PERFORMANCE MODELS

Purpose:
This module introduces the use of pavement performance models to predict future pavement conditions for the highway network as part of the agency’s pavement management activities. The types of models normally used at the network and project level are introduced and examples of the principal approaches are provided. Guidelines on determining the reliability of the performance models and update requirements are also provided.

Objectives:
Upon completion of this module, the participant will be able to accomplish the following:

- Understand the use of performance models in pavement management.
- Identify the common modeling approaches used to develop models for pavement management.
- Understand methods for evaluating the reliability of the pavement performance models.
- Describe the requirements for updating the models over time.

Reference:
Module 8 of the Participant’s Notebook

Duration:
100 minutes

Equipment:
Laptop computer, multimedia projector, flipchart, overhead projector, blank transparencies, transparency pens

Teaching Aids:
43 Microsoft PowerPoint® Slides
**Approach:**
This module is taught through Slide presentations and discussion with the participants. The module provides an overview of the use of models in pavement management and introduces the most common modeling techniques. Examples from Washington State and Illinois are also provided.

**Distance Learning:**
There are no special instructions on Distance Learning for this module. All slides prepared can also be used for distance learning.

Encourage questions from and promote discussion with the participants.
PERFORMANCE MODELS

Instructional Objectives

- Understand use of performance models
- Identify common modeling approaches
- Understand methods for evaluating reliability
- Describe requirements for updating models
**Overview**

- Serviceability-performance concepts
- Deterioration as a representation of change in performance

**Uses of Performance Models in Pavement Management**

- Network Level
- Project Level

Notes:

Introduce the early work of Careys-Irick to define pavement performance in terms of serviceability-performance concepts.

Today, it is common practice among practitioners and researchers to use terms such as deterioration to represent the change in pavement performance over time.

For this course, performance models represent the pavement deterioration patterns that are modeled.

Notes:

Pavement performance models are an important component of a multi-year analysis for these types of activities.

Pavement performance models are used differently at the network and project levels. These are the primary activities that performance models are used for at the network level.

Discuss typical network-level modeling approaches

- Deterministic models
- Probabilistic models

Have participants read from text Page 8-2.
Notes:

This is Table 8.1 on Page 8-3. It shows the principal types of models used at different levels within transportation agencies.

Point out that higher levels of management are more interested in models that predict composite indexes of network condition. At the national level, models are used for policy and economic matters. At the district level, there is less concern about the performance of individual sections and more of a focus on the overall condition of the pavement network for the entire state or a subset of the network.

Point out that at the project level, the focus is on the performance of individual sections or design approaches.

Notes:

This slide illustrates the importance of accurate models to predict future conditions. It is presented in the course materials as Figure 8.1. It illustrates that a pavement condition of 60 could be predicted in 10 years or 20 years, depending on which model is used.
Performance Model Development Criteria

- Adequate database
- Inclusion of all significant variables that affect performance
- Adequate functional form of the model
- Satisfaction of the statistical criteria concerning the precision of the model
- Understanding of the principles behind each modeling approach

Data Requirements

- Requirements vary depending on the type of model being developed
- Inventory Information
- Monitoring Data

Notes:

In 1980, Darter introduced the basic criteria that should be followed to develop reliable performance models. These criteria are included.

In addition to these points, it is important that the limitations of each model be understood so that they are not used outside of the range of their intended use.

Notes:

Depending on the type of model being developed, data requirements will vary.

At the most basic level, inventory and monitoring data are used to develop the models.

Examples of inventory information include geographic location or section length.

Examples of monitoring data include pavement condition, cracking quantities, and AADT.
Lack of Historical Data

- If historical databases are not available due to changes in survey procedures, new rehabilitation techniques, or other factors, other techniques are available:
  - incorporate input from experienced practitioners
  - update the models as additional data are available

On-the-Diagonal Issue

This slide is Figure 8.2. It shows that it is difficult to observe differences in pavement performance at the network level due to factors such as traffic, material variances, and climatic conditions because these factors are accounted for in the design of the pavement structure through design programs. As a result, if an agency sought to model the effect of traffic on pavement performance, this is difficult to do without also looking at pavement thickness because the thickness is a related factor that is affected by the anticipated level of traffic. Without considering thickness data in the models, pavements with equal design periods would show little variation in condition with traffic alone.
**Data Requirements**

- Sufficient amounts of data must be used
- Data must be measured accurately and without bias
- Data must be representative
- Data must be maintained over time

**Model Limitations**

- Models must be used appropriately
- Limitations of models must be considered
- Boundary conditions should be identified and satisfied
**Deterministic vs. Probabilistic**

- Predicted Occurrence
- Techniques

Notes:

A number of different types of deterministic models can be developed. This slide emphasizes the primary approaches used to develop deterministic models.

If deterministic models are not used, the agency probably uses probabilistic models.

To date, no purely mechanistic models have been developed because they are only applicable to calculating pavement response in terms of mechanisms such as stress, strain, or deflection. These factors could be used as the inputs for an empirical prediction model.

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**Mechanistic Models**

- No purely mechanistic performance models have been developed
- Calculated stress and strain attributes from mechanistic models can be used as the input for an empirical prediction model

Notes:

Mechanistic Models

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- Calculated stress and strain attributes from mechanistic models can be used as the input for an empirical prediction model
Mechanistic-Empirical Models

- Models developed using pavement response as the dependent variable
- Use elements of both mechanistic models (fundamental principles of pavement behavior) and empirical models (results from experience or experiments)
- \[ N = A \times (1/e)^B \]

Regression Analysis

- A technique used to determine the relationship between variables
- Often used in agencies with historical databases available

Notes:

Mechanistic-Empirical Models

- Models developed using pavement response as the dependent variable
- Use elements of both mechanistic models (fundamental principles of pavement behavior) and empirical models (results from experience or experiments)
- \[ N = A \times (1/e)^B \]

Regression used when historical data are available.
Subjective Approaches

- Used in agencies that do not have historical data available
- Can be used to develop either deterministic or probabilistic models

Notes:
Subjective models are used when no historical data are available.

Development of Deterministic Performance Models

- Very common modeling techniques in pavement management
- Predict a single number based on its relationship with one or more variables
- Can be empirical or mechanistic-empirical correlations calibrated using regression
- Condition is modeled as a function of other variables

Notes:
Deterministic models are the most common types of models for pavement management.

With these models, some type of condition (such as an overall condition index or distress quantity) is modeled as a function of variables such as pavement age, traffic, environment, pavement construction characteristics, and maintenance and rehabilitation actions.
Regression Analysis

- Statistical tool used to establish the relationship between two or more variables
- Models can be linear or non-linear, depending on the relationship between variables

Regression Model Forms

- Linear Regression
  - \( Y = a + bX \)
- Multiple Linear Regression
  - \( Y = a_0 + a_1X_1 + a_2X_2 + \ldots + a_nX_n \)
- Non-Linear Regression
  - \( Y = a_0 + a_1X^1 + a_2X^2 + \ldots + a_nX^n \)
  - Polynomial regression models may be constrained
  - Least squares fit is used to improve the models

Notes:

Regression Analysis

- Statistical tool used to establish the relationship between two or more variables.
- Models can be linear or non-linear, depending on the relationship between variables.

This slide shows the equations for various regression model forms.

In polynomial regression, the number of curves in the regression line is equal to one less than the degree of the polynomial. These curves may be constrained so that the curve can not increase over time.

The term least squares fit comes from the minimization of the squared differences between the actual data points and their corresponding points on the fitted line (or curve). Polynomial least squares models are popular for predicting the change in the dependent variable as a function of the independent variable(s).
The functional form of a performance model, or the way in which the variables are arranged, can only be determined through consideration of the actual relationships between the variables and the trends from the data on the plots.

These figures are shown in the notebook as Figure 8.3. It illustrates several types of deterministic model forms.

The individual developing the model must understand the relationships between the variables being considered in order to select the appropriate form.

**Family Models**

- Reduces number of variables
- Group pavement sections by characteristics
- Assume similar deterioration patterns
- Reflects average deterioration for family
- Allows ranges of values to be used for developing families

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**Deterministic Model Forms**

- Linear
- Polynomial
- Hyperbolic
Figure 8.4 discusses diagram.

The performance of each section is found by shifting the family curve to intersect the condition point for the section. The shift is always parallel to the family prediction curve.

Advantages/Disadvantages to Family Models

**Advantages**
- Fairly easy to develop and interpret
- Reduces the number of variables in the model
- Allows ranges of values to be used rather than exact measurements

**Disadvantages**
- Does not explicitly deal with errors in data or model form
- Difficult to measure the effect of independent variables
Statistical Evaluation of Models

- Coefficient of determination (R²)
- Root mean square error (RMSE)
- Number of data points (n)
- Hypothesis tests on regression coefficients

Coefficient of Determination (R²)

- Provides an indication of how much of the total variation in the data is explained by the regression equation or performance curve
- Network Level normally < 0.9
- Project Level normally > 0.9

Notes:

These are some of the statistical tools that are available for evaluating the fit of the performance models to the data from which they were developed.

Before performing a statistical evaluation, the agency must ensure that the form of its models adheres to the boundary conditions or other physical principles that influence the predicted value of the dependent variable.

Notes:

This test provides an indication of how much of the total variation in the data is explained by the regression equation or performance curve.
RMSE

- Standard deviation of the predicted dependent variable value for a specific value of the independent variable
- Project Level: $\leq 5$
- Network Level: $> 5$

Other Tests

- Number of Data Points
- Hypothesis Test of Regression Constants

Notes:

The RMSE is the standard deviation of the predicted dependent variable value for a specific value of the independent variable.

Root – Mean – Square – Error

This might be drawn graphically on a flipchart.

Notes:

- Other Tests
  - Number of Data Points should be at least 30 to test validity of regression equation.
  - Statistician should be involved in this process.
  - Hypothesis Test of Regression Constants
Limitation of Statistical Evaluations

- Statistical analyses only evaluate reliability of model for data used in its development.
- A model can be statistically valid but not representative of actual deterioration patterns of network if poor quality data are used.

Reliability of Performance Models

- Network Level
- Project Level

Notes:

Limitation of Statistical Evaluations

- Statistical analysis only evaluate reliability of model for data used in its development.
- A model can be statistically valid but not representative of actual deterioration patterns of network if poor quality data are used.

Reliability of Performance Models

- Network level
  - Transformations may be required
  - Correlations between independent variables may influence reliability
  - Significance of coefficients must be considered
- Project level
  - Expect higher coefficients of determination and lower RMSE
Reliability of Performance Models

Regression Parameter Expectations

<table>
<thead>
<tr>
<th>PMS Analysis Level</th>
<th>R²</th>
<th>RMSE</th>
<th>Sample Size</th>
<th># of Independent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network</td>
<td>Medium to Low</td>
<td>Medium to Low</td>
<td>Large Sample</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Project</td>
<td>High</td>
<td>Low</td>
<td>Small Sample</td>
<td>1</td>
</tr>
</tbody>
</table>

Notes:
This is Table 8.3. It summarizes the expectations of regression parameters as a function of the use of the model at the network and project levels.

Update Requirements

- Performance models must be updated regularly to continue to reflect deterioration patterns
- Feedback loops should be established to link deterioration models with engineering practices.

Notes:
Update Requirements

- Performance models must be updated regularly to continue to reflect deterioration patterns
- Feedback loops should be established to link deterioration models with engineering practices
Examples

- Washington DOT
  - Deterministic models
- Illinois DOT
  - Deterministic models

Notes:

- Washington Department of Transportation
  - Deterministic models
- Illinois Department of Transportation
  - Deterministic models

Washington State DOT

- Priority programming process
- Developed in-house
- Prediction models developed for combined ratings
- Raw distress severity and extent data are stored so models can be modified as needed
- Capabilities exist for statistical analysis of performance trends
- Performance models for individual sections

Notes:

This slide provides an overview of the modeling activities in WSDOT.
This is Figure 8.8. It shows the general shape of WSPMS performance curves. Define variables for students.

The deceleration rate of deterioration is attributed to the application of temporary fixes to hold the pavement together until a major remedy can be applied. These temporary fixes tend to cause short duration, random fluctuations in the pavement rating – probably best represented by a curve that passes through the mean value in this phase.

WSDOT Limitations to Regression Analysis

- New surfaces without historical data points
  - Default models used
  - When three points are available, regression is used.

Random fluctuation in data (poor data fit).

The degree of curvature in the model is influenced by the constant selected for P, as shown in Figure 8.10.

The P that provides the highest $R^2$ is selected as the best fit model.
Notes:

This is Figure 8.11. Because the WSDOT performance curves overestimate remaining life in early states, a process was established to add the default curve to the last data point. The default curves are used to establish two artificial points that are added to the existing data point, then a regression equation is developed that best fits both actual and artificial data points. This process provides a more realistic estimate of specific project performance by recognizing the past performance trends unique to each project and also incorporating knowledge of the most likely rate of future deterioration from typical pavement performance experience.

Notes:

In order to understand the performance model development in Illinois, it is important to provide a little background on the CRS and the changes that occurred to the process when they automated the data collection activities.

**IDOT Model Objectives**

- **B** Describe the expected conditions at any point in the future
- **B** Develop alternative rehabilitation strategies
- **B** Prioritize need pavement improvements

**Illinois DOT Deterministic Models**

- **Condition Rating Survey (CRS)**
  - 1.0 to 9.0
  - Type, severity, and extent of 5 predominant distress
- **Automated the CRS Process**
  - Safety of expert panel
  - Reduction in staff
  - PaveTech vans purchased
  - Calculation of CRS value
Notes:

These are the family groups that were established for model development.

<table>
<thead>
<tr>
<th>System</th>
<th>Surface</th>
<th>District</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interstate</td>
<td>Composite (2)</td>
<td>1-4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Concrete (2)</td>
<td>1-4</td>
<td>4</td>
</tr>
<tr>
<td>Non-Interstate</td>
<td>Flexible (3)</td>
<td>1-4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Overlays (5)</td>
<td>1-4</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Concrete (4)</td>
<td>1-4</td>
<td>8</td>
</tr>
<tr>
<td>SMART</td>
<td>Flexible &amp; OL</td>
<td>All</td>
<td>4</td>
</tr>
</tbody>
</table>

IDOT Polynomial Approach

This is Figure 8.12. This is the first attempt at developing the models. Note the flat spot in the deterioration curves, usually occurring between a condition rating (CRS) of 7.5 to 6.0, the time when IDOT typically schedules pavement sections for rehabilitation. This was not acceptable for programming purposes, so a new approach was developed.
IDOT Trajectories

D-Crack Adjustments

- Asphalt concrete overlays: deducts increased by 20%
- Jointed reinforced concrete: deducts increased by 20%
- CRCP: deducts increased by 50%

Notes:
This is Figure 8.13. It shows the trajectories of CRS for each pavement section in a family. The average deterioration rate of each section is calculated to determine the average deterioration rate associated with the family type. The deterioration rates were then translated into deduct points.

Adjustments were made if the pavements are susceptible to D-cracking, as shown here.
Instructional Objectives

- Understand use of performance models
- Identify common modeling approaches
- Understand methods for evaluating reliability
- Describe requirements for updating models

Notes:
Review the objectives for this module.