{Defect Score}}$

III. Summation

1. Can a resulting numerical rating be defined? **Yes**

2. If yes, define range: 
   
   \[
   \begin{array}{c}
   \text{Better Pavements}
   \end{array} \quad \begin{array}{c}
   0 \quad 176
   \end{array} \quad \begin{array}{c}
   \text{Poorer Pavements}
   \end{array}
   \]

3. Numerical rating adjusted for traffic? **No, but traffic considered in maintenance decisions.**

4. Is assistance of rating system used in determining maintenance priorities at this time? **Yes**

COLORADO

**General:** Colorado uses a sufficiency type of rating system. Unfortunately, part of the information package sent was not received
precluding a complete examination of their system. It was determined from the information available that the rating includes measurements of skid and slope variance.

CONNECTICUT

General: Connecticut does not use a numerical weighting system for evaluating pavements. Visual inspections are made twice a year to determine priority lists of work requirements.

FLORIDA

I. General

1. Basic Composition: Florida uses a condition rating number to rate flexible pavements and will evaluate rigid pavements as soon as procedures are developed. The condition rating is derived from both mechanical and visual measurements.


3. Rating Team Composition: Five teams, two men each team

4. Rating Frequency: Annually

5. Other: The present system may be adjusted somewhat as data becomes available.

II. Brief Outline of System

1. Ride Rating Max Available Points 100

Using Mays Meter, rating will be calculated from a value of 0 to 100 with 100 being the theoretically perfect ride.
2. **Defect Rating**

Max Available Points 100

Allotted initial value of 100 with defect values deducted from this number for various degrees of pavement distress. Defect values based on cracking, rutting and patching.

A. **Cracking**

<table>
<thead>
<tr>
<th>% of Area (up to)</th>
<th>Nonconnected</th>
<th>Alligator</th>
<th>Spalling</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>5</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>50</td>
<td>10</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>75</td>
<td>15</td>
<td>22</td>
<td>30</td>
</tr>
<tr>
<td>100</td>
<td>20</td>
<td>30</td>
<td>40</td>
</tr>
</tbody>
</table>

Note: Can combine different types of cracking

B. **Deduct Points for Patching**

- 5 Light (less than 50 ft²/100 ft of lane)
- 10 Moderate (50 to 100 ft²/100 ft of lane)
- 15 Severe (more than 100 ft²/100 ft of lane)

C. **Rutting**

<table>
<thead>
<tr>
<th>Avg. Depth</th>
<th>Deduct Points</th>
<th>Avg. Depth</th>
<th>Deduct Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8&quot;</td>
<td>5</td>
<td>5/8&quot;</td>
<td>25</td>
</tr>
<tr>
<td>1/4&quot;</td>
<td>10</td>
<td>3/4&quot;</td>
<td>30</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>15</td>
<td>7/8&quot;</td>
<td>35</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>20</td>
<td>1&quot;</td>
<td>40</td>
</tr>
</tbody>
</table>

3. **Final Rating** = \sqrt{\text{Ride Rating} \times \text{Defect Rating}}

III. **Summation**

1. Can a resulting numerical rating be defined? **Yes**

2. If yes, define range: Better Pavements 100 | 0 Poorer Pavements

3. Numerical rating adjusted for traffic? **Yes**

4. Is assistance of rating system used in determining maintenance priorities at this time? **Yes**
I. General
1. **Basic Composition:** Georgia uses a numerical rating system for flexible pavements only. The rating system in use is mainly a function of mechanical measurements such as those made with the Dynaflect, Wisconsin Roadmeter and skid measurements. Additionally, a subjective visual rating is or can be performed.

2. **Measuring Equipment Used:** Dynaflect, Wisconsin Roadmeter and skid measurements.

3. **Rating Team Composition:** Unknown

4. **Rating Frequency:** Unknown

5. **Other:** The visual rating is based on a 0 to 10 scale with 10 representing very poor pavements and 0 very good or excellent pavements. This system is primarily used to evaluate the system described below.

II. Brief Outline of System

1. **Serviceability Condition**
   
   Serviceability condition is determined by obtaining the average roughness per mile with the Wisconsin Roadmeter. A roughness count of 1200 is assigned a rating of 100 and a roughness count of 200 is assigned a rating of 0.

2. **Structural Condition**
   
   The Dynaflect is used in determining structural condition. The three deflection parameters calculated are Dynaflect Maximum Deflection, Surface Curvature Index and Base Curvature Index. The actual deflection parameters are compared against maximum
deflection parameters which should exist at the present time in order to obtain a serviceability level of 2.5 at the end of the design period. This comparison results in an appropriate rating for the structural condition.

3. **Skid Resistance**

   Max Available Negative Points 100

   Skid resistance is a function of the skid level at 40 mph and an adjustment factor which depends on mix type and vehicle speed. This information is placed into an equation to obtain the skid resistance rating:

   \[ \text{Total Rating} = \text{Traffic Factor} \times \left( \frac{\text{Roughness} + 1.5 \times \text{Skid} + 1.5 \times \text{Structure}}{4} \right) \]

III. **Summation**

1. Can a resulting numerical rating be defined? **Yes**

2. If yes, define range:

   Better Pavements 0 - 100

   Poorer Pavements

3. Numerical rating adjusted for traffic? **Yes**

4. Is assistance of rating system used in determining maintenance priorities at this time? **Unknown**

**HAWAII**

**General:** Hawaii does not use a numerical rating system for evaluating pavements.

**IDAHO**

**General:** Idaho uses a sufficiency rating system similar to that used by Arizona. Idaho is currently reassessing its position relative to the present system.
INDIANA

I. General

1. **Basic Composition:** A sufficiency rating system is used to evaluate both flexible and rigid pavements. Ratings are obtained primarily from visual observations.

2. **Measuring Equipment Used:** None

3. **Rating Team Composition:** Two, two man teams from each district for each of the six districts in Indiana.

4. **Rating Frequency:** Annually

5. **Other:** Indiana uses separate rating systems for rural and urban highways. The two are similar with only slight variations. The rural system is presented below.

II. Brief Outline of System

1. **Geometrics**

<table>
<thead>
<tr>
<th></th>
<th>Point Range</th>
<th>Max Available Points 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Surface type</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>B. Surface width</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>C. Shoulder Type</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>D. Shoulder width</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>E. Stopping sight distance</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>F. Alignment consistency</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>G. Passing opportunity</td>
<td>0</td>
<td>9</td>
</tr>
</tbody>
</table>
2. **Condition**

<table>
<thead>
<tr>
<th></th>
<th>Max Available Points</th>
<th>Point Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Structural adequacy</td>
<td>40</td>
<td>Min Max</td>
</tr>
<tr>
<td>B. Drainage adequacy</td>
<td>40</td>
<td>Min Max</td>
</tr>
<tr>
<td>C. Rideability</td>
<td>40</td>
<td>Min Max</td>
</tr>
<tr>
<td>D. Traffic control</td>
<td>40</td>
<td>Min Max</td>
</tr>
</tbody>
</table>

III. **Summation**

1. Can a resulting numerical rating be defined? **Yes**

2. If yes, define range. **100** Better Pavements **0** Poorer Pavements

3. Numerical rating adjusted for traffic? **Yes**

4. Is assistance of rating system used in determining maintenance priorities at this time? **No**

**KANSAS**

I. **General**

1. **Basic Composition:** Kansas has a point rating system for both flexible and rigid pavements. Ratings are derived primarily from visual observations.

2. **Measuring Equipment Used:** Roughmeter

3. **Rating Team Composition:** One man surveys entire state.

4. **Rating Frequency:** Unknown

5. **Other:** System based on a maximum of 100 points available for a theoretically perfect pavement. In the outline below is shown the maximum amount of points allowed for the various items listed.
II. Brief Outline of System

1. Flexible Pavements

<table>
<thead>
<tr>
<th></th>
<th>Point Range</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td></td>
</tr>
<tr>
<td>A. Surface information</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>B. Transverse cracks</td>
<td>1</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>C. Transverse crack type</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>D. Longitudinal cracking</td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>E. Crack pouring</td>
<td>3</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>F. Original roadway design</td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>G. Surface required</td>
<td>3</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>H. Dilute seal</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>I. Skid resistance</td>
<td>2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>J. Uniformity of surface texture and color</td>
<td>2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>K. Wheel ruts</td>
<td>3</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>L. Structural adequacy</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

2. Rigid Pavements

<table>
<thead>
<tr>
<th></th>
<th>Point Range</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td></td>
</tr>
<tr>
<td>A. Roughometer</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>B. Curb Condition</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>C. Joints Filled</td>
<td>0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>D. Undulations</td>
<td>1</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>E. Scaling</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>F. Faulting</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>G. Spalling</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>H. Structural adequacy</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
I. Cracking

(1) Random 1 5
(2) Longitudinal 1 6
(3) Transverse 1 5

J. Surface patching required 3 18

K. "D" Cracking 2 8

L. Skid resistance 1 4

M. Crack pouring completed 0 10

III. Summation

1. Can a resulting numerical rating be defined? _Yes_

2. If yes, define range. 100 | | | | | | | | | | | | | | | | | | | | 18
   Better Pavements 16
   Poorer Pavements

3. Numerical rating adjusted for traffic? _No_

4. Is assistance of rating system used in determining maintenance priorities at this time? _Yes_

KENTUCKY

General: Kentucky uses a numerical rating system to establish priorities for their resurfacing program. The system applies to bituminous surfaces only and considers three categories. They are:

1. Service
2. Condition
3. Safety

LOUISIANA

I. General

1. Basic Composition: Louisiana uses a sufficiency rating for both
flexible and rigid pavements. Ratings are derived from a combination of both visual and mechanical measurements.

2. Measuring Equipment Used: Roughometer (Mays Meter) and skid measurements.

3. Rating Team Composition: Unknown

4. Rating Frequency: Unknown

5. Other: Louisiana uses separate rating systems for rural and urban highways. Both systems are similar in composition. The rural rating system is presented below.

II. Brief Outline of System

1. Condition

<table>
<thead>
<tr>
<th>Max Available Points 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point Range</td>
</tr>
<tr>
<td>Min</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>A.</td>
</tr>
<tr>
<td>B.</td>
</tr>
<tr>
<td>C.</td>
</tr>
<tr>
<td>D.</td>
</tr>
<tr>
<td>E.</td>
</tr>
<tr>
<td>F.</td>
</tr>
</tbody>
</table>

2. Service - volume/capacity ratio

3. Safety

<table>
<thead>
<tr>
<th>Max Available Points 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point Range</td>
</tr>
<tr>
<td>Min</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>A.</td>
</tr>
<tr>
<td>B.</td>
</tr>
<tr>
<td>C.</td>
</tr>
<tr>
<td>D.</td>
</tr>
</tbody>
</table>
III. Summation

1. Can a resulting numerical rating be defined? Yes

2. If yes, define range. Better Pavements
   ↓
   100
   ↓
   Poorer Pavements

3. Numerical rating adjusted for traffic? Yes

4. Is assistance of rating system used in determining maintenance
   priorities at this time? Yes

MAINE

I. General

1. Basic Composition: Maine uses a numerical rating system employing
   weighting coefficients for flexible pavements. It is not known if
   Maine employs a separate system for rigid pavements. Ratings are
   derived from visual observations.

2. Measuring Equipment Used: None

3. Rating Team Composition: Unknown

4. Rating Frequency: Unknown

5. Other: Maine has more than one rating system some of which are
   mechanical and visual systems. Each system is designed for use
   on a specific problem or is directly correlated to the system
   outlined below. For the system outlined, ratings are obtained
   for the surfacing, base, and overall pavement structure. This
   is done to account for the distress as exhibited by their pavements.
II. Brief Outline of System

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Pavement</th>
<th>Base</th>
<th>Overall</th>
<th>Point Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Centerline Crack</td>
<td>0.08</td>
<td>0.02</td>
<td>0.05</td>
<td>1 5</td>
</tr>
<tr>
<td>B. Random Cracks</td>
<td>0.03</td>
<td>0.03</td>
<td>0.14</td>
<td>1 5</td>
</tr>
<tr>
<td>C. Hairchecks</td>
<td>0.05</td>
<td>0.03</td>
<td>0.02</td>
<td>1 5</td>
</tr>
<tr>
<td>D. Alligator Cracks</td>
<td>0.08</td>
<td>0.22</td>
<td>0.15</td>
<td>1 5</td>
</tr>
<tr>
<td>E. Temperature Cracks</td>
<td>0.17</td>
<td>0.08</td>
<td>0.08</td>
<td>1 5</td>
</tr>
<tr>
<td>F. Rutting</td>
<td>0.07</td>
<td>0.20</td>
<td>0.14</td>
<td>1 5</td>
</tr>
<tr>
<td>G. Distortion</td>
<td>0.05</td>
<td>0.23</td>
<td>0.14</td>
<td>1 5</td>
</tr>
<tr>
<td>H. Washboard</td>
<td>0.09</td>
<td>0.10</td>
<td>0.05</td>
<td>1 5</td>
</tr>
<tr>
<td>I. Pitting</td>
<td>0.29</td>
<td>0.09</td>
<td>0.14</td>
<td>1 5</td>
</tr>
<tr>
<td>J. General Overall</td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
<td>1 5</td>
</tr>
</tbody>
</table>

2. Calculated Rating = Σ(characteristic point scores x weighting coeff.)

Note: All characteristic point scores are multiplied by the appropriate weighting coefficient and summed. This results in a pavement rating number between 1 and 5.

III. Summation

1. Can a resulting numerical rating be defined? Yes

   Better Pavements

2. If yes, define range: 5 | | | | | | | | | | 1

   Poorer Pavements

3. Numerical rating adjusted for traffic? No

4. Is assistance of rating system used in determining maintenance priorities at this time? Unknown
MARYLAND

I. General

1. Basic Composition: Present system uses visual observations to
determine pavement rating and is used to evaluate both flexible
and rigid pavements.

2. Measuring Equipment Used: None

3. Rating Team Composition: One man assisted by local personnel.

4. Rating Frequency: Annually

5. Other: Maryland is currently participating in a research project
to develop a Highway Serviceability Index. This index will con-
sider surface roughness, visual ratings and skid resistance. The
end result will be a method that assists in determining where
safety and maintenance appropriations should be spent. Presented
below is the current composition of the present rating system.

II. Brief Outline of System

1. Surface Rating

   Max Available Points 40

   Considers: A. Cracking

   B. Alligatoring

   C. Rutting

   D. Patching

   E. Raveling

   F. Defective joints

   G. Cracked panels

   H. Scaling

   I. Cross section

   J. Profile section
2. **Drainage Rating**

3. **Shoulder Rating**

4. **Major Structures Rating**

5. **Minor Structures Rating**

6. **Roadside Rating**

7. **Traffic Service Rating**

Max Available Points: 25  
Max Available Points: 10  
Max Available Points: 10  
Max Available Points: 5  
Max Available Points: 5  
Max Available Points: 5

### III. Summation

1. Can a resulting numerical rating be defined? **Yes**

2. If yes, define range:

   
   ![Range Diagram]

   Better Pavements  

   Poorer Pavements

3. Numerical rating adjusted for traffic? **No**

4. Is assistance of rating system used in determining maintenance priorities at this time? **Unknown**

**Michigan**

**General:** Michigan uses two procedures for determining resurfacing or reconstruction requirements. First, an annual sufficiency type of survey is performed which is a general opinion of the rater and involves no measurements. This survey is used to identify those roads which should be inspected in more detail. Secondly, a measurement of Present Serviceability Index (PSI) may be made as additional justification for resurfacing or reconstruction projects. For determining PSI, ride quality (using a General Motors type Travel Profilometer), linear feet of cracks, areas of patches, and rut depths (bituminous pavements only) are measured.
MINNESOTA

I. General

1. Basic Composition: Minnesota uses a condition rating system for both flexible and rigid pavements. Ratings are derived primarily from visual observations and from mechanical measurements.


3. Rating Team Composition: One rating team for each of the nine districts, generally two men each team.

4. Rating Frequency: Annually

5. Other: Minnesota uses a Present Serviceability Rating (PSR) and Structural Rating (SR) combined to result in a Condition Rating (CR). Initially, they used three man teams to rate PSR but found this did not result in the desired accuracy. Therefore, the decision was made to use the PCA Roadmeter to achieve greatly improved results.

II. Brief Outline of System

Pavements are rated according to composition in three separate categories: bituminous, concrete and bituminous overlayed concrete pavements.

1. Present Serviceability Rating Max Available Points 5
   Determined for all three types of pavements with the PCA Roadmeter.

2. Structural Rating Max Available Points 5
**Bituminous Pavements**

SR = $\Sigma(\% \text{ occurrence each deficiency } \times \text{ weighting factor})$, converted to a number between 0 and 5.

<table>
<thead>
<tr>
<th>Deficiency</th>
<th>Weighting Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Transverse cracking</td>
<td>0.02</td>
</tr>
<tr>
<td>B. Longitudinal cracking</td>
<td>0.02</td>
</tr>
<tr>
<td>C. Multiple cracking</td>
<td>0.15</td>
</tr>
<tr>
<td>D. Alligator cracking</td>
<td>0.35</td>
</tr>
<tr>
<td>E. Rutting</td>
<td>0.15</td>
</tr>
<tr>
<td>F. Patching</td>
<td>0.30, 0.99</td>
</tr>
</tbody>
</table>

**Concrete Pavements**

SR = $\Sigma(\% \text{ occurrence each deficiency, converted to a number between 0 and 5 } \times \text{ weighting factor})$

<table>
<thead>
<tr>
<th>Deficiency</th>
<th>Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Joints</td>
<td></td>
</tr>
<tr>
<td>(1) Spalled</td>
<td>0.25</td>
</tr>
<tr>
<td>(2) Faulted</td>
<td>0.10</td>
</tr>
<tr>
<td>B. Panels</td>
<td></td>
</tr>
<tr>
<td>(1) Cracked</td>
<td>0.10</td>
</tr>
<tr>
<td>(2) Broken</td>
<td>0.10</td>
</tr>
<tr>
<td>(3) Faulted cracks</td>
<td>0.10</td>
</tr>
<tr>
<td>C. Patches</td>
<td></td>
</tr>
<tr>
<td>(1) Area of 5 ft$^2$ or more</td>
<td>0.20</td>
</tr>
<tr>
<td>(2) Complete overlay</td>
<td>0.10</td>
</tr>
<tr>
<td>D. Scale</td>
<td>0.05, 1.00</td>
</tr>
</tbody>
</table>

**Bituminous Overlaid Concrete Pavements**

SR = $\Sigma(\% \text{ occurrence each deficiency, converted to a number between 0 and 5 } \times \text{ weighting factor})$
Deficiency  

<table>
<thead>
<tr>
<th></th>
<th>Weighting Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Cracking</td>
<td></td>
</tr>
<tr>
<td>(1) Slight transverse</td>
<td>0.05</td>
</tr>
<tr>
<td>(2) Severe transverse</td>
<td>0.30</td>
</tr>
<tr>
<td>(3) Slight longitudinal</td>
<td>0.05</td>
</tr>
<tr>
<td>(4) Severe longitudinal</td>
<td>0.30</td>
</tr>
<tr>
<td>(5) Multiple</td>
<td>0.10</td>
</tr>
<tr>
<td>B. Patching</td>
<td>0.20</td>
</tr>
</tbody>
</table>

3. Condition Rating = \( \frac{PSR + SR}{2} \)

III. Summation

1. Can a resulting numerical rating be defined? Yes

2. If yes, define range: \( 5 \leq \frac{PSR + SR}{2} \leq 0 \)

3. Numerical rating adjusted for traffic? No, but Minnesota considers traffic in arriving at final maintenance priorities.

4. Is assistance of rating system used in determining maintenance priorities at this time? Yes

MISSISSIPPI

General: Mississippi does not use a rating system at the present time.

MISSOURI

General: Missouri does not use written guidelines or rating criteria at this time.
MONTANA

General: Montana uses a sufficiency rating system. One individual rates all the highways maintained by the Department of Highways. A detailed summary of the Montana system was not received.

NEBRASKA

I. General

1. Basic Composition: A sufficiency rating system is used for both flexible and rigid pavements. Ratings are derived primarily from mechanical measurements with contributions from visual determinations.

2. Measuring Equipment Used: Dynaflect, Nebraska Roadmeter, skid measuring equipment conforming to ASTM E 274.

3. Rating Team Composition: Unknown

4. Rating Frequency: Every two years

5. Other: System as described below will be used for the 1975 rating survey and is a modified version of the one used for the 1973 survey.

II. Brief Outline of System

1. Condition

<table>
<thead>
<tr>
<th>Max Available Points</th>
<th>40</th>
</tr>
</thead>
</table>

Point Range

<table>
<thead>
<tr>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

A. Structural Adequacy

(1) Flexible pavement: Computed from a formula which is a function of average daily traffic and dynaflect deflection.
(2) Rigid pavement: Two separate categories - one for rigid pavement with flexible overlay and one for rigid pavement without flexible overlay. A formula is used for both categories to compute structural adequacy. Formula for rigid pavement with flexible overlay is a function of average daily traffic, thickness of concrete, thickness of asphaltic concrete overlay and roadmeter data. Formula for rigid pavement without flexible overlay is function of average daily traffic, thickness of concrete and roadmeter data.

<table>
<thead>
<tr>
<th>Point Range</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. Roughness</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

(1) Flexible pavement: Computed from a formula which is a function of roadmeter data, cracking, patching and rut depth.

(2) Rigid pavement: Computed from a formula which is a function of roadmeter data, rigid pavement age and rigid pavement thickness for rigid pavements without flexible overlay. Function of roadmeter data and flexible overlay age for rigid pavements with flexible overlay.

2. Safety and Service

<table>
<thead>
<tr>
<th>Max Available Points</th>
<th>60</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Point Range</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Surface width</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>B. Shoulder width and condition</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>
C. Stopping sight distance 0 10
D. Passing opportunity 0 10
E. Consistency 0 7
F. Foreslopes 0 8
G. Skid 0 10

III. Summation
1. Can a resulting numerical rating be defined? Yes
   Better Pavements
2. If yes, define range: 100 | | | | 0
   Poorer Pavements
3. Numerical rating adjusted for traffic? Yes
4. Is assistance of rating system used in determining maintenance priorities at this time? Yes

NEW HAMPSHIRE

General: New Hampshire does not use a rating system for evaluating pavements at the present time. For flexible pavements, most of their observed pavement distress is either longitudinal or transverse cracking. New Hampshire has only a small amount of rigid pavement.

NEW JERSEY

General: New Jersey is currently in the process of establishing a sufficiency rating system for both flexible and rigid pavements. The rating system will be comprised of surface roughness as measured by the Mays Meter and physical measurement of pavement deterioration and failures. Three pavement categories will be rated: rigid, flexible, and composite (asphalt concrete overlays over portland cement concrete). Rigid pavements
shall receive heavy weighting on spalling, cracking, and patching. Flexible pavement weighting shall concentrate on rutting, patching, and cracking. Composite pavements shall be primarily weighted on patching and degree of reflection cracking.

NEW MEXICO

I. General

1. Basic Composition: New Mexico uses a sufficiency type rating system for both flexible and rigid pavements. Ratings are derived from visual observations.

2. Measuring Equipment Used: None

3. Rating Team Composition: One man

4. Rating Frequency: Annually

5. Other: Evaluation of New Mexico highways is not based solely on the point system as summarized below. If any highway section has a "critical deficiency" in any one of its major rating categories, the section is singled out for corrective action.

II. Brief Outline of System

1. Structural Adequacy

   A. Foundation
   B. Surface
   C. Drainage

   Max Available Points 50

   
   \[
   \begin{array}{c|c|c}
   \text{Point Range} & \text{Min} & \text{Max} \\
   \hline
   \text{A. Foundation} & 0 & 10 \\
   \text{B. Surface} & 0 & 30 \\
   \text{C. Drainage} & 0 & 10 \\
   \end{array}
   \]

2. Safety

3. Capacity

   Max Available Points 20

   Max Available Points 30

L-25
III. Summation

1. Can a resulting numerical rating be defined? Yes

2. If yes, define range: 100 Better Pavements 0 Poorer Pavements

3. Numerical rating adjusted for traffic? Yes

4. Is assistance of rating system used in determining maintenance priorities at this time? Yes

NORTH CAROLINA

General: For flexible pavements, North Carolina uses the rating system contained in HRB Digest #48, July, 1973, entitled "Surface Condition Rating System for Bituminous Pavements". North Carolina has no established rating system for rigid pavements at the present time, but the heaviest weights are placed on pumping, broken pavement, and intersecting cracks.

NORTH DAKOTA

I. General

1. Basic Composition: North Dakota uses a pavement condition rating for flexible pavements only. This rating is derived from visual observations and used in conjunction with a Mays Meter survey and other considerations to establish maintenance priorities.

2. Measuring Equipment Used: None

3. Rating Team Composition: Unknown

4. Rating Frequency: Unknown

5. Other: A pavement with a score of 25 or greater is generally considered in need of immediate maintenance.
II. Brief Outline of System

1. Surface Cracking

Max Available Negative Points 24

<table>
<thead>
<tr>
<th></th>
<th>Point Range</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>A. Transverse cracking</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>B. Fatigue cracking</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>C. Transverse crack widths</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>D. Longitudinal cracking</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>E. Crack spalling</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>F. Map cracking</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>G. Alligator cracking</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

2. Surface Distortion

Max Available Negative Points 13

<table>
<thead>
<tr>
<th></th>
<th>Point Range</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>A. Rutting</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>B. Shoving</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>C. Potholes</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>D. Raveling</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

3. Maintenance Effort

Max Available Negative Points 6

<table>
<thead>
<tr>
<th></th>
<th>Point Range</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>A. Scotch patching</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>B. Mix patching</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

4. Other considerations

Max Available Negative Points 6

<table>
<thead>
<tr>
<th></th>
<th>Point Range</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>A. Seal condition</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>B. Shoulder condition</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>
III. Summation

1. Can a resulting numerical rating be defined? Yes
   ← Better Pavements

2. If yes, define range: 0 | | | | | | | | | | | | | 49
   Poorer Pavements →

3. Numerical rating adjusted for traffic? Unknown

4. Is assistance of rating system used in determining maintenance
   priorities at this time? Yes

OHIO

General: Ohio does not use a statewide numerical rating system for
pavement evaluation. Some of the field districts have developed various
methods for surveying pavements with the main considerations being
general maintenance costs and rideability.

OREGON

I. General

1. Basic Composition: Oregon uses a surface condition rating system
   for flexible pavements. Ratings are derived primarily from
   visual observations and a mechanical measurement.

2. Measuring Equipment Used: PCA Roadmeter

3. Rating Team Composition: Initially, five surface rating teams and
   one rideability team were used. Each team apparently consisted
   of two members. The present number of teams and team composition
   may be different.

4. Rating Frequency: Unknown
5. **Other**: Oregon presently does not incorporate a structural strength rating into their system such as that obtained with deflection measurements. They intend to do this provided a fast method of measuring surface deflections can be obtained.

II. **Brief Outline of System**

1. **Surface Summation**: The combined effects of alligating, patching, wheel rutting and traffic erosion.

2. **Surface Rating**: The combined effects of the surface summation and rideability. Rideability is measured with a PCA Roadmeter.

3. **Surface Condition Rating**: The combined effects of the surface rating and average daily traffic. This number (SCR) gives a rank order listing of the roads most in need of repair.

III. **Summation**

1. Can a resulting numerical rating be defined? **Yes**

2. If yes, define range: **Not definable with information available**

3. Numerical rating adjusted for traffic? **Yes**

4. Is assistance of rating system used in determining maintenance priorities at this time? **Yes**

**Pennsylvania**

**General**: Pennsylvania does not use a formal visual rating system for assessing pavement distress.
SOUTH CAROLINA

**General:** South Carolina does not use a formal procedure for evaluating pavements. Routine inspections by maintenance personnel are utilized to determine pavement maintenance requirements. During these inspections, the type and amount of cracking, rutting, patching, raveling and other distress types are considered.

SOUTH DAKOTA

**General:** South Dakota does not use a distress weighting system. Their correspondence does not state if they use some other type of rating system.

TENNESSEE

I. **General**

1. **Basic Composition:** Tennessee uses a pavement condition rating system based solely on visual observations. This one system is used to rate both flexible and rigid pavements.

2. **Measuring Equipment Used:** None

3. **Rating Team Composition:** One team rates the entire state. Number of members in this one team is unknown.

4. **Rating Frequency:** Annually

5. **Other:** None

II. Brief Outline of System

1. Cross Section

   Consider: A. Uniformity of crown
   B. Superelevation of curves
   C. Raveling and/or spalling of pavement edges
   D. Longitudinal depressions (rutting)

Max Available Points 25
2. **Profile**

   **Max Available Points 25**

   Considers:  
   A. Transverse undulations (waves and corrugations)  
   B. Bumps  
   C. Dips  
   D. Riding quality  

3. **Surface Characteristics**

   **Max Available Points 50**

   Considers:  
   A. Cracking  
   B. Potholes  
   C. Surface raveling and disintegration  
   D. Blow ups  
   E. Pumping  
   F. Bleeding  
   G. Patching  

---

**III. Summation**

1. Can a resulting numerical rating be defined? **Yes**

   [Better Pavements]

2. If yes, define range:  
   [100]———[0]  
   [Poorer Pavements]

3. Numerical rating adjusted for traffic? **No**

4. Is assistance of rating system used in determining maintenance priorities at the time? **Yes**

---

**TEXAS**

I. **General**

1. **Basic Composition**: Texas uses a numerical rating system for both flexible and rigid pavements. Ratings are derived primarily from visual observations augmented by the Mays Meter to determine riding quality.
2. **Measuring Equipment Used**: Mays Meter

3. **Rating Team Composition**: Two men each team and one team for each of the 25 districts.

4. **Rating Frequency**: Annually

5. **Other**: The data collected for the system results in a computer printout stating a Pavement Rating Score, Shoulder Rating Score - Paved, Shoulder Rating Score - Unpaved, Roadside Rating Score, Drainage Rating Score and Traffic Services Rating Score.

---

**II. Brief Outline of System**

1. **Pavement Rating Score**

<table>
<thead>
<tr>
<th>Type of Distress for Flexible Pavement</th>
<th>Point Deduction Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>A. Rutting</td>
<td>0</td>
</tr>
<tr>
<td>B. Raveling</td>
<td>0</td>
</tr>
<tr>
<td>C. Flushing</td>
<td>0</td>
</tr>
<tr>
<td>D. Corrugations</td>
<td>0</td>
</tr>
<tr>
<td>E. Alligator cracking</td>
<td>0</td>
</tr>
<tr>
<td>F. Patching</td>
<td>0</td>
</tr>
<tr>
<td>G. Longitudinal cracking</td>
<td>0</td>
</tr>
<tr>
<td>H. Transverse cracking</td>
<td>0</td>
</tr>
<tr>
<td>I. Failures/mile</td>
<td>0</td>
</tr>
<tr>
<td>J. Mays Meter</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Distress for Rigid Pavement</th>
<th>Point Deduction Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>A. Pumping</td>
<td>0</td>
</tr>
<tr>
<td>B. Failures/mile</td>
<td>0</td>
</tr>
<tr>
<td>Item</td>
<td>Points</td>
</tr>
<tr>
<td>---------------------------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>C. Surface deterioration</td>
<td>0  60</td>
</tr>
<tr>
<td>D. Spalling</td>
<td>0  60</td>
</tr>
<tr>
<td>E. Longitudinal cracking</td>
<td>0  25</td>
</tr>
<tr>
<td>F. Patching</td>
<td>0  20</td>
</tr>
<tr>
<td>G. Faulting</td>
<td>0  40</td>
</tr>
<tr>
<td>H. Crack Spacing</td>
<td>0  40</td>
</tr>
<tr>
<td>I. % intersection cracks</td>
<td>0  40</td>
</tr>
<tr>
<td>J. Transverse cracking</td>
<td></td>
</tr>
<tr>
<td>(a) joint spacing &lt; 20 feet</td>
<td>0  40</td>
</tr>
<tr>
<td>(b) joint spacing &gt; 20 feet</td>
<td>0  30</td>
</tr>
<tr>
<td>K. Joints (joint sealer condition)</td>
<td>0  20</td>
</tr>
<tr>
<td>L. Mays Meter</td>
<td>0  50</td>
</tr>
</tbody>
</table>

2. **Shoulder Rating Score - Paved**

Max Available Points 100

\[ SRS = 100 - 1.428 \Sigma (\text{deduct points}) \]

Deduct Points Function of:

A. Ride
B. Contrast
C. Pavement edge
D. Shoulder edge
E. Cracks
F. Raveling
G. Vegetation

3. **Shoulder Rating Score - Unpaved**

Max Available Points 100

\[ SRS = 100 - 2.00 \Sigma (\text{deduct points}) \]

Deduct Points Function of:

A. Pavement edge
B. Rutting, corrugations, loose rock
4. **Roadside Rating Score**
   Max Available Points 100
   
   \[ \text{RRS} = 100 - 2.5 \sum \text{ (deduct points)} \]
   
   **Deduct Points Function of:**
   A. Litter
   B. Mowing
   C. Vegetation
   D. Slope erosion

5. **Drainage Rating Score**
   Max Available Points 100
   
   \[ \text{DRS} = 100 - 3.33 \sum \text{ (deduct points)} \]
   
   **Deduct Points Function of:**
   A. Culverts
   B. Ditches, outfall, channels
   C. Roadside drainage

6. **Traffic Services Rating Score**
   Max Available Score 100
   
   \[ \text{TRS} = 100 - 2.0 \sum \text{ (deduct points)} \]
   
   **Deduct Points Function of:**
   A. Guardrails
   B. Signs
   C. Delineators
   D. Striping
   E. Auxiliary markings

III. **Summation**

1. Can a resulting numerical rating be defined? **Yes**
   
   \[ \text{Better Pavements} \rightarrow \text{100} \rightarrow \text{0} \rightarrow \text{Poorer Pavements} \]

2. If yes, define range: 100 - 0

3. Numerical rating adjusted for traffic? **No**
4. Is assistance of rating system used in determining maintenance priorities at this time? **No, but it will be in the future.** System is in the process of being implemented.

**UTAH**

I. **General**

1. **Basic Composition:** A Pavement Evaluation System is used for flexible pavements. It is not known if a separate system is used for rigid pavements. The evaluation is derived primarily from mechanical measurements and from visual determinations.

2. **Measuring Equipment Used:** Dynaflect, Cox Roadmeter and Mu Meter.

3. **Rating Team Composition:** Two teams, two men each team.

4. **Rating Frequency:** New pavements evaluated every second or third year. Older pavements are evaluated annually.

5. **Other:**

   A. The system as described is part of an overall pavement management system which is being developed. The PMS will be a management tool and store the following types of data:

      (1) Geometrics - widths, grades, etc.

      (2) Pavement design

      (3) Construction control

      (4) Environmental conditions

      (5) Maintenance activities

      (6) Pavement rehabilitation

      (7) Traffic data

      (8) Pavement evaluation
B. The Pavement Evaluation System does not as yet compute an overall numerical pavement rating. Certain distress items in the system are assigned numerical ratings from 1 (very poor) to 5 (excellent.)

II. **Brief Outline of System**: The following items listed under each subheading are collected, computed (if required) and displayed on a computer print-out.

1. **Structural**
   A. Deflection readings for each of 5 sensors at each test site
   B. Average Dynaflect Maximum Deflection (DMUD)
   C. Surface Curvature Index (SCI)
   D. Base Curvature Index (BCI)
   E. Predicted remaining structural life in 18 kip axle loads and years.
   F. Bituminous overlay thickness required for pavement to achieve 10 or more years of structural life from the time the measurements were taken
   B. Condition statement based on DMD, SCI and BCI.

2. **Serviceability**
   A. Present serviceability index
   B. Predicted remaining serviceability life in 18 kip axle loads and years until the pavement reaches the terminal serviceability index.

3. **Slipperiness**
   A. Skid Index valves from the Mu Meter
   B. Predicted remaining safe skid resistance life in traffic loads and years.
4. **Surface Defects**

A. Transverse cracking (L.F. per 1000 ft$^2$)

B. Longitudinal cracking (L.F. per 1000 ft$^2$)

C. Load associated cracking (ft$^2$ per 1000 ft$^2$)

D. Patching (ft$^2$ per 1000 ft$^2$)

E. Average condition of transverse and longitudinal cracks:

<table>
<thead>
<tr>
<th></th>
<th>Point Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>Opening</td>
<td>1</td>
</tr>
<tr>
<td>Abrasion or erosion</td>
<td>1</td>
</tr>
<tr>
<td>Multiplicity</td>
<td>1</td>
</tr>
<tr>
<td>Average surface ware</td>
<td>1</td>
</tr>
<tr>
<td>Average weathering</td>
<td>1</td>
</tr>
<tr>
<td>Average pop outs</td>
<td>1</td>
</tr>
<tr>
<td>Average uniformity</td>
<td>1</td>
</tr>
<tr>
<td>Average rut depth (in.)</td>
<td>1</td>
</tr>
</tbody>
</table>

III. **Summation**

1. Can a resulting numerical rating be defined? _No_

2. If yes, define range: 

   ![Rating Range](attachment:image.png)

3. Numerical rating adjusted for traffic? The evaluation system does consider traffic.

4. Is assistance of rating system used in determining maintenance priorities at this time? _Yes_

**VERMONT**

**General:** Vermont uses a flexible pavement condition survey to monitor the results of a transverse cracking study. The survey is a function of
rideability, objective and subjective data. Rideability is an estimate of riding quality ranging from 0 (poor) to 5 (excellent). The objective data consists of measurements of transverse cracking, longitudinal load cracking, alligator cracking and rutting. Subjective data considers pitting, raveling, texture, settlement, bleeding and loss in matrix. This method does not result in an overall numerical rating.

VIRGINIA

**General:** Virginia uses a rating system for both flexible and rigid pavements. The percentage of weighting given a specific distress factors is as follows:

<table>
<thead>
<tr>
<th>1. Flexible Pavements</th>
<th>% of Total Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Transverse cracking</td>
<td>Min 10 Max -</td>
</tr>
<tr>
<td>B. Longitudinal cracking</td>
<td>Min 10 Max -</td>
</tr>
<tr>
<td>C. Multiple cracking</td>
<td>Min 10 Max -</td>
</tr>
<tr>
<td>D. Alligator cracking</td>
<td>Min 5 Max -</td>
</tr>
<tr>
<td>E. Rutting</td>
<td>Min 5 Max -</td>
</tr>
<tr>
<td>F. Flushing</td>
<td>Min 5 Max -</td>
</tr>
<tr>
<td>G. Waves, Humps</td>
<td>Min 2 Max -</td>
</tr>
<tr>
<td>H. Raveling</td>
<td>Min 1 Max -</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Rigid Pavements - All Types</th>
<th>% of Total Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Patching</td>
<td>Min 30 Max -</td>
</tr>
<tr>
<td>B. Pumping</td>
<td>Min 20 Max -</td>
</tr>
<tr>
<td>C. Spalling</td>
<td>Min 20 Max -</td>
</tr>
<tr>
<td>D. Faulting</td>
<td>Min 10 Max -</td>
</tr>
<tr>
<td>E. Scaling</td>
<td>Min 5 Max -</td>
</tr>
<tr>
<td>F. Longitudinal cracking</td>
<td>Min 1 Max 0</td>
</tr>
</tbody>
</table>
J o i n t e d

A. Spalled joints 25 -
B. Faulted joints 10 -
C. Transverse cracking 5 -
D. Cracked panels 1 -
E. Broken panels 1 -

C o n t i n u o u s l y R e i n f o r c e d

A. % Intersecting cracks 1 5

W A S H I N G T O N

I. General

1. Basic Composition: Washington uses a numerical rating system for both flexible and rigid pavements. Ratings are derived from both visual observations and mechanical measurements.

2. Measuring Equipment Used: PCA Roadmeter

3. Rating Team Composition: Four, two man teams

4. Rating Frequency: Every two years

5. Other: The rating system has recently been changed from using subjective ride ratings to ride measurements as determined by the PCA Roadmeter. Certain categories of defect ratings will also be changed or rearranged. A summary outline of the previously used system is presented below.

II. Brief Outline of System

1. Ride Rating

Max Available Points 100

RR = 100 = (10 x Deduct Points)

Point Deduct Range

Min Max

A. Ride Score

0 10
2. **Defect Riding**

Max Available Points 100

\[
DR = 100 - \Sigma \text{Deduct Points}
\]

### Flexible Pavement

<table>
<thead>
<tr>
<th>Point Deduct Range</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Rutting</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>B. Waves, sags, humps</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>C. Alligator cracking</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>D. Corrugations, potholes</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>E. Longitudinal cracking</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>F. Transverse Cracking</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>G. Patching</td>
<td>0</td>
<td>15</td>
</tr>
</tbody>
</table>

### Rigid Pavement

<table>
<thead>
<tr>
<th>Point Deduct Range</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Cracking</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>B. Raveling, disintegration, pop outs, scaling</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>C. Spalling at joints and cracks</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>D. Pumping, blowing</td>
<td>0</td>
<td>45</td>
</tr>
<tr>
<td>E. Blowups</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>F. Faulting, curling, warping, settlement</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>G. Patching</td>
<td>0</td>
<td>15</td>
</tr>
</tbody>
</table>

**Note:** Total of deduct points for both types of pavement cannot exceed 100 points.

3. **Final Rating** = \( \sqrt{\text{Ride Rating} \times \text{Defect Rating}} \)

### III. Summation

1. Can a resulting numerical rating be defined? **Yes**

   \[ \text{Better Pavements} \]

2. If yes, define range: \( 100 | \frac{100}{\text{Better Pavements}} | 0 \)

   \[ \text{Poorer Pavements} \]

   L-40
3. Numerical rating adjusted for traffic?  No
4. Is assistance of rating system used in determining maintenance priorities at this time?  Yes

WEST VIRGINIA

General: West Virginia does not use a standard pavement evaluation method at the present time. Provided was a rank order listing of what they consider the most important distress variables for both flexible and rigid pavements. The following flexible pavement variables are listed by order of importance: patching, rutting, waves, humps, corrugation, skid resistance, flushing, alligator cracking, and longitudinal cracking. For jointed rigid pavements, the following were listed by order of importance: faulted joints, joint spacing, broken panels, spalled joints, transverse cracking, and cracked panels.

WISCONSIN

General: Wisconsin uses a present serviceability index evaluation procedure. Lineal feet of cracking and rut depth measurements are obtained for use in the PSI formulas.

ONTARIO

General: Ontario uses a surface condition rating system based on determinations of ride quality and distress variables. The rating system as described is for flexible pavements. New rating techniques are being developed for rigid pavements. Ride quality is generally determined by experienced personnel which make a subjective assessment of pavement roughness. Ride ratings can range from "excellent" to "very poor".
Distress variables are arranged into three groups and are identified as follows:

1. Surface Defects
   A. Loss of aggregate
   B. Raveling
   C. Flushing

2. Surface disturbance or deformation
   A. Rippling
   B. Shoving
   C. Rutting
   D. Distortion

3. Cracking
   A. Longitudinal wheel track cracking
   B. Longitudinal mid-lane crack
   C. Centerline crack
   D. Meandering crack
   E. Pavement edge crack
   F. Transverse crack
   G. Random crack
   H. Alligator crack
   I. Settlement crack
   J. Miscellaneous

Each item of distress is described by a standardized word description which considers the severity and extent of each type of distress. Using these standard descriptions and the attached sheet reproduced from Ontario's "Manual for Condition Rating of Flexible Pavements - Distress Manifestations", the selection of the condition rating score can be made.
KING COUNTY, WASHINGTON

I. General

1. Basic Composition: King County has under consideration a Present Maintenance Rating (PMR) for flexible pavements. Ratings are derived primarily from visual observations augmented by the Cox Roadmeter to determine riding quality.

2. Measuring Equipment Used: Cox Roadmeter. Additional equipment to be used if warranted is a skid trailer conforming to ASTM E 275 and/or a Benkelman Beam. Other types of deflection measuring devices may be used in the future.

3. Rating Team Composition: Unknown

4. Rating Frequency: Annually

5. Other:

A. A rating given a pavement not only assigns numerical values to the various distress descriptions but also lists the type of maintenance required for each kind of distress and when the maintenance should be performed.

B. Rating system results in a rank order listing of all pavements with those in the poorest condition having the lowest numerical value.

C. Deflection and skid measurements for a given pavement are conducted after the PMR has been obtained and indicates the need for such measurements.

D. Rating system also considers roadside hazards and shoulder distress.
II. Brief Outline of System

1. Paving Distress

<table>
<thead>
<tr>
<th>Item</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Corrugations, shoving, slippage</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>B. Flushing</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>C. Raveling</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>D. Rutting</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>E. Alligator cracking</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>F. Longitudinal cracking</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>G. Transverse cracking</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>H. Waves, sages, humps</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

Note: Each item listed above is a function of % area affected and severity.

2. Roughness

Roughness count made with Cox Roadmeter converted to Present Serviceability Rating (PSR) on a scale from 0 to 5 with 5 being the best possible ride.

Then: Roughness = PSR \times 20 \text{ for major and secondary roads or } 25 \text{ for collector and access roads}

3. PRM = Roughness + \sum Paving Distress Points

III. Summation

1. Can a resulting numerical rating be defined? Yes

\[ \begin{array}{c}
160 \quad \text{Better Pavements} \\
185 \quad 0 \quad \text{Poorer Pavements}
\end{array} \]

L-44
3. Numerical rating adjusted for traffic? No, but the overall maintenance method does.

4. Is assistance of rating system used in determining maintenance priorities at this time? Yes

CORPUS CHRISTI, TEXAS

General: The city of Corpus Christi assigns a subjective numerical value ranging from 100 to 60 for each pavement section. The value of 100 represents a pavement in perfect condition whereas 60 represents a pavement that has completely deteriorated. The pavement sections are surveyed annually and the inputs assist in development of the annual maintenance program. Additionally, ditches and shoulders are rated.

WACO, TEXAS

General: The City of Waco uses a maintenance/priority system to assist in determining maintenance budgeting. Visual inspections of the pavement are made annually. These inspections determine the five types of maintenance functions required for a pavement section with the functions defined as: surface overlay, seal coat, mix seal, crack/joint maintenance and reconstruction. After the required maintenance function has been selected, priorities are chosen for the section within that maintenance function. Priority selections are based on such items as % of area exhibiting base failures, surface failures, loss of aggregate, etc.