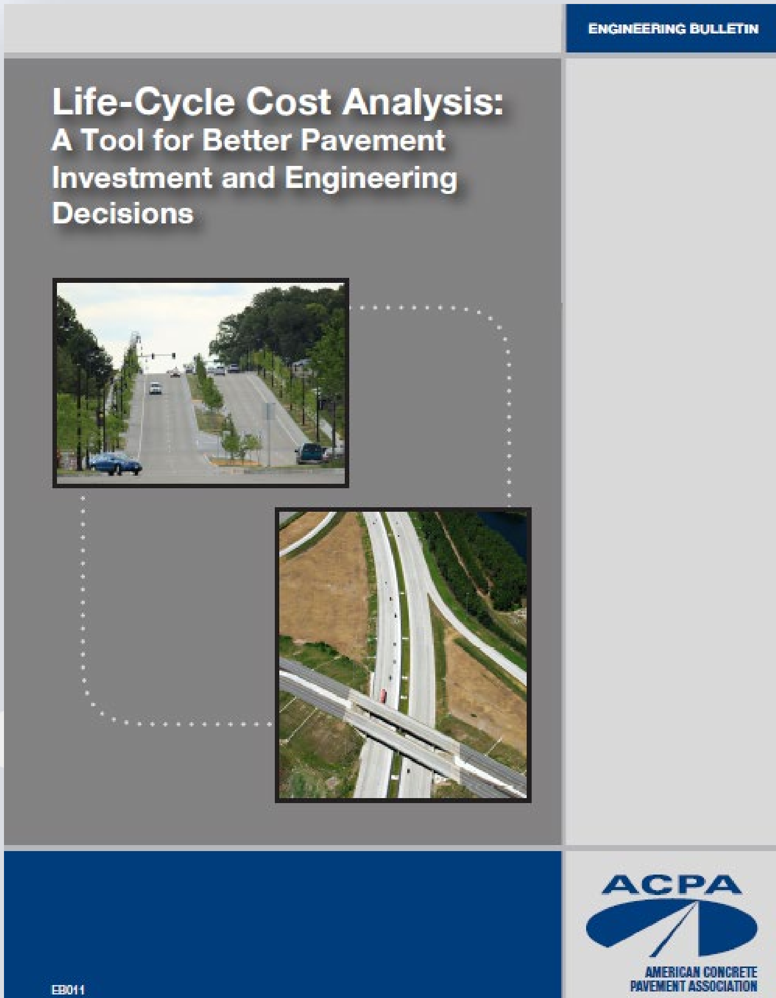
Life-Cycle Cost Analysis for Pavements



June 13, 2023

Tim Martin, P.E.
Senior Vice President of Technical Services

Life-Cycle Cost Analysis

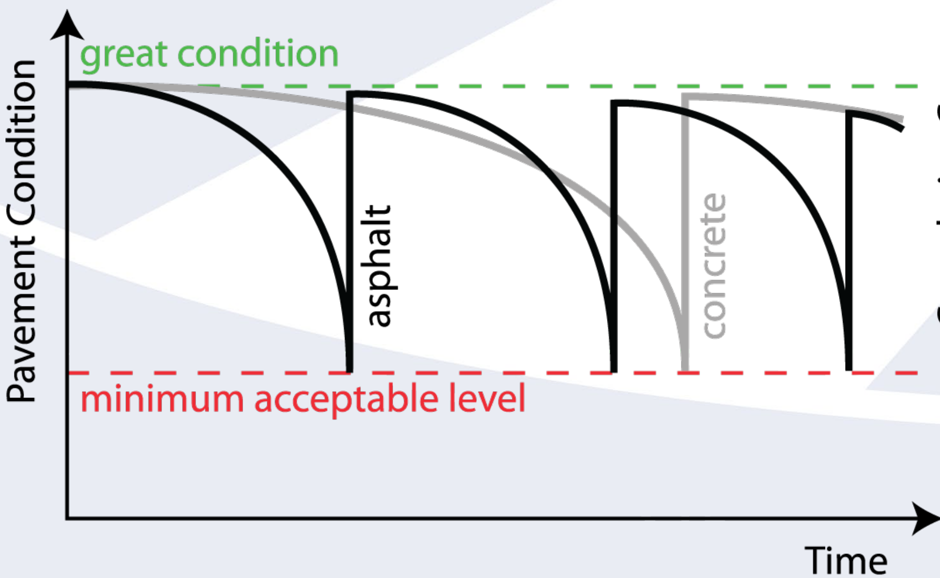
Introduction

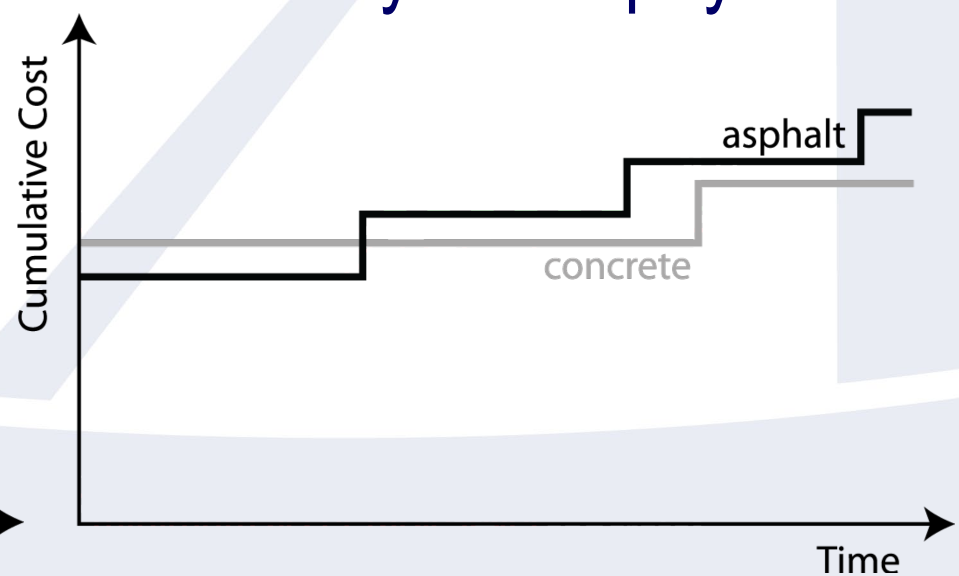
What is Life-Cycle Cost Analysis?

- **Life-cycle cost analysis (LCCA)**:
  - **An analysis technique** used to evaluate the overall long-term economic efficiency between competing alternate investment options (e.g., pavements).
  - Based on well-founded economic principles.
  - Identifies the strategy that will yield the **best value** by providing the expected performance **at the lowest cost** over the analysis period.
  - **Is not an engineering tool** for determining how long a pavement design or rehabilitation alternative will last or how well it will perform.

Why Bother with an LCCA?

- Pavement types perform differently over time.
- Equivalent designs are not always achievable.
- LCCA compares the total discounted cost of each design over a specific analysis period to minimize the financial burden of the roadway on taxpayers.





We Must Consider Life Cycle Costs!

- “Economic principles tell us that if we want to minimize the cost of a durable good that requires repair, maintenance and replacement over time, **we must minimize present value of those costs, not minimize initial costs**. If the myopic strategy is adopted to accept the lower up-front price despite higher [present value], the buyers are actually made worse off.”

- Dr. William Holahan

Chair and Professor

Department of Economics

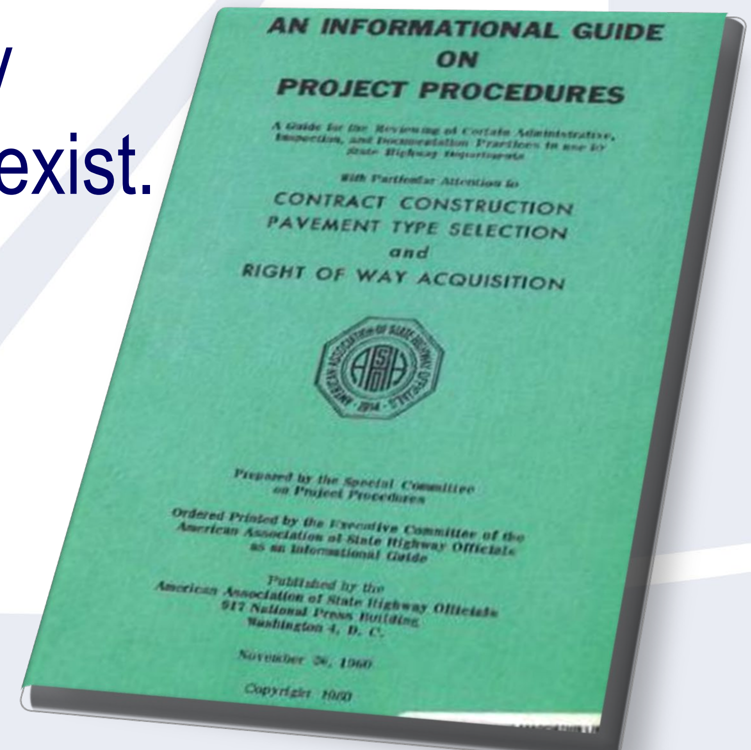
University of Wisconsin - Milwaukee

LCCA in context of COMPETITION

- Greatest impediment to successful adoption?

  Lack of competition!

- Acknowledged 63 years ago…
- LCCA cannot work effectively where "*monopoly situations*" exist.



LCCA in context of COMPETITION

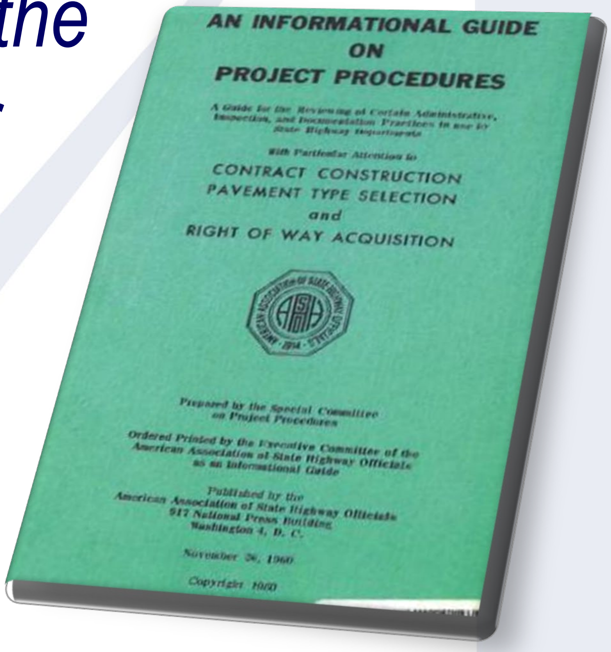
- LCCA can be a very powerful tool to help agencies make better long-term decisions for the public!
- BUT, only in the presence of competition can we *"ensure the tax-payers of this country are receiving full value of every highway dollar spent."*

History of LCCA

- *Manual of the Principles and Practices of Road Making*, Gillespie 1847
  - Defined the most cost-effective highway project as the one with the highest return to the cost associated with its construction <u>and</u> maintenance
- Concepts not widely used until 1950s and 1960s, the beginning of …

AASHO 1960 Guide on Pavement Type Selection

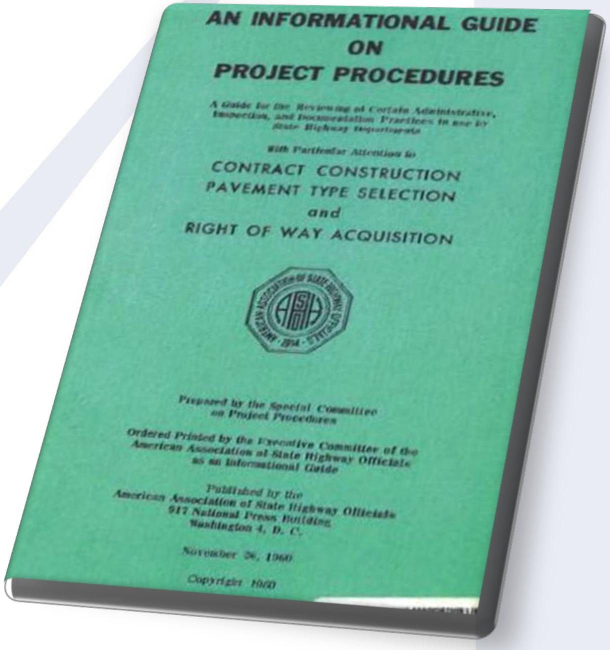
- *V. Cost Comparison: Where circumstances permit, a better and more realistic measure would be the cost on the basis of service life or service rendered by a pavement structure. Such cost computation should reflect original investment, anticipated life, maintenance expenditures, and salvage value.*



AASHO 1960 Guide on Pavement Type Selection

- **It does caution however**:

  Original cost can be fairly accurately estimated. Doubt as to validity arises in the case where on(e) type of pavement has been given monopoly status by the long-term exclusion of a competitive type.

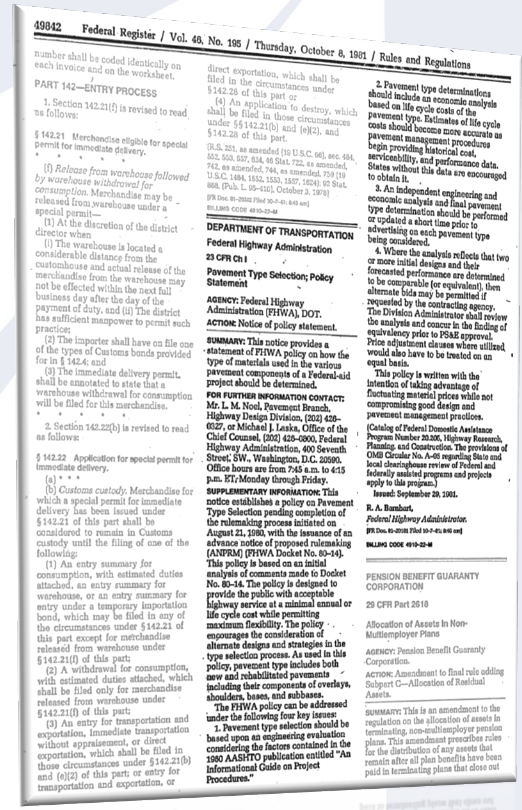


AASHTO 1972 Pavement Design

- Pavement Design Guide
- Recommended the concept of life cycle costing
- Builds and refers to 1960 AASHO guide
- Carries to AASHTO 1983 and 1993 Design Guide recommendations endorsing LCCA use as a means for economic evaluation and decision support tool.

FHWA 1981 Pavement Type Selection Policy Statement

- *2. Pavement type determinations should include an economic analysis based on life cycle costs of the pavement type. Estimates of life cycle costs should become more accurate as pavement management procedures begin providing historical cost, serviceability, and performance data.*



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number shall be coded identically on each invoice and on the worksheet.

PART 142—ENTRY PROCESS

1. Section 142.21(f) is revised to read as follows:

§ 142.21 Merchandise eligible for special permit for immediate delivery.

* * * * *

(f) *Release from warehouse followed by warehouse withdrawal for consumption.* Merchandise may be released from warehouse under a special permit—

(1) At the discretion of the district director when

(i) The warehouse is located a considerable distance from the customhouse and actual release of the merchandise from the warehouse may not be effected within the next full business day after the day of the payment of duty, and (ii) The district has sufficient manpower to permit such practice;

(2) The importer shall have on file one of the types of Customs bonds provided for in § 142.4; and

(3) The immediate delivery permit shall be annotated to state that a warehouse withdrawal for consumption will be filed for this merchandise.

* * * * *

2. Section 142.22(b) is revised to read as follows:

§ 142.22 Application for special permit for immediate delivery.

(a) * * *

(b) *Customs custody.* Merchandise for which a special permit for immediate delivery has been issued under §142.21 of this part shall be considered to remain in Customs custody until the filing of one of the following:

(1) An entry summary for consumption, with estimated duties attached, an entry summary for warehouse, or an entry summary for entry under a temporary importation bond, which may be filed in any of the circumstances under §142.21 of this part except for merchandise released from warehouse under §142.21(f) of this part;

(2) A withdrawal for consumption, with estimated duties attached, which shall be filed only for merchandise released from warehouse under §142.21(f) of this part;

(3) An entry for transportation and exportation, immediate transportation without appraisement, or direct exportation, which shall be filed in those circumstances under §142.21(b) and (e)(2) of this part; or entry for transportation and exportation, or direct exportation, which shall be filed in the circumstances under §142.28 of this part or

(4) An application to destroy, which shall be filed in those circumstances under §§142.21(b) and (e)(2), and §142.28 of this part.

(R.S. 251, as amended (19 U.S.C. 66), sec. 484, 552, 553, 557, 624, 46 Stat. 722, as amended, 742, as amended, 744, as amended, 759 (19 U.S.C. 1484, 1552, 1553, 1557, 1624); 92 Stat. 888, (Pub. L. 95–410), October 3, 1978)

[FR Doc. 81–29302 Filed 10–7–81; 8:45 am]

BILLING CODE 4810–22–M

DEPARTMENT OF TRANSPORTATION

Federal Highway Administration

23 CFR Ch I

Pavement Type Selection; Policy Statement

AGENCY: Federal Highway Administration (FHWA), DOT.

ACTION: Notice of policy statement.

SUMMARY: This notice provides a statement of FHWA policy on how the type of materials used in the various pavement components of a Federal-aid project should be determined.

FOR FURTHER INFORMATION CONTACT: Mr. L. M. Noel, Pavement Branch, Highway Design Division, (202) 426–0327, or Michael J. Laska, Office of the Chief Counsel, (202) 426–0800, Federal Highway Administration, 400 Seventh Street, SW., Washington, D.C. 20590. Office hours are from 7:45 a.m. to 4:15 p.m. ET, Monday through Friday.

SUPPLEMENTARY INFORMATION: This notice establishes a policy on Pavement Type Selection pending completion of the rulemaking process initiated on August 21, 1980, with the issuance of an advance notice of proposed rulemaking (ANPRM) (FHWA Docket No. 80–14). This policy is based on an initial analysis of comments made to Docket No. 80–14. The policy is designed to provide the public with acceptable highway service at a minimal annual or life cycle cost while permitting maximum flexibility. The policy encourages the consideration of alternate designs and strategies in the type selection process. As used in this policy, pavement type includes both new and rehabilitated pavements including their components of overlays, shoulders, bases, and subbases.

The FHWA policy can be addressed under the following four key issues:

1. Pavement type selection should be based upon an engineering evaluation considering the factors contained in the 1980 AASHTO publication entitled "An Informational Guide on Project Procedures."

2. Pavement type determinations should include an economic analysis based on life cycle costs of the pavement type. Estimates of life cycle costs should become more accurate as pavement management procedures begin providing historical cost, serviceability, and performance data. States without this data are encouraged to obtain it.

3. An independent engineering and economic analysis and final pavement type determination should be performed or updated a short time prior to advertising on each pavement type being considered.

4. Where the analysis reflects that two or more initial designs and their forecasted performance are determined to be comparable (or equivalent), then alternate bids may be permitted if requested by the contracting agency. The Division Administrator shall review the analysis and concur in the finding of equivalency prior to PS&E approval. Price adjustment clauses where utilized would also have to be treated on an equal basis.

This policy is written with the intention of taking advantage of fluctuating material prices while not compromising good design and pavement management practices.

(Catalog of Federal Domestic Assistance Program Number 20.205, Highway Research, Planning, and Construction. The provisions of OMB Circular No. A–95 regarding State and local clearinghouse review of Federal and federally assisted programs and projects apply to this program.)

Issued: September 29, 1981.

R. A. Barnhart,

Federal Highway Administrator.

[FR Doc. 81–29181 Filed 10–7–81; 8:45 am]

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PENSION BENEFIT GUARANTY CORPORATION

29 CFR Part 2618

Allocation of Assets in Non-Multiemployer Plans

AGENCY: Pension Benefit Guaranty Corporation.

ACTION: Amendment to final rule adding Subpart C—Allocation of Residual Assets.

SUMMARY: This is an amendment to the regulation on the allocation of assets in terminating, non-multiemployer pension plans. This amendment prescribes rules for the distribution of any assets that remain after all plan benefits have been paid in terminating plans that close out

FHWA 1981 Pavement Type Selection Policy Statement (cont.)

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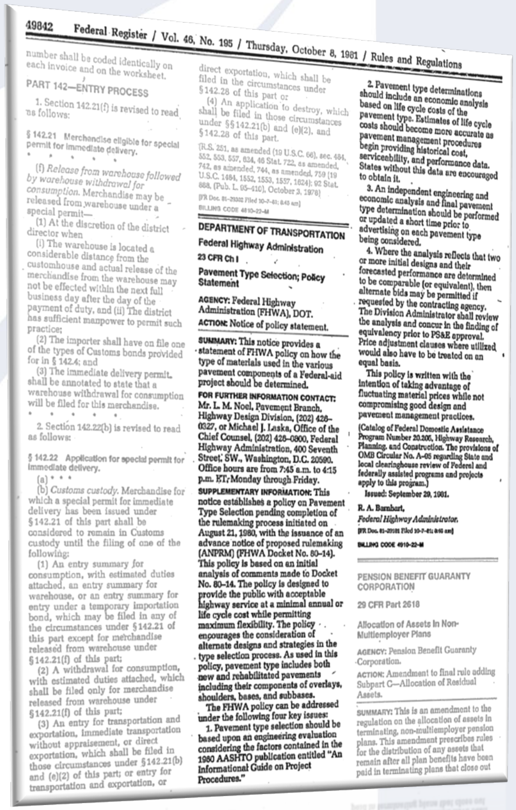

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Issued: September 29, 1981.

R. A. Barnhart,

Federal Highway Administrator.

[FR Doc. 81–29191 Filed 10–7–81; 8:45 am]

BILLING CODE 4910–22–M

PENSION BENEFIT GUARANTY CORPORATION

29 CFR Part 2618

Allocation of Assets in Non-Multiemployer Plans

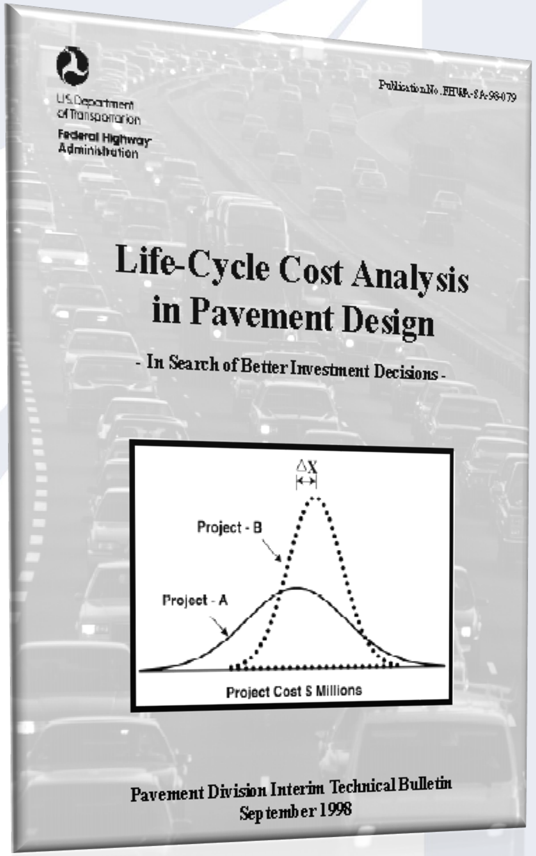
AGENCY: Pension Benefit Guaranty Corporation.

ACTION: Amendment to final rule adding Subpart C—Allocation of Residual Assets.

SUMMARY: This is an amendment to the regulation on the allocation of assets in terminating, non-multiemployer pension plans. This amendment prescribes rules for the distribution of any assets that remain after all plan benefits have been paid in terminating plans that close out

1998 FHWA Interim Tech Bulletin

- Broad fundamental principles as well as detailed procedures
- Introduces probabilistic approach
- Demo Project 115 :*LCCA in Pavement Design*
- Foundation of later FHWA LCCA guidance and tools including RealCost (2004)



1998 FHWA Interim Tech Bulletin has a well-structured LCCA framework

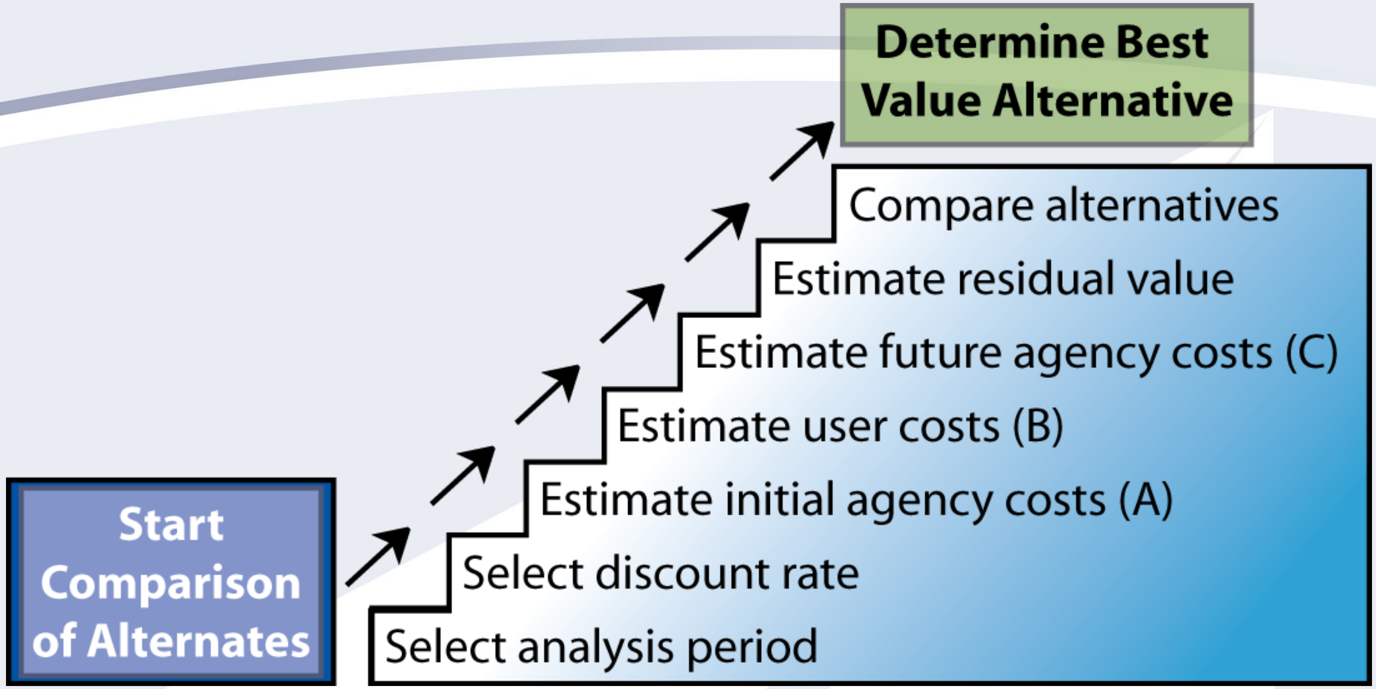
Establish LCCA Framework

- Establish analysis period
- Establish how inflation will be treated (nominal or real)
- Establish discount rate to be used (nominal or real)

Perform LCCA

1. Establish Alternative Pavement Designs
2. Determine Timing of Required Rehabilitation Activities
3. Estimate Agency and User Costs
   - Initial Construction Costs
   - Rehabilitation Costs
4. Compute Life-Cycle Costs
5. Analyze the Results

State DOTS and the Concrete & Asphalt Industries generally agree with this Structure and Process



Life-Cycle Cost Analysis

Basic Steps in a Single Project LCCA

Life-Cycle Cost Analysis

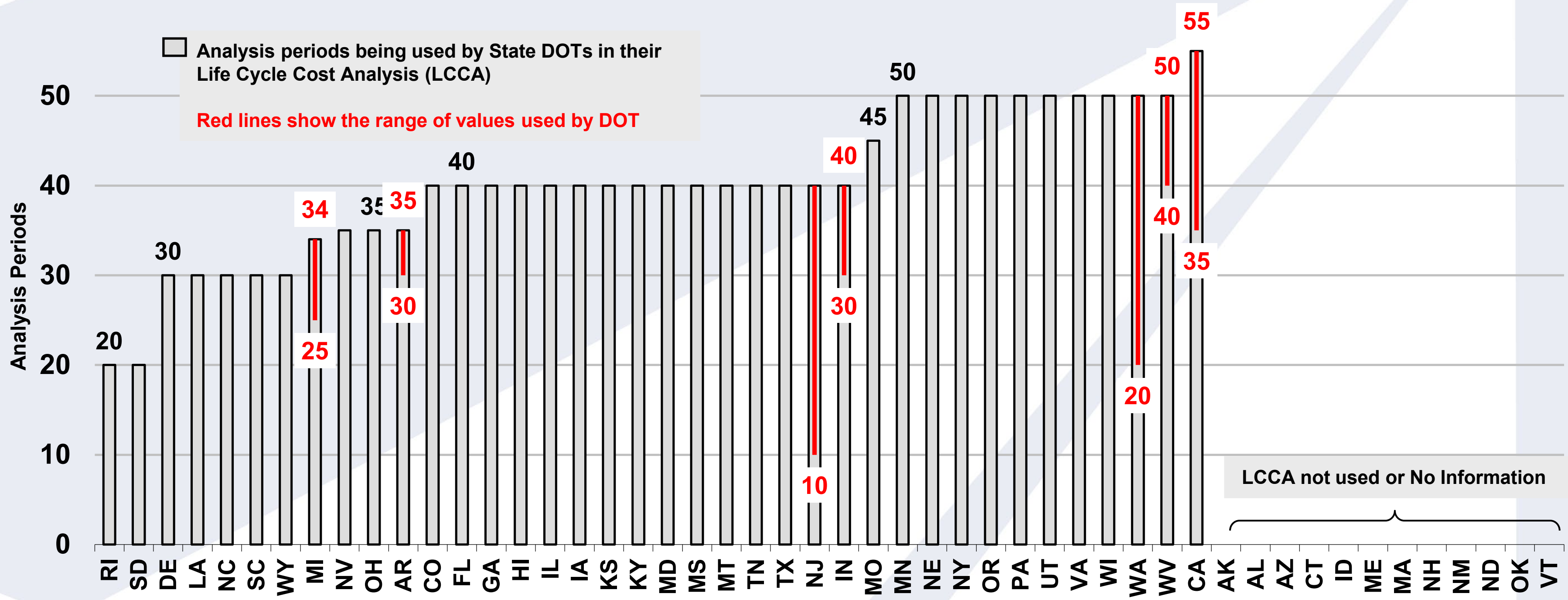
Selecting the Analysis Period

LCCA Analysis Period

- The **analysis period** is the timeframe over which the alternative strategies/treatments are compared.
  - Must encompass the initial performance period and **at least one major follow-up** preservation/ rehabilitation activity for each strategy.
    - FHWA recommends an analysis period of at least 35 years for all pavement projects.
    - ***ACPA recommends an analysis period of 45-50+ years because common practice in many states is to design the concrete pavement alternate for 30+ years.***

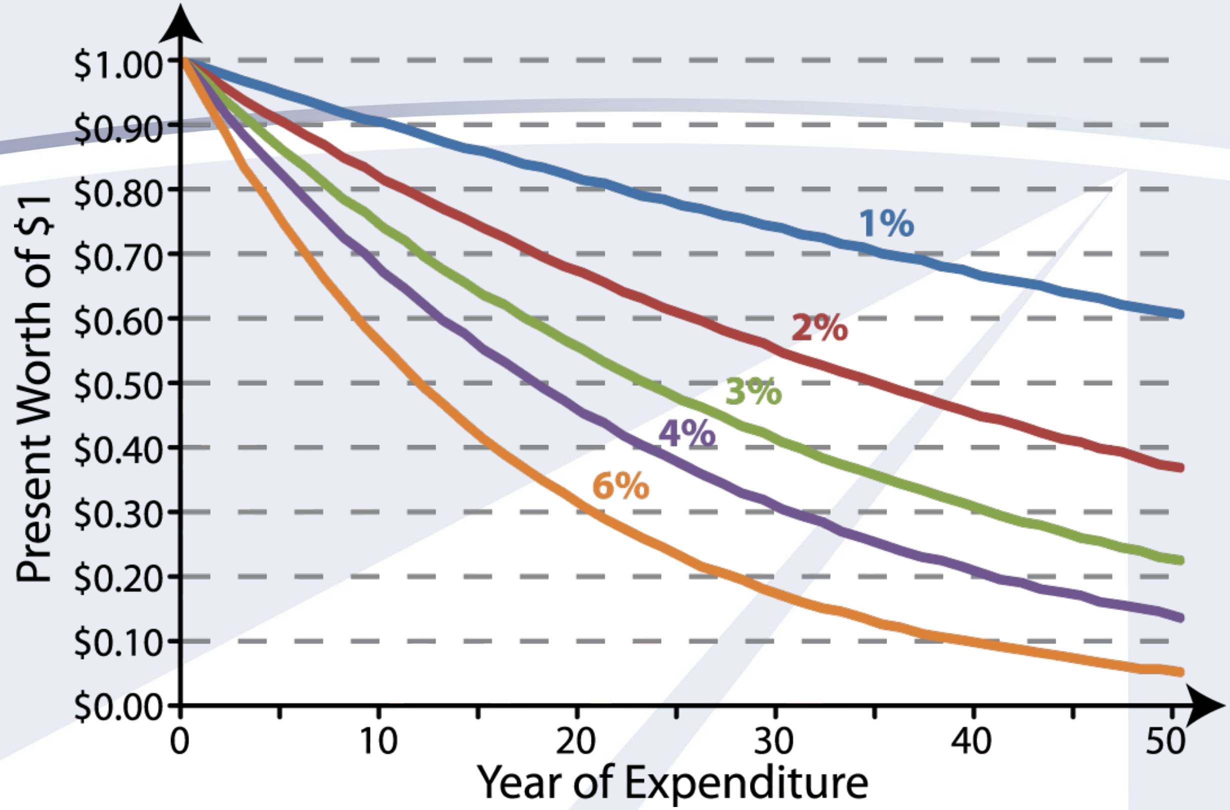
Analysis Periods used by DOTS

In general, Analysis Periods have been getting longer



If changing the analysis period changes the results, EXTEND the analysis period

1. 2007 National LCCA Survey by Mississippi DOT
2. National LCCA Survey Conducted by South Carolina DOT
3. State DOT Pavement Design and/or Pavement Type Selection Manuals
4. Survey of American Concrete Pavement Association Chapter Executives
5. Performance Assumptions Used to Support LCCA - State Reports - Fall 2013 NCC Meeting



Life-Cycle Cost Analysis

Step 2 – Select a Discount Rate

LCCA Discount Rate

- The **real discount rate** (also known as the real interest rate) is used in pavement LCCAs.
  - Accounts for fluctuations in both investment **interest rates** and the **rate of inflation**.

$$d = \frac{1 + i_{int}}{1 + i_{inf}} - 1$$

d = the real discount rate, %
i_{int} = the interest rate, %
i_{inf} = the inflation rate, %

LCCA Discount Rate

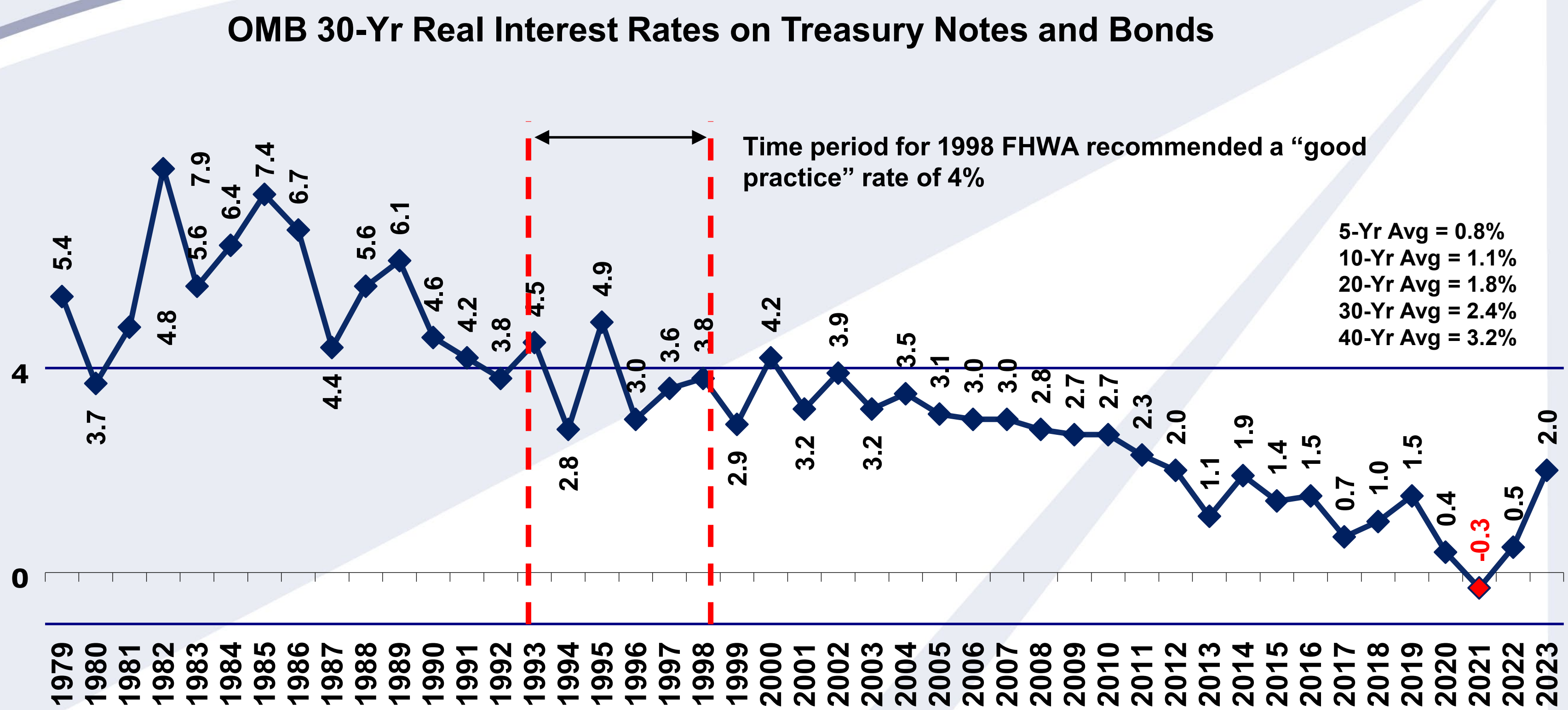
- Low Discount Rate
  - Favors high initial cost and low future cost options
  - Long term (Concrete) solutions over short term solutions
  - Capital expansion over preservation

- High Discount Rate
  - Favors low initial cost and high future cost options
  - Short term solutions (asphalt) over long term solutions
  - Maintaining existing capacity over building new capacity (roads, ports etc)

Calculating the Real Discount Rate

- ***ACPA supports the use of the United State's Office of Management and Budget (OMB) real discount rate.***
- If there is concern with the variability in the OMB real discount rate, a moving average of the value can be considered.

Real Discount Rates from OMB Circular A-94



Best practice is to update and use OMB Discount Rates each year
Ensure the analysis is line with current economic conditions

1. Guidelines and Discount Rates For Benefit-Cost Analysis Of Federal Programs, OMB , Circular A-94, Appendix C. (http://www.whitehouse.gov/omb/circulars_a094_a94_appx-c/),
2. FHWA Technical Advisory on "Use Alternate Bidding for Pavement Type Selection, December 20, 2012. See http://www.fhwa.dot.gov/pavement/t504039.cfm

Life-Cycle Cost Analysis

Step 3 – Estimate Initial Agency Costs (A)

Initial Agency Costs

- Only those **initial agency costs that are different** among the various alternatives need to be considered for reasonably similar alternates.
- **Pavement costs** include items such as subgrade preparation; base, subbase, and surface material; associated labor and equipment; etc.
- **When historical bid prices are used as estimates**, consider the impact of material price escalators, payment practices, and bidding practices.

Initial Costs Drive the LCCA Results

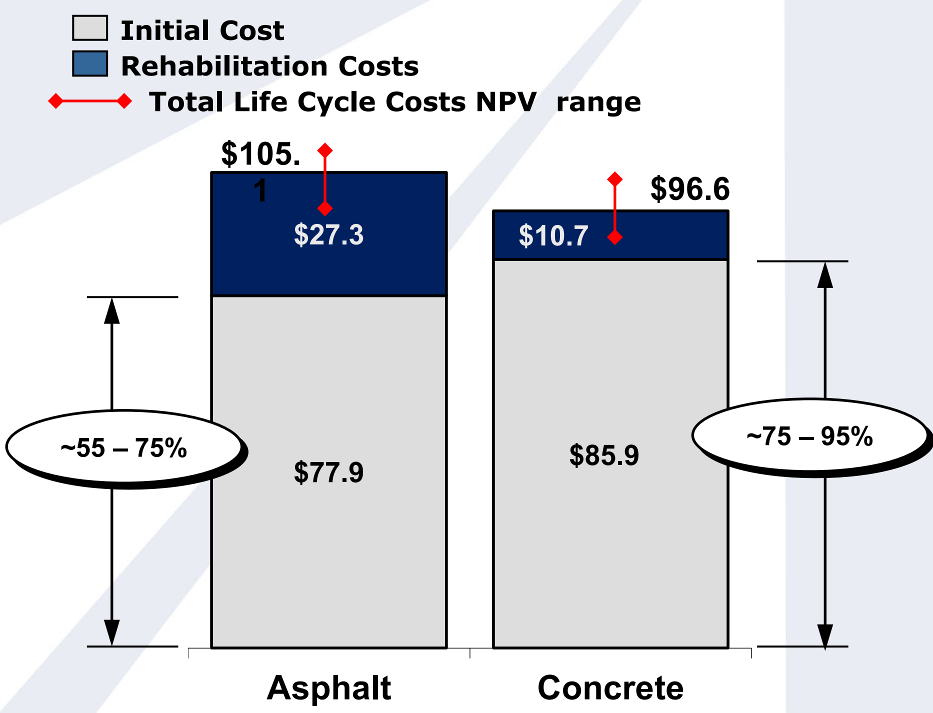
Initial costs account for

- 55-75% for Asphalt
- 75-95% for Concrete
  - *Depends on initial designs, rehabilitation activities, rehabilitation timing, discount rates, etc.*

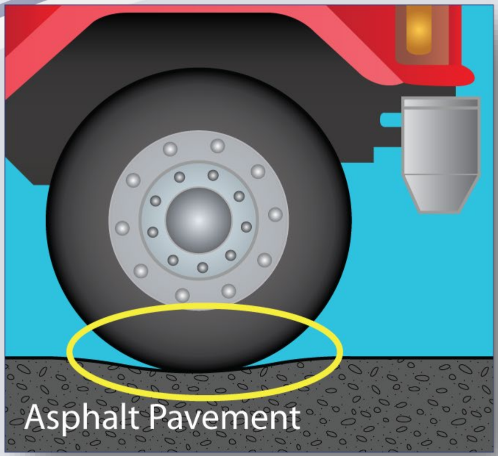
Design and selection of features plays an important role

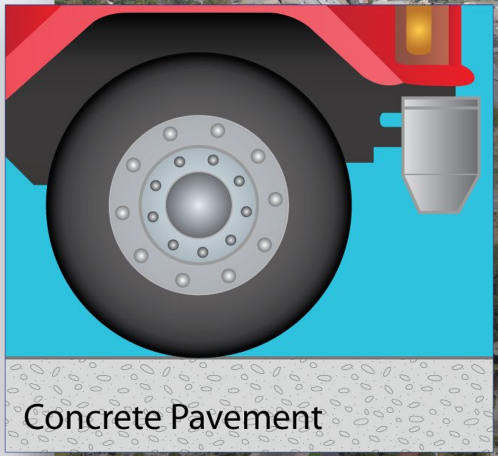
- Need to optimize designs (no unnecessary features)
- Need to account for improved pavement designs on performance life

Initial Cost as % of Total Life Cycle Costs



Initial costs need to – as best as possible – accurately reflect the DOT most likely expenditures





Life-Cycle Cost Analysis

Step 4 – Estimate User Costs (B)

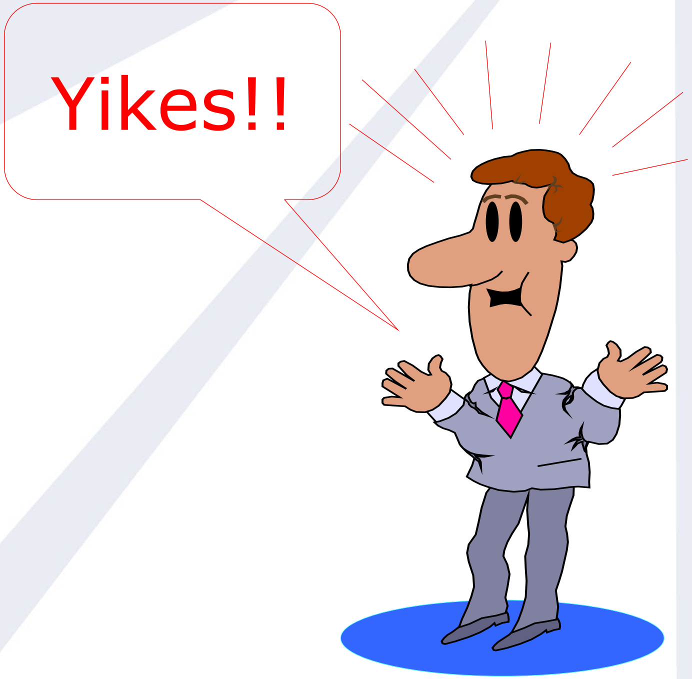
User Costs

- Costs that are incurred by **users of the roadway** over the analysis period.
  - **Work zone costs:** Incurred during lane closures and other periods of construction, preservation/rehabilitation, and maintenance work.
  - **Vehicle operating costs:** Incurred during the normal use of the roadway.
  - **Delays due to capacity issues:** Primarily a function of demand for use of the roadway with respect to roadway capacity (not likely to vary between alternates).
  - **Accidents:** Damage to the user's/other's vehicle and/or public or private property; injury costs.

A Not Uncommon User Costs Example

When User's costs are this high, need to re-look at the options being evaluated

- 6 Lane Facility (3 Lane per dir.)
- Work Zone 1 Lane Open
- 30 Year Analysis Period
- Initial AADT = 110,000 vpd
- 2 Rehabs including maint. plan



User Cost = $12 Billion

If user costs are included, recommend to NOT combine agency & user costs (Keep separate - each tells a different story)

Life-Cycle Cost Analysis

Step 5 – Estimate Future Agency Costs (C)

Future Agency Costs

- **All cost components must be considered** because the present value of costs associated with engineering, administrative, and traffic control are impacted by the time value of money.
- Future activities are dependent on the initial pavement design.
- Must consider both maintenance/operation and preservation/rehabilitation costs and timing.

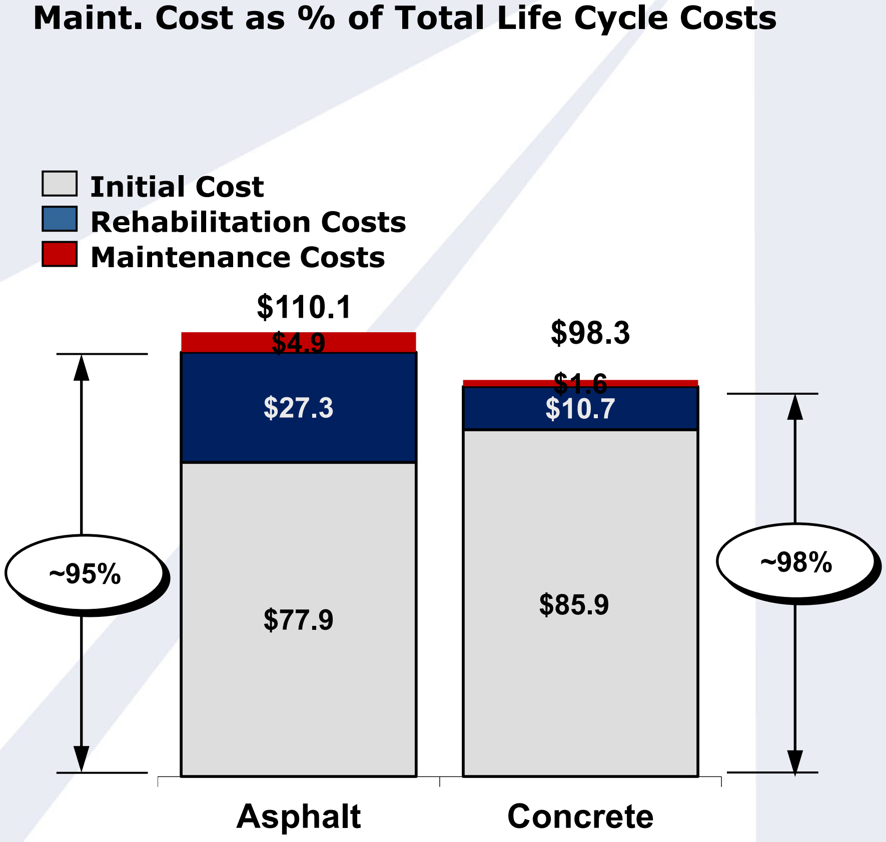
Maintenance and Operation Costs

- **Daily costs** associated with keeping the pavement at a given level of service.
- **Several billion dollars** are spent each year on pavement maintenance by highway agencies in the U.S.
- Short-term solutions typically have significantly larger maintenance requirements than long-life solutions, regardless of the size of the project.

Still, Maintenance Costs have Minimal Effect on the Results

While the outlay of Maintenance costs is high, they have minimal effect on the results

- Initial construction costs
  ~ $1,000,000 / mi
- Rehabilitation costs
  ~ $150,000 – $300,000 / mi
- Yearly maintenance costs
  ~ $1,000 to $5,000 / mi



Standard practice is to exclude maintenance costs as they are small compared to initial and rehabilitation costs

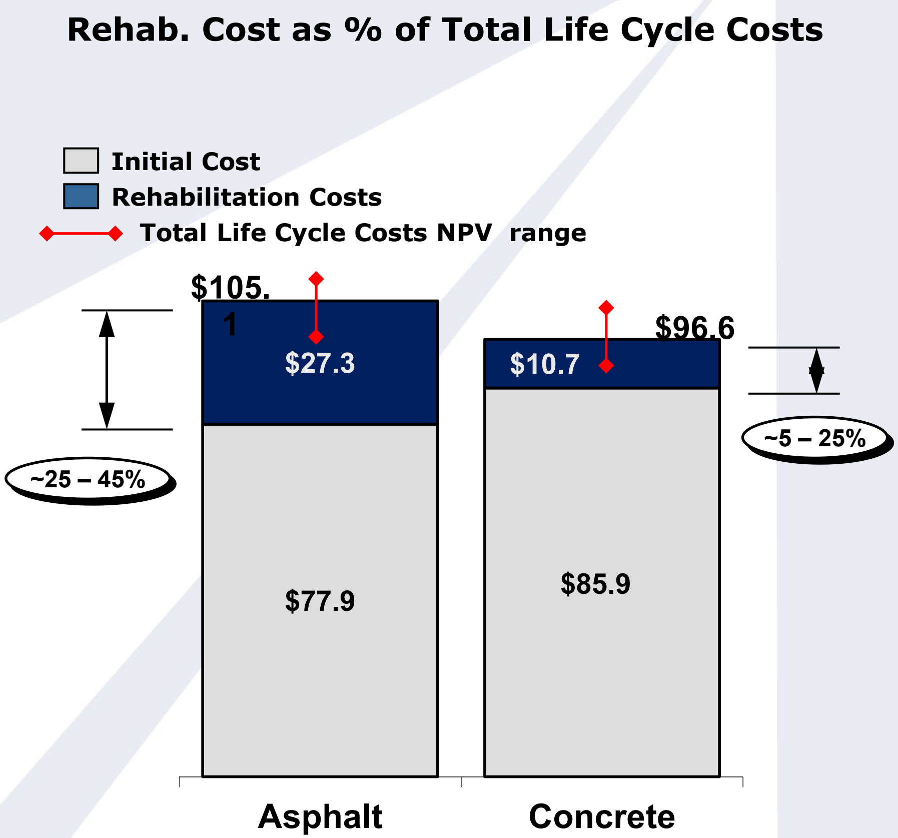
Preservation and Rehab. Costs

- **Large future agency costs** associated with improving the condition of the pavement or extending its service life.
- Preservation and rehabilitation **activities and their timing** should be based on the distresses that are predicted to develop in the pavement.
- One approach to developing performance predictions is to **rely on local performance data**
- Otherwise, software such as Pavement-ME™ can be used.

Preservation and Rehab. Costs

The longer a rehabilitation activity is delayed, the less impact it has on NPV (eg. discounted more)

- Being off with early rehabilitation activities is more “wrong” than being off on later activities



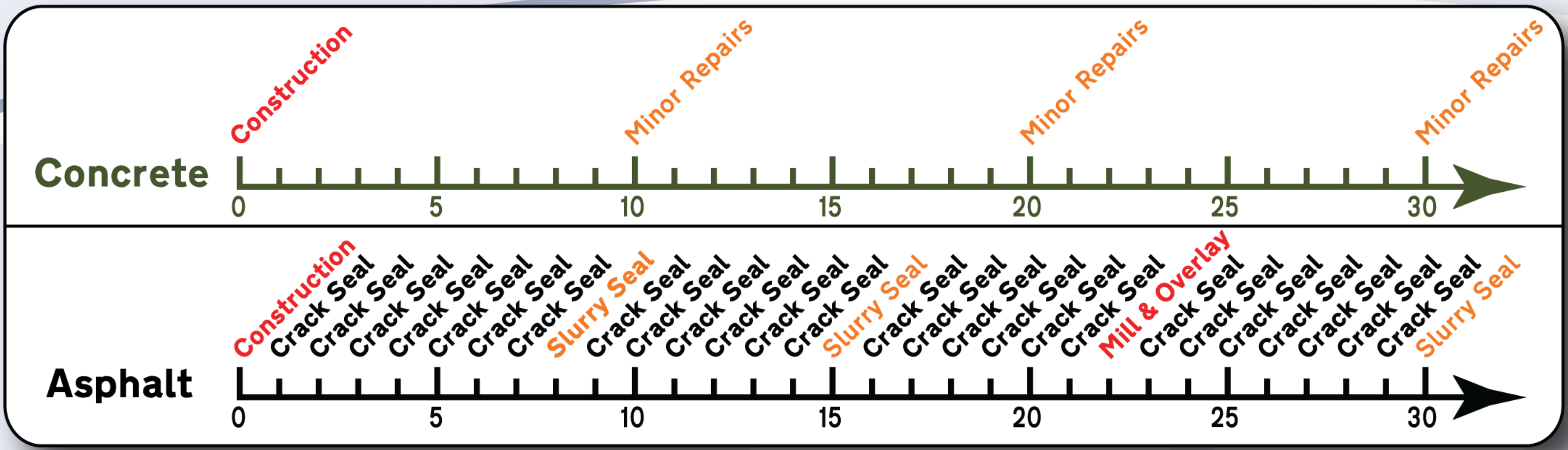
Because concrete rehab’s NPV are typically low, extending life of the pavement has little impact on Life Cycle Costs

Life-Cycle Cost Analysis

Step 6 – Estimate Residual Value

Residual Value

- Defined in one of two ways:
  - The net value that the pavement would have in the marketplace if it is **recycled at the end of its life** (also known as salvage value),
  - The value of the **remaining service life (RSL)** at the end of the analysis
    - RSL= (Remaining Life / Last Rehabilitation Life) x Last Rehabilitation Cost
- Residual value **must be defined the same way** for all alternatives.



Pavement Management Plan from City of Leawood, Kansas

Life-Cycle Cost Analysis

Step 7 – Compare Alternatives

Compare Alternatives

- Alternatives considered must be compared using a **common measure of economic worth**.
- Investment alternatives such as pavement strategies are most commonly compared on the basis of:
  - Present worth (also called net present value [**NPV**])
  - Annual worth (also called equivalent uniform annual cost [**EUAC**])
  - NPV and EUAC will provide the same ranking!

Net Present Value (NPV)

- NPV analyses are directly applicable only to **mutually exclusive alternates** each with the **same analysis period**.
- The formula for the **present value or worth** ($P) of a **one-time future cost or benefit** ($F) is:

$$\$P = \$F \times \left[\frac{1}{(1+\mathrm{d})^{\mathrm{t}}} \right]$$

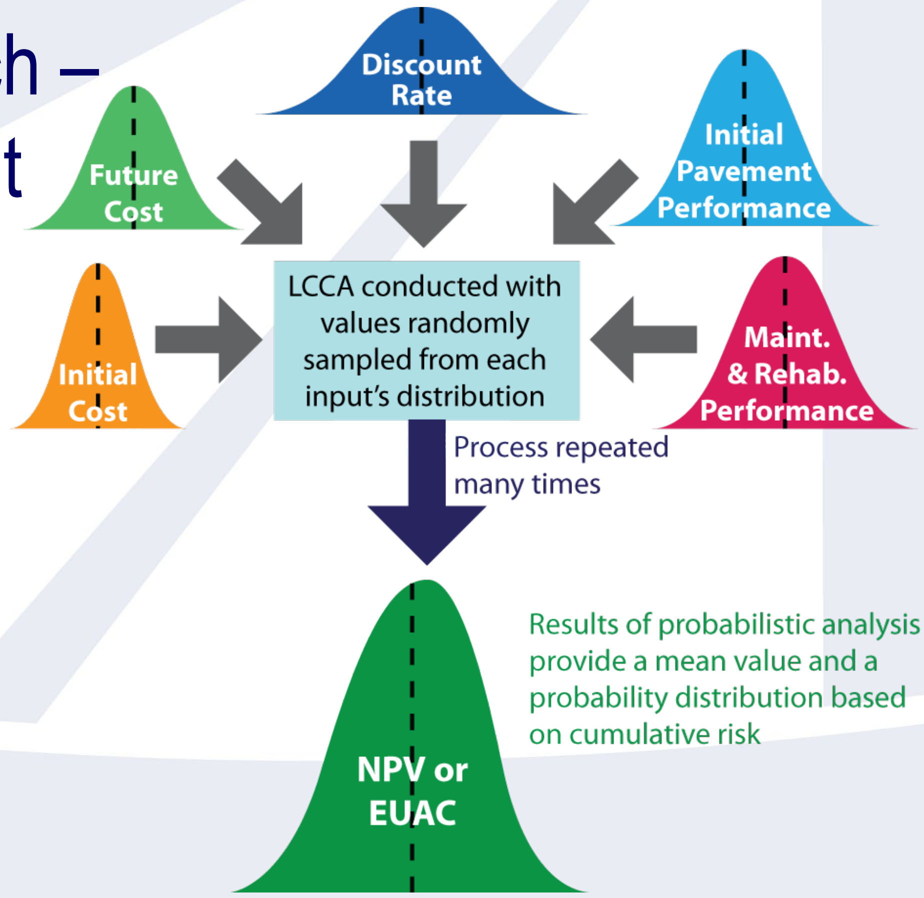
d = the real discount rate, %
t = the year in which the one-time future cost or benefit occurs

Accounting for Material Inflation

- **Material-specific real discount rates OR**
- **Escalating the future value** of an item before calculating its present or annual worth.
  - PennDOT uses an **Asphalt Adjustment Multiplier** (AAM) to adjust asphalt bid prices; current AAM is 1.7419, effectively escalating asphalt prices 74%.
  - MIT has proposed **"real price" escalators** that are dependent on the year in the LCCA in which the activity is conducted.

Analysis Methods

- **Deterministic** approach – a single defined value is assumed and used for each activity.
- **Probabilistic** approach – variability of each input is accounted for and used to generate a probability distribution for the calculated life-cycle cost.



Analysis Tools

- Most modern **spreadsheet software** include standard functions for calculating the present worth and annual worth.
- **Proprietary software** to compute LCCAs include:
  - AASHTO's DARWinME™ (deterministic)
  - FHWA's RealCost (deterministic and probabilistic)
  - ACPA's StreetPave & WinPAS (both deterministic)
  - CAC's CANPave (deterministic)
  - Asphalt Pavement Alliance's (APA's) LCCA Original and LCCA Express (both deterministic)

THANK YOU!

Questions?

Tim Martin, PE

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ACPA

www.acpa.org

IMPROVING LIFE CYCLE COST ANALYSIS (LCCA) TO MAKE THE RESULTS "ROBUST"

June 2023

Jim Mack, P.E.
CEMEX

jamesw.mack@cemex.com

LIFE-CYCLE ANALYSIS IS USED TO EVALUATE THE TOTAL IMPACTS OVER THE LIFE OF AN ASSET

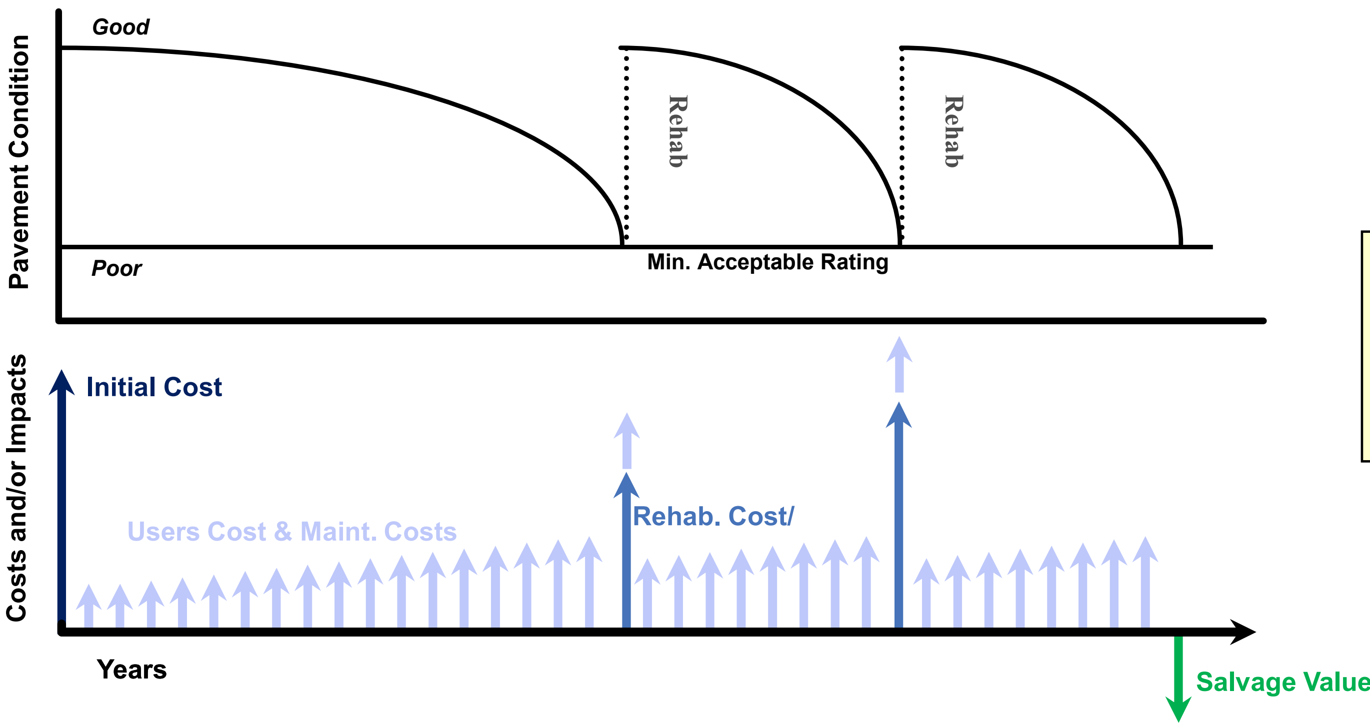
Impacts can be Cost or Environmental

Life-Cycle Cost Analysis (LCCA)	• **An economic analysis tool that quantifies the differential costs of alternative investment options for a given project** • **LCCA determines which pavement design is most cost effective**
Life-Cycle Assessment (LCA)	• **An environmental analysis that evaluates the material and energy flows for a product from cradle to grave, which includes raw material extraction, material processing, manufacturing, distribution, use, repair and maintenance, and disposal** • **LCA determines which pavement design is most "sustainable"**

To be meaningful and reliable, the analysis needs to – as best as possible – accurately represent the Agency's expected pavement activities for each alternative over the analysis period.

LIFE CYCLE COST ANALYSIS IS PROJECT ANALYSIS TOOL THAT QUANTIFIES THE TOTAL "COSTS OF OWNERSHIP"

Accounts for initial costs and discounted future rehabilitation costs



LCCA compares different options for a given project and determines which pavement design is most cost effective over the analysis period

$$NPV = \text{Initial Cost} + \sum Rehab\ cost \times \frac{1}{(1+d)^{n_k}} + \sum Maint\ cost \times \frac{1}{(1+d)^{n_k}} + \sum User\ cost \times \frac{1}{(1+d)^{n_k}} - Salvage\ Value \times \frac{1}{(1+d)^{n_k}}$$

Where

NPV = Net Present Value; d = real discount rate; n_k = year of expenditure

LIFE CYCLE COST ANALYSIS IS PROJECT ANALYSIS TOOL THAT QUANTIFIES THE TOTAL "COSTS OF OWNERSHIP"

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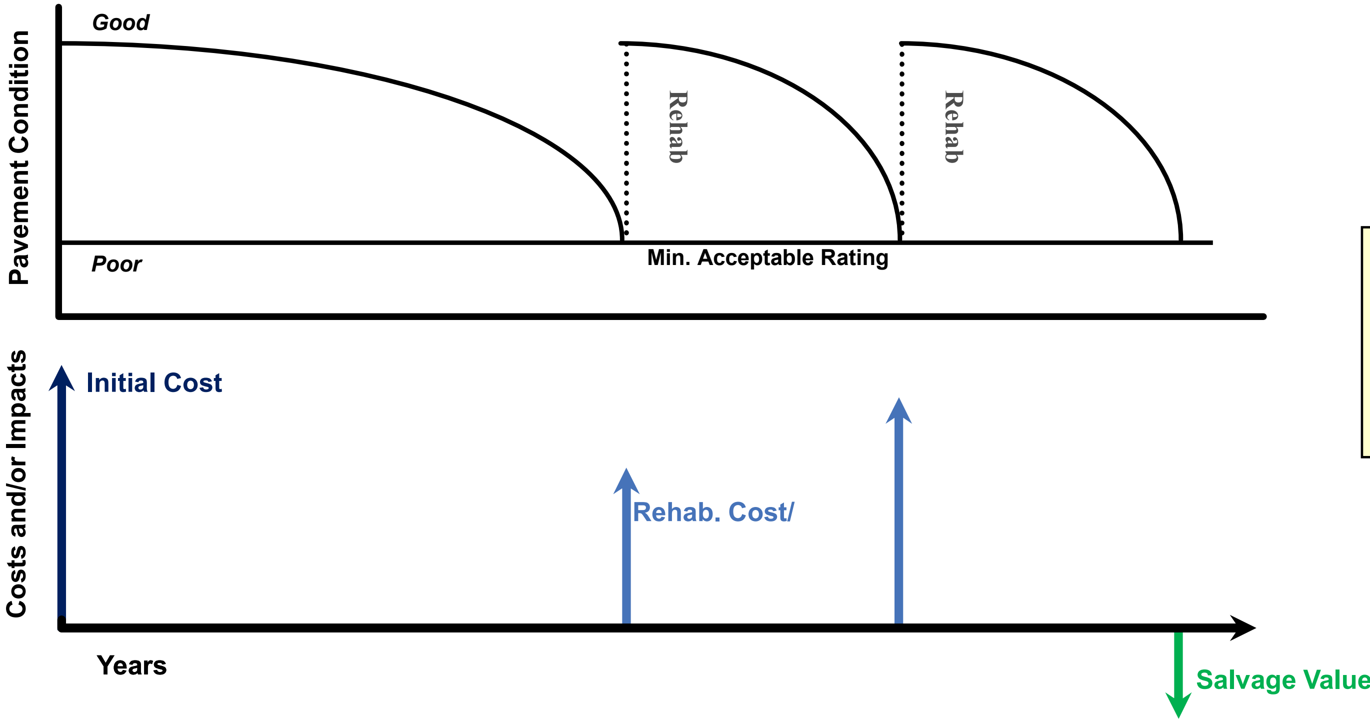

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Where
NPV = Net Present Value; d = real discount rate; n_k = year of expenditure

CEMEX

TO GET CREDIBLE AND RELIABLE LCCA RESULTS

The Process, Engineering and Economics need to be correct

1. **Process needs to well-structured and follows best practices**

2. **Engineering must be fundamentally sound and pertain to <u>that specific</u> design for a particular project**
   - **Equivalent designs with similar performance**
   - **Realistic rehabilitation strategies for each particular design based on anticipated performance**

3. **Economics needs to accurately represent – as best as possible – the current economic conditions**
   - **Cost need to accurately represent the Agency's <u>probable expenditures</u> for the expected rehabilitation strategy for <u>that specific</u> design**

The LCCA must be based on the designs "Being Proposed" for the Project (Not on a "Average or Standard Pavement")

FHWA HAS A WELL-STRUCTURED FRAMEWORK AND 5-STEP PROCESS FOR PERFORMING A LCCA

Establish LCCA Framework

- Establish analysis period
- Establish how inflation will be treated (nominal or real)
- Establish discount rate to be used (nominal or real)

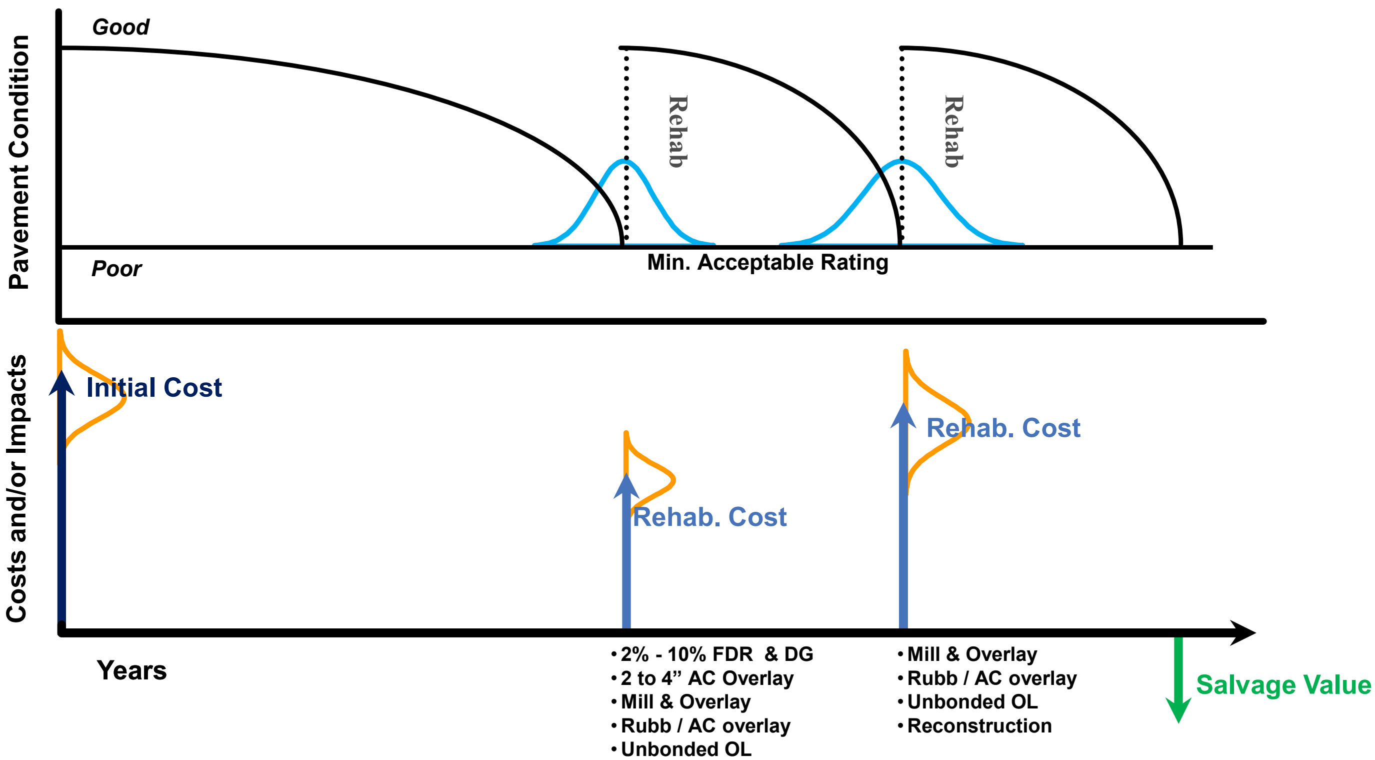
Perform LCCA

1. Establish Alternative Pavement Designs
2. Determine Timing of Required Rehabilitation Activities
3. Estimate Agency and User Costs (often considered optional)
   - Initial Construction Costs
   - Rehabilitation Costs
4. Compute Life-Cycle Costs
5. Analyze the Results

State DOTS and the Concrete & Asphalt Industries generally agree with this Structure and Process

WHILE THERE IS GENERAL AGREEMENT ON THE PROCESS

There is “lack of trust” in the results because of disagreements over the “correctness” of the inputs



Sources of Uncertainty & Variability

1. **Temporal - Timing of Rehabilitation Activities**
   - **Initial Performance**
   - **Rehabilitation Performance**
2. **Scenario – Which rehabilitation activities are done**
   - **Preservation Options**
   - **Overlay Options**
3. **Measurement - Cost**
   - **Inflation**
   - **Price Adjustment Clauses**
   - **Unit Price**
   - **Material Quantities**
   - **Bidding Practices (Incentives/Disincentives, SY vs Tons, etc.)**

Goal is to develop a Robust Process to reflect the broadest sets of activities for each specific alternative being evaluated

AGENDA

Improving "Timing of Rehabilitation Activities"

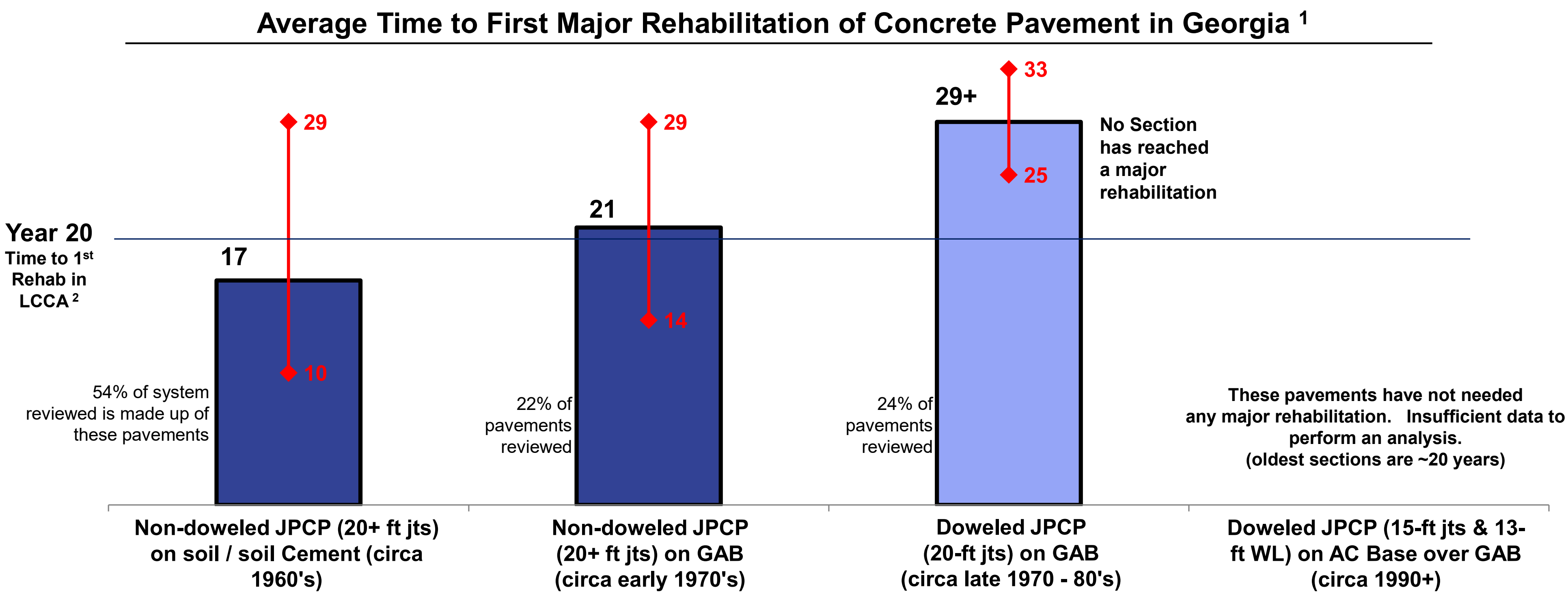
Improving "Which rehabilitation activities are done"

Improving "Cost Estimates"

Combining Parts to Develop a Robust LCCA

BE WARY OF BASING REHAB TIMING ON HISTORICAL PERFORMANCE

Basing timing on pavement designs no longer used will bias the results



Historical performance must be based on data from "like roadways" to avoid biasing the results

1. Georgia Concrete Pavement Performance and Longevity, Final Report, GDOT Research Project No. 10-10, Task Order No. 02-74
   Dr. James (Yichang) Tsai, P.E., Yiching Wu, Chieh (Ross) Wang, Georgia Institute of Technology, February 2012
2. Time to 1st Rehabilitation in GDOT LCCA procedure = 20 years, time to 2nd Rehabilitation = 40 years

PAVEMENT ME IS THE MOST ADVANCED DESIGN PROCEDURE

Covers a wide range of applications, including nearly all new & rehabilitation options
Can account of new and diverse materials and various failure mechanisms

State-of-the practice design procedure based on advanced models & actual field data

- **Calibrated to more than 2,400 asphalt & concrete pavement test sections across the U.S. and Canada, ranging in ages up to ~37 years**

Uses mechanistic-empirical principles that account for site specific:

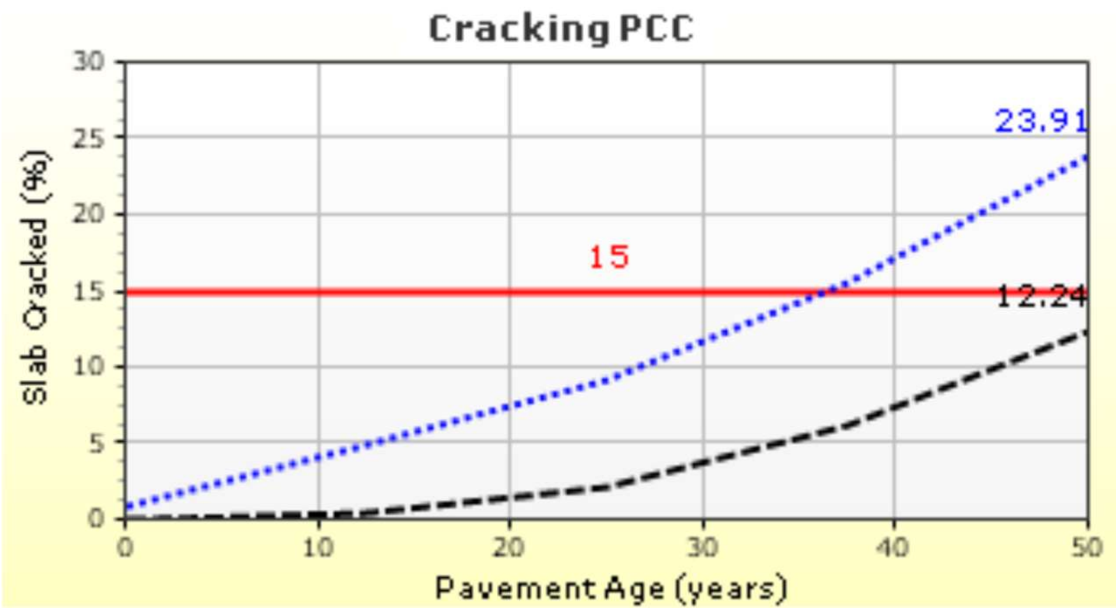
- **Traffic**
- **Climate**
- **Materials**
- **Proposed structure (layer thicknesses & features)**

Provides estimates of cracking, faulting, IRI, and other distresses during the analysis period

Performance modeling allows designers to create specific pavement designs to meet performance objectives

PAVEMENT–ME DEFINES A SPECIFIC PAVEMENT'S PERFORMANCE

Predicting performance for key distresses improves designs and allows for trade-off analysis of features with Life Cycle Cost Estimates



Red Line – Predefined Distress Threshold Value. When major rehabilitation is needed (i.e. patching & DG or overlay).

Black Dashed Line - The 50% Reliability (most likely) level of distresses predicted

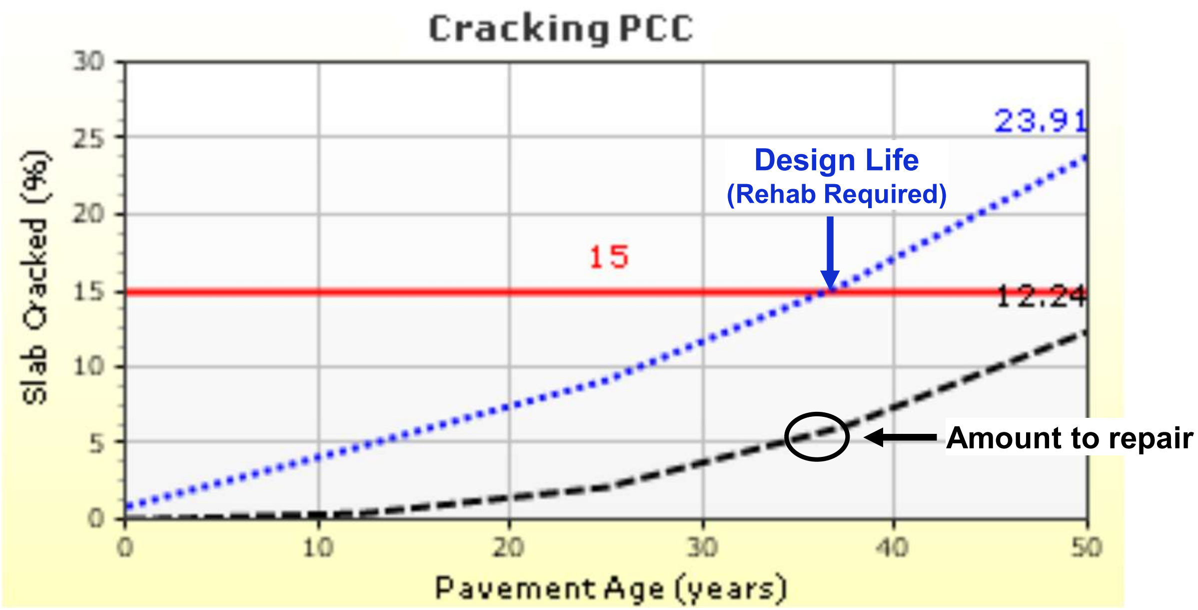
Blue Dotted Line - The predicted distresses at the Specified Reliability Level (i.e. 90%). Designs are based on when this line hits the defined distress limit

Design life is when the Blue Reliability curve hits red Predefined Threshold Value (~37 years in this case)

CEMEX

PAVEMENT–ME DEFINES A SPECIFIC PAVEMENT'S PERFORMANCE

Predicting performance for key distresses improves designs and allows for trade-off analysis of features with Life Cycle Cost Estimates



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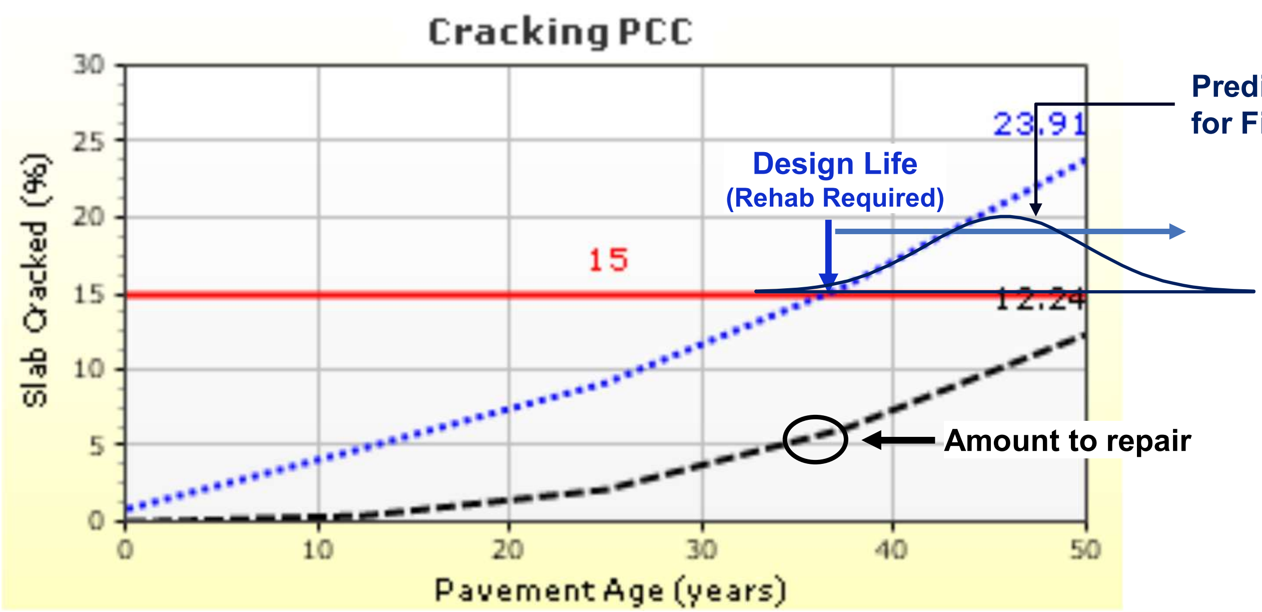
Design life is when the Blue Reliability curve hits red Predefined Threshold Value (~37 years in this case)

CEMEX

PAVEMENT ME DEFINES A SPECIFIC PAVEMENT'S PERFORMANCE

Predicting performance for key distresses allows for trade-off analysis of Features with Life Cycle Analysis



As move "Time to first Rehab" across predicted time range, category of repair changes (in order):

1. Concrete Pavement Preservation
2. Overlays
3. Reconstruction

Red Line – Predefined Distress Threshold Value. When major rehabilitation is needed (i.e. patching & DG or overlay).

Black Dashed Line - The 50% Reliability (most likely) level of distresses predicted

Blue Dotted Line - The predicted distresses at the Specified Reliability Level (i.e. 90%). Designs are based on when this line hits the defined distress limit

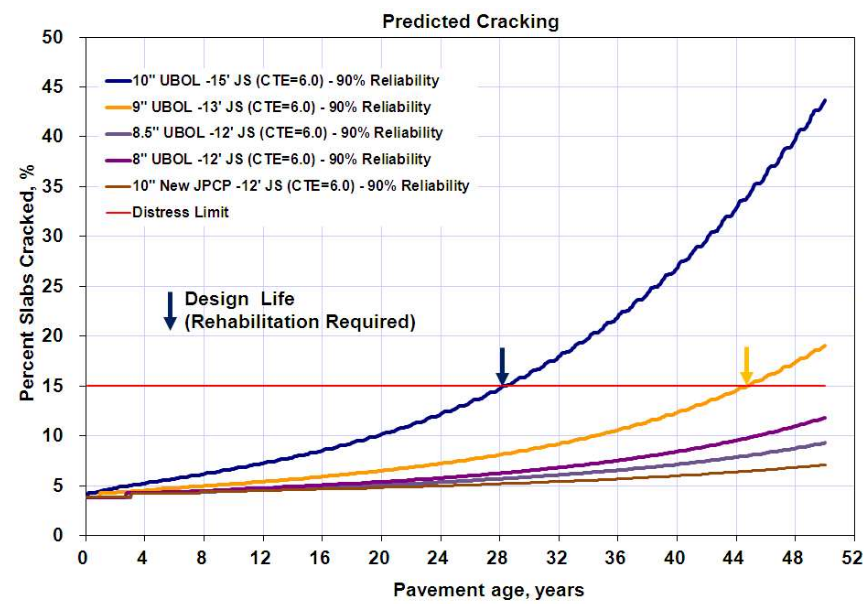
Design life is when the Blue Reliability curve hits red Predefined Threshold Value (~33 years in this case)

CEMEX

PAVEMENT ME ALLOWS FOR COMPARISONS OF DIFFERENT DESIGNS

Predicted Performance Curves for Pavement Designs	

	• Many pavement designs will meet the design criteria
	  • Pavement ME predicts what the actual performance could be
	  • Allows for comparisons and evaluation of different design features / thickness
	• Performance estimates help determine the "when" and "what" rehabilitation activities to perform



Comparing Designs	
	• Pavement ME output was set for 50 years to give long term performance for each design • Pavement design must meet the "design criteria" (eg less than 15% cracking at year 30)

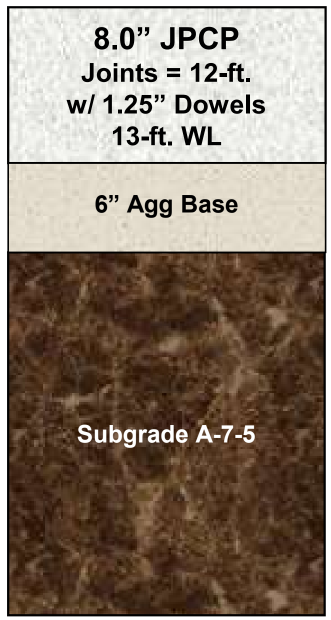
Combining performance with the LCCA finds the design that best balances the costs, sustainability impacts, and performance over the full life cycle

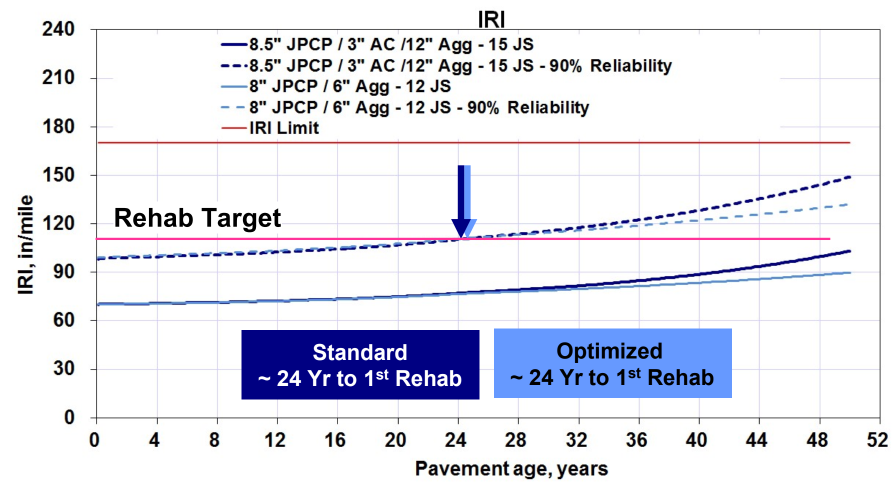
MANY PAVEMENT DESIGNS WILL MEET THE DESIGN CRITERIA

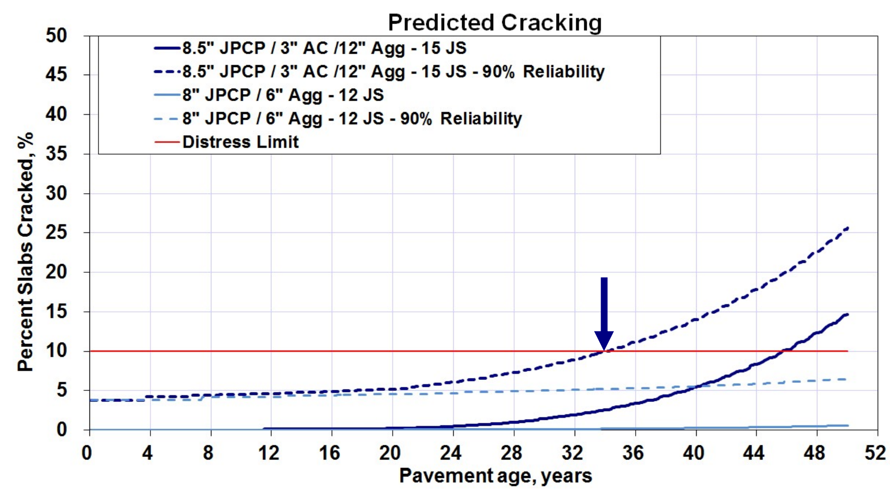
Pavement ME allows for comparisons of different designs so different features can be evaluated

Original Concrete Design

Optimized Concrete Design







Pavement ME gives a repeatable, un-biased process that shows how a specific pavement design will perform

CEMEX

AGENDA

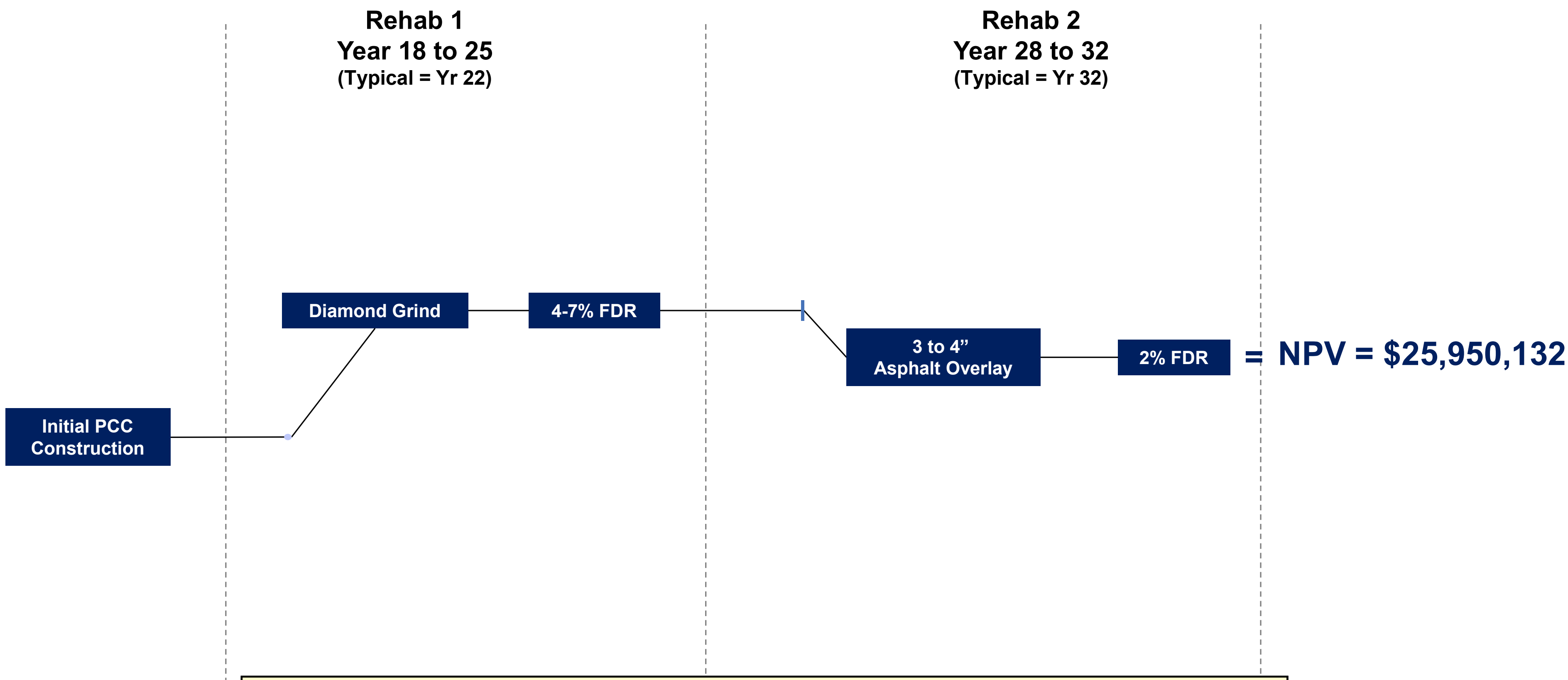
Improving “Timing of Rehabilitation Activities”

Improving “Which rehabilitation activities are done”

Improving “Cost Estimates”

Combining Parts to Develop a Robust LCCA

MOST LCCA GUIDELINES PROVIDE A SINGLE SET OF ACTIVITIES



Question - is the selection of activities representative of the most likely set of activities for the pavement option?

PCC Rehab Schedule, Ohio DOT LCCA Manual

Predictive Models for Pavement Treatment Timings Utilizing Decision Tree Analysis (Paper 13-4983)

Saeed Abdollahipour; David Jeong, PhD

School of Civil & Environmental Engineering, Oklahoma State University, Stillwater, Oklahoma

Introduction

Fact

- Lack of consensus on life-cycle cost analysis (LCCA) models of different pavement families.
- A large amount of highway project data is stored throughout the life cycle of highway projects.

Need

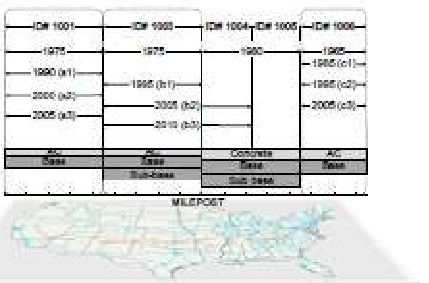
- Identify the factors influencing the performance of pavements.
- Determine timing of maintenance and rehabilitation (M&R) activities.

Objective

- To predict the timing of treatment activities of flexible and rigid pavements for the Interstate 40.
- To identify the factors influencing the performance of pavement segments during their lifecycle

Data

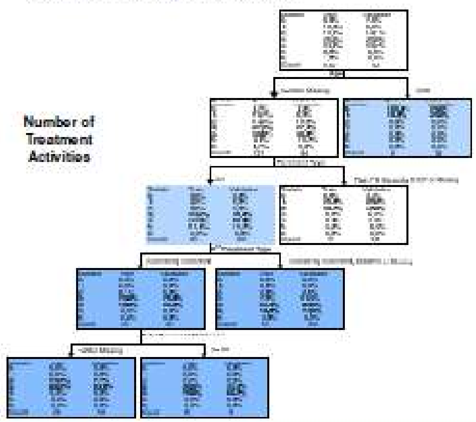
- Historical pavement treatment data set (I-40)



Decision Tree Analysis

- The 222 sections of the data set are divided into training and validation data sets with the ratio of 60:40.

Number of Treatment Activities

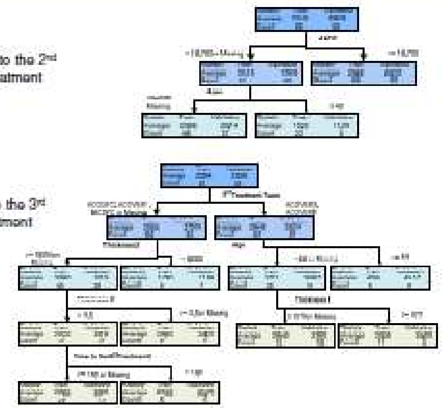


Flexible Pavement Treatment Timing

Time to the 1st Treatment

Time to the 2nd Treatment

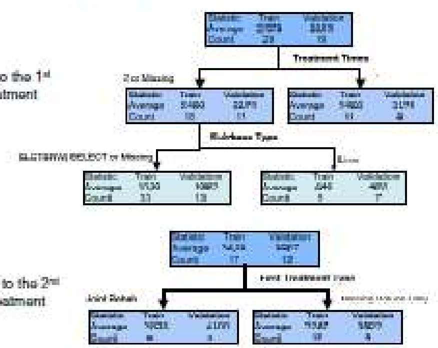
Time to the 3rd Treatment



Rigid Pavement Treatment Timing

Time to the 1st Treatment

Time to the 2nd Treatment



Results

This paper focused on identifying new factors to reclassify pavement sections using the historical pavement treatment data set of Interstate 40 in Oklahoma.

1. Number of times a pavement is treated and time to the first, the second, and the third treatment are predicted with decision tree models.
2. Unlike traditional approach that only uses the average values to determine the timing of treatment activities, this study suggests that the timings of LCCA models can be determined utilizing predictive decision trees that are learned based on the historical treatment activities.

Range of Treatment Timings for Flexible and Rigid Pavements

Pavement Type	1st Treatment	2nd Treatment	3rd Treatment
Flexible Pavement	4 - 15 years	11.3 - 23.3 years	17.9 - 45.2 years
Rigid Pavement	4 - 31.8 years	35.2 - 41 years	-

Factors Influencing the Performance of Pavements

Pavement Type	Factors Influencing Performance
Flexible	AADT; Age; 1st Treatment; County; 2nd Treatment; Thickness of 3rd Treatment; Thickness of 1st Treatment; Time to the 2nd Treatment
Rigid	Treatment Times; Sub-base Type; 1st Treatment Type

Conclusions

- Number of treatments depends on the Age, Pavement Type, 2nd Treatment Type, and Total Pavement Thickness.
- Assuming the same performance for pavement sections that fall under the same pavement family can result in suboptimal results. Therefore, pavement performance is not only dependent on the pavement type, traffic, county, sub-base type, but also on the factors such as the timing and the type of treatment activities that is applied on the pavement through the lifecycle of pavement.

Acknowledgments

The authors would like to acknowledge the financial support from the Oklahoma Transportation Center (OTCREOS10.1-20) for this research study.

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Phone: 515-294-7271

1. Realistic Life-Cycle Cost Analysis Using Typical Sequential Patterns of Pavement Treatments via Association Analysis (TRB Paper 12-3390)
2. Predictive Models for Pavement Treatment Timings Utilizing Decision Tree Analysis (TRB Paper 13-4983) Saeed Abdollahi Pour and Dr. David Jeong, PhD, School of Civil & Environmental Engineering, Oklahoma State University, Stillwater, Oklahoma

RESEARCH AT OKLAHOMA STATE UNIV. LOOKED AT THIS FOR OKLAHOMA

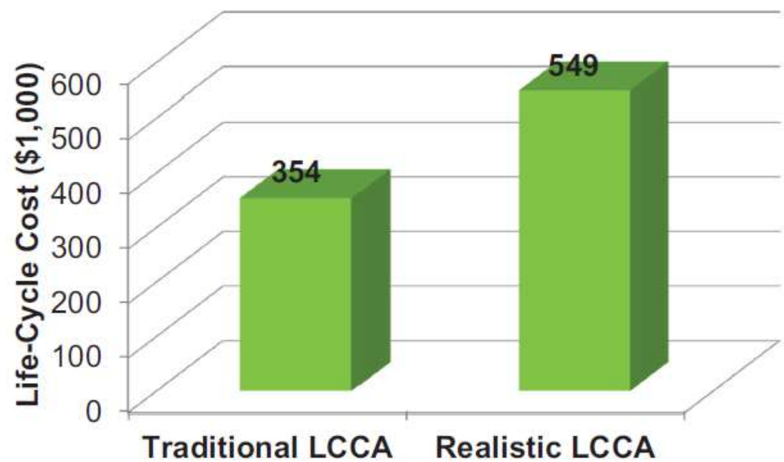
Interstate 40

Probability (%)	1st Treatment	2nd Treatment	3rd Treatment
17	OGFC	maintover	micsfc
17	OGFC	maintover	Acover3
13	OGFC	Acover2	Acover3
12	OGFC	Acover1	Acover2
11	Acover1	ACOGFC	Acover3
10	Acover1	ACOGFC	Acover2
9	OGFC	Acover3	Acover2
9	OGFC	Acover1	acover1
1	maintover	micsfc	Acover3
1	Acover4	Acover3	Acover2

Realistic Life-Cycle Cost Analysis model for AC pavements

$$\textbf{Traditional}\ LCC = NPV = \sum_{j=1}^{J} F_j \left[\frac{1}{(1+i)^{n_j}}\right]$$

$$\textbf{Realistic}\ LCC = \sum_{k=1}^{K} ((Probability)_k * NPV_k)$$



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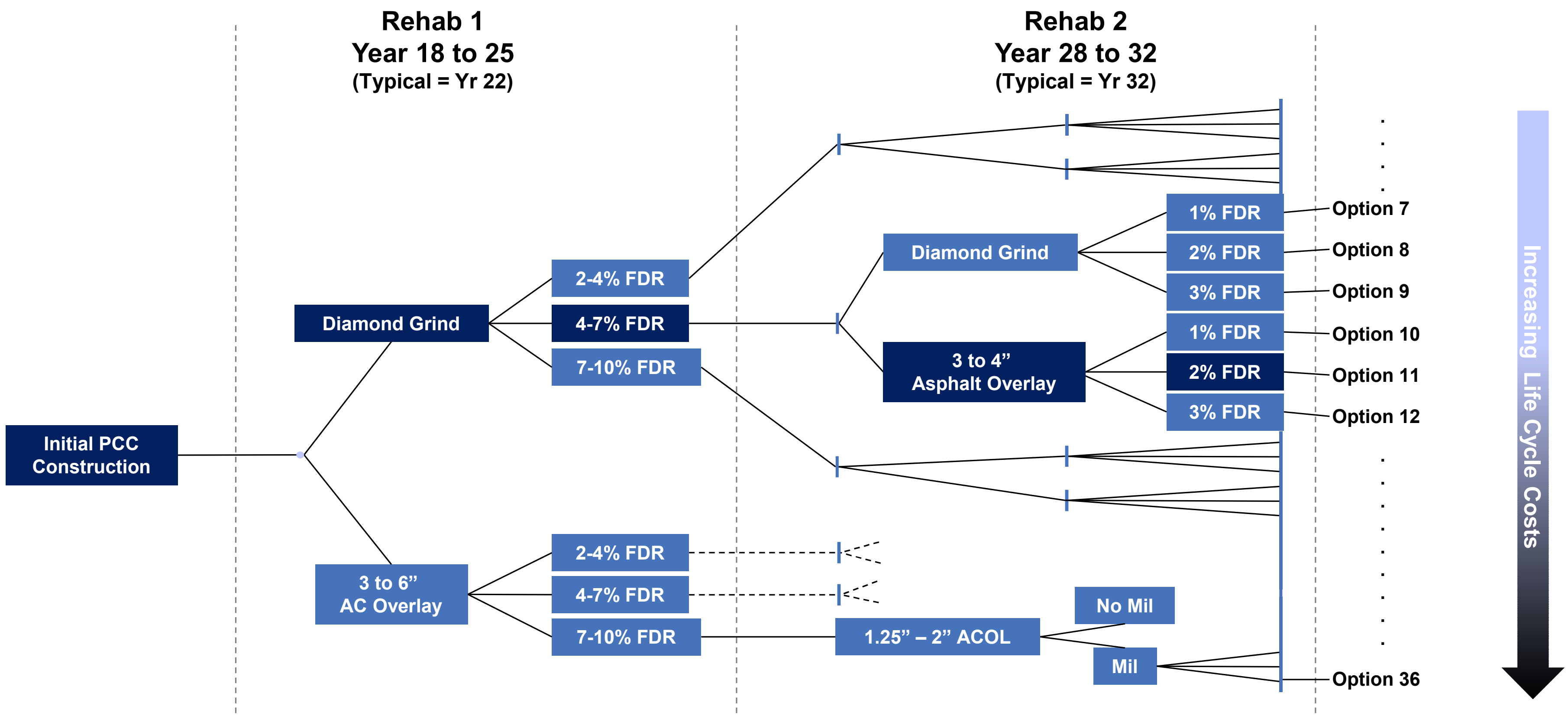
Saeed Abdollahi Pour and Dr. David Jeong, PhD, School of Civil & Environmental Engineering, Oklahoma State University, Stillwater, Oklahoma

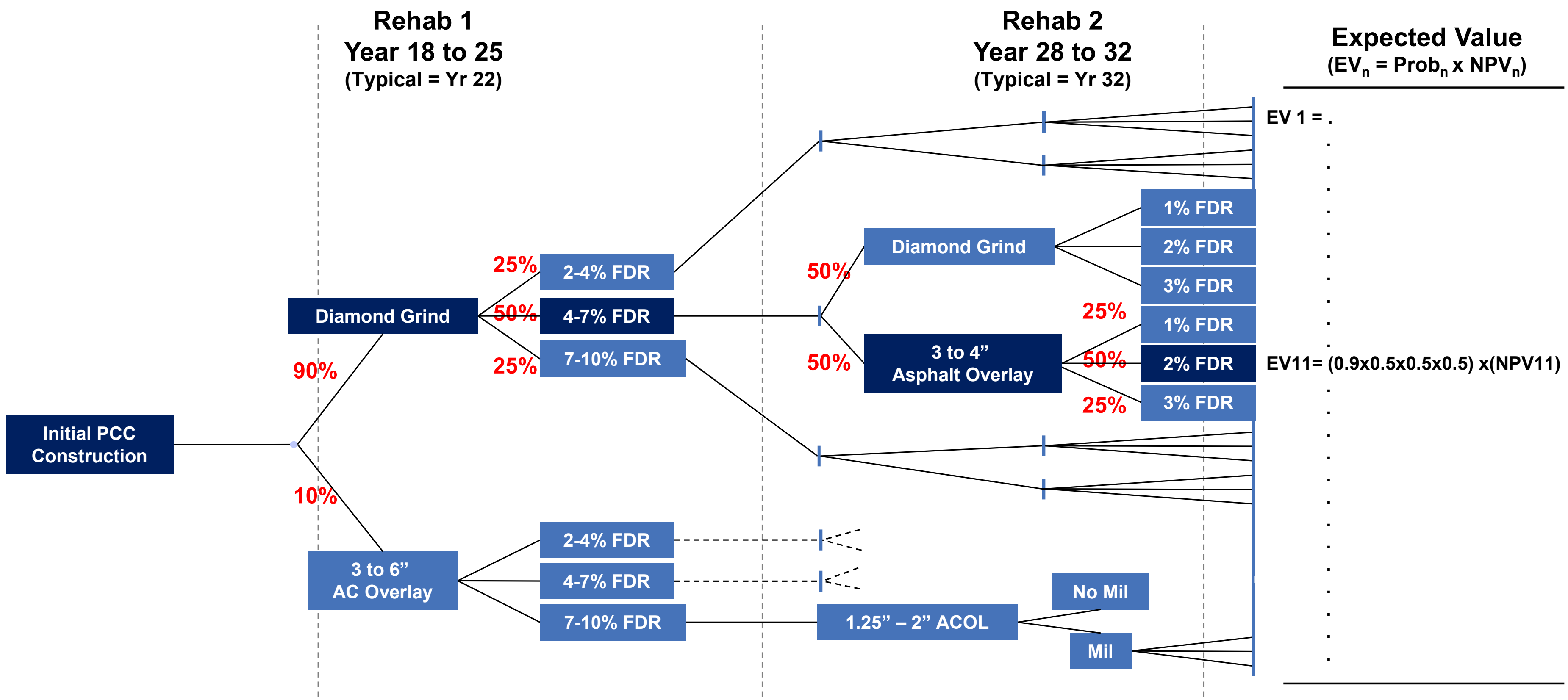
THE FACT IS THERE ARE MANY POSSIBLE ACTIVITIES

Some agencies provide a series of activities, but still use a "standard"



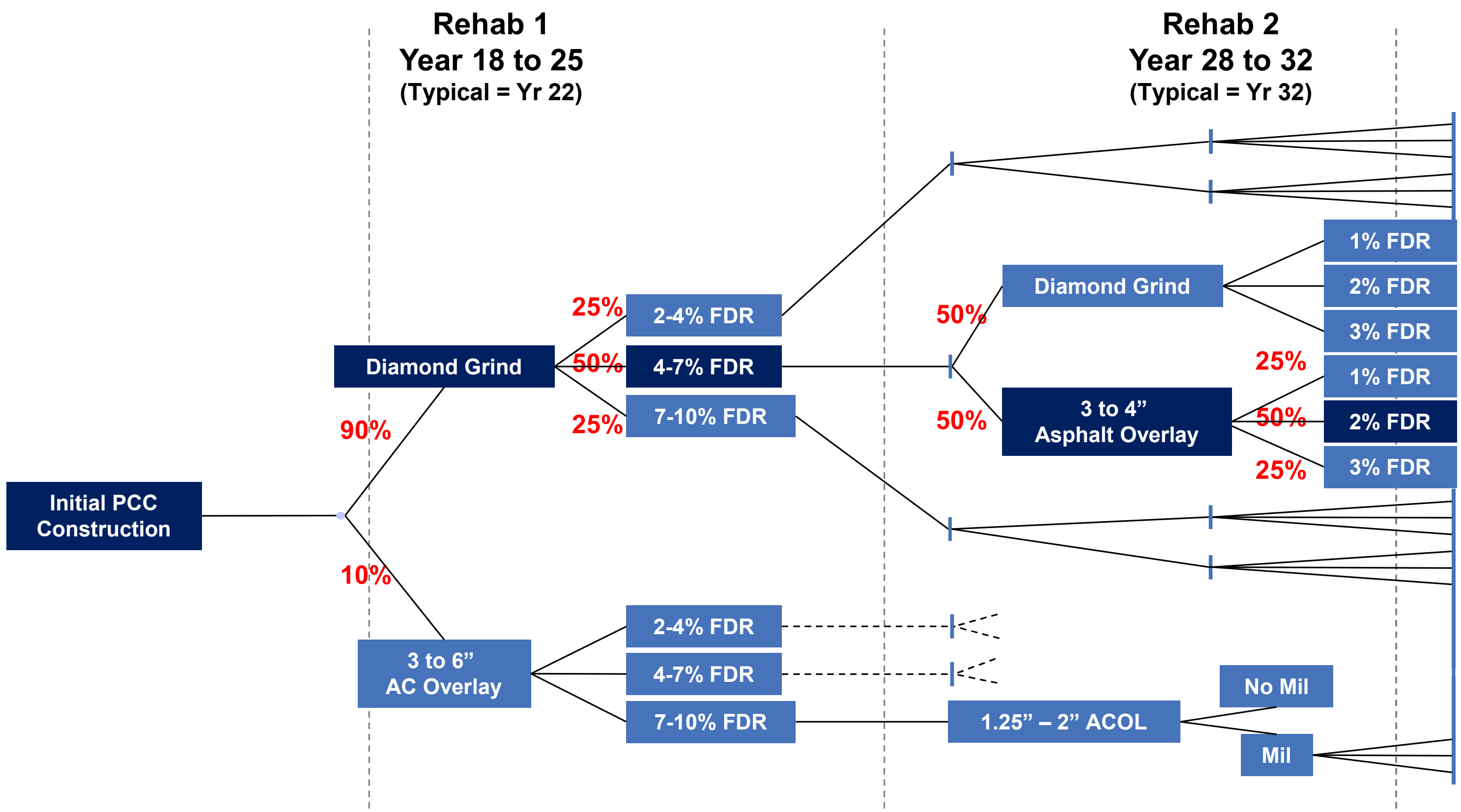
Decision Trees can evaluate the "Cost Impacts" of all Alternate Rehabilitation Options

ASSIGN PROBABILITIES TO THE DECISION TREE TO DETERMINE THE "MOST LIKELY" LIFE CYCLE COSTS



EV11= Probability x NPV11 = (0.9 x 0.5 x 0.5 x 0.5) x ($25,950,132) = $2,919,390

ASSIGN PROBABILITIES TO THE DECISION TREE TO DETERMINE THE "MOST LIKELY" LIFE CYCLE COSTS



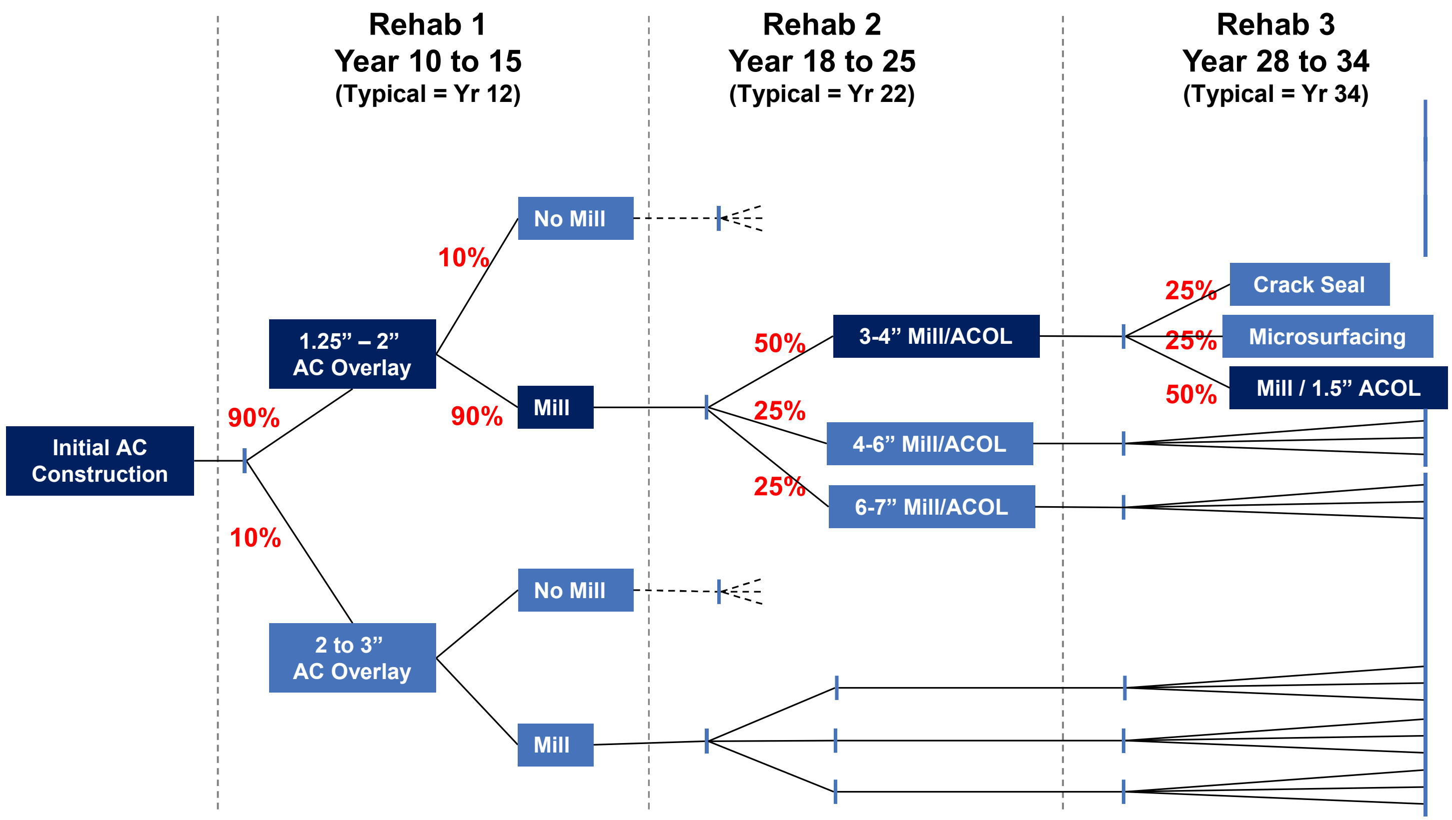
Expected Value
($EV_n = Prob_n \times NPV_n$)

EV1	=	$675,271.93
EV2	=	$1,358,096.10
EV3	=	$682,824.17
EV4	=	$715,921.76
EV5	=	$1,439,395.76
EV6	=	$723,474.00
EV7	=	$1,370,843.01
EV8	=	$2,756,790.50
EV9	=	$1,385,947.49
EV10	=	$1,452,142.67
EV11	=	$2,919,389.81
EV12	=	$1,467,247.14
EV13	=	$695,571.08
EV14	=	$1,398,694.40
EV15	=	$703,123.32
EV16	=	$736,220.91
EV17	=	$1,479,994.05
EV18	=	$743,773.14
EV19	=	$193,607.52
EV20	=	$194,033.81
EV21	=	$195,039.77
EV22	=	$21,342.90
EV23	=	$21,390.77
EV24	=	$21,502.54
EV25	=	$346,282.88
EV26	=	$347,034.48
EV27	=	$348,822.85
EV28	=	$85,894.53
EV29	=	$86,084.46
EV30	=	$86,531.55
EV31	=	$152,413.90
EV32	=	$152,739.98
EV33	=	$153,522.39
EV34	=	$64,813.10
EV35	=	$64,954.37
EV36	=	$65,289.69

EV11= Probability x NPV11 = (0.9 x 0.5 x 0.5 x 0.5) x ($25,950,132) = $2,919,390

NPV = Σ EV = $25,306,023

SAME PROCESSES IS DONE FOR ASPHALT



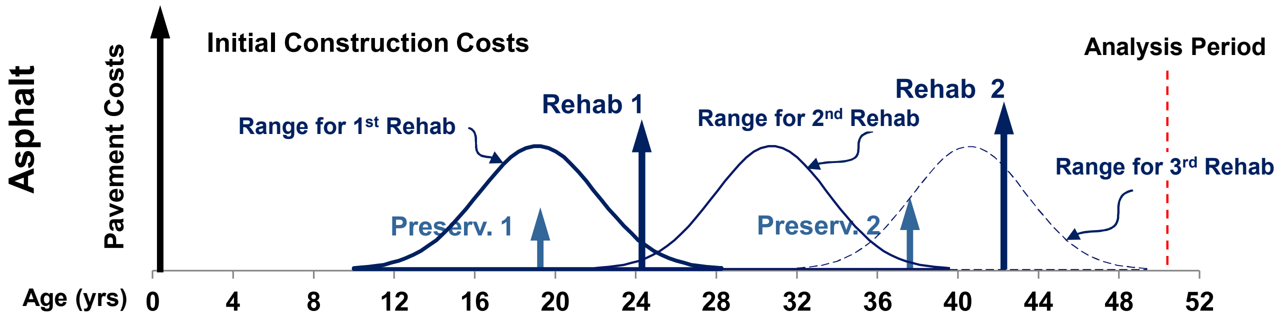
Expected Value
(EV_n = $Prob_n$ x NPV_n)

EV1	=	$195,133.40
EV2	=	$196,732.50
EV3	=	$399,861.39
EV4	=	$102,518.67
EV5	=	$103,318.22
EV6	=	$209,834.63
EV7	=	$107,470.64
EV8	=	$108,270.19
EV9	=	$219,738.58
EV10	=	$1,775,397.15
EV11	=	$1,789,789.04
EV12	=	$3,637,145.62
EV13	=	$932,266.31
EV14	=	$939,462.25
EV15	=	$1,907,708.28
EV16	=	$976,834.05
EV17	=	$984,029.99
EV18	=	$1,996,843.75
EV19	=	$90,147.82
EV20	=	$90,833.14
EV21	=	$184,407.60
EV22	=	$47,196.18
EV23	=	$47,538.85
EV24	=	$96,448.35
EV25	=	$49,318.45
EV26	=	$49,661.12
EV27	=	$100,692.89
EV28	=	$819,557.45
EV29	=	$825,725.40
EV30	=	$1,676,122.61
EV31	=	$428,879.18
EV32	=	$431,963.16
EV33	=	$876,262.22
EV34	=	$447,979.64
EV35	=	$451,063.62
EV36	=	$914,463.14

EV12= Probability x NPV12 = (0.9 x 0.9 x 0.5 x 0.5 x 0.5) x ($23,092,988) = $3,637,146

NPV = Σ EV = $24,210,615

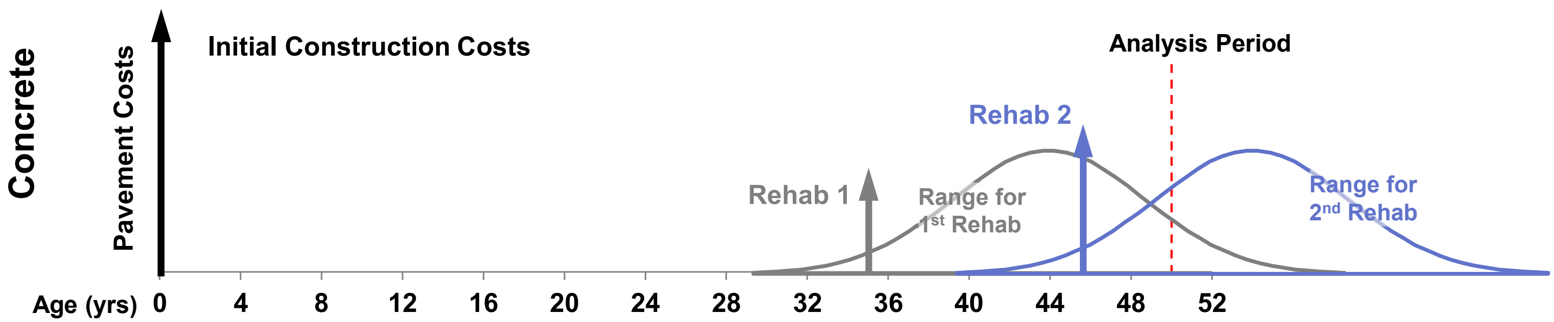
WHEN COMPARING ALTERNATIVES, RISK ASSUMPTIONS FOR REHABILITATION ACTIVITIES & TIMING NEED BE SIMILAR



Proposed Schedule

- Yr 19: Pres. 1 - Crack Seal
- Yr 24: Rehab 1 - Mill & Fill
- Yr 37.5: Pres. 2 – Microsurface
- Yr 42.5: Rehab 2 - Mill & Fill

Asphalt Designs have greater risk for the timing of their rehabilitation activities
(Second major rehab is outside of the historical ranges)



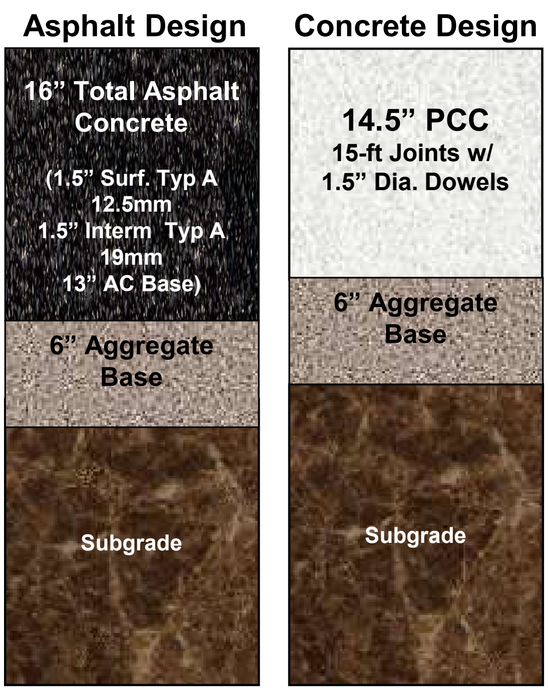
Prolposed Schedule

- Yr 35: Rehab 1 - Patch & DG
- Yr 45: Rehab 2 - Patch & DG

Concrete Designs on the conservative on the timing of their rehabilitation activities

Proposed Rehabilitation Schedules for ALDOT LCCA Procedures: Asphalt based Auburn recommendation sand Concrete based on University of Alabama recommendations.

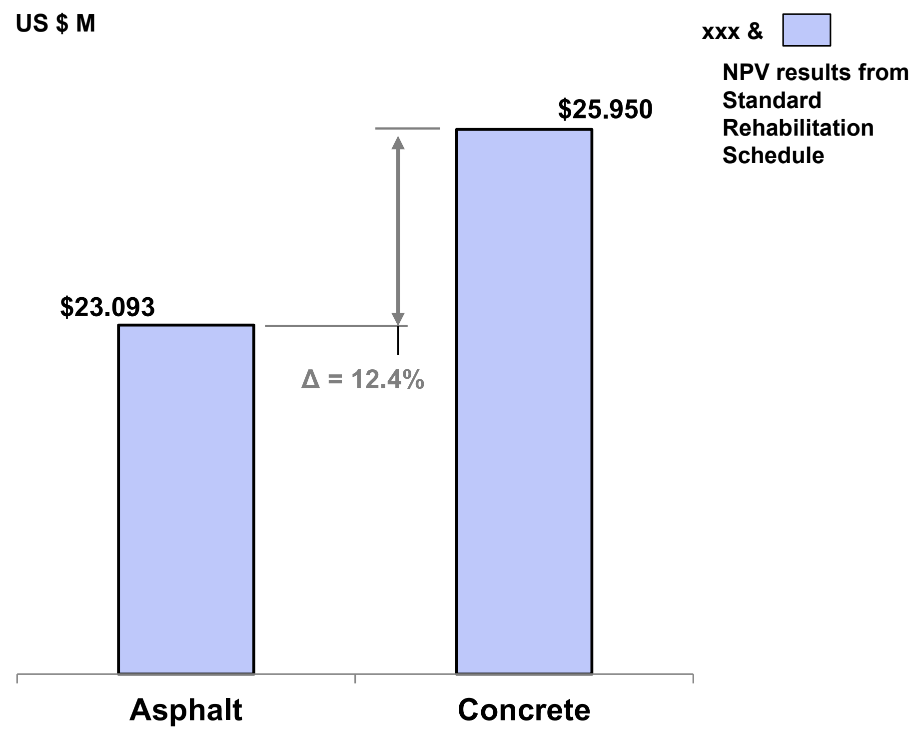
PROBABILITY AND DECISION TREE ANALYSIS CAN IDENTIFY "RISKS" IN THE LCCA RESULTS



IC = $18.432 M

IC = $22.190 M

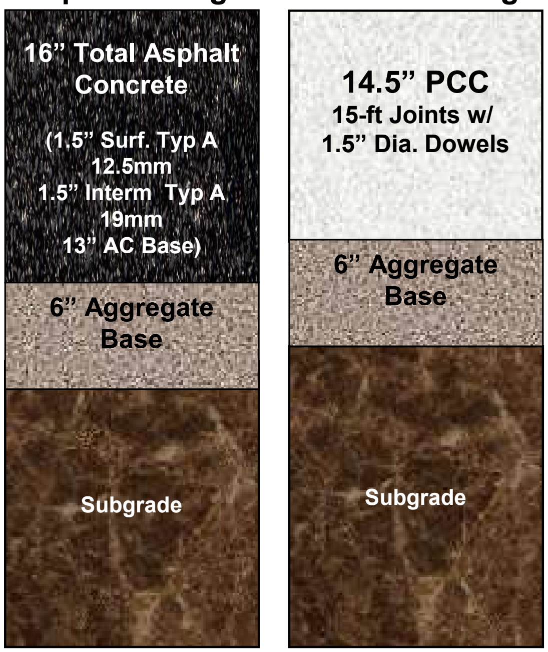
LCCA Results



Standard LCCA provides basic results – but just gives an "A" is better than "B"

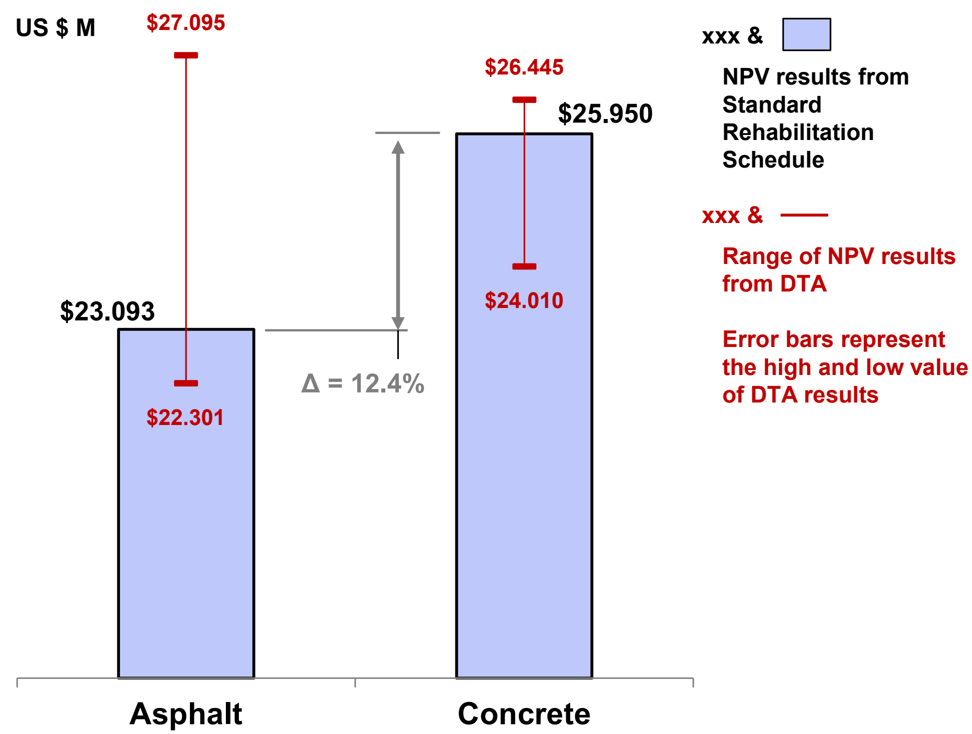
PROBABILITY AND DECISION TREE ANALYSIS CAN IDENTIFY "RISKS" IN THE LCCA RESULTS

Asphalt Design | **Concrete Design**



IC = $18.432 M | IC = $22.190 M

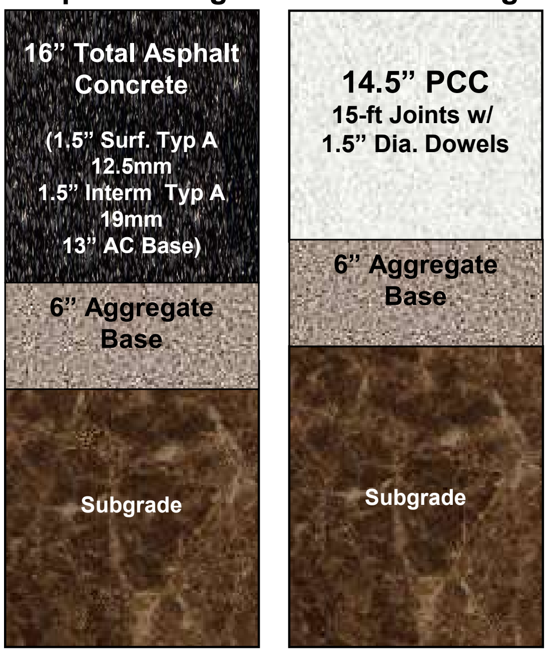
LCCA Results



Range of results shows the "Risks" between the two alternates are not balanced

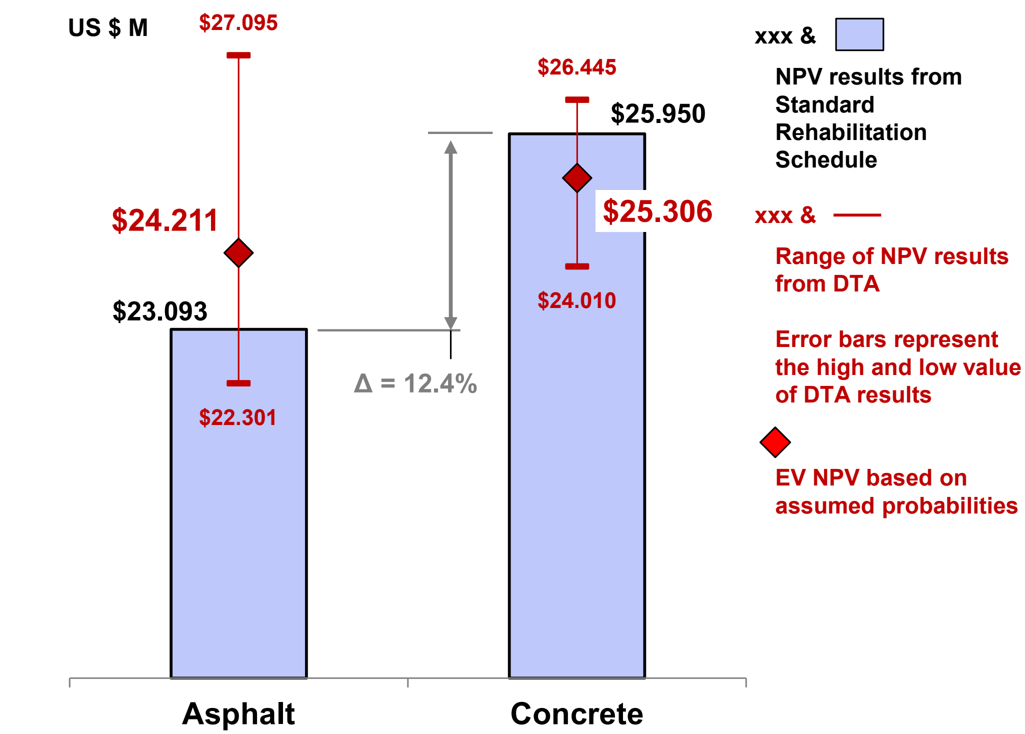
PROBABILITY AND DECISION TREE ANALYSIS CAN IDENTIFY "RISKS" IN THE LCCA RESULTS

Asphalt Design	Concrete Design



IC = $18.432 M — IC = $22.190 M

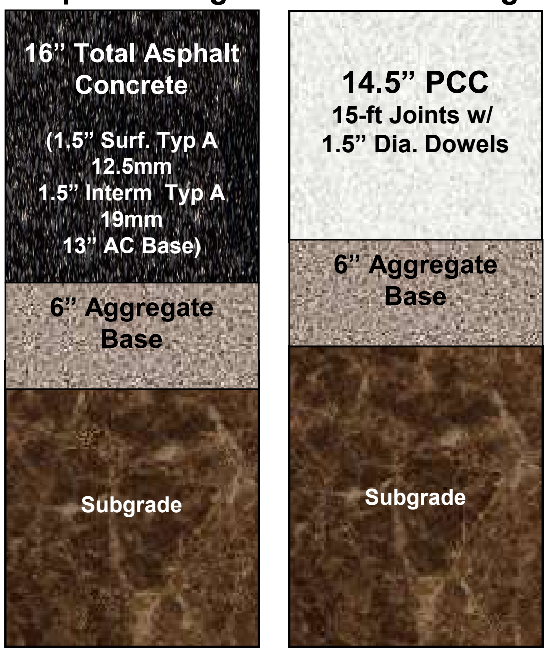
LCCA Results



Probability provides a "risk adjusted" NPV that is more represented of potential future costs

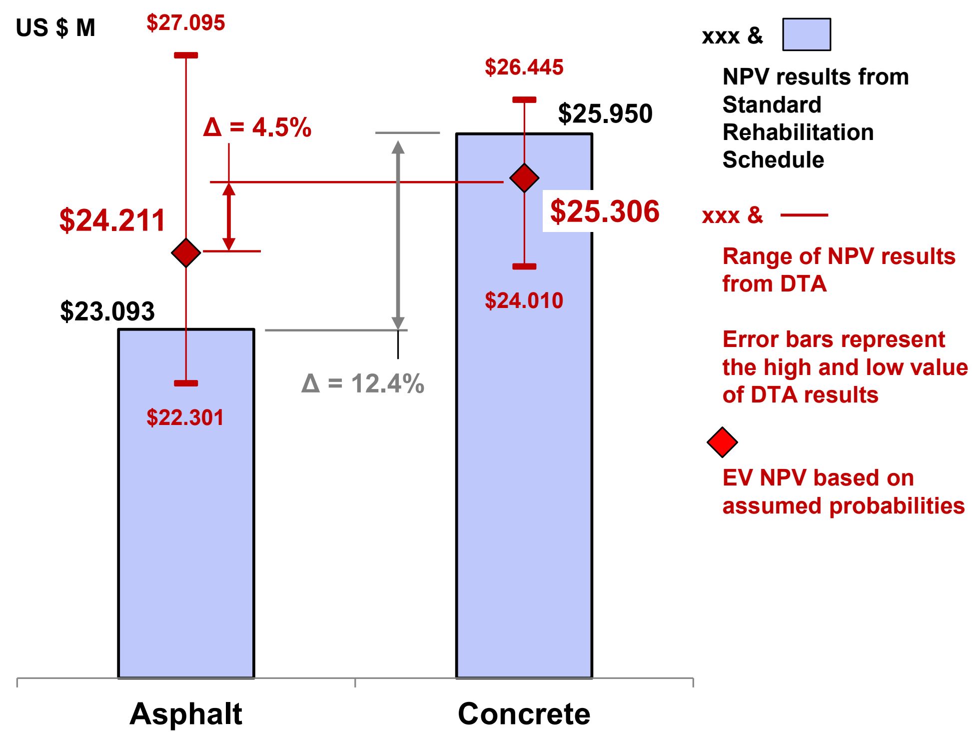
PROBABILITY AND DECISION TREE ANALYSIS CAN IDENTIFY "RISKS" IN THE LCCA RESULTS

Asphalt Design | **Concrete Design**



IC = $18.432 M | IC = $22.190 M

LCCA Results



Probability provides a "risk adjusted" NPV that is more represented of potential future costs

AGENDA

Improving “Timing of Rehabilitation Activities”

Improving “Which rehabilitation activities are done”

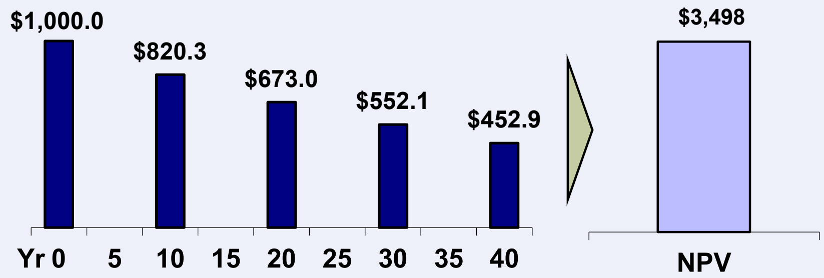
Improving “Cost Estimates”

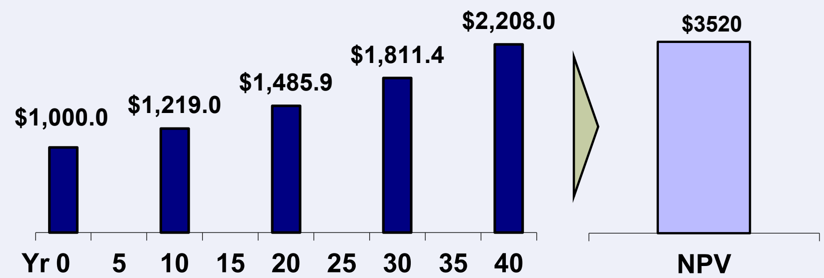
Combining Parts to Develop a Robust LCCA

DISCOUNT RATES ACCOUNT FOR THE "TIME VALUE OF MONEY"

Current Practice is to use Real Discount Rates

	Description	Cash Flow Diagram of \$1000 (today's \$) Expenditure every 10 years

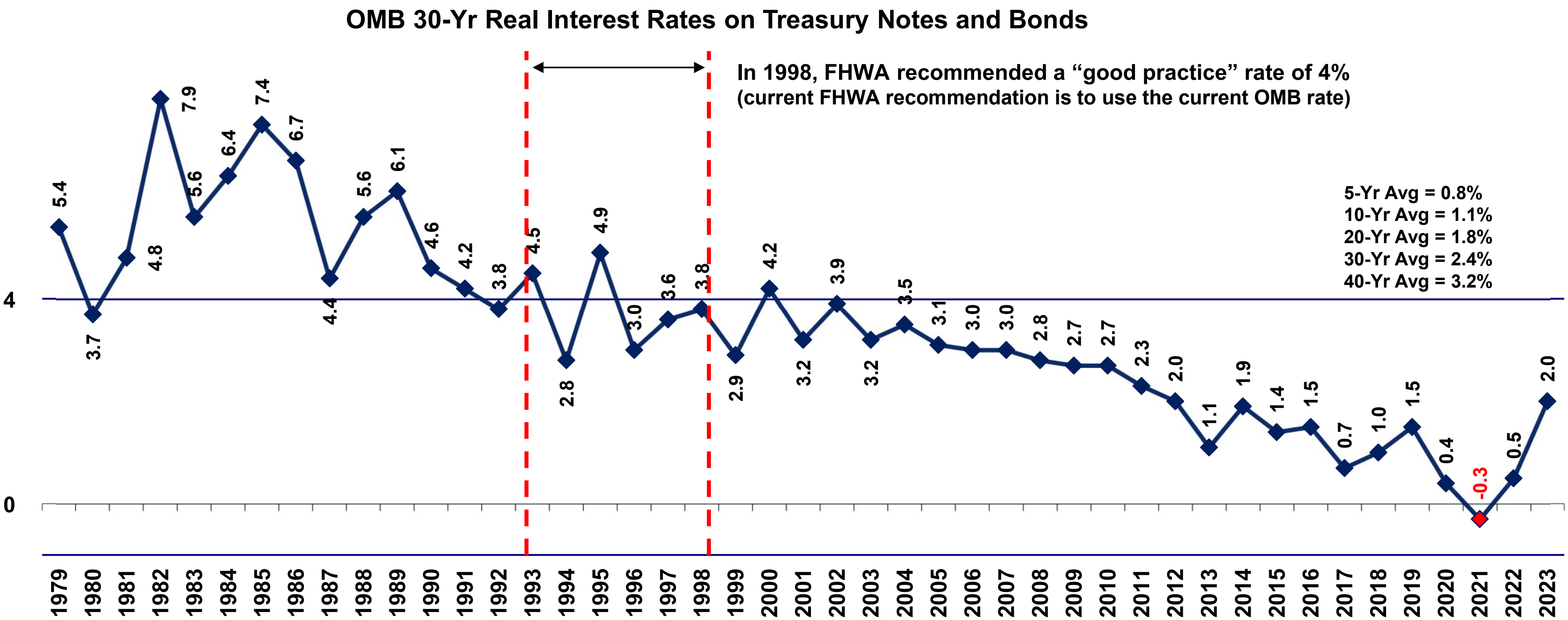
Real Discount Rates	• Reflects the time value of money with no inflation
	  • Used with non-inflated cost estimates (i.e. use "*today's dollars*" in the LCCA)
	• Real DR ≈ Interest Rate – Inflation Rate [1]
	• NPV = Σ Discounted Cash Flows
	  • $NPV_{10} = 1000/(1+.02)^{10} = \$820.3$
		Real Discount Rate = 2% 

Nominal Discount (Interest) Rates	• Reflects the amounts of actual payables
	  • Includes an inflation component and used with inflated future cost estimates
	• Costs are inflated at the Inflation rate and discounted to NPV using Nominal Interest Rate
	  • $Cost_{10} = 1000*(1+.02)^{10} = \$1219.0$
	  • $NPV_{10} = 1219.0/(1+.04)^{10} = \$825.3$
		Nominal Inflation Rate = 2%
		Nominal Discount (Interest) Rate = 4% 

Real Discount Rates assumes the difference between Interest and inflation is relatively constant
Allows agencies to use "today's cost estimates" in the LCCA

1. The actual equation for real DR is DR=(Interest– Inflation)/(1+Inflation). This simplification introduces small error. If the actual equation were used, the results would be equal.

FHWA GUIDANCE IS TO USE REAL DISCOUNT RATES FROM OMB CIRCULAR A-94



Best practice is to update and use OMB Discount Rates each year
Ensure the analysis is line with current economic conditions

1. Guidelines and Discount Rates For Benefit-Cost Analysis Of Federal Programs, OMB , Circular A-94, Appendix C. (http://www.whitehouse.gov/omb/circulars_a094_a94_appx-c/),
2. FHWA Technical Advisory on "Use Alternate Bidding for Pavement Type Selection, December 20, 2012. See http://www.fhwa.dot.gov/pavement/t504039.cfm

IMPACTS OF DISCOUNT RATE ON NPV OF EXPENDITURES IN THE LCCA

$NPV = (\text{Today's Cost}) / (1+DR)^{Year}$

	Short Life Solution				Long Life Solution			
		Estimated Life Cycle Costs				Estimated Life Cycle Costs		
	Today's Cost	Real DR =1%	Real DR =3%	Real DR =5%	Today's Cost	Real DR =1%	Real DR =3%	Real DR =5%
Year 0 - Initital Costs	$ 1,000,000	**$ 1,000,000**	$ 1,000,000	**$ 1,000,000**	$ 1,200,000	**$ 1,200,000**	$1,200,000	**$ 1,200,000**
Year 10 - Rehab Cost	$ 150,000	**$ 135,793**	$ 111,614	**$ 92,087**				
Year 20 - Rehab Costs	$ 150,000	**$ 122,932**	$ 83,051	**$ 56,533**				
Year 30 - Rehab Cost	$ 150,000	**$ 111,288**	$ 61,798	**$ 34,707**	$ 150,000	**$ 111,288**	$ 61,798	**$ 34,707**
Year 40 - Rehab Costs	$ 150,000	**$ 100,748**	$ 45,984	**$ 21,307**	$ 150,000	**$ 100,748**	$ 45,984	**$ 21,307**
Year 50 - Rehab Cost	$ 150,000	**$ 91,206**	$ 34,216	**$ 13,081**	$ 150,000	**$ 91,206**	$ 34,216	**$ 13,081**
55 Year Total LCCA		**$ 1,561,967**	$ 1,336,663	**$ 1,217,714**		**$ 1,503,242**	$ 1,341,998	**$ 1,269,094**

Difference in 55 year estimated Life cycle Costs (Short life – Long Life)	**$ 58,725**	**$ (5,335)**	**$ (51,380)**

Positive = Long life the optimal solution

Low Discount Rate - NPV of future expenditure is reduced less

- **Favors high initial cost and low future cost options (Long term (Concrete) solutions over short term solutions)**
- **Capital expansion over preservation**

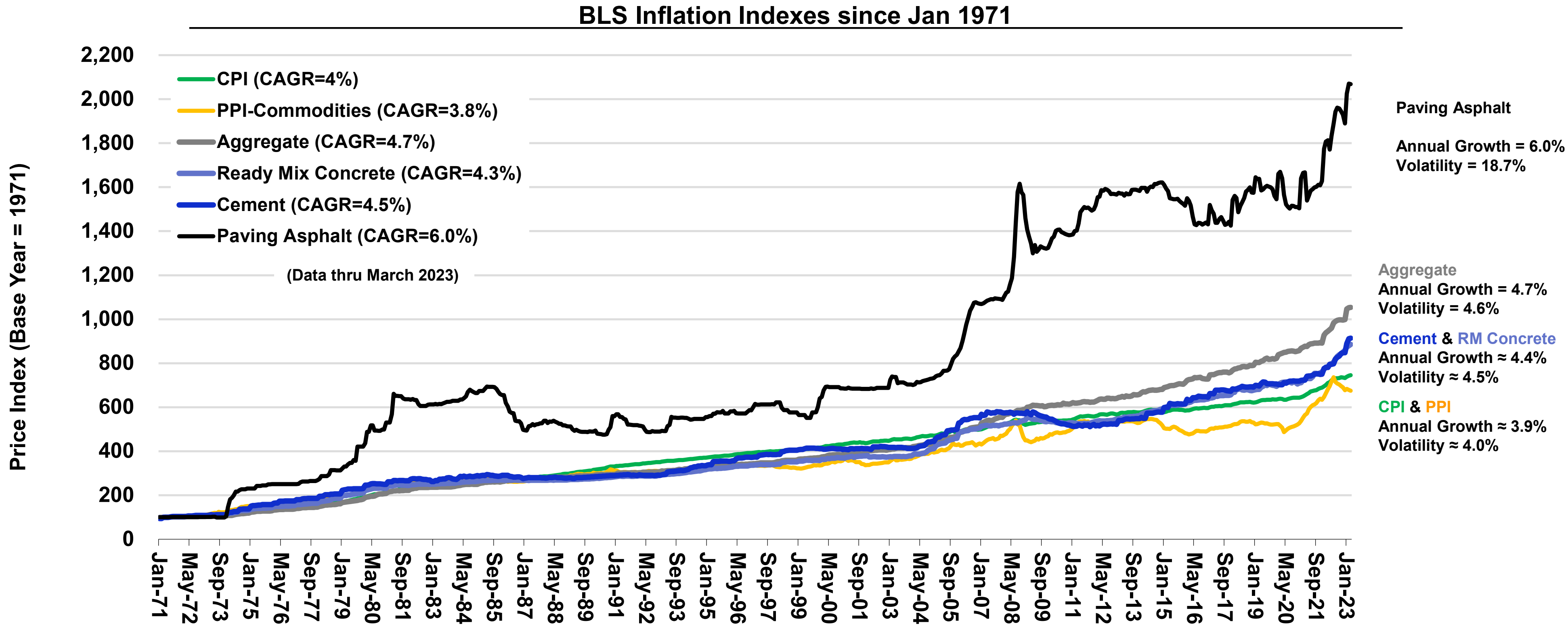
High Discount Rate - NPV of future expenditure is greatly reduced

- **Favors low initial cost and high future cost options (Short term solutions (asphalt) over long term solutions)**
- **Maintaining existing capacity over building new capacity (roads, ports, etc.)**

REAL DISCOUNT RATES ASSUME THAT INFLATION IS THE SAME

It is intended to show "constant dollars" and "constant purchasing power"

***"Real price change"* is the difference between a specific product's inflation rate & the general rate of inflation**



Asphalt Inflation Rates are significantly higher than General Inflation (& Concrete)
Not accounting for "real price change" when estimating Costs biases the results

1. Real Price change is also known as aka changes in relative prices, differential Inflation rates, material specific inflation, & constant dollar changes.
2. U.S. Department of Labor, Bureau of Labor Statistics, http://www.bls.gov/ppi/home.htm
3. CAGR = Compound Annual Growth Rate

ASPHALT INFLATION vs. PPI ALL COMMODITIES RATE

Chart shows the difference in inflation rates between Paving Asphalt and PPI-All commodities (general inflation) over any 10 year or greater period, by month since 1970

- **Each lines starts a new base month / year**
  - **1st line – Jan 1971 to Jan 1981, Feb 1981, etc.**
  - **2nd line – Feb 1971 to Feb 1981, Mar 1981, etc.**
  - **13th line – Jan 1972 to Jan 1982, Feb 1982, etc.**
  - **etc.**

Light Blue = Asphalt Higher
- **Occurs 85% of the time**
- **Average % higher = 2.12%**

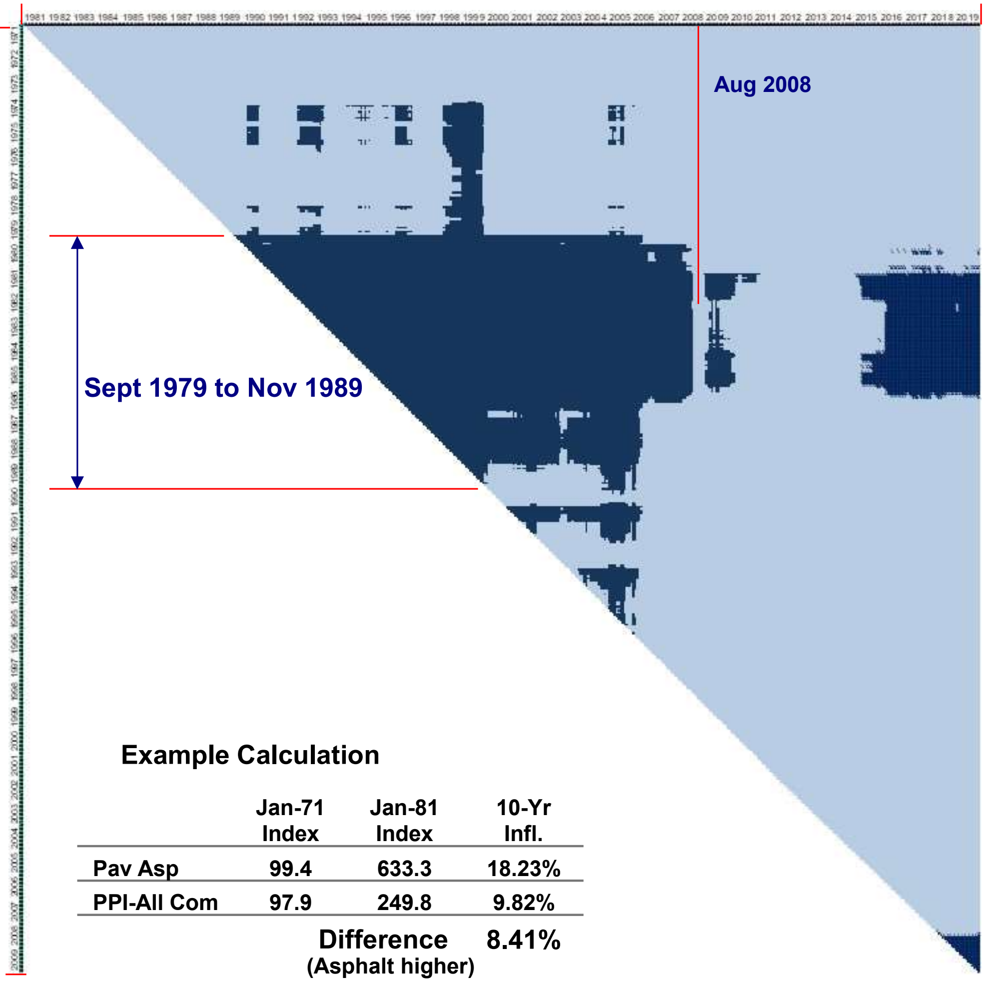
Dark Blue = PPI-All Commodities Higher
- **Occurs 15% of the time**
- **Average % higher = 1.31%**

Average Difference of All Data = 1.60% (asphalt higher)

Difference in Inflation Rates since Jan 1970

Jan 1981 → End Month, Year → Dec 2019

Jan 1, 1971 — Beginning Month, Year — Dec 2009



Example Calculation

	Jan-71 Index	Jan-81 Index	10-Yr Infl.
Pav Asp	99.4	633.3	18.23%
PPI-All Com	97.9	249.8	9.82%
		Difference (Asphalt higher)	8.41%

1. U.S. Department of Labor, Bureau of Labor Statistics, http://www.bls.gov/ppi/home.htm (Data thru Dec 2019)
2. Difference is calculated as Asphalt inflation – Concrete Inflation

CONCRETE INFLATION vs. PPI ALL COMMODITIES RATE

Chart shows the difference in inflation rates between **Ready Mix Concrete** and **PPI-All commodities (general inflation)** over any 10 year or greater period, by month since 1970

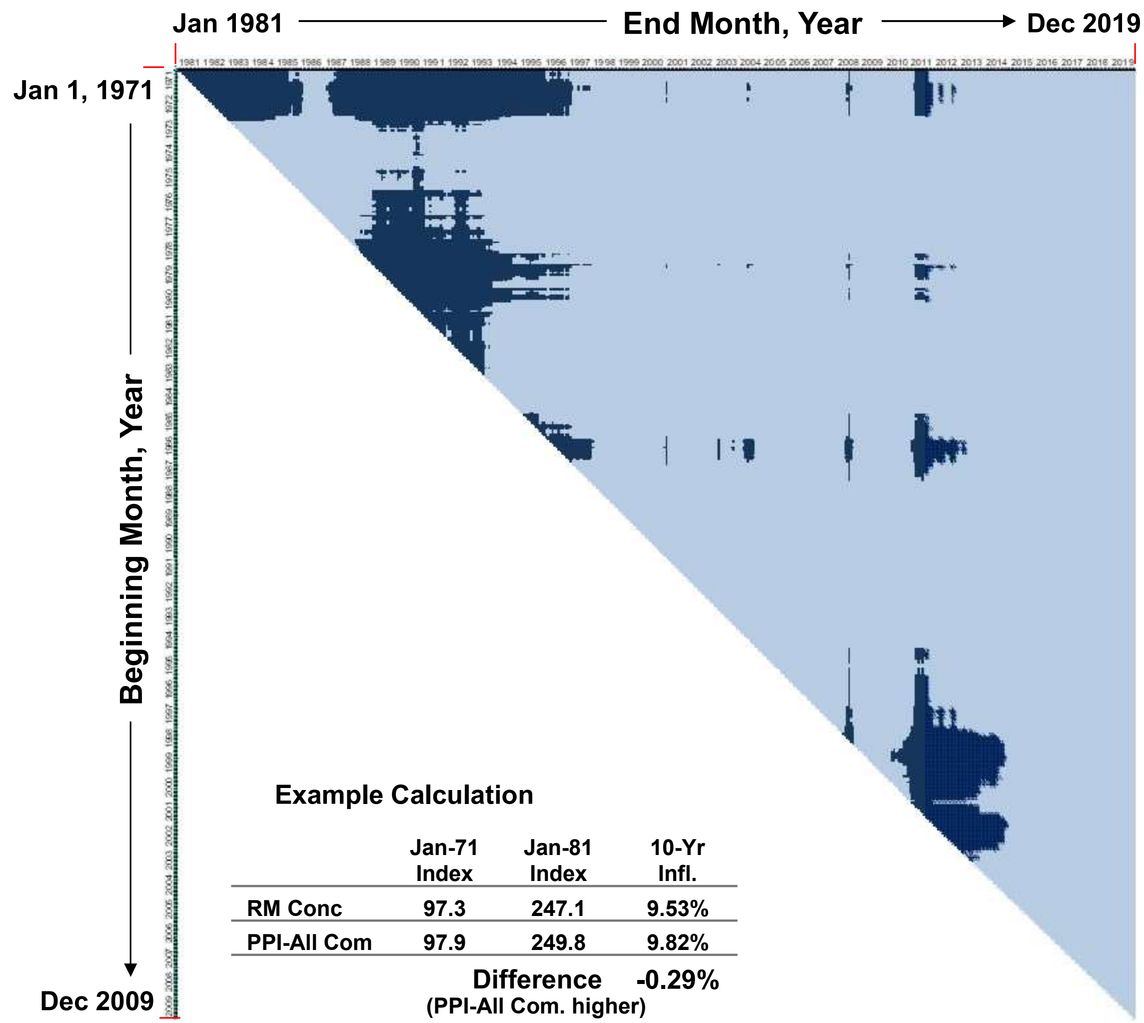
- Each lines starts a new base month / year
  - 1st line – Jan 1971 to Jan 1981, Feb 1981, etc.
  - 2nd line – Feb 1971 to Feb 1981, Mar 1981, etc.
  - 13th line – Jan 1972 to Jan 1982, Feb 1982, etc.
  - etc.

Light Blue = Concrete Higher
- Occurs 89% of the time
- Average % higher = 0.66%

Dark Blue = PPI-All Commodities Higher
- Occurs 11% of the time
- Average % higher = 0.27%

Average Difference of All Data = 0.56% (concrete higher)

Difference in Inflation Rates since Jan 1970



Example Calculation

	Jan-71 Index	Jan-81 Index	10-Yr Infl.
RM Conc	97.3	247.1	9.53%
PPI-All Com	97.9	249.8	9.82%
		Difference	-0.29%

(PPI-All Com. higher)

1. U.S. Department of Labor, Bureau of Labor Statistics, http://www.bls.gov/ppi/home.htm (Data thru Dec 2019)
2. Difference is calculated as Asphalt inflation – Concrete Inflation

CEMEX

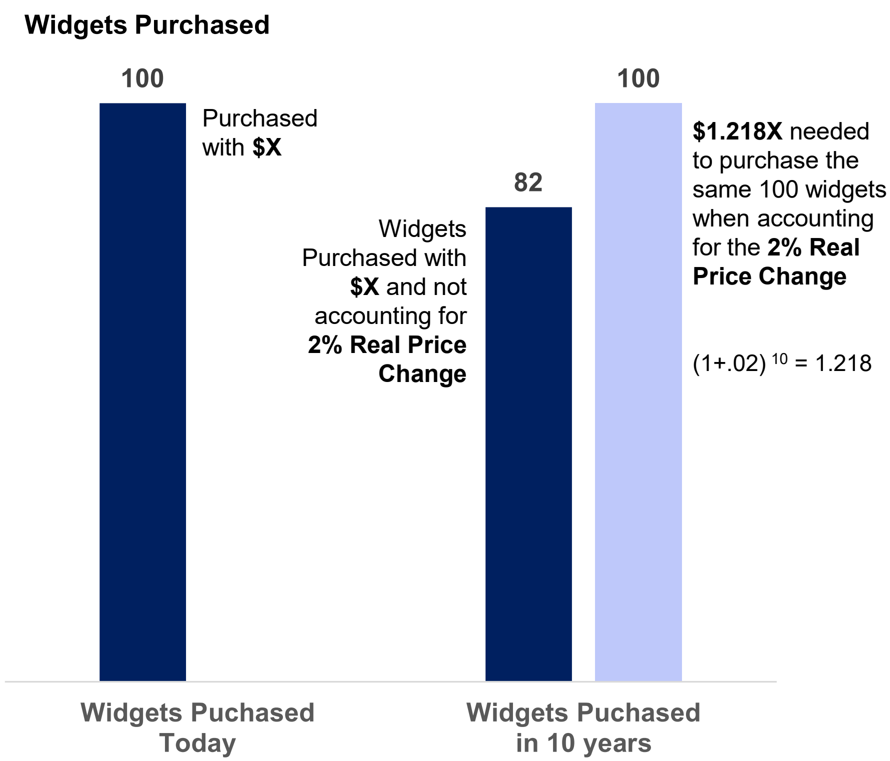
ACCOUNTING FOR REAL PRICE CHANGER ENSURES "CONSTANT PURCHASING POWER"

If I buy a 100 widgets with $X dollars today, I still need to be able to buy that same 100 widgets in the future.

If widgets inflate at a higher (or lower rate) then the general rate of inflation, the same dollars ($X) will not buy the same amount widgets.

- **To get the same 100 widgets in the future, I need spend more (or less) dollars ($X ± z%)**

The amount of actual payables can go up or down depending on whether the widgets inflate faster of slower than the general rate of inflation.



Its not about the Dollars being the Same - It's about what is Purchased with those Dollars being the Same

CEMEX

TO ACCOUNT FOR REAL PRICE CHANGES IN A LCCA REQUIRES TWO ITEMS

Items

1. **LCCA process must be able to account for "real price changes" when it does exists.**
   - **Current FHWA / DOT guidelines for pavement LCCAs do not**
   - **Most other non-pavement applications of LCCA do**

2. **Need to be able to predict future "real price" changes**
   - **MIT has developed "real price" forecasting models" that are ready to be implemented**

Inflation and Real Price Changes does exist and the process must be able to account for these changes for the LCCA process to be reliable

ESCALATION IS NOT A NEW PROCESS

It was presented at the January 1965 TRB meeting in Washington DC

First described for pavement type selection in the paper *Inflation and Highway Economy Studies* by Lee and Grant [1]

- **Stated that differential price changes should be included in the analysis, but at the time it, there was no price differential and so it was ignored**

"Real price changes" guidelines used by other Governmental Agencies:

- **The Office of Management & Budget (OMB) Circular A-94, section 7**
- **GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Program Costs**
- **Economic Analysis Primer, FHWA Publication Number FHWA-IF-03-032, August 2003 (pp. 10-11)**
- **Economic Analysis of Investment and Regulatory Decisions – Revised Guide, FAA Report No: FAA-APO-98-4, January 1998 (Chapter 7)**
- **ASTM standard E 917 "Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems."**
- **Life-Cycle Costing Manual for the Federal Energy Management Program, Department of Commerce,**
- **Department of Army, Economic Analysis: Description and Methods, Army Pamphlet 415-3**

Rehabilitation Costs need to be escalated to account for Real Price Change
(otherwise the cost estimates will severely underestimate future costs)

Inflation and Highway Economy Studies

ROBERT R. LEE and E. L. GRANT
Respectively, Assistant Professor of Civil Engineering, and
Professor Emeritus of Economics of Engineering,
Stanford University

The nature of inflation and other price changes is investigated to determine procedures for treating them in highway economy studies. Long-and short-term trends of general inflation and highway costs are calculated to aid in future prediction. Current prices should be used for estimates of future costs and benefits because it is difficult to predict inflation or differential highway cost trends. In instances of great certainty of differential price trends, they should be used, but only in a sensitivity analysis.

•THE FACT that inflation has been a feature of the American economy for many years is a matter of record. For example, food purchased for $1.00 in 1940 cost about $2.60 in 1963. Clothing prices increased about 110 percent during the same period. In the highway field, construction costs had an average compounded annual increase of about 4 percent for the same period (Tables 1 and 2). Figure 1 shows the general rise in prices as measured by the Consumer Price Index, the Wholesale Price Index and Gross National Product Deflators.

TABLE 1
WHOLESALE PRICE, CONSUMER PRICE, AND GNP DEFLATOR INDEXES, 1913-1963

Year	Wholesale[a] Price	Consumer[a] Price	GNP[b] Deflator	Year	Wholesale Price	Consumer Price	GNP Deflator
1913	38.2	34.5	-	1938	43.0	49.1	48.7
1914	37.3	35.0	-	1939	42.2	48.4	48.1
1915	38.0	35.4	-	1940	43.0	48.8	48.9
1916	46.8	38.0	-	1941	47.8	51.3	52.9
1917	64.3	44.7	-	1942	54.0	56.8	59.6
1918	71.7	52.4	-	1943	56.5	60.3	64.9
1919	75.8	60.3	-	1944	56.9	61.3	66.5
1920	84.5	69.8	-	1945	57.9	62.7	68.0
1921	53.4	62.3	-	1946	66.1	68.0	74.6
1922	52.9	58.4	-	1947	81.2	77.8	83.0
1923	55.1	59.4	-	1948	87.9	83.8	88.5
1924	53.6	59.6	-	1949	83.5	83.0	88.2
1925	56.6	61.1	-	1950	86.8	83.8	89.5
1926	54.8	61.6	-	1951	96.7	90.5	96.2
1927	52.3	60.5	-	1952	94.0	92.5	98.1
1928	53.0	59.7	-	1953	92.7	93.2	99.0
1929	52.1	59.7	57.4	1954	92.9	93.6	100.0
1930	47.3	58.2	55.4	1955	93.2	93.3	101.2
1931	39.9	53.0	49.9	1956	96.2	94.7	104.6
1932	35.6	47.6	44.9	1957	99.0	98.0	108.4
1933	36.1	45.1	44.2	1958	100.4	100.7	110.8
1934	41.0	46.6	46.9	1959	100.6	101.5	112.6
1935	43.8	47.8	47.4	1960	100.7	103.1	114.2
1936	44.2	48.3	47.7	1961	100.3	104.2	115.7
1937	47.2	50.0	49.5	1962	100.6	105.4	116.9
				1963	99.9	106.2	118.7

[a]Data derived from Ref. 8.
[b]Data derived from Ref. 6.

Paper sponsored by Committee on Highway Engineering Economy.

1. R. R. Lee and E.L. Grant, *Inflation and Highway Economy Studies*, In Highway Research Record 100,, Washington, D.C., 1965, pp. 20–37.

CEMEX

THE ECONOMIC PROCEDURE USED TO ACCOUNT FOR REAL PRICE CHANGES IS A CALLED ESCALATION or INDEXING

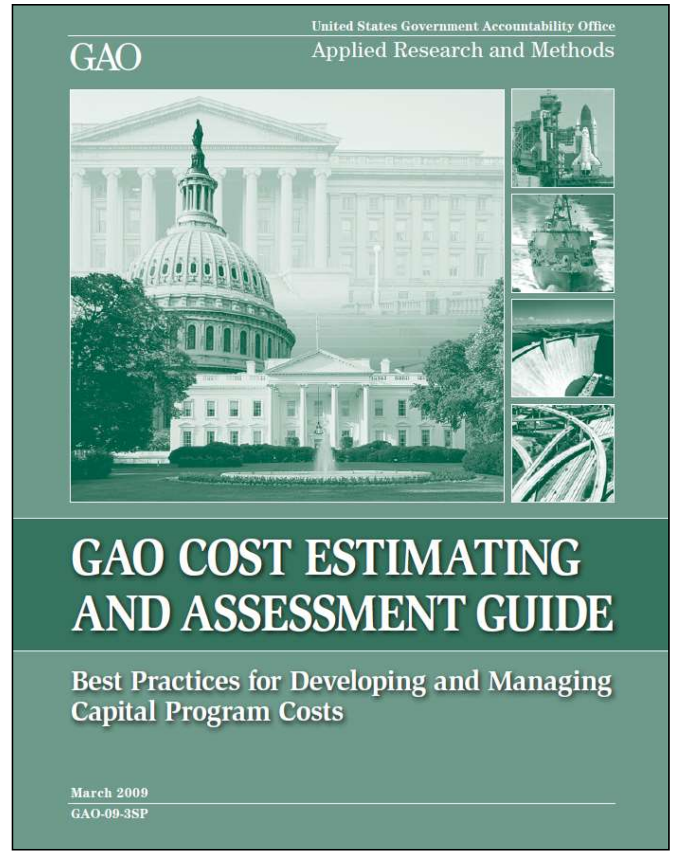
Escalation / Indexing takes into account inflation by increasing (decreasing) future year costs

Index Values are used to escalate costs in any given future year

$$\text{Cost in Yr X} = \frac{\text{Yr X Index}}{\text{Base Year Index}} \times \text{Base Year Costs}$$

Steps:

1. ***Estimate current costs and year of rehabilitation***
2. ***Select index values for year of rehabilitation and calculate future costs using above formula***
   - Key aspect is determining the correct index values to determine future price projections for concrete & asphalt.
3. ***Calculate adjusted LCC values for different confidence levels (optional)***
   - eg. 5th/95th percentile estimates.



GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Program Costs, March 2009
Chapter 9 – see pages 80 – 81, Chapter 10 – see pages 102 – 104 and Case Study 33: Inflation and Chapter 11 – see page 115

MIT HAS DEVELOPED REAL PRICE PROJECTIONS MODELS FOR USE IN PAVEMENT LIFE CYCLE COST ANALYSIS

Research Brief
September 2014

Material-Specific Price Projections: Implementation

PROBLEM

Developing an effective life-cycle cost analysis (LCCA) model, similar to sound engineering practice, requires (a) accurate estimates of input parameters and (b) consideration of uncertainty and variation. One would expect that an LCCA would take into consideration the potential dissimilar growth of pavement materials. Yet current practice assumes all commodities will (a) grow at the same rate and (b) increase at the rate of inflation. This is partly because of the difficulty in developing effective forecasting models. Researchers at the CSHub have developed probabilistic price projections that outperform current practice and account for the volatility in paving prices (Figure 1). The purpose of this brief is to demonstrate how such models can be implemented within the scope of current LCCA models.

Figure 1 Average error of forecast asphalt prices using CSHub model versus current practice for one state DOT

APPROACH

The price projections developed by the CSHub can be implemented either by integrating the forecasting models into a probabilistic LCCA software tool such as FHWA's RealCost or utilizing the price projection tables provided at the end of this brief. The former approach is the preferred method, but given its complexity, the methodology to develop the latter is demonstrated via a case study the CSHub conducted with a state DOT.

Step 1: Estimate costs and years of rehabilitation - Key inputs, listed in Table 1, have all been estimated via an LCCA model integrated with Pavement-ME software. Note that material costs are broken out in order to incorporate material price projections (labeled as "adjusted cost portion").

Table 1 Description of information and calculation for each step (cost in millions of $'s)

	Initial Construction		Rehabilitation 1		Rehabilitation 2	
Step 1 - Estimate costs and years of rehabilitation	Rigid	Flexible	Rigid	Flexible	Rigid	Flexible
Year	0	0	27	15	N/A	29
Non-Adjusted Cost Portion	$1.28	$1.16	$0.69	$0.14	N/A	$0.23
Adjusted Cost Portion (e.g., material costs)	N/A	N/A	$0.07	$0.30	N/A	$0.30
Step 2 - Select index values from table for years of rehabilitation and calculate future costs						
Adjustment Index @ 5th percentile	N/A	N/A	0.890	0.810	N/A	0.964
Adjustment Index @ 95th percentile	N/A	N/A	1.151	1.349	N/A	1.501
$Cost\ Adjusted\ Portion\ at\ X\% = Cost\ Adjusted\ Portion * Adjustement\ Index\ @\ X\%$						
Adjusted Cost Portion @ 5th percentile	N/A	N/A	$0.06	$0.24	N/A	$0.29
Adjusted Cost Portion @ 95th percentile	N/A	N/A	$0.08	$0.40	N/A	$0.45

Step 3 – Calculate adjusted LCC values for different confidence levels

$$Cost\ Adjusted\ LCCA = Initial + \Sigma Discounted\ (Ajdjusted\ Cost + Non - Adjusted\ Costs)$$

(i.e. 5th Percentile LCC for Rigid Pavement = $\$1.28 + \frac{\$0.69+\$0.06}{(1.019)^{27}} = \$1.73$

	Rigid	Flexible
5th Percentile LCC for Pavement	$1.73	$1.75
95th Percentile LCC for Pavement	$1.74	$1.96
LCC for Pavement without Adj. Index (represents current practice estimate)	$1.74	$1.80

Concrete *(Constituent model)*

Year	5th	Concrete Mean	95th
0	100	100	100
1	88	101.3	114.6
2	86.5	102.2	118.1
.			
.			
.			
10	86.7	106.2	126.5
11	86.5	106.4	126
12	86.9	107.1	127.3
13	86.9	106.9	126.7
14	86.2	106.9	127.1
15	86.2	106.9	127.3
16	87	107.3	127.7
17	85.9	107.3	129
18	86.3	107.3	128.5
19	87.7	107.8	129.2
20	87.9	108	128.3
21	86.3	107.7	128.8
.			
.			
.			
48	86.3	107.7	129.4
49	86.9	107.7	128.8
50	86.8	107.5	129.1

Asphalt *(Constituent Based)*

Year	5th	Asphalt Mean	95th
0	100	100	100
1	85	100	116.7
2	80.7	99.5	119.8
.			
.			
.			
10	76.4	102.8	133.5
11	78	103.6	136
12	77.3	105	137.5
13	78.4	106	140.3
14	78.9	107.3	140.1
15	79.3	108.6	144.4
16	80.2	110.2	145.5
17	81.3	111.3	147.3
18	81.9	113.1	149
19	83.3	114.6	151.1
20	84.1	116.8	152.2
21	86.8	119	154.9
.			
.			
.			
48	125.4	144.5	164.4
49	126	144.4	163.6
50	125.3	144.3	163.6

MIT HAS DEVELOPED REAL PRICE PROJECTIONS MODELS FOR USE IN PAVEMENT LIFE CYCLE COST ANALYSIS

Concrete (Constituent model)

		Concrete	
Year	5th	Mean	95th
0	100	100	100
1	88	101.3	114.6
2	86.5	102.2	118.1
.			
.			
.			
10	86.7	106.2	126.5
11	86.5	106.4	126
12	86.9	107.1	127.3
13	86.9	106.9	126.7
14	86.2	106.9	127.1
15	86.2	106.9	127.3
16	87	107.3	127.7
17	85.9	107.3	129
18	86.3	107.3	128.5
19	87.7	107.8	129.2
20	87.9	108	128.3
21	86.3	107.7	128.8
.			
.			
.			
48	86.3	107.7	129.4
49	86.9	107.7	128.8
50	86.8	107.5	129.1

Mean Index Values are used to forecast the "most likely" costs in any given future year

$$\text{Cost in Yr X} = \frac{\text{Yr X Index}}{\text{Base Year Index}} \times \text{Base Year Costs}$$

To bracket the range of potential values, use 5th and 95th Index values

Example

- **$1 M concrete expenditure at year 20 (mean value)**
  Forecasted cost = 108/100 x $1,000,000 = 1,080,000.
- **$1 M Concrete expenditure at year 20 (5th and 95th values)**
  Forecasted cost = 84.1/100 x $1,000,000 = $879,000
  Forecasted cost = 128.3/100 x $1,000,000 = $1,283,000.

Material-Specific Price Projections: Implementation, Research Brief, MIT Concrete Sustainability Hub, September 2014

MIT HAS DEVELOPED REAL PRICE PROJECTIONS MODELS FOR USE IN PAVEMENT LIFE CYCLE COST ANALYSIS

Asphalt (Constituent Based)

		Asphalt	
Year	5th	Mean	95th
0	100	100	100
1	85	100	116.7
2	80.7	99.5	119.8
.			
.			
.			
10	76.4	102.8	133.5
11	78	103.6	136
12	77.3	105	137.5
13	78.4	106	140.3
14	78.9	107.3	140.1
15	79.3	108.6	144.4
16	80.2	110.2	145.5
17	81.3	111.3	147.3
18	81.9	113.1	149
19	83.3	114.6	151.1
20	84.1	116.8	152.2
21	86.8	119	154.9
.			
.			
.			
48	125.4	144.5	164.4
49	126	144.4	163.6
50	125.3	144.3	163.6

Mean Index Values are used to forecast the "most likely" costs in any given future year

$$\text{Cost in Yr X} = \frac{\text{Yr X Index}}{\text{Base Year Index}} \times \text{Base Year Costs}$$

To bracket the range of potential values, use 5th and 95th Index values

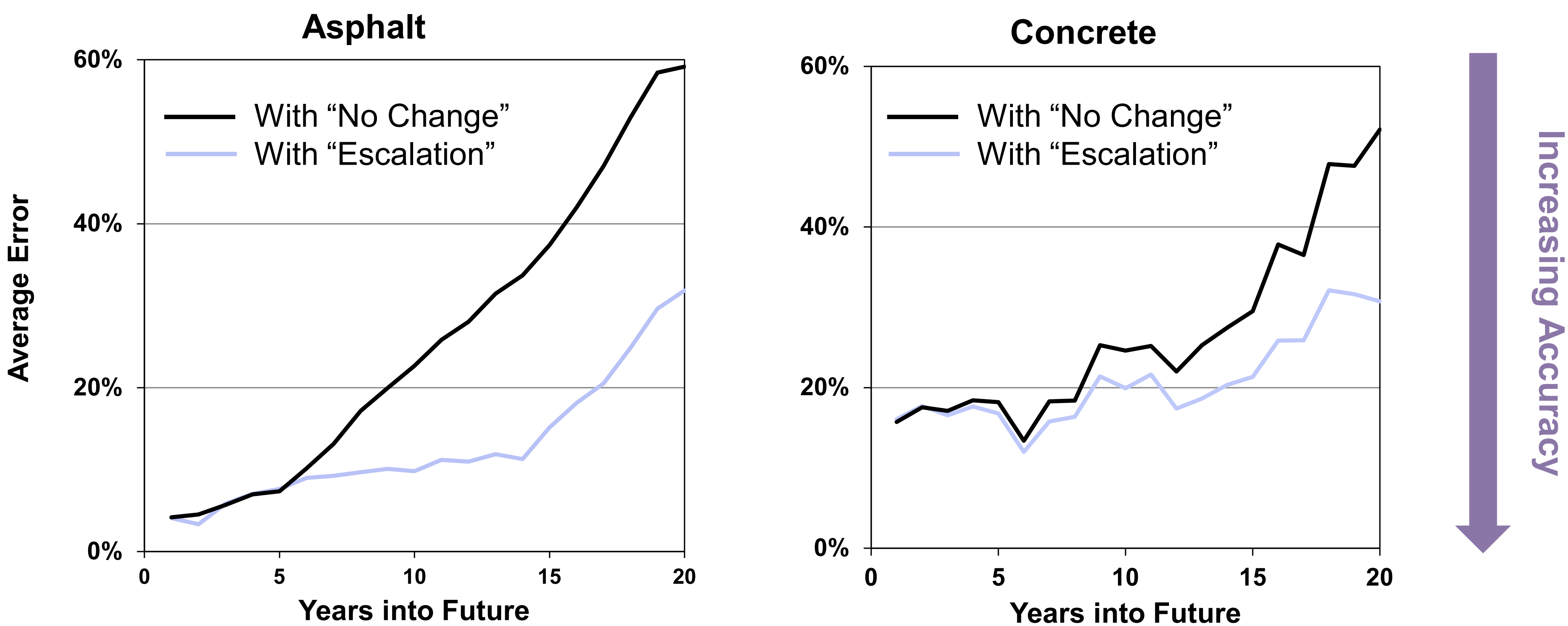
Example

- **$1 M asphalt expenditure at year 20 (mean value)**
  Forecasted cost = 116.8/100 x $1,000,000 = 1,168,000.
- **$1 M asphalt expenditure at year 20 (5th and 95th values)**
  Forecasted cost = 84.1/100 x $1,000,000 = $841,000
  Forecasted cost = 152.2/100 x $1,000,000 = $1,522,000.

Material-Specific Price Projections: Implementation, Research Brief, MIT Concrete Sustainability Hub, September 2014

MIT FORECASTS HAVE SHOWN USING ESCALATION IS MORE ACCURATE THAN CURRENT PRACTICE

Average error of price forecasts made between 1976-1990 for Colorado using current-practice (labeled "No Change") and CSHub method (labeled "National – Scaled").



Slide: Courtesy of MIT Concrete Sustainability Hub, CSHub Forecast based on Mean Value

CEMEX

AGENDA

Improving “Timing of Rehabilitation Activities”

Improving “Which rehabilitation activities are done”

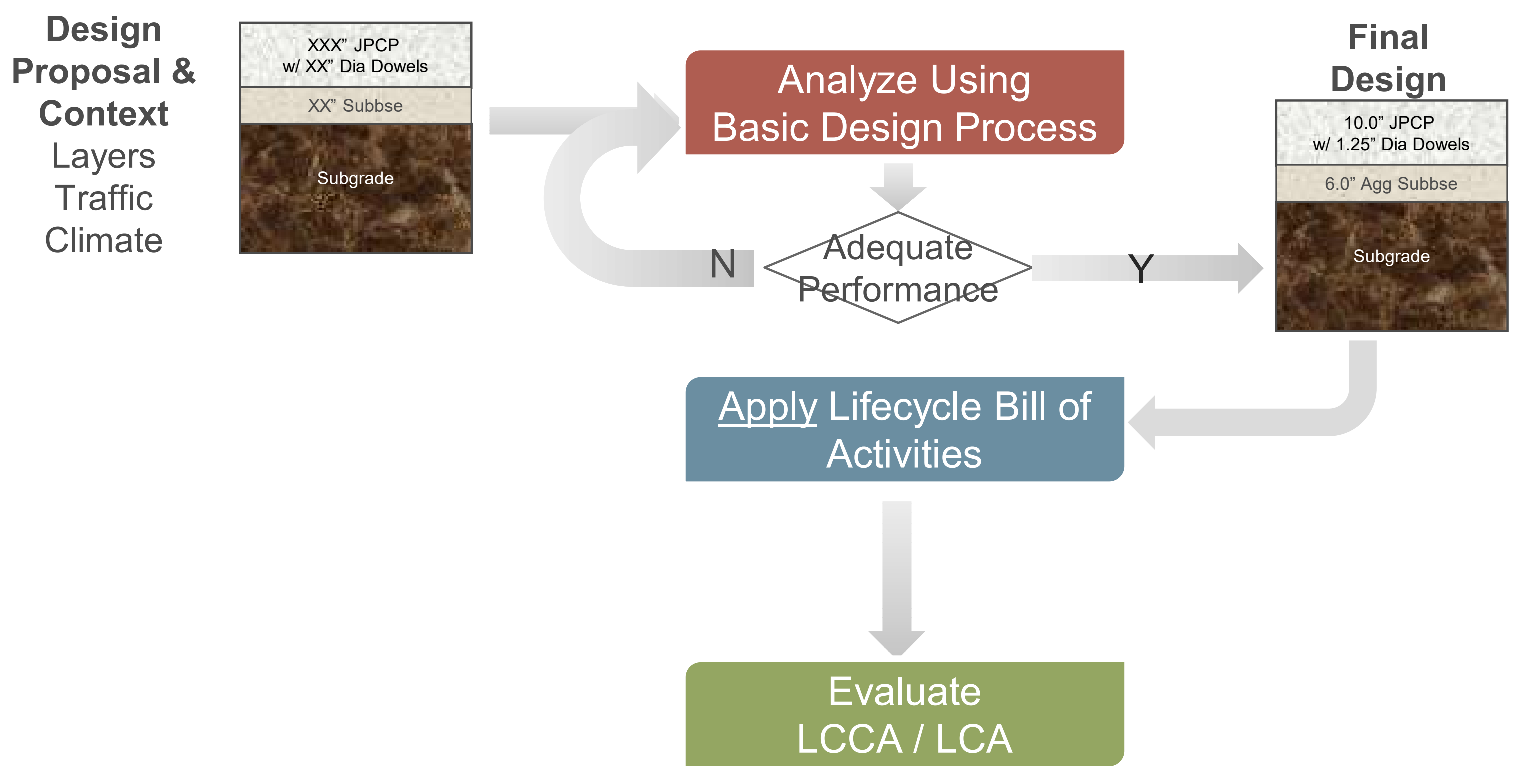
Improving “Cost Estimates”

Combining Parts to Develop a Robust LCCA

CEMEX

CURRENTLY LCCA IS DONE IN A “STATIC” MODE

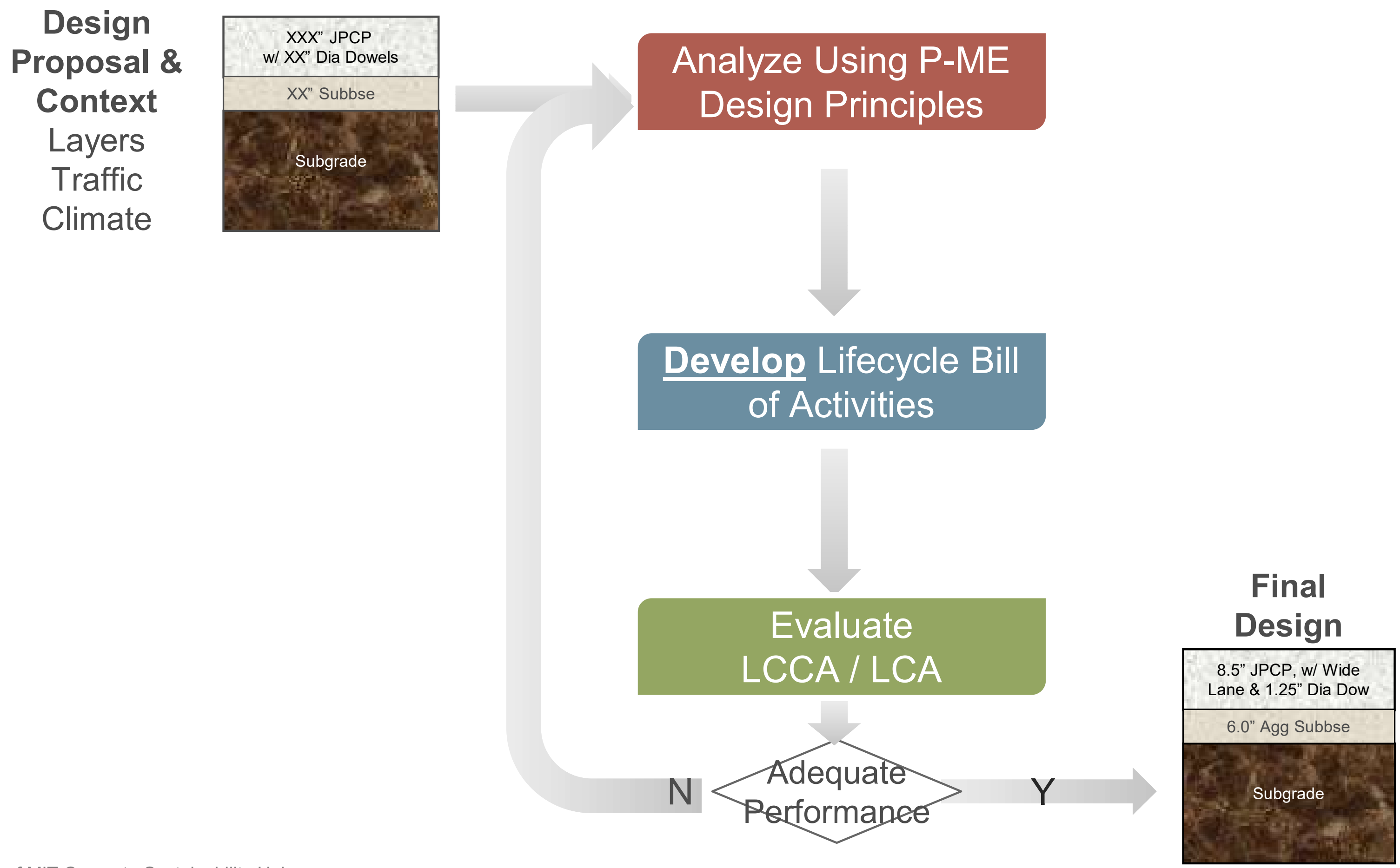
LCCA done after designs are developed to select the final pavement design



Doing a LCCA at the end misses the opportunities to make design changes

TO IMPROVE THE LCCA PROCESS (& PAVEMENT DESIGNS)

Need to create a link between Design and Evaluation in an iterative design process



Slide: Courtesy of MIT Concrete Sustainability Hub

TO IMPROVE THE LCCA PROCESS (& PAVEMENT DESIGNS)

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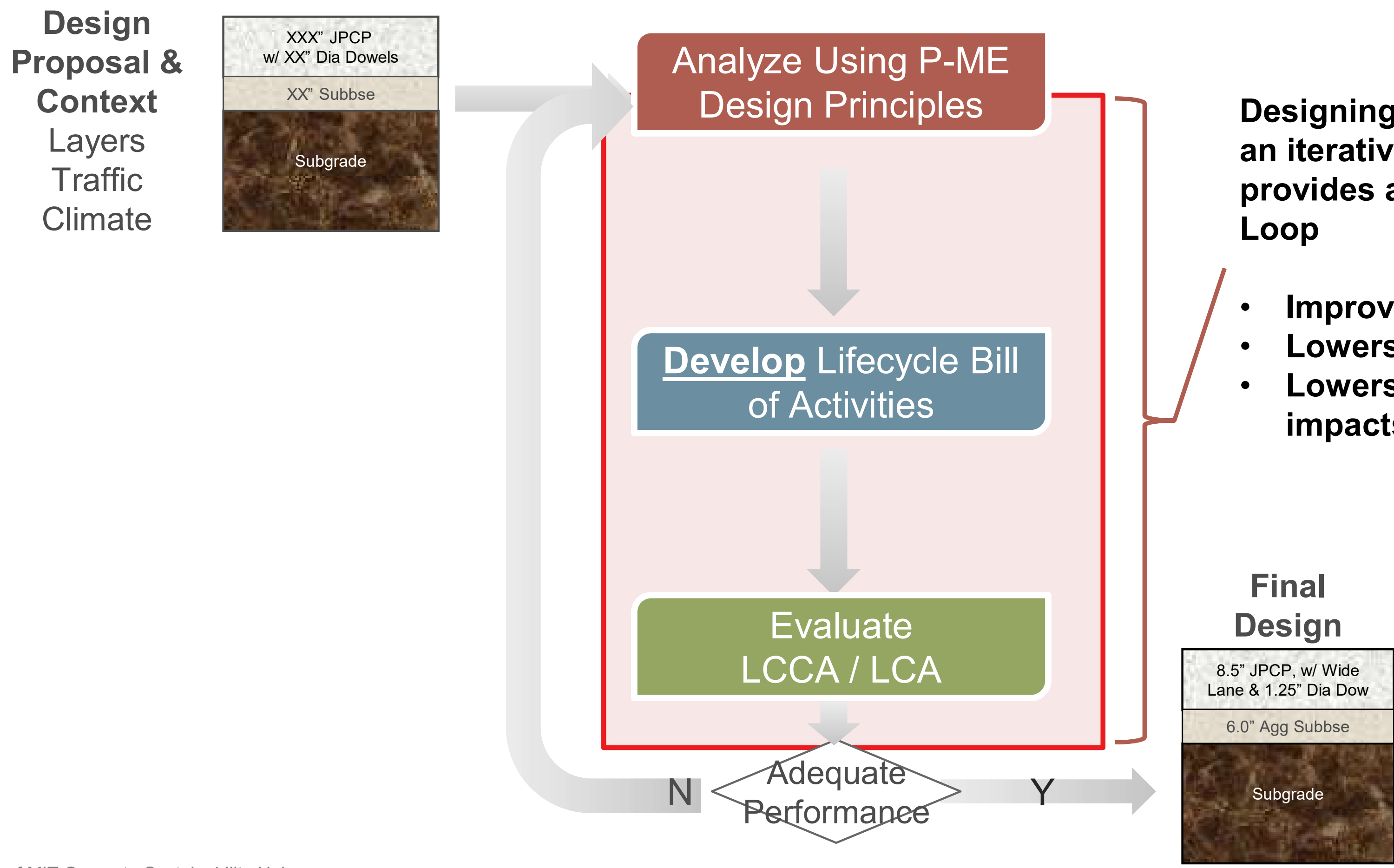


Designing pavements in an iterative procedure provides a Feedback Loop

- **Improves performance**
- **Lowers cost**
- **Lowers environmental impacts**

Slide: Courtesy of MIT Concrete Sustainability Hub

CEMEX

TO MAKE FHWA'S LCCA PROCESS MORE ROBUST REQUIRES MINOR MODIFICATIONS

Establish LCCA Framework

- Establish analysis period
- Establish how inflation will be treated (nominal or real)
  - Verify material inflation rates are similar to the general rate of inflation
  - Select "escalation indexes" as needed
- Establish discount rate to be used (nominal or real)

Perform LCCA

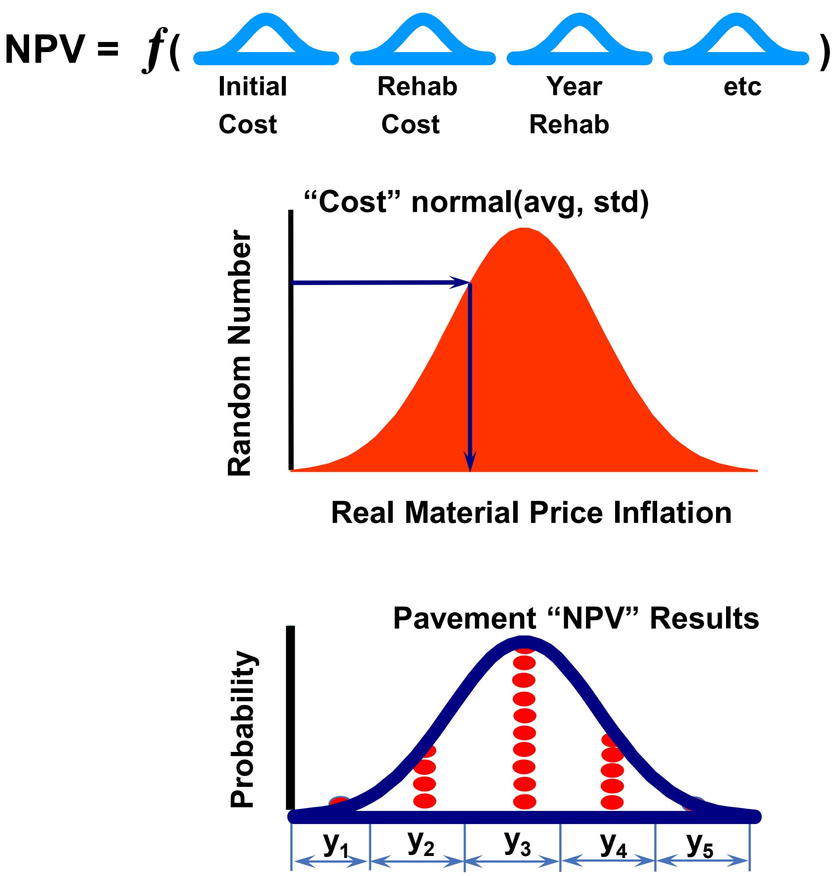
1. Establish Alternative Pavement Designs
2. Determine Timing of Required Rehabilitation Activities
   - Develop multiple scenarios representing "good–poor–expected" performance"
3. Estimate Agency and User Costs (often considered optional)
   - Initial Construction Costs
   - Rehabilitation Costs
   - Escalate cost to the activity year using the appropriate escalation index
4. Compute Life-Cycle Costs (use probabilistic analysis)
5. Analyze the Results

Updating LCCA Procedures to account for these changes will make LCCA more reliable and informative

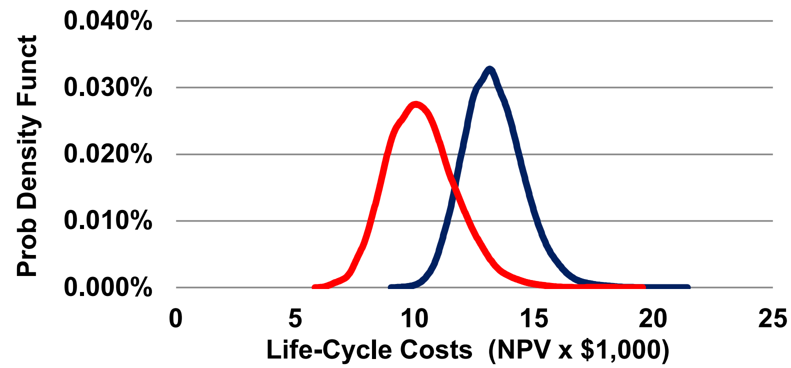
A ROBUST LCCA LOOKS AT MANY POSSIBLE SOLUTIONS

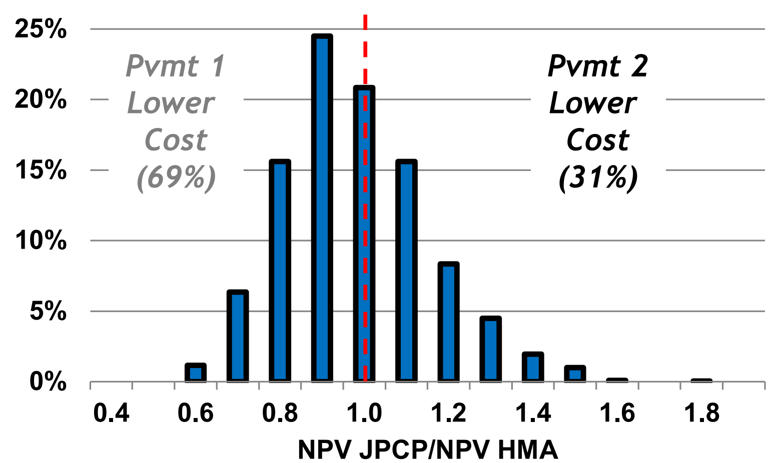
Use Probabilistic Analysis to runs 1000's of LCCAs to create a distribution of outcomes

Inputs & Sampling



Outputs





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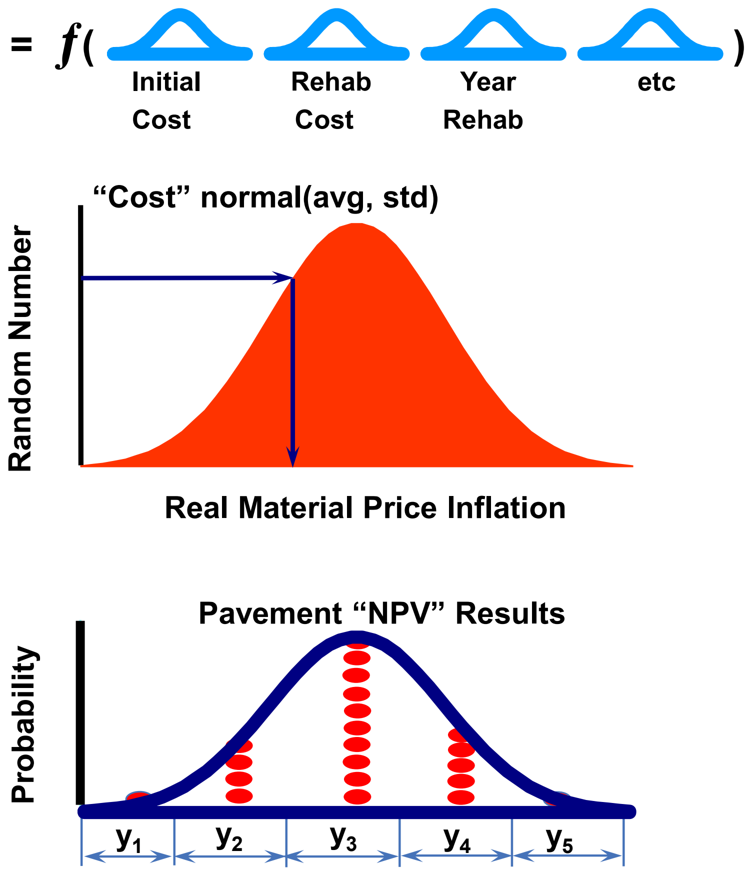
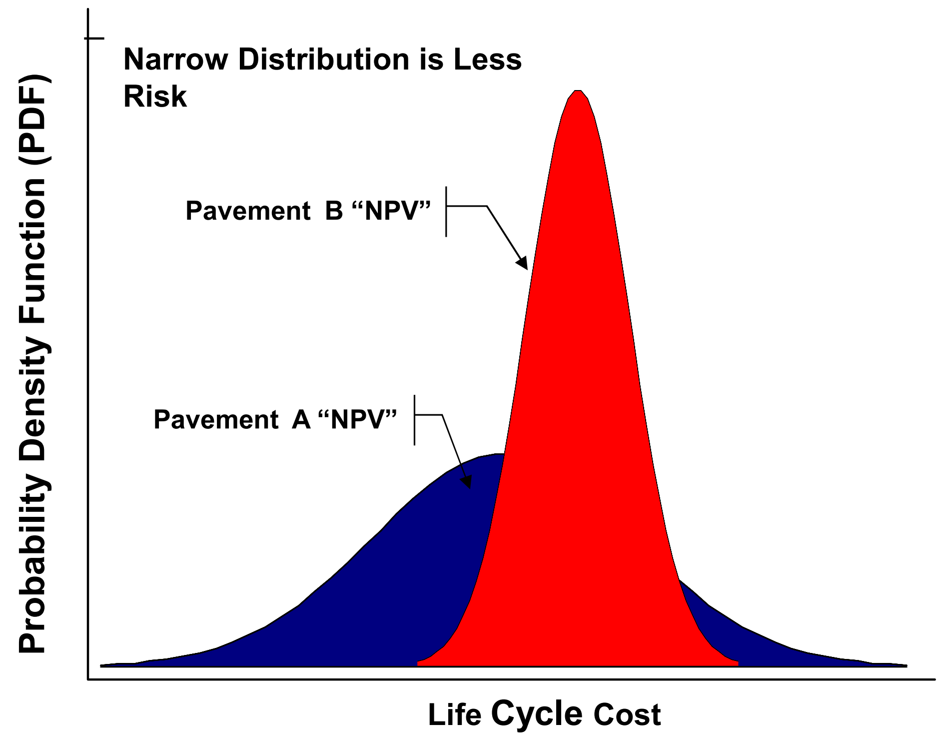


Outputs



CEMEX

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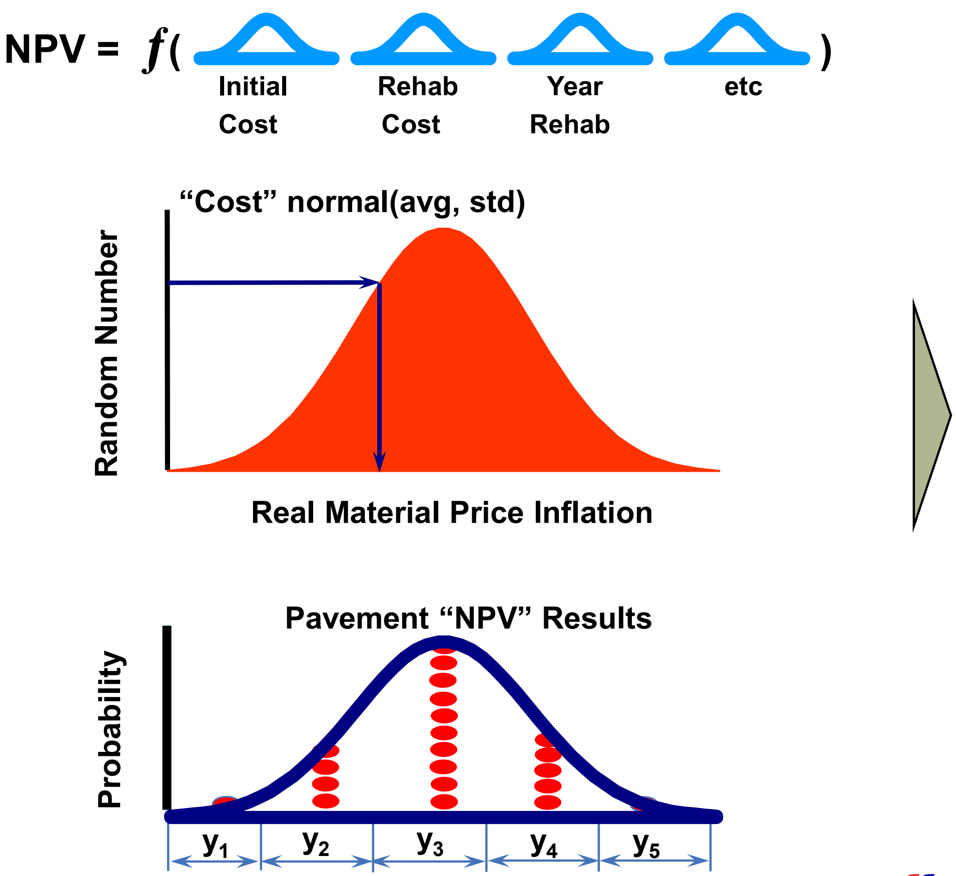
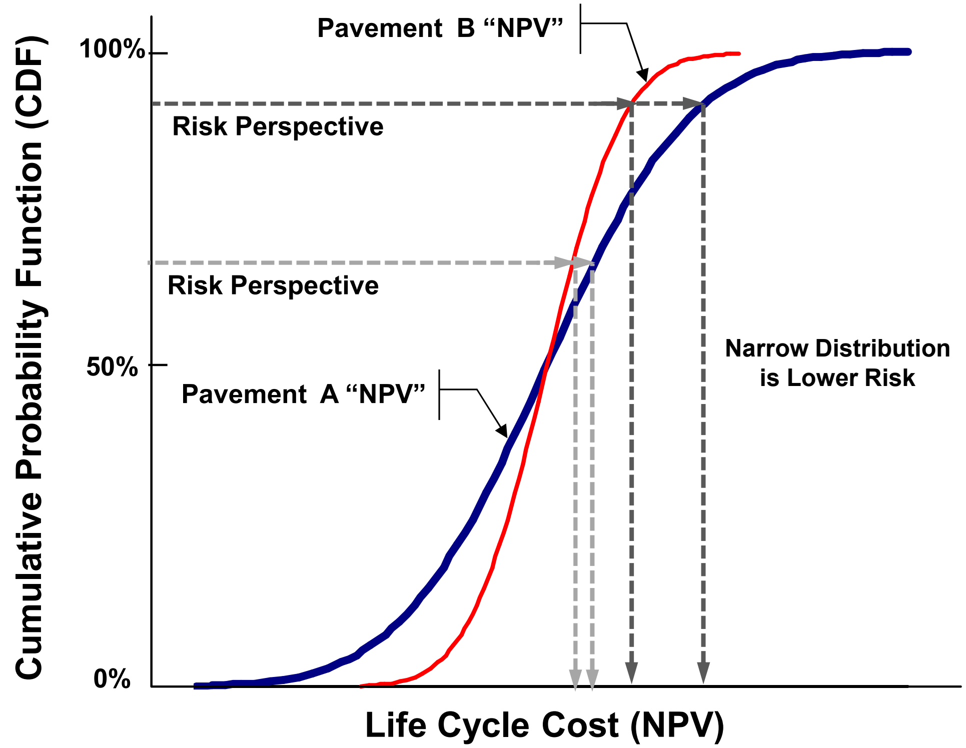
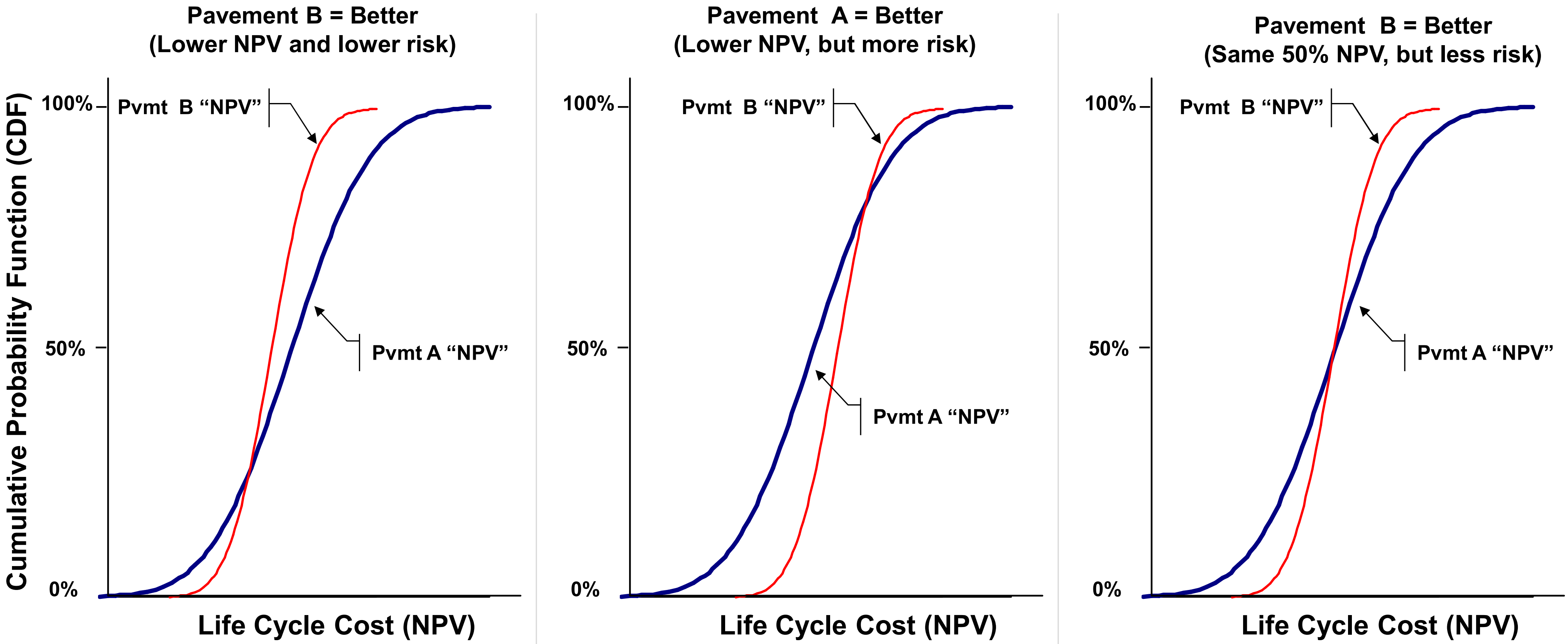


Outputs



CEMEX

A PROBABILITY ANALYSIS ALLOWS FOR DIFFERENT RISK PERSPECTIVES TO BE EVALUATED



Slide: Courtesy of MIT Concrete Sustainability Hub

CEMEX

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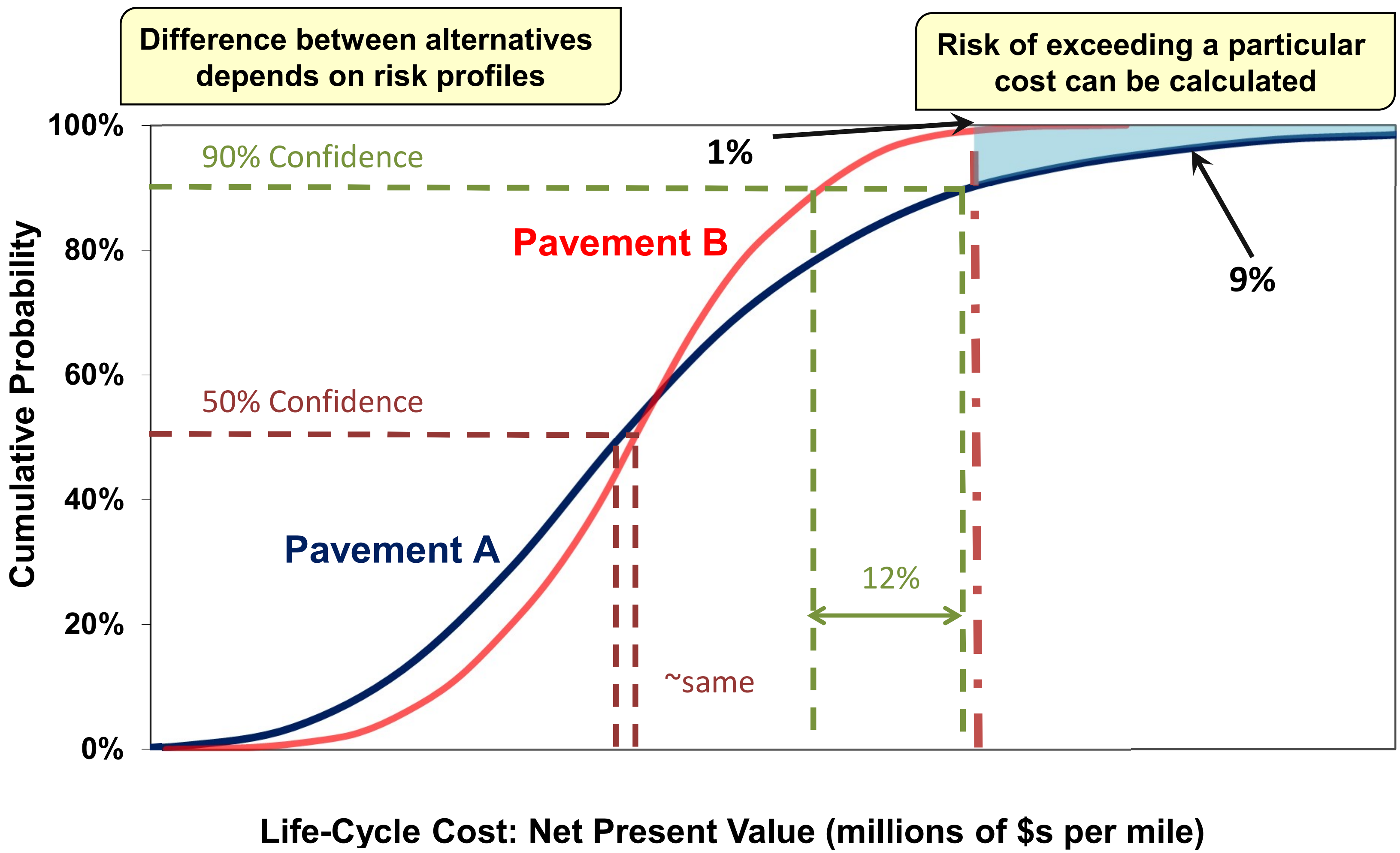

Slide: Courtesy of MIT Concrete Sustainability Hub

CONCLUSIONS

The true benefit of LCCA is it makes designers ask questions about their designs

1. **There is "lack of trust" in LCCA results because of disagreements over the inputs**
   - **Uncertainty about timing of activities, which activities are done, and costs**
2. **There are tools that can be used to evaluate these uncertainties to make LCCA results Credible and Reliable**
   - **Pavement ME can help inform "when activities will be done"**
   - **Decision Tree Analysis looks at many potential rehabilitation options**
   - **Escalation accounts for real price changes**
3. **Probabilistic Analysis can be used to account for all these uncertainty / variabilities by running 1000's of LCCA simulations to see how different inputs change the results**

A "Robust LCCA" addresses the inherent uncertainty in LCCA's to balance the risk assumptions to make them more transparent, credible, and defensible