Impacts of Pavement Condition Analysis Length on Treatment Transition Matrices and Treatment Benefits

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Impacts of Pavement Condition Analysis Length on the Treatment Transition Matrices

ABSTRACT

In general, pavement treatment actions transform pavement segments from one condition state to another. The transformation could be summarized using treatment transition matrices (\(T^2\)Ms) that indicate the probability that a pavement segment transfers from one condition state to another. This probability is a function of the before treatment pavement condition state and the treatment type. Some State Highway Agencies (SHAs) collect and store pavement condition data along 0.1 mile pavement survey or segment lengths while others use different survey lengths. The data variability makes it difficult to model the pavement conditions of each segment over time and to assess its transition from one condition state to another. It has been suggested that increasing the pavement length over which the conditions are analyzed may decrease the data variability and improve the modeling of pavement conditions over time.

Nearly 445 miles of flexible pavements that were subjected to asphalt concrete (AC) overlay and 349 miles of the same subjected to mill and fill were analyzed to determine the effects of the pavement analysis length on the \(T^2\)Ms. In the analysis, the data of each 0.1 mile pavement segment were used to generate analysis lengths of 0.1, 0.4, 0.7, and 1.0 miles. Results of the analysis are presented and discussed in this paper. It is shown that, for IRI and rut depth data, the \(T^2\)Ms are independent of the pavement analysis length. However, \(T^2\)Ms based on cracking data are a function of the pavement analysis length.
INTRODUCTION AND BACKGROUND

In general, the application of pavement treatment actions transforms pavement segments from one condition state to another. The transformation could be summarized using treatment transition matrices ($T^2Ms$) that indicate the probability that a pavement segment transfers from one condition state to another. This probability is a function of the before treatment pavement condition state and the treatment type. A condition state is defined herein as the pavement condition (rut depth, crack length, etc. and the rates of deterioration). The collection and analyses of pavement condition data are essential steps to support decisions regarding the selection of cost-effective pavement treatments (1). Some State Highway Agencies (SHAs) collect, store, and analyze pavement condition data along 0.1 mile pavement survey or segment lengths while others use different survey lengths. In reality, the pavement data collection practice is limited by resources, practicality, and economical constraints within the SHAs. The National Cooperative Highway Research Program (NCHRP) synthesis of highway practice 222 states that some of the practical constraints can be attributed to the size and variability of the condition of the pavement network (2). In the NCHRP 2004 synthesis of highway practice 334, 42 states, the District of Columbia, 2 FHWA offices, 10 Canadian provinces and territories, and Transport Canada (airfields) were surveyed regarding pavement condition data collection (3). It was found that:

1. Most agencies use an automated means for data collection along the entire outer traffic lane every other year.

2. For pavement cracking; nine agencies reported that they survey 100% of the pavement lane to be evaluated, three collect cracking data on a varying lengths basis, five sample 10% to 30% of the roadway using a random sampling technique, and other agencies videotape 100% of the survey lane but, for each one mile, they digitize the data along 50 to 1,000 feet segment.

3. For pavement roughness, many agencies collect the data along the entire surveying lane and report the data for each 0.1 mile interval. The State of Arizona uses a reporting interval of 1 mile.

The above information indicates that the data collection practice varies greatly from one highway agency to another. For example, some use 0.1 mile pavement segment as the survey length while others use different lengths. As a result, the data storage needs vary significantly. A SHA that collects and reports data for each 0.1 mile pavement segment requires ten times the data storage capacity compared to another agency that uses 1 mile intervals. Saving on data storage capacity is not necessarily beneficial or cost effective. The consequences of reporting the data using longer pavement segments include the loss of detail of the pavement surface conditions along the road. In more general terms, data that are collected, reported, and analyzed along longer pavement segments may lack the necessary details to accurately understand the variability and distribution of the pavement conditions along a given pavement section.

Analysis of the effectiveness of pavement rehabilitation and preservation programs relies partly on the pavement treatment evaluation processes (4). In general, pavement treatment actions transform the pavement from one condition state to another. The transformation could be summarized using $T^2Ms$, which indicate the probability that a pavement segment transfers from one condition state to another (5). Pavement $T^2Ms$ could be used to express the effectiveness of the treatments by using pre- and post-treatment condition states attributes. Dawson et. al. (6)
used TMs and developed three treatment effectiveness parameters; the pavement remaining service life (RSL), service life extension (SLE), and treatment life (TL). The three parameters are depicted in Figure 1 and are defined below.

1. **RSL** – RSL is the time in years between now or the year when the latest distress data point was collected and the year when the pavement distress reaches a certain condition threshold.

2. **SLE** – SLE is the time in years that the pavement section will perform over and above those years if no action is taken. Stated differently, the SLE is the difference between the RSL values after and before treatment.

3. **TL** – TL is the time in years between the year when the pavement treatment was applied and the year when the pavement condition reaches the same condition state as that at the time of treatment.

It is important to note that, for each of the treatment effectiveness parameters defined above, the proper mathematical function must be used to model each of the time series pavement condition data. For example, exponential function is used to model the International Roughness Index (IRI), power function for rut depths, and logistic (s-shaped curve) for cracking.

Finally, the variability of pavement condition data makes it difficult to model pavement conditions over time and to assess the transition of pavement segments from one condition state to another. It has been suggested that increasing the pavement length over which the conditions are analyzed may decrease the variability and simplify the modeling of pavement conditions over time. Hence, this study was undertaken with the objectives stated below.

**OBJECTIVE**

The main objective of this study is to analyze the effects of the pavement analysis length on the TMs. To accomplish the objective, nearly 445 miles of flexible pavements that were subjected to asphalt concrete (AC) overlay and 349 miles of the same subjected to mill and fill were analyzed. In the analysis, the data for each 0.1 mile pavement segment were used to generate pavement analysis lengths of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 miles. Because of length limitations, the results for the 0.1, 0.4, 0.7 and 1.0 miles are presented and discussed in this paper.

**PAVEMENT CONDITION DATA**

Time-series pavement condition data were requested and obtained from the Louisiana Department of Transportation and Development (LADOTD). The LADOTD collect the data on a continuous basis along the entire network and store it for each 0.1 mile pavement segment. The IRI data are expressed in inch/mile, the rut depth in inches, transverse and longitudinal cracks in linear feet, and alligator cracks in square feet of the wheel path. To facilitate compatibility between the cracking data, the alligator cracking data were transformed from square feet to linear feet. This was done by dividing the cracking area by an assumed width of the wheel path of three feet. It is important to note the following unit conversions: 1 inch = 25.4 mm, 1 foot = 0.3 m, and 1 mile = 1.61 km.
a) Illustration of RSL using three mathematical models

b) SLE

c) TL

FIGURE 1 Illustrations of RSL, SLE, and TL.
DATA ANALYSIS

Using the pavement condition data from the State of Louisiana, the effects of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0 mile analysis lengths on the pavement T²Ms were scrutinized. Due to length limitations, the results of the 0.1, 0.4, 0.7, and 1.0 mile analysis lengths are presented and discussed herein. For all lengths, the same analysis steps were used and they are presented below.

Step One – Data Mining
Construction and maintenance records obtained from the LADOTD were examined to identify the boundaries (beginning and ending mile points (BMPs and EMPs)) of pavement projects where AC overlays or mill and fill treatments were conducted in the past. The two treatments were selected because the PMS database contains adequate time series data for comprehensive analyses. In addition, the identified pavement projects must not have had more than one treatment applied during the analysis period. With the data requirements in mind, 199 pavements projects totaling nearly 794 miles from the State of Louisiana were identified for analysis. Asphalt concrete (AC) overlay treatments were applied to 121 of these projects (445 miles), while 78 projects (348.9 miles) were subjected to mill and fill treatment.

Step Two – Analysis Lengths
The time-series distress data for each 0.1 mile pavement segment of the 199 pavement projects identified in step one were downloaded from the LADOTD pavement management system (PMS) database. During the data analysis, it was noted that a substantial number of the 0.1 mile pavement segments did not meet the acceptance criteria. A thorough examination of the reported rut depth data indicated that the first rut depth data collection cycle after treatment was accomplished a few months to two years later. That is the first measured rut depth data do not correspond to time zero (immediately after treatment). In order to increase the number of 0.1 mile pavement segments included in the analysis, a logical and reasonable assumption was made. It was assumed that immediately after the completion of AC overlay or mill and fill treatments, the maximum rut depth along each of the 0.1 mile pavement segments is almost zero inch (0.01-inch was assigned). Thus, the modification of the rut depth data consisted of the addition of 0.01 inch rut depth data point immediately after the treatment was completed or at time zero. Two methods were used to calculate the data for pavement analysis lengths of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0 mile.

1. For IRI and rut depth – The IRI and rut depth data for each analysis length (0.2, 0.3, 0.4 mile and so forth) were calculated as the respective average IRI or rut depth of the corresponding number of 0.1 mile long segments making-up the analysis length. For example, the IRI and rut depth data for each one mile long analysis length is the average of the ten data points corresponding to the ten 0.1 mile pavement segments along the mile.

2. For cracking – The cracking data for each analysis length (0.2, 0.3, 0.4 mile and so forth) were calculated as the sum of the data of the corresponding number of 0.1 mile pavement segments. For example, the cracking data for each one mile analysis length is the sum of the ten data points corresponding to the ten 0.1 mile pavement segments along the mile.
Although the analysis length methodology is simple in nature, it is necessary to address the
analysis technique employed at the end of pavement projects. To illustrate, consider a 2.3 mile
long pavement treatment project. The project starts at the BMP 10.4 and ends at the EMP 12.6.
When the data is analyzed over a length of 0.5 miles, four analyzed pavement segments are
obtained accounting for the first two miles of the project. The 0.3 mile long pavement left over is
analyzed using the data from three 0.1 mile pavement segments and is counted as 0.6 or 60
percent of the 0.5 mile length. Therefore, in this example, there would be 4.6 analyzed pavement
segments. In more general terms, the remaining length at the end of a pavement treatment project
is analyzed and counted as a fraction of an analyzed segment. The same methodology was used
for all pavement treatment projects.

Step Three – Acceptance Criteria
For each pavement treatment and analysis length identified in steps one and two, it is possible that
data were not collected along portions of the project. It is also possible that the pavement distress
data show decreasing distress over time without any pavement treatment. Therefore the pavement
condition data for each project and analysis length were tested using two criteria to determine
whether or not portions of the project should be excluded from the analyses. The two acceptance
criteria are discussed below.

1. Three data points – A minimum of three data points are required before treatment
(BT) and after treatment (AT) to fit any non-linear functions, since any model can be fit to two or
one data points.

2. Positive regression parameters – Positive BT and AT regression parameters of the
exponential and power functions are required for time-series distress data that are consistent for
pavement sections that did not receive any treatment. Negative regression parameters imply that
the pavement is healing with time (decreasing distress) without any treatments, which is not
reasonable and would yield undefined RSL.

Results of the acceptance criteria are detailed in Table 1. The pavement segments that did not
satisfy either of the acceptance criteria were not included in any further analysis. As an example,
results of the analysis of the IRI data of the 0.1 mile long segments listed in Table 1 indicate that
only 225.5 miles of 445 total miles or about 51 percent were accepted for analysis. The
relatively low acceptance rate can be attributed to data variability. For example, cracking has the
highest variability and thus the lowest acceptance rates. Similar results were found for the mill
and fill treatment type.

Step Four – Data Modeling
For the pavement sections that satisfy the two acceptance criteria defined in step three, the proper
mathematical function was used to model the time series pavement condition data. As stated
previously, exponential function is used to model the IRI data, power function for rut depth, and
logistic (s-shaped curve) for cracking (7). Note that the logistic function was divided into two
parts, exponential for newly constructed or treated pavement sections and power for older
sections. For most cases, the pavement segments were newly treated; hence, the cracking data
supported exponential function modeling. Nevertheless, the regression parameters of all models
were calculated using the Microsoft Excel program. Additionally, the standard error of the best-fit
<table>
<thead>
<tr>
<th>Treatment type</th>
<th>Distress type</th>
<th>Analysis length (mile)</th>
<th>Total number of analysis segments</th>
<th>Total length of analysis segments</th>
<th>Number of analysis segments satisfying the acceptance criteria</th>
<th>Cumulative segment lengths satisfying the acceptance criteria</th>
<th>Percent acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC overlay</td>
<td>IRI</td>
<td>0.1</td>
<td>4450.0</td>
<td>445.0</td>
<td>2255.0</td>
<td>225.5</td>
<td>50.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.4</td>
<td>1112.5</td>
<td>445.0</td>
<td>624.8</td>
<td>249.9</td>
<td>56.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.7</td>
<td>635.7</td>
<td>445.0</td>
<td>367.6</td>
<td>257.3</td>
<td>57.8</td>
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<td></td>
<td></td>
<td>1.0</td>
<td>445.0</td>
<td>445.0</td>
<td>260.5</td>
<td>260.5</td>
<td>58.5</td>
</tr>
<tr>
<td>Mill and fill</td>
<td>Rut depth</td>
<td>0.1</td>
<td>4450.0</td>
<td>445.0</td>
<td>2001.0</td>
<td>200.1</td>
<td>45.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.4</td>
<td>1112.5</td>
<td>445.0</td>
<td>518.0</td>
<td>207.2</td>
<td>46.6</td>
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<td>0.7</td>
<td>635.7</td>
<td>445.0</td>
<td>302.7</td>
<td>211.9</td>
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<td></td>
<td></td>
<td>1.0</td>
<td>445.0</td>
<td>445.0</td>
<td>210.1</td>
<td>210.1</td>
<td>47.2</td>
</tr>
<tr>
<td>Longitudinal cracking</td>
<td>IRI</td>
<td>0.1</td>
<td>4450.0</td>
<td>445.0</td>
<td>1125.0</td>
<td>112.5</td>
<td>25.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.4</td>
<td>1112.5</td>
<td>445.0</td>
<td>297.0</td>
<td>118.8</td>
<td>26.7</td>
</tr>
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<td></td>
<td>0.7</td>
<td>635.7</td>
<td>445.0</td>
<td>166.6</td>
<td>116.6</td>
<td>26.2</td>
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<td></td>
<td>1.0</td>
<td>445.0</td>
<td>445.0</td>
<td>113.3</td>
<td>113.3</td>
<td>25.5</td>
</tr>
<tr>
<td>Longitudinal cracking</td>
<td>IRI</td>
<td>0.1</td>
<td>3489.0</td>
<td>348.9</td>
<td>1542.0</td>
<td>154.2</td>
<td>44.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.4</td>
<td>872.3</td>
<td>348.9</td>
<td>466.5</td>
<td>186.6</td>
<td>53.5</td>
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<tr>
<td></td>
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<td>0.7</td>
<td>498.4</td>
<td>348.9</td>
<td>269.0</td>
<td>188.3</td>
<td>54.0</td>
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<tr>
<td></td>
<td></td>
<td>1.0</td>
<td>348.9</td>
<td>348.9</td>
<td>194.5</td>
<td>194.5</td>
<td>55.7</td>
</tr>
<tr>
<td>Longitudinal cracking</td>
<td>Rut depth</td>
<td>0.1</td>
<td>3489.0</td>
<td>348.9</td>
<td>1848.0</td>
<td>184.8</td>
<td>53.0</td>
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<tr>
<td></td>
<td></td>
<td>0.4</td>
<td>872.3</td>
<td>348.9</td>
<td>482.0</td>
<td>192.8</td>
<td>55.3</td>
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<td></td>
<td>0.7</td>
<td>498.4</td>
<td>348.9</td>
<td>277.6</td>
<td>194.3</td>
<td>55.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0</td>
<td>348.9</td>
<td>348.9</td>
<td>195.5</td>
<td>195.5</td>
<td>56.0</td>
</tr>
<tr>
<td>Longitudinal cracking</td>
<td>IRI</td>
<td>0.1</td>
<td>3489.0</td>
<td>348.9</td>
<td>579.0</td>
<td>57.9</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.4</td>
<td>872.3</td>
<td>348.9</td>
<td>141.5</td>
<td>56.6</td>
<td>16.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.7</td>
<td>498.4</td>
<td>348.9</td>
<td>91.6</td>
<td>64.1</td>
<td>18.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0</td>
<td>348.9</td>
<td>348.9</td>
<td>48.0</td>
<td>48.0</td>
<td>13.8</td>
</tr>
</tbody>
</table>
curve for each analysis length was calculated using Equation 1. The standard error is a measure of the differences between the predicted and the measured values relative to the number of data points. It should be noted that the standard error of the model prediction is typically calculated by statistical software for linear models only. However, Equation 1 is also applicable to non-linear models (8, 9). This equation was used to calculate the standard errors of the model before and after treatments.

\[
SE = \sqrt{\frac{\sum_{i=1}^{n} (y_{mi} - y_{pi})^2}{(n - df)}}
\]

(1)

Where, \( SE \) = standard error

\( n \) = number of data points

\( y_{m} \) = measured distress data

\( y_{p} \) = predicted distress data

\( df \) = degrees of freedom = 2

**Step Five – Treatment Transition Matrices (T\(^2\)Ms)**

For each distress type, treatment type, and analysis length the BT and AT RSL were calculated using the regression parameters of the data that satisfied the acceptance criteria. Any pavement segments with RSL values greater than 25 years were assumed to have an RSL of 25 years. In reality, pavement sections rarely perform for more than 25 year period without additional treatments. The BT and AT RSL values were then grouped into the five RSL brackets shown in Table 2. The grouping of the pavement segments into the five RSL brackets was done for two reasons: a) For most cases, each bracket is associated with probable cost-effective pavement treatment options listed in Table 2; and b) the bracket decreases the effects of inaccurate calculation of RSL, which increases as the value of RSL increases.

As stated earlier, pavement T\(^2\)Ms provide a list of probabilities associated with the transformation of pavement segments from one condition state BT to other states AT. For each treatment type, distress type, and analysis length, transition matrices were formed. The T\(^2\)Ms summarize the number and percent of analysis segments in each BT and AT RSL bracket as well as the average standard error per RSL bracket. Furthermore, the data in each T\(^2\)M were used to calculate the weighted average RSL, SLE, and TL. The results were stored in the same T\(^2\)M. Table 3 is a treatment transition matrix for the AC overlay treatment using the IRI data and analysis length of 0.1 miles. The data in Table 3, as well as for all T\(^2\)Ms, are arranged in the following order:

- Column A – BT RSL bracket numbers.
- Column B – BT RSL bracket ranges in years.
- Column C – The number of analysis segments in each BT RSL bracket.
- Column D – The percent of analysis segments in each BT RSL bracket.
- Column E – The average model standard error for each BT RSL bracket.
- Column F – From top to bottom, AT RSL bracket 1, the range in years of RSL bracket 1, the percent of analysis segments transitioned from each BT RSL bracket, and, in the last row, the total number of analysis segments transitioned to AT RSL bracket 1 from all BT RSL brackets.
## TABLE 2  BT and AT RSL Brackets and the Most Probable Pavement Treatments for Each Bracket

<table>
<thead>
<tr>
<th>RSL range (year)</th>
<th>RSL bracket number</th>
<th>Type of distress producing the given RSL bracket</th>
<th>The most probable pavement treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 2</td>
<td>1</td>
<td>Severe transverse cracking (crack spacing ≤ 3 feet)</td>
<td>Replace the surface layer or extensive patching &amp; overlay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Severe longitudinal cracks (crack length ≥ 1056 ft)</td>
<td>Replace the surface layer or extensive patching &amp; overlay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Severe alligator cracks (more than 10 percent of the pavement section)</td>
<td>Remove the asphalt layer and replace it with fresh asphalt Recycle the asphalt layer Crush and shape and place asphalt or concrete overlay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rut depth ≥ 0.5-inch</td>
<td>Mill and fill or fill rut channel &amp; overlay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IRI ≥ 210 inch/mile</td>
<td>Mill and fill or Overlay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Raveling</td>
<td>Replace the surface layer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Friction (polished aggregate or bleeding)</td>
<td>Mill and fill or overlay</td>
</tr>
<tr>
<td>3 - 5</td>
<td>2</td>
<td>Severe transverse cracking (crack spacing 3 to 6 feet)</td>
<td>Replace the surface layer or moderate patching &amp; overlay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Severe longitudinal cracks (crack length 500 to 1056 ft)</td>
<td>Replace the surface layer or moderate patching &amp; overlay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Severe alligator cracks (less than 10 percent of the pavement section)</td>
<td>Remove the asphalt layer and replace it with fresh asphalt Recycle the asphalt layer Full depth patching along localized areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rut depth 0.3 – 0.5-inch</td>
<td>Mill and fill or fill rut channel &amp; overlay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IRI 150 - 210 inch/mile</td>
<td>Mill and fill or overlay</td>
</tr>
<tr>
<td>6 - 10</td>
<td>3</td>
<td>Transverse cracking (crack spacing 6 – 12 feet)</td>
<td>Moderate patching with &amp; without overlay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Longitudinal cracks (crack length 100 to 500 ft)</td>
<td>Moderate patching with &amp; without overlay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alligator cracks of variable severity and extent</td>
<td>Crack seal Full depth patching along localized areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rut depth 0.10 – 0.3-inch</td>
<td>fill rut channel &amp; overlay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IRI 100 - 150 inch/mile</td>
<td>Mill and fill or overlay</td>
</tr>
<tr>
<td>11 - 15</td>
<td>4</td>
<td>Transverse or longitudinal cracks</td>
<td>Patching, crack sealing, thin overlay, etc.</td>
</tr>
<tr>
<td>16 - 25</td>
<td>5</td>
<td>Transverse or longitudinal cracks</td>
<td>Light preventive maintenance</td>
</tr>
</tbody>
</table>
### TABLE 3 Treatment Transition Matrix for Analysis Length 0.1 Miles, AC Overlay, IRI Data

<table>
<thead>
<tr>
<th>Row designation</th>
<th>Column designation</th>
<th>Distress type: IRI</th>
<th>After treatment (AT) data</th>
<th>Weighted average treatment life, service life extension, and remaining service life of the treatment (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Column designation</td>
<td>Before treatment (BT) data</td>
<td>RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A B C D E F G H I J K L M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSL bracket number</td>
<td>RSL bracket range (year)</td>
<td>0.1 mile pavement segments</td>
<td>Average standard error (SE) (in/mi)</td>
<td>1</td>
</tr>
<tr>
<td>Number</td>
<td>Percent</td>
<td>Number</td>
<td>Percent</td>
<td>Number</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>-------</td>
<td>--------</td>
<td>-------</td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>0 to 2</td>
<td>1260</td>
<td>55.9</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>3 to 5</td>
<td>178</td>
<td>7.9</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>6 to 10</td>
<td>191</td>
<td>8.5</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>11 to 15</td>
<td>137</td>
<td>6.1</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>16 to 25</td>
<td>489</td>
<td>21.7</td>
</tr>
<tr>
<td>F</td>
<td>Total</td>
<td>2255</td>
<td>100.0</td>
<td>20</td>
</tr>
</tbody>
</table>

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Columns G through J – The contents of these columns are similar to those of Column F for AT RSL brackets 2, 3, 4 and 5, respectively.

- Column K – The average TL of all pavement segments transferred from each BT RSL bracket to the five AT RSL brackets and the overall average TL.
- Column L – The average SLE of all pavement segments transferred from each BT RSL bracket to the five AT RSL brackets and the overall average SLE.
- Column M – The average RSL of all pavement segments transferred from each BT RSL bracket to the five AT RSL brackets and the overall average RSL.

The light grey shaded area in Table 3 contains the number of 0.1 mile long pavement segments that moved from a lower BT RSL bracket to higher AT brackets (positive benefits). Stated differently, the light grey area displays the numbers of pavement segments whose condition states improved due to the treatment action. Since pavement treatments typically improve the condition of the roadway, one should expect that the majority of the pavement segments are located in the light grey shaded areas of the transition matrix. The bolded numbers of the 0.1 mile long pavement segments along the diagonal of each T^2M indicate the number of segments where the AT and BT RSL brackets are the same (no benefit from the treatment). On the other hand, the dark grey shaded area contains the number of 0.1 mile long pavement segments that moved from a higher BT RSL bracket to a lower AT bracket. That is, the AT condition states of these segments worsened as a result of the treatment (negative benefits).

**Step Six – Analysis Length and Treatment Benefits**

The results of the calculated treatment benefits in terms of the weighted average RSL, SLE, and TL were studied as a function of the pavement analysis length. Results of the analysis, for each distress type, are summarized and discussed below.

**IRI**

Figure 2 depicts, for the AC overlay treatment type, the three calculated benefits (TL, SLE, and RSL) versus pavement analysis length. As it can be seen in Figure 2a, the TL decreases slightly with increasing analysis length. The TL for the 0.1 mile analysis length ranges from approximately 16 years for RSL bracket 5 to 18 years for RSL bracket 1. Whereas, for the 1.0 mile analysis length, the TL ranges from about 14 years for bracket 5 to about 16 years for RSL bracket 1. Figure 2b depicts the SLE benefit as a function of the analysis length for all BT RSL brackets. The data in the figure indicate that the SLE does not vary by more than 1 year as the analysis length increases from 0.1 to 1.0 mile. Finally, Figure 2c shows plots of the AT RSL versus analysis length for the five BT RSL brackets. It can be seen that the AT RSL is almost independent of the analysis length. The data in Figure 2 indicate that the benefits from AC overlay treatment are largely unaffected by the pavement segment length for which the pavement condition data are reported, stored, and analyzed.

Similarly, Figure 3 displays the three calculated benefits as a function of the analysis length for the mill and fill treatment type. The data in the figure show similar trends to those presented in Figure 2. The data in Figures 2 and 3 suggest that, in general, the benefits of AC overlay and mill and fill treatments are independent of the pavement analysis length.
a) TL versus analysis length for all BT RSL brackets

b) SLE versus analysis length for all BT RSL brackets

c) AT RSL versus analysis length for all BT RSL brackets

FIGURE 2 TL, SLE, and AT RSL versus analysis length, IRI data, AC overlay treatment type.
a) TL versus analysis length for all BT RSL brackets

b) SLE versus analysis length for all BT RSL brackets

c) AT RSL versus analysis length for all BT RSL brackets

FIGURE 3 TL, SLE, and AT RSL versus analysis length, IRI data, mill and fill treatment type.
**Rut Depth**

Figures 4 and 5 display plots of the TL, SLE, and RSL benefits (based on rut depth data) versus pavement analysis length for the AC overlay and mill and fill treatment types, respectively. The data in both figures indicate that the TL, SLE, and RSL are independent of the pavement analysis length. To illustrate, consider Figures 4a and 5a. The data in each figure show that, for each BT RSL bracket, the TL values do not vary by more than 1 year as the analysis length increases from 0.1 to 1.0 mile. In the worst case scenario depicted in Figure 5a, the TL for the BT RSL bracket increases by only 3 years as the analysis length increases from 0.1 to 1.0 mile. Such increase is due to data variability and hence, it is the exception and not the rule. Similar scenarios were found when examining the data in Figures 4b and 4c, as well as 5b and 5c.

**Longitudinal cracking**

Results of the longitudinal cracking analyses are shown in Figures 6 and 7 for the AC overlay and the mill and fill treatment types, respectively. Each figure depicts the treatment benefits in terms of TL, SLE, and RSL versus pavement analysis length based on the longitudinal cracking data. The data in both figures indicate that the treatment benefits vary substantially from one analysis length to another without any specific trends. For example, the data shown in Figure 6a indicate that for BT RSL bracket 4, the TL:

1. Decreases by about 8 years as the analysis length increases from 0.1 to 0.4 miles.
2. Increases by about 7 years as the analysis length increases from 0.4 to 0.7 miles.
3. Decreases by about 5 years as the analysis length increases from 0.7 to 1.0 mile.

Similar scenarios can be deduced from the examination of Figures 6b and 6c. These observations clearly indicate that the variations in the benefits do not follow a specific trend and they are mainly related to the high variability of the longitudinal cracking data. Similarly, the data for the longitudinal cracking and the mill and fill treatment depicted in Figure 7 show no specific relationships between the treatment benefits and the analysis length.

The above stated observations were expected because it was noticed during the analysis that the longitudinal cracking data are more variable than the IRI and rut depth data. One reason for such variability is that the LADOTD state-of-the-practice regarding cracking data is that when the cracks are sealed, their lengths are not recorded. Furthermore, the PMS databank does not have any data regarding the timing and/or the locations of crack sealing activities. It should be noted that similar results were obtained from the analyses of alligator and transverse cracking data. Those results could not be included because of paper length limitations.

**SUMMARY, CONCLUSIONS AND RECOMMENDATIONS**

Time series IRI, rut depth, and cracking data were obtained for the entire pavement network of the LADOTD. The data were analyzed to study the impact of pavement analysis length on the T^2Ms and treatment benefits. Although pavement analysis lengths of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0 miles were analyzed, results of the 0.1, 0.4, 0.7, and 1.0 miles analysis lengths of 121 AC overlay projects (445 miles) and 78 mill and fill projects (348.9 miles) are presented and discussed in this paper. Based on the analysis results, the following conclusions were drawn.
FIGURE 4  TL, SLE, and AT RSL versus analysis length, rut depth data, AC overlay treatment type.

1 mile = 1.61 km
a) TL versus analysis length for all BT RSL brackets

b) SLE versus analysis length for all BT RSL brackets

c) AT RSL versus analysis length for all BT RSL brackets

**FIGURE 5** TL, SLE, and AT RSL versus analysis length, rut depth data, mill and fill treatment type.
a) TL versus analysis length for all BT RSL brackets

b) SLE versus analysis length for all BT RSL brackets

c) AT RSL versus analysis length for all BT RSL brackets

FIGURE 6 TL, SLE, and AT RSL versus analysis length, longitudinal cracking data, AC overlay treatment type.
FIGURE 7 TL, SLE, and AT RSL versus analysis length, longitudinal cracking data, mill and fill treatment type.
1. Various SHAs collect and store pavement condition data using different segment lengths (0.1 to 1.0 mile).

2. Sensor collected pavement condition data such as IRI and rut depths show lower variability than image collected cracking data. Said variability affects the number of pavement segments that can be modeled for analysis.

3. The impact of the analysis length on the treatment transition matrices is insignificant.

4. The data listed in the T²M simplify the complexity of calculating treatment benefits.

5. For image-collected data (cracking), analysis of the treatment benefits appears to indicate that the pavement analysis length impacts the TL, SLE, and weighted average RSL values. However, such impacts are mainly related to data variability and show no specific trends or relationships with analysis length.

6. For sensor collected data (IRI and rut depth), increasing the pavement analysis length has no impact on the calculated treatment benefits. That is, the calculated treatment benefits are independent of the pavement analysis length.

7. Using longer pavement lengths for data storage and subsequent analysis precipitate saving in data storage capacity. However, the variability of the pavement conditions cannot be analyzed in details.

8. The use of longer pavement segments (such as one mile) for data storage and analysis would constrain the project boundaries to at least one mile. If the pavement conditions change significantly within one mile segment, the change cannot be captured. Stated differently, the pavement analysis length affects the selection of project boundaries.

Given the variability of the pavement condition data along and across the pavement, it is highly recommended that:

1. The pavement condition data be stored and analyzed for each 0.1 mile segment. Increasing the length over which the pavement condition data is analyzed does not improve the ability of the data to be modeled as was suggested. Furthermore, analyzing the data for each 0.1 mile segment would assist the SHAs to pin point hot spots along the pavement network and better select suitable pavement treatments.

2. Regardless of the pavement survey or analysis length, inaccurate pavement condition data are not sufficient for modeling and reduce the number of pavement sections satisfying the data modeling acceptance criteria. Hence, more attention or better quality control procedures should be necessary.

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REFERENCES


