An Outcome-based Scenario Approach for Analyzing Risk in Infrastructure Asset Management

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What is Scenario Planning?

- “A scenario is an internally consistent view of what the future might turn out to be—not a forecast, but one possible future.”
  – Michael Porter

- “Scenario planning is that part of strategic planning which relates to the tools and technologies for managing the uncertainties of the future.”
  – Gill Ringland

Scenario Planning is the process of considering:
(1) What future conditions or events are probable?
(2) What will be the consequences or effects of these events?
(3) How can we respond to or benefit from them?

* Definition from http://www.businessdictionary.com/
Overview of Scenario Planning

- A tool for long-range and medium-range planning
- Visualize a set of possible futures
- Consider a limited number of scenarios
- Event-based vs. outcome-based scenarios
History of Scenario Planning

- 1940s – RAND “Future-Now” method
- Mid-1970s – scenario planning adopted by DHL, Shell, and GE
- Late-1970s – Majority of Fortune 1000 corporations adopted a form of scenario planning
- In 2004, a survey demonstrated that 45% of MPOs use a form of scenario planning
# Using Scenarios in Transportation Planning

<table>
<thead>
<tr>
<th>Topic</th>
<th>Scenario A</th>
<th>Scenario B</th>
<th>Scenario C</th>
<th>Scenario D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural Land Consumed: 1998 - 2020</td>
<td>174 sq mi</td>
<td>143 sq mi</td>
<td>65 sq mi</td>
<td>43 sq mi</td>
</tr>
<tr>
<td>Infrastructure Cost 1998-2020 (Transportation, water, sewer, utilities)</td>
<td>$3.8 billion</td>
<td>$3.0 billion</td>
<td>$2.2 billion</td>
<td>$2.3 billion</td>
</tr>
<tr>
<td>Single Family Homes vs. Condos, Apts. &amp; Townhomes</td>
<td>77% SF, 23% Condos, etc.</td>
<td>75% SF, 25% Condos, etc.</td>
<td>68% SF, 32% Condos, etc.</td>
<td>62% SF, 38% Condos, etc.</td>
</tr>
<tr>
<td>Transportation Choices</td>
<td><img src="image1.png" alt="Cars" /></td>
<td><img src="image2.png" alt="Cars" /></td>
<td><img src="image3.png" alt="Bicycles" /></td>
<td><img src="image4.png" alt="Buses" /></td>
</tr>
<tr>
<td>Walkable Communities (Walk to work, stores, school, transit)</td>
<td><img src="image5.png" alt="People" /></td>
<td><img src="image6.png" alt="People" /></td>
<td><img src="image7.png" alt="People" /></td>
<td><img src="image8.png" alt="People" /></td>
</tr>
</tbody>
</table>

Source: Nashville Area MPO Website
Using Scenarios in Transportation Planning

**Transportation Indicators**
The following charts show each scenario’s performance relating to getting around the region.

**Land Use and Housing Indicators**
The following charts show each scenario’s performance relating to land consumption, housing choices and walkable neighborhoods.

**New Housing Units in Walkable Areas**
Walkable Areas = mixed use and pedestrian oriented design

**Acres of Farm and Forest Land Consumed**

**New Homes and Multifamily Units**

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Source: “Oregon Scenario Planning Guidelines”, Oregon Department of Transportation
Asset Management
Decision-making Levels

- Strategic Level
- Network Level
- Program Level
- Project Selection Level
- Project Level (a.k.a., Field Level)

Asset Management
Decision-making Levels

- Organization Management Level
- Portfolio Management Level
- Systems Management Level
- Individual Assets

Institute of Asset Management. “Asset Management—An Anatomy.”
Asset Management Decision-making Levels

- Strategic Management Level
- Planning/Programming Level
- Project (Selection) Level
- Field Level
Dimensions of Uncertainty

- **Location:**
  - Context, Model, Inputs, or Outcome

- **Level:**
  - Four Levels of Uncertainty

- **Nature:**
  - Lack of Knowledge vs. Inherent Variability

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Levels of Uncertainty in Decision Analysis

- Level 1: A clear, single vision of the future
- Level 2: A limited set of possible future outcomes, one of which will occur
- Level 3: A specific range of possible future outcomes
- Level 4: A limitless range of possible future outcomes

Levels of Uncertainty in Asset Management

- Which level of uncertainty is most suitable for asset management?
Applying Scenario Planning in Asset Management

- Define the expected range of the budget required to maintain asset performance above a certain level (and/or)
- Define the expected range of asset performance given a certain amount of budget

![Pavement Performance Curves](image.png)
Applying Scenario Planning in Asset Management

- The performance of assets over time is subject to uncertainty

- Managers can benefit from an outcome-based scenario approach

- Quantiles are used to summarize the outcome distribution
  - The “worst case” or lower-limit scenario is defined as the 5th percentile
  - The “best case” or upper-limit scenario is defined as the 95th percentile
  - The “most likely” scenario is defined as the 50th percentile
Scenario Planning in Asset Management

- **Three Scenarios:**
  - “Best Case,” “Worst Case,” and “Most Likely Case”

![Pavement Performance Curves](image)
Quantile Regression

- Introduced in the late 1970s by Koenker
- Defines the Quantiles of the Response Variable
- Provides a More Complete Picture of the Relationships Between Variables
- Primarily Developed for Ecological Applications

Example 1 – Education and Income*

Quantile Regression

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- Defines the Quantiles of the Response Variable
- Provides a More Complete Picture of the Relationships Between Variables
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Example 2 – Changes in Trout Density*

Scenario Planning in Asset Management

- Three Scenarios:
  "Best Case," "Worst Case," and "Most Likely Case"
Quantile Curves

Pavement Performance Curve (Deshmukh, 2009):

\[ y_i = PCI_i = 100 - \frac{\rho}{\left[ \ln \left( \frac{\alpha}{Age_i} \right) \right]^{\frac{1}{\beta}}} \]

where:

- \( Age \) is the age of the current pavement surface
- \( ln \) is the natural logarithm
- \( \alpha, \beta, \) and \( \rho \) are regression constants.
Quantile Curves

Based on this equation, the loss function $L(\alpha, \beta, \rho)$ can be written as follows:

$$e_i(\alpha, \beta, \rho) = y_i(\alpha, \beta, \rho) - \hat{y}_i(\alpha, \beta, \rho)$$

$$L(\alpha, \beta, \rho) = (\tau - 1) \sum_{i=1}^{n} e_i(\alpha, \beta, \rho) \, 1(e_i < 0) + \tau \sum_{i=1}^{n} e_i(\alpha, \beta, \rho) \, 1(e_i \geq 0)$$

where:

$1(e_i < 0)$ is the indicator function and is defined as:

$$1(e_i < 0) = \begin{cases} 1 & \text{if } e_i < 0 \\ 0 & \text{if } e_i \geq 0 \end{cases}$$
Case Study

- City of Bryan
- Pavement Condition Index (PCI)
- Historical Performance Data
Historical Performance Data
Performance Curves for Historical Data

Pavement Performance Curves - Past Performance Data

- Worst Case Scenario
- Most Likely Scenario
- Best Case Scenario

Pavement Condition Index (PCI) vs. Age (years)
Results

Area Under Performance Curve

- Past Performance Data - Worst Case Scenario
- Past Performance Data - Most Likely Scenario
- Past Performance Data - Best Case Scenario
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