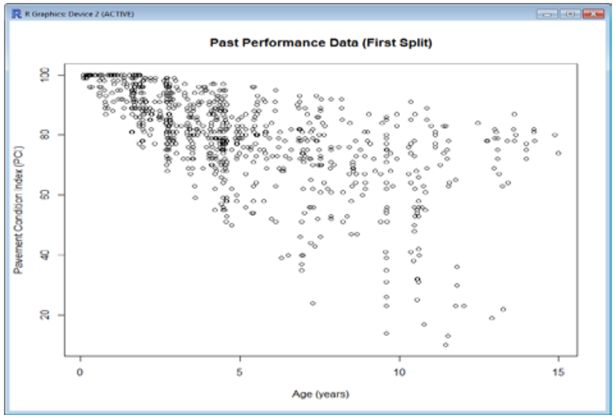
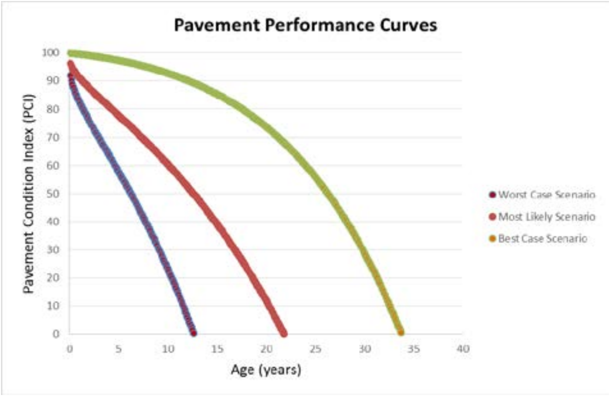
An Outcome-based Scenario Approach for Analyzing Risk in Infrastructure Asset Management



Amir Hessami
Roger E. Smith



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Picture from: https://www.coag.gov.au/infrastructure_and_transport

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/

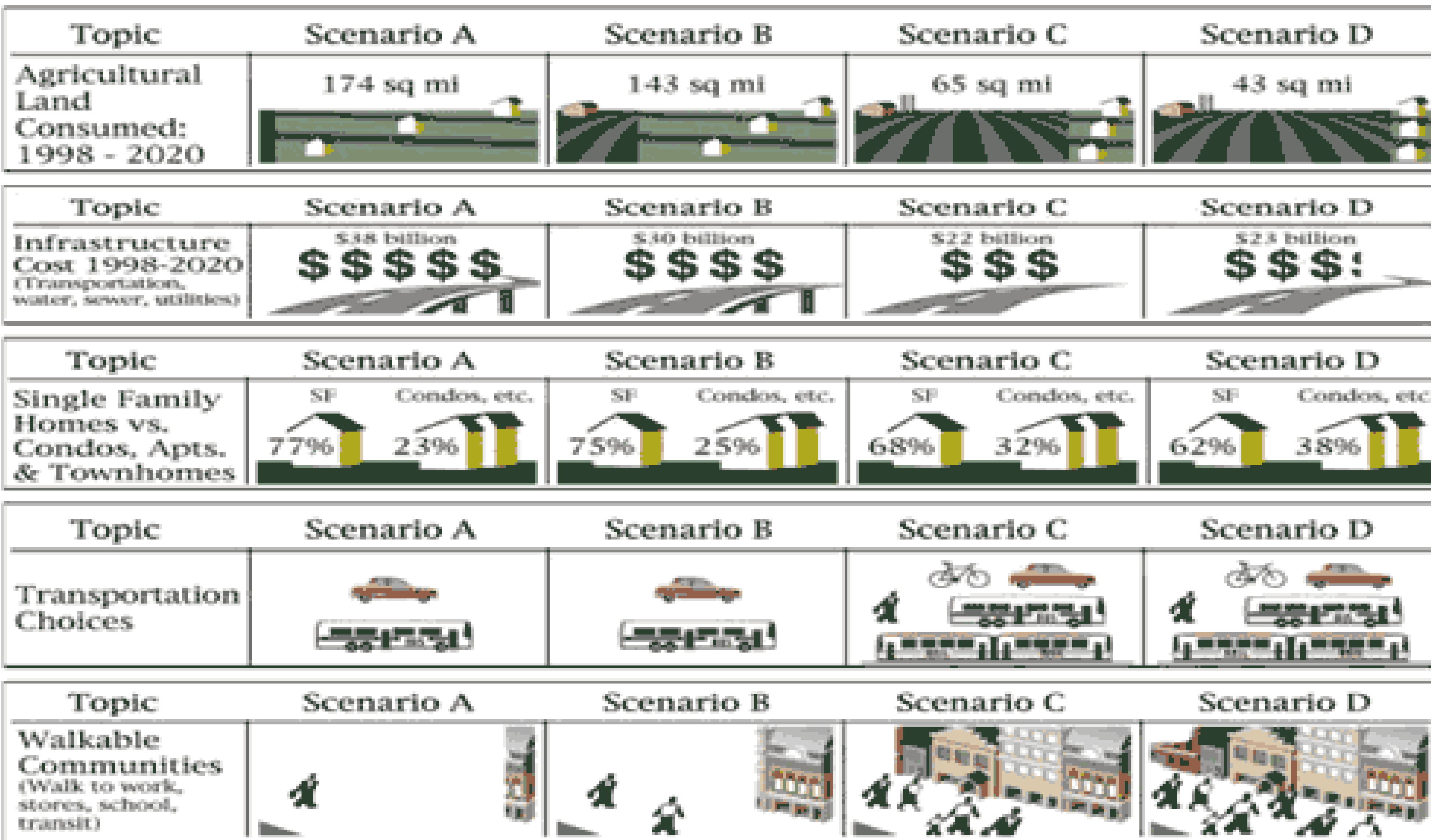
Overview of Scenario Planning

- 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

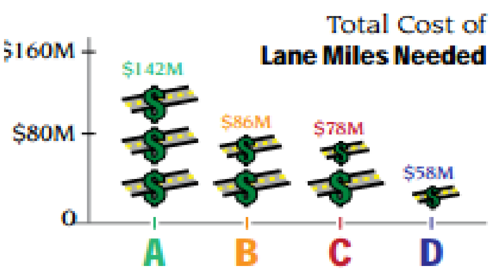


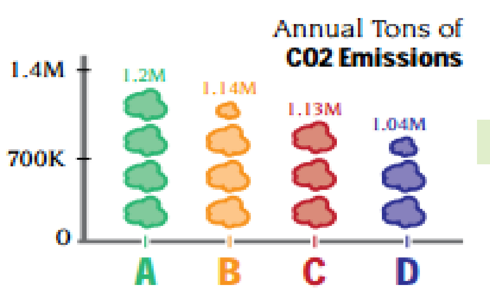
Source: Nashville Area MPO Website
http://www.nashvillempo.org/regional_plan/land_use/regional_land_use_model.aspx

Using Scenarios in Transportation Planning

Transportation Indicators

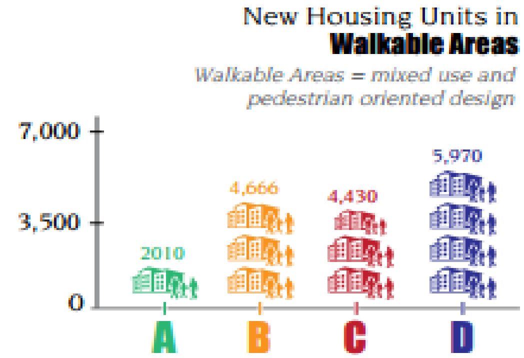
The following charts show each scenario's performance relating to getting around the region.

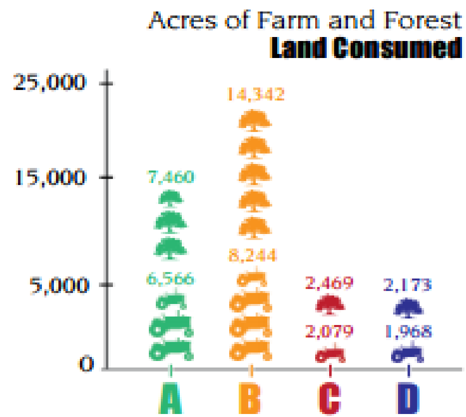


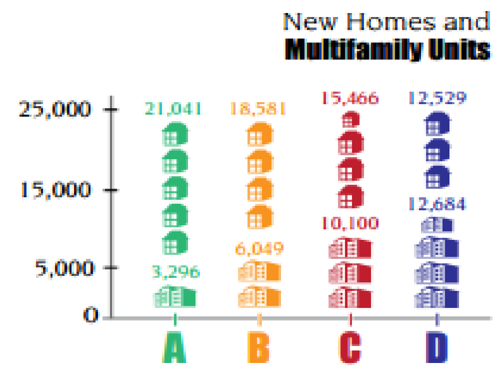


Land Use and Housing Indicators

The following charts show each scenario's performance relating to land consumption, housing choices and walkable neighborhoods.







Source: "Oregon Scenario Planning Guidelines" , Oregon Department of Transportation
http://www.oregon.gov/ODOT/TD/OSTI/pages/scenarios.aspx

Asset Management Decision-making Levels

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

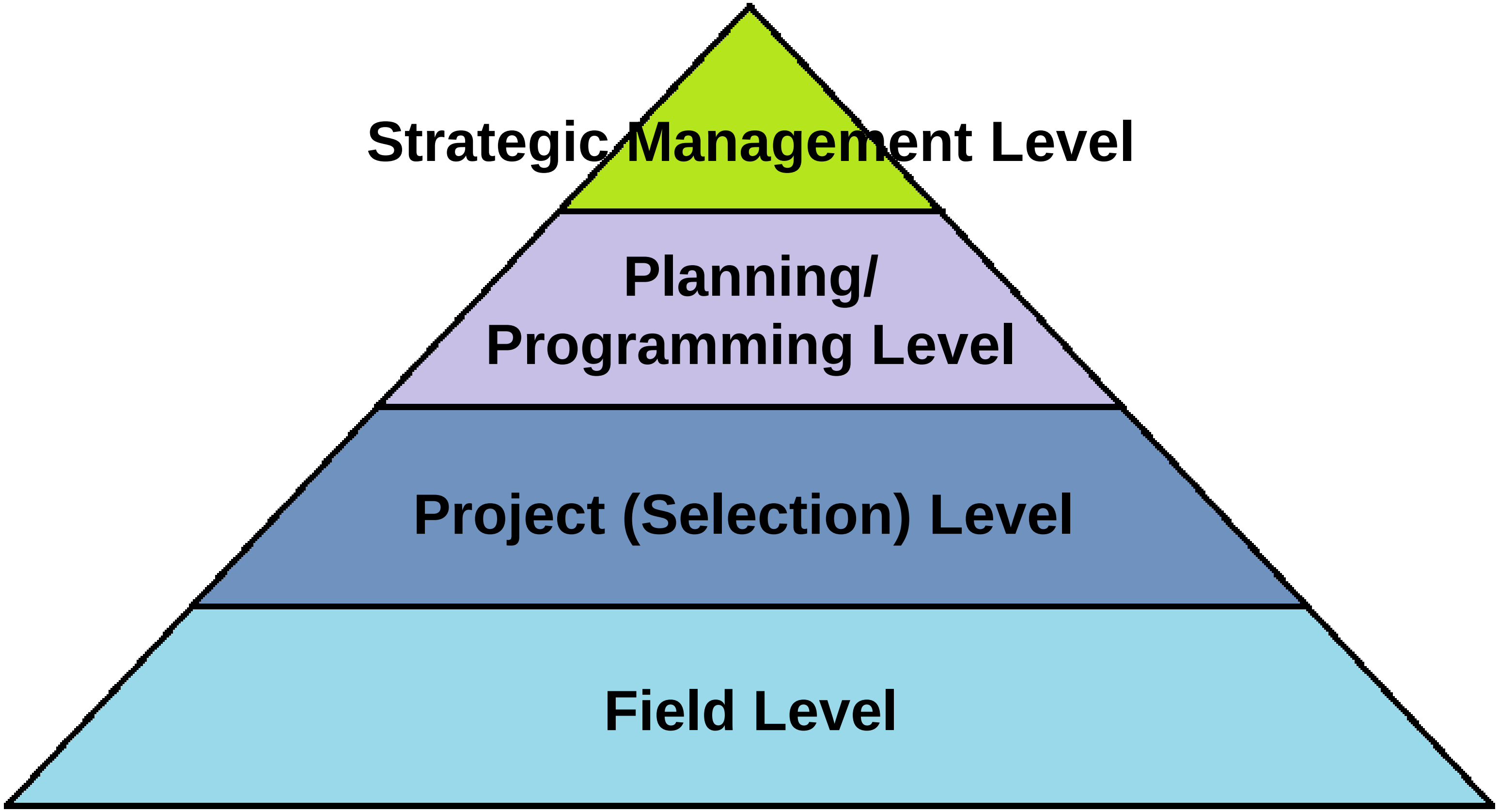
Flintsch, G. W., & Bryant, J. (2006). Asset management data collection for supporting decision processes. *US Department of Transport, Federal Highway Administration, Washington, DC*.

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



Dimensions of Uncertainty

- **Location:**
  - **Context, Model, Inputs, or Outcome**
- **Level:**
  - **Four Levels of Uncertainty**
- **Nature:**
  - **Lack of Knowledge vs. Inherent Variability**

Walker, W. E., Harremoës, P., Rotmans, J., van der Sluijs, J. P., van Asselt, M. B., Janssen, P., & Krayer von Krauss, M. P. (2003). Defining uncertainty: A conceptual basis for uncertainty management in model-based decision support. *Integrated Assessment*, *4*(1), 5–17.

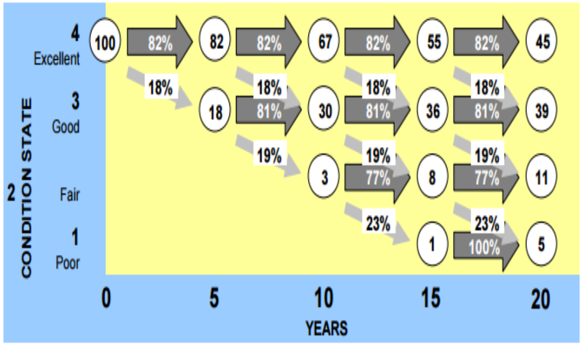
Levels of Uncertainty in Decision Analysis

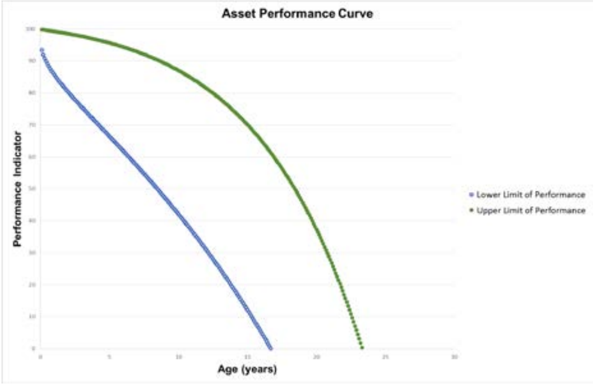
- **Level 1: A clear, single vision of the future**
- **Level 2: A limited set of possible future outcomes, one of which will occur**
- **Level 3: A specific range of possible future outcomes**
- **Level 4: A limitless range of possible future outcomes**

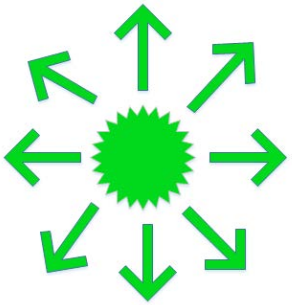
Courtney, H. (2001). *20/20 foresight: Crafting strategy in an uncertain world*. Harvard Business Press.

Levels of Uncertainty in Asset Management

- **Which level of uncertainty is most suitable for asset management?**





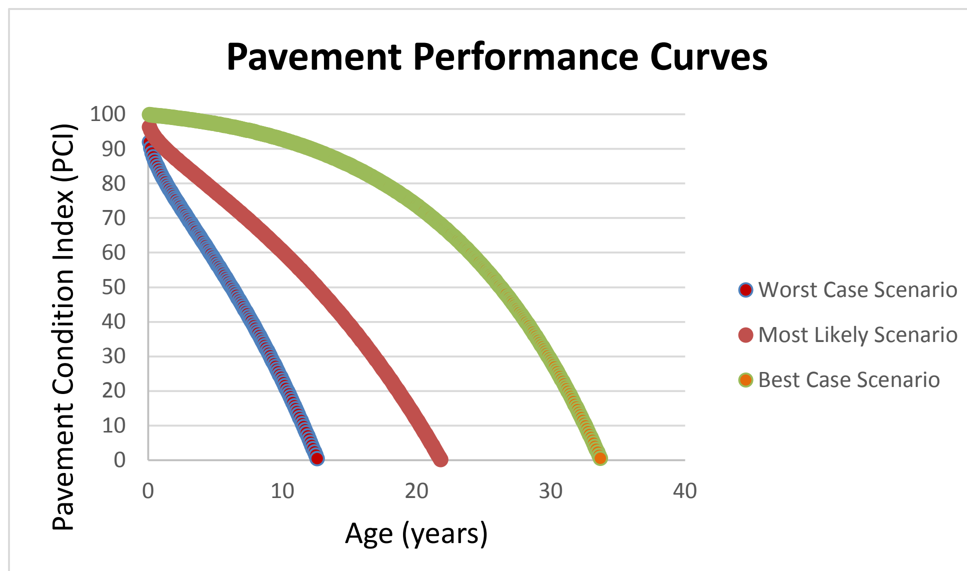


Applying Scenario Planning in Asset Management

- **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**



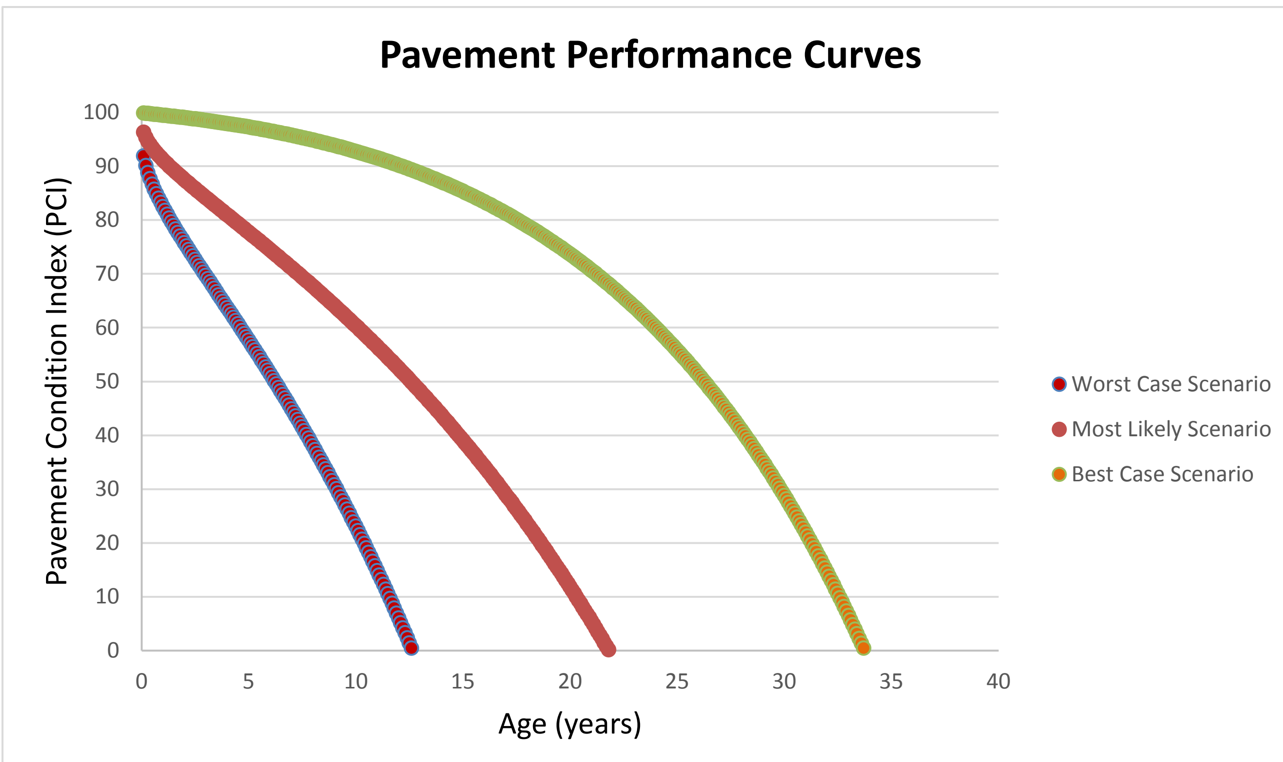
Applying Scenario Planning in Asset Management

- **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:**

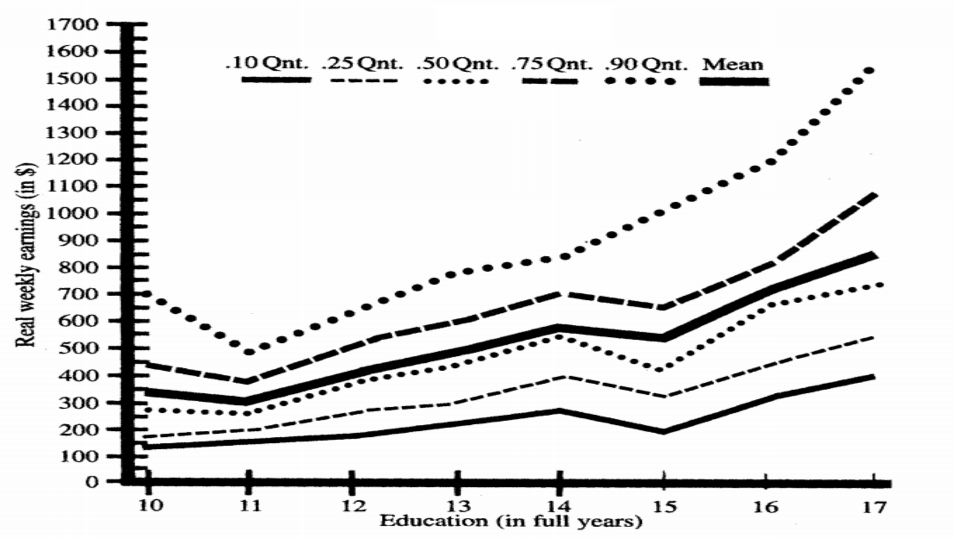
  “Best Case,” “Worst Case,” and “Most Likely Case”



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*



* Buchinsky, Moshe. "Recent advances in quantile regression models: a practical guideline for empirical research." *Journal of Human Resources* (1998): 88–126.

Quantile Regression

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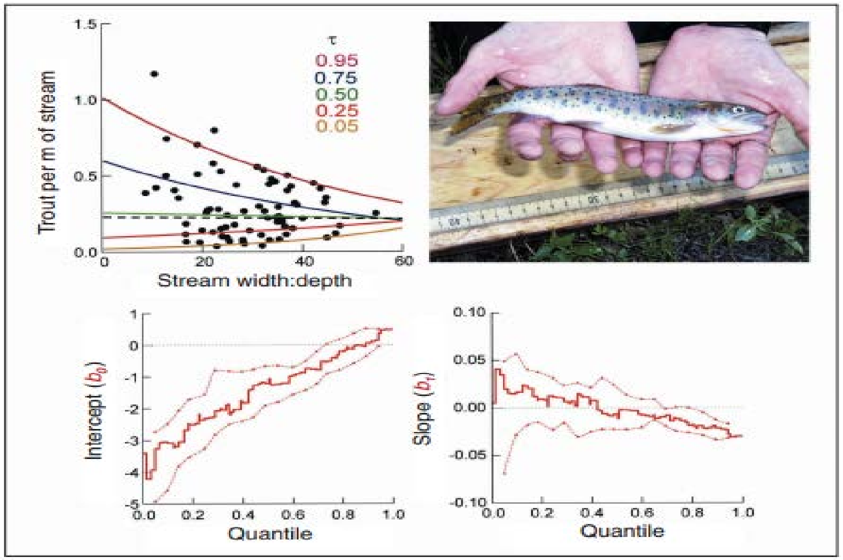
Example 2 – Changes in Trout Density*

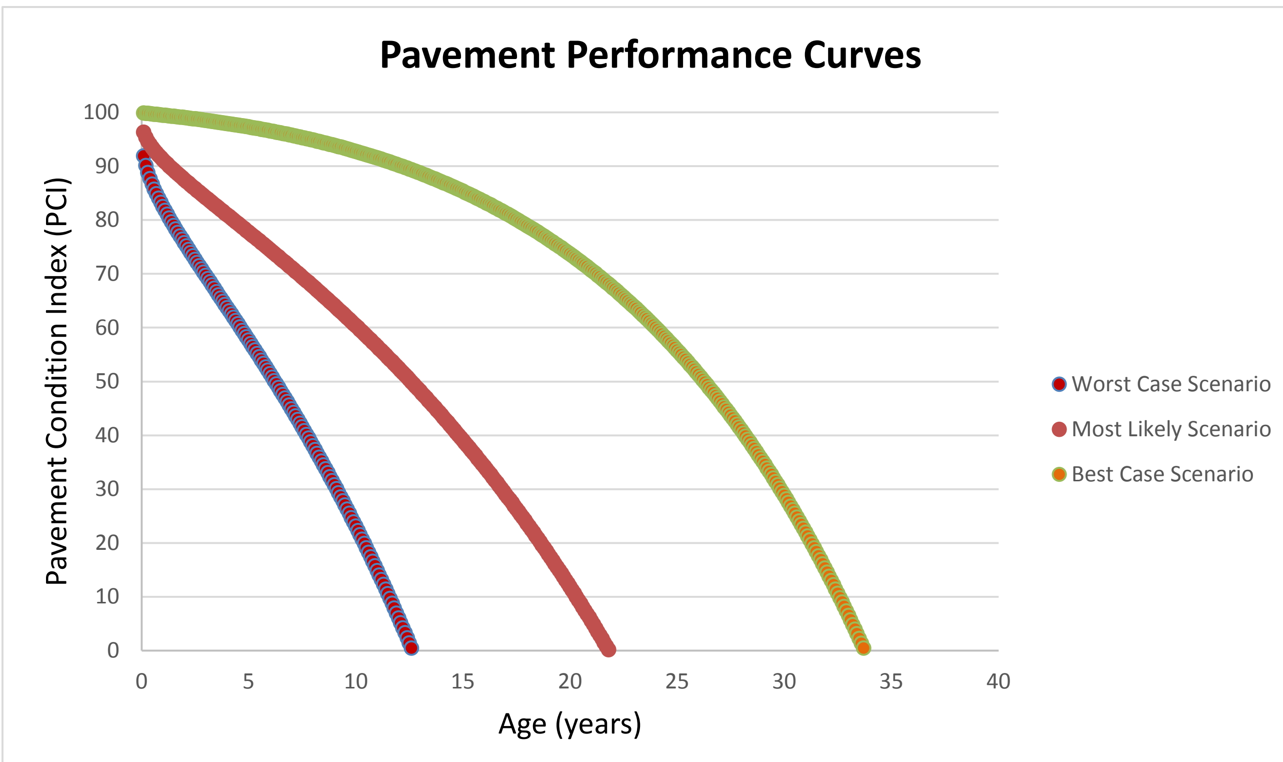


* Cade, Brian S., and Barry R. Noon. "A gentle introduction to quantile regression for ecologists." *Frontiers in Ecology and the Environment* 1.8 (2003): 412–420.

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

α, β, and ρ 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:

$$1(e_i < 0) = \begin{cases} 1 \; if \; e_i < 0 \\ 0 \; if \; e_i \geq 0 \end{cases}$$

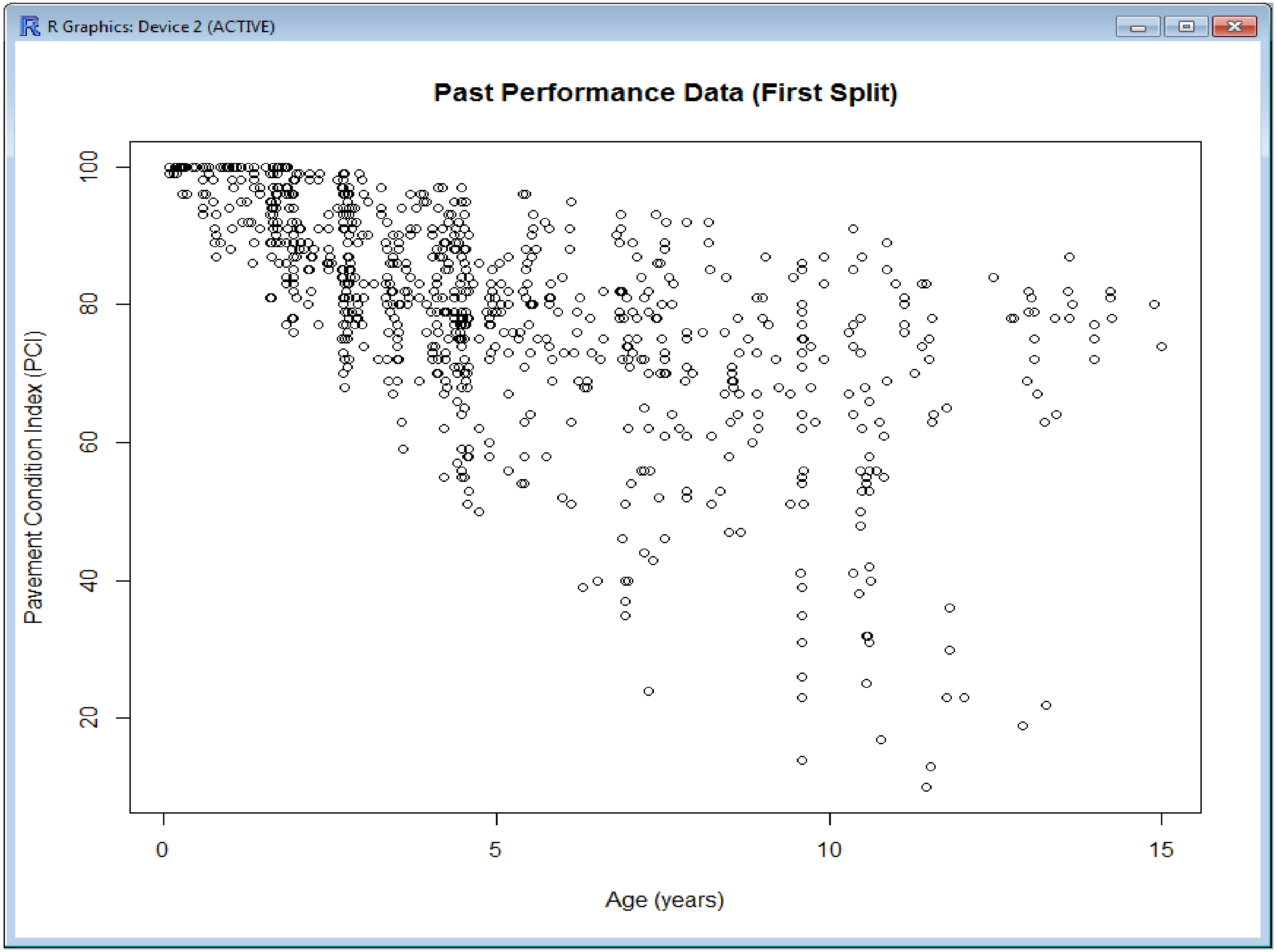
Case Study

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

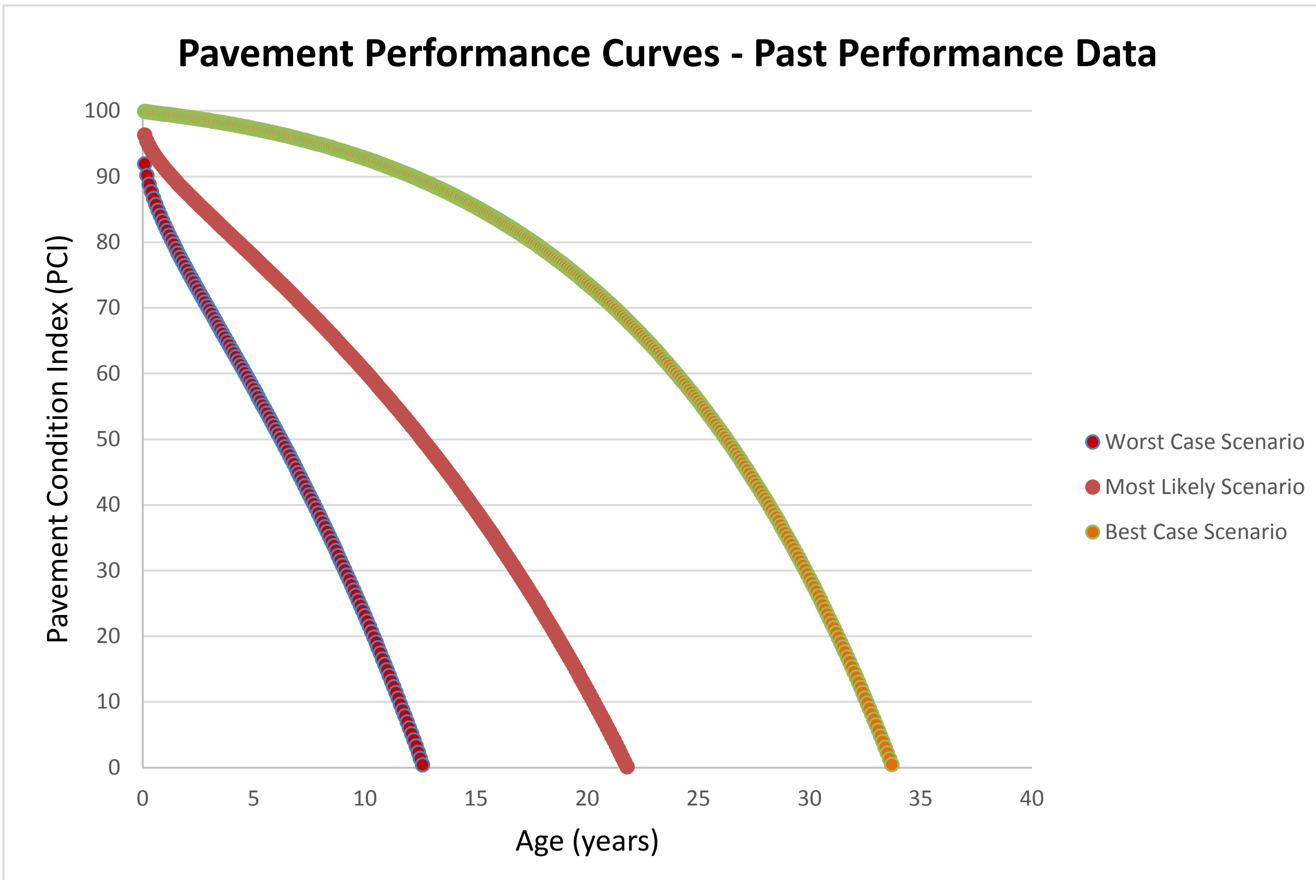
sec con rep.REV [Compatibility Mode] - Excel

	Name	Section	LCD	SurTyp	Rank	Area	Insp Date	# Samps	PCI
2	14th St W (West 14th Street)	Sims-Parke	05/21/1981	AAC	N	7,272	07/30/2008	27	55.00
3	14th St W (West 14th Street)	Ster-Hwy21	06/17/1978	AC	E	9,552	07/31/2008	30	52.00
4	14th St W (West 14th Street)	Sterl-Sims	01/04/1974	AC	N	6,468	07/31/2008	34	47.00
5	15th St E (East 15th Street)	Hous-Just	05/26/1950	AC	N	3,345	07/28/2008	58	31.00
6	15th St E (East 15th Street)	Plum-Tex	09/01/2010	AC	E	10,678	09/01/2010	0	100.00
7	15th St E (East 15th Street)	Tabor-Tex	01/01/2005	AC	E	20,430	07/30/2008	3	94.00
8	15th St W (West 15th Street)	Sims-Hall	12/01/1976	ST	E	24,300	07/31/2008	32	87.00
9	15th St W (West 15th Street)	Tabor-Sims	05/01/2008	AC	E	34,368	07/30/2008	0	100.00
10	16th St E (East 16th Street)	Tabor-Wash	12/01/2008	AC		9,131	12/01/2008	0	100.00
11	16th St W (West 16th Street)	Bryan-Tab	02/06/1952	AC		4,960	07/30/2008	56	35.00
12	16th St W (West 16th Street)	Parke-Brya	10/01/1988	AAC		5,008	07/30/2008	20	57.00
13	16th St W (West 16th Street)	Sims-Hwy21	08/01/1967	PCC		45,120	07/31/2008	41	12.00
14	16th St W (West 16th Street)	Sims-Parke	10/01/1988	AC	E	6,220	07/30/2008	20	57.00

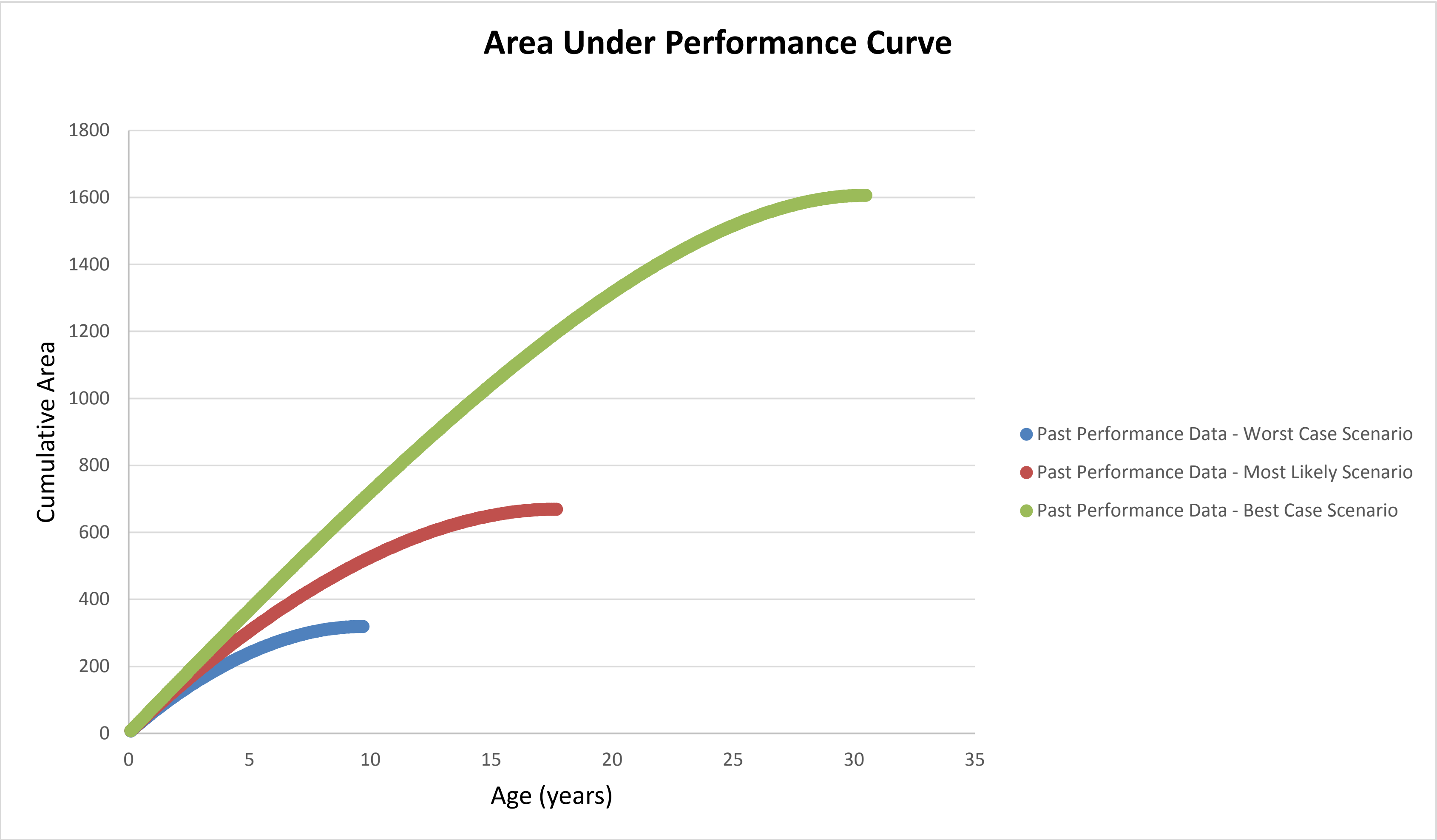
Historical Performance Data



Performance Curves for Historical Data



Results


Area Under Performance Curve
Cumulative Area
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
35
Age (years)
Past Performance Data - Worst Case Scenario
Past Performance Data - Most Likely Scenario
Past Performance Data - Best Case Scenario

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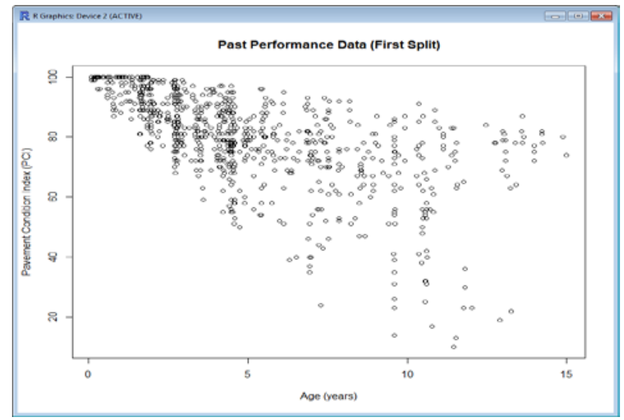

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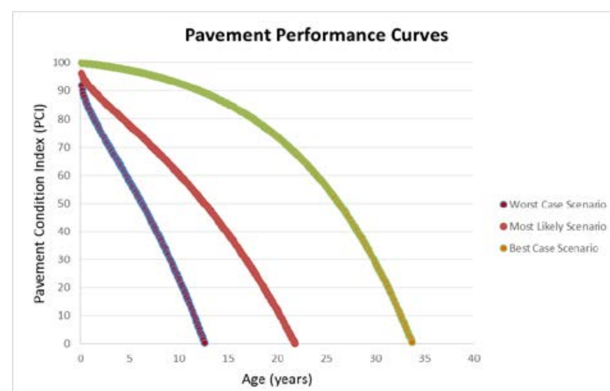

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