Life Cycle Cost Analysis in Pavement Design

In Search of Better Investment Decisions

Northwest Pavement Management Association
2016 Conference
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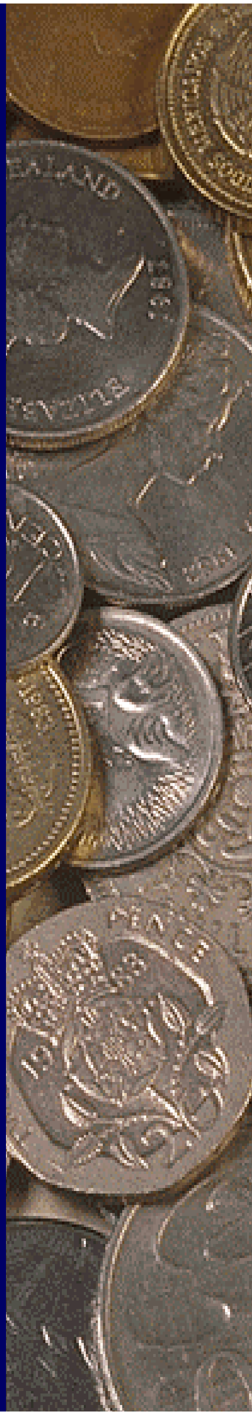


Life-Cycle Cost Analysis

What is it ?

- Economic procedure
  - That uses Engineering inputs
- Compares competing alternates over their life
  - by considering all significant costs (and benefits)
    - Construction, Maintenance, Rehabilitation
    - User
    - Performance
- Expressed in equivalent dollars.

Life-Cycle Cost Analysis

What it is not

- An analysis of expected agency expenditures
- A Magical Black Box
  - There is no concrete LCCA or asphalt LCCA
- Complicated
  - Does not need a computer program

Life-Cycle Cost Analysis

What it takes to do one:

- An understanding of the process
- An understanding of the sensitivity of each input so that they are chosen with care

Life-Cycle Cost Analysis

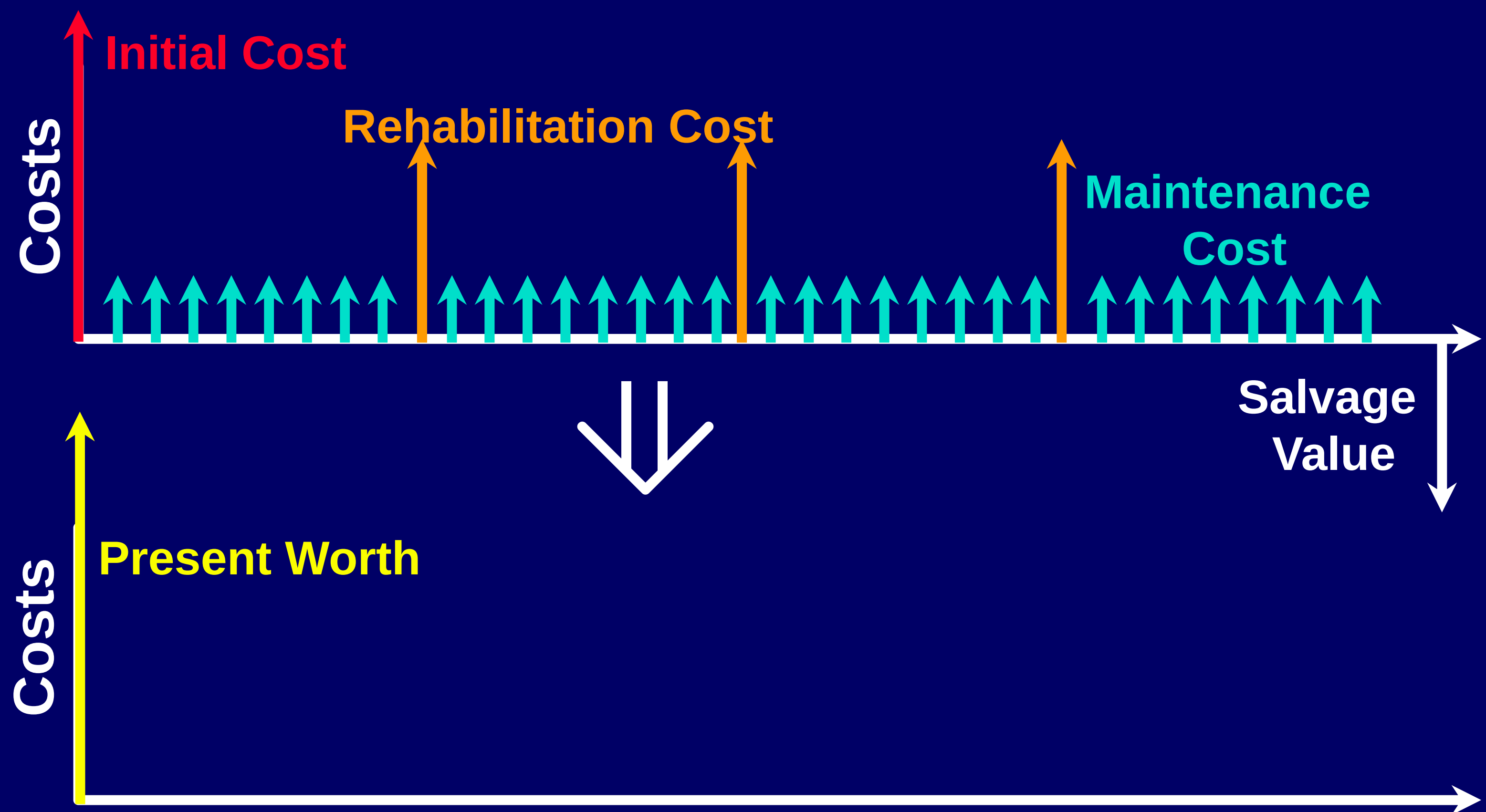
How it is done:

- Present Worth Analysis (PW)
- Equivalent Uniform Annual Cost Analysis (EUAC)

Life-Cycle Cost Analysis

Present Worth Analysis:

Discounts all future costs (benefits) to the present



Life-Cycle Cost Analysis

Present Worth Analysis:

Discounts all future costs (benefits) to the present

$$PW = IC + \sum_{t=0}^{t=n} pwf\,[MC+UC+FRC] - pwf(S)$$

IC = Initial Cost
MC = Maintenance Cost
UC = Users Cost
FRC = Rehabilitation Cost
S = Salvage (Recycling value)
pwf = Present Worth Factor

Life-Cycle Cost Analysis

Present Worth Factor:

$$\text{pwf} = \frac{1}{(1 + i)^n}$$

pwf = Present Worth Factor for discount rate i and year n

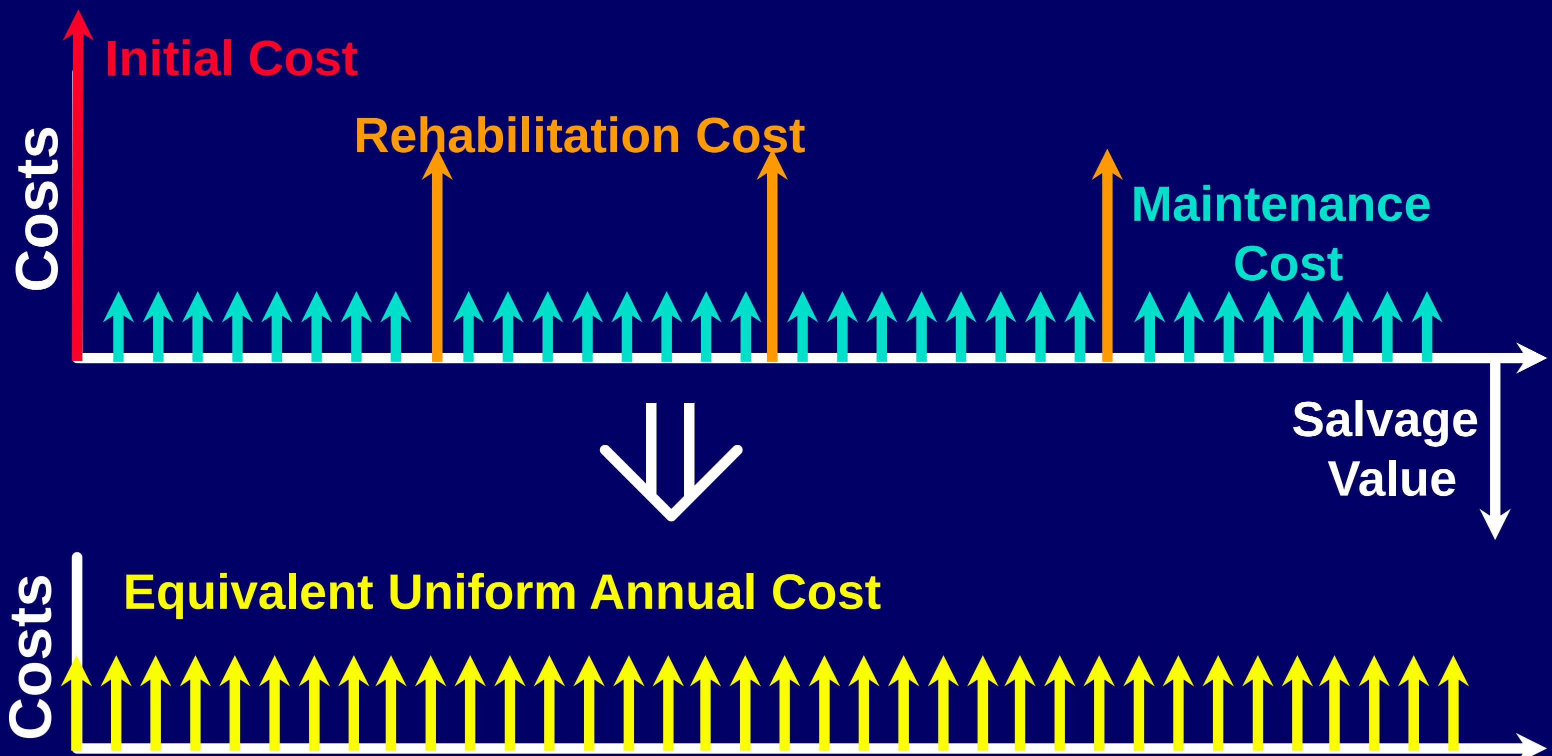
i = Discount rate

n = Number of years when cost (benefit) will occur

Life-Cycle Cost Analysis

Equivalent Uniform Annual Cost:

Combines all present and future costs (benefits) into equal annual payments



Life-Cycle Cost Analysis

Equivalent Uniform Annual Cost:

Combines all present and future costs (benefits) into equal annual payments

$$EUAC = crf\,(IC) + AM + AUC + \left[crf \sum_{t=0}^{t=n} pwf(FRC) \right] - crf(S)$$

IC	= Initial Cost
AM	= Annual Maintenance Cost
AUC	= Annual Users Cost
FRC	= Future Rehabilitation Cost(s)
S	= Salvage Value
crf	= Capital Recovery Factor
pwf	= Present Worth Factor

Life-Cycle Cost Analysis

Capital Recovery Factor:

$$crf = \frac{i\,(1 + i)^n}{(1 + i)^n - 1}$$

crf = Capital Recovery Factor for discount rate i and year n

i = Discount rate

n = Number of years when cost (benefit) will occur

Life-Cycle Cost Analysis

Basic Factors:

- Engineering Factors
  - Agency costs
  - User costs
  - Rehabilitation selection
  - Comparable sections
- Economic Factors
  - Analysis period
  - Discount rate

Life-Cycle Cost Analysis

Agency Costs:

- Initial cost of pavement
- Maintenance and operation cost
- Anticipated future rehabilitation costs
  - Engineering
  - Construction
- Salvage (recycling value)

Life-Cycle Cost Analysis

User Costs:

- Delay-of-use
  - Time delays - New construction & Rehabilitation
  - Fuel consumption
  - Driver discomfort
- Roadway deterioration
  - Cargo damage
  - Vehicle wear
- Accidents

Life-Cycle Cost Analysis

User Costs:

- Presently not used by most states
- Cons
  - Can not recoup costs
  - Not in my budget
  - Drives the results
- Pros
  - User fees collected pay for public transportation investments
  - Drives the results

Life-Cycle Cost Analysis

- For high traffic volume sections, user costs frequently DWARF direct costs.
- May skew analysis

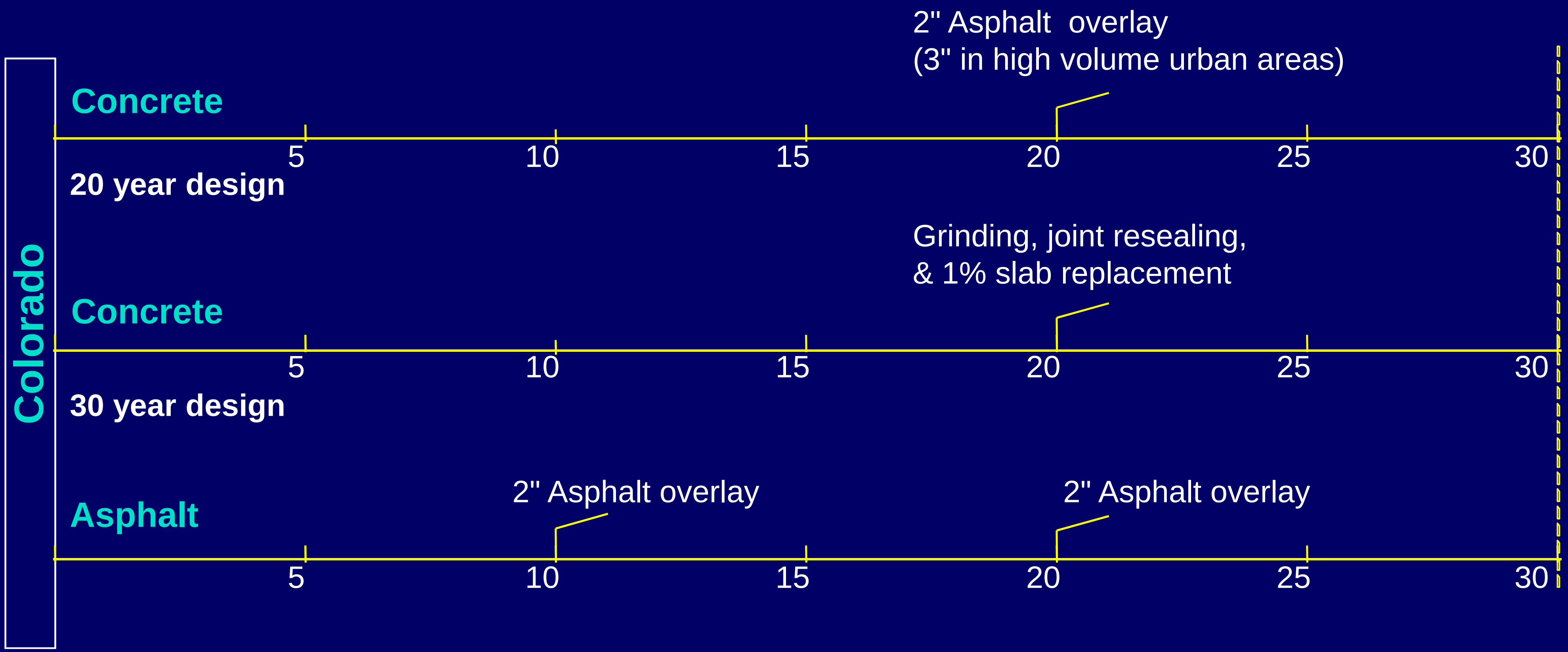
Life-Cycle Cost Analysis

Rehabilitation Selection

- Deciding WHAT activities to do and WHEN to do them effects the results significantly.
- Has wide spread and varying practices.
  - A change in 1 year in rehabilitation, in either direction, can alter the LCC results.

Life-Cycle Cost Analysis

Rehabilitation Selection



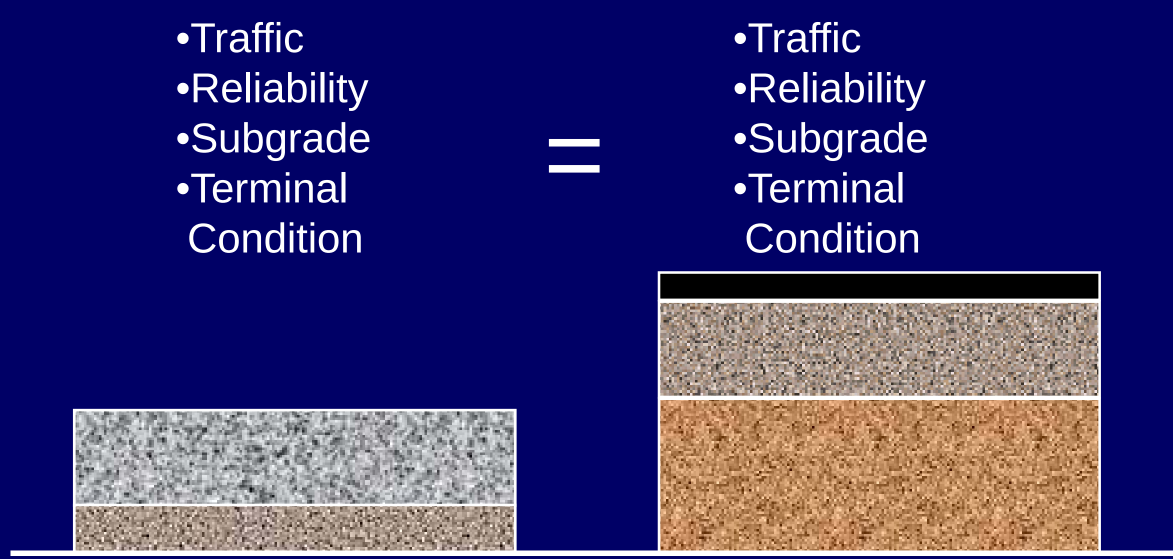
Life-Cycle Cost Analysis

Rehabilitation Selection

Life-Cycle Cost Analysis

What are comparable sections?

- Same structural capacity
- Similar traffic-carrying capacity over the analysis period
- Provide reasonably similar level of service



Life-Cycle Cost Analysis

Analysis Period:

- Normally equal for each alternative
  - Highway: 30-50 years
  - Street: 20-50 years
  - Airport: 30 years
- Include at least one rehabilitation
  - Needed to capture the true economic benefit of each alternate

Life-Cycle Cost Analysis

Discount Rate:

$$DR = \frac{\text{Interest} - \text{Inflation}}{1 + \text{Inflation}}$$

Discount Rate = *Real Interest Rate*

Interest - The return of an investment that raises the future value of a dollar

Inflation - The erosion of a dollar’s value that raises the cost of future expenses

Life-Cycle Cost Analysis

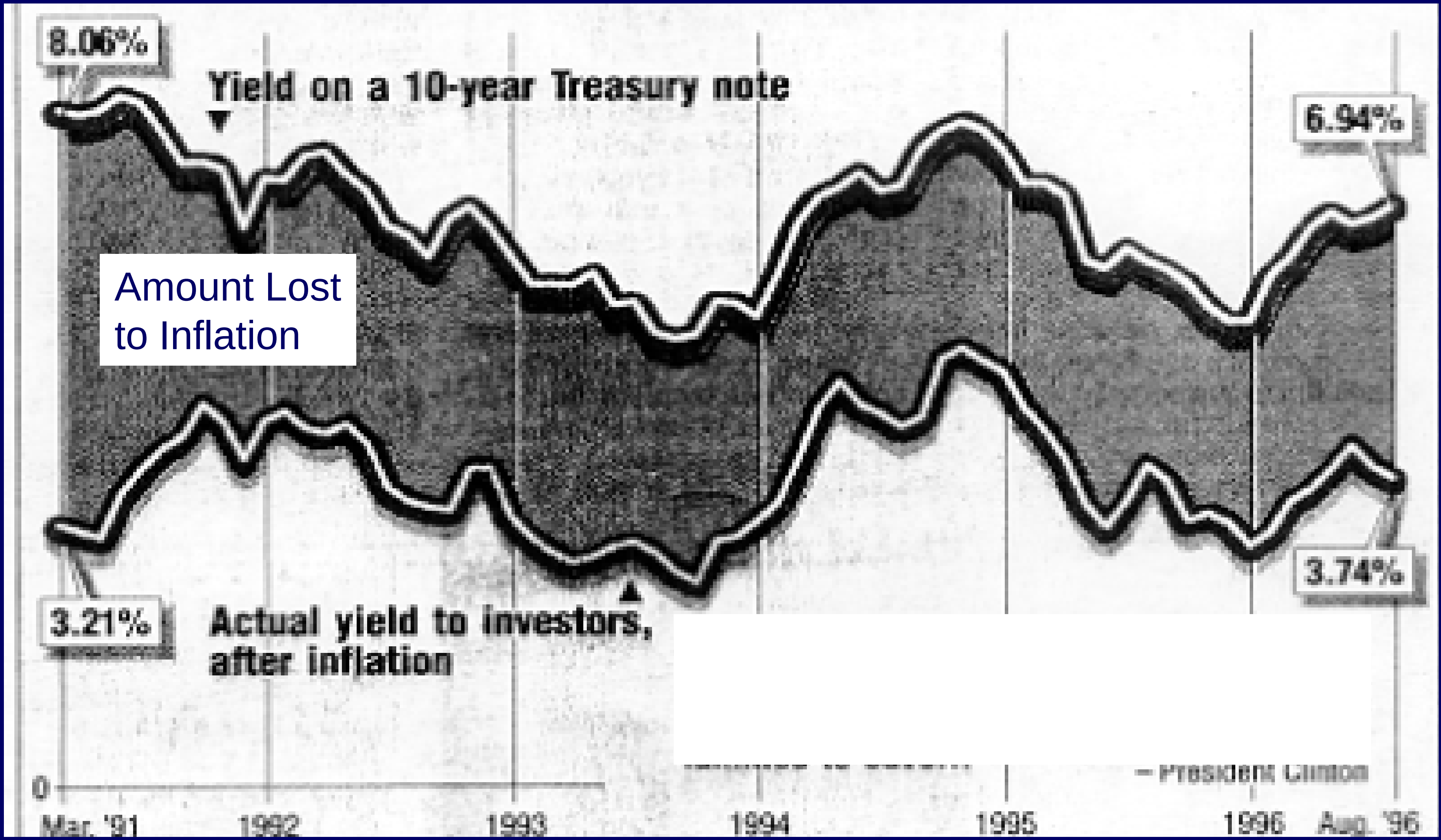
Why use the Discount Rate?

- Difference between interest & inflation is significant
  - Absolute values of interest & inflation are not significant
  - Free market keeps the difference between interest & inflation relatively constant
- Allows user to use constant (today's) dollars in the analysis

Discount Rate

- Discounts future costs
- Reflects LOST OPPORTUNITY
- Does NOT reflect actual agency expenditures

Real Discount Rate



Life-Cycle Cost Analysis

Selecting the Discount Rate:

- The choice is between two alternatives
  - Not with investing in the market
  - Not confounded with social opportunity cost
- Rate should reflect the cost of borrowing money for the agency undertaking the project
- FHWA Recommends OMB Circular a-94

Life-Cycle Cost Analysis

	State Agencies Municipal Bond Rate (%)	Federal Agencies US Govt. Securities Composite (%)	Private Sector Moody's AAA Corp. Bonds (%)
1987-1997*	3.65	4.79	5.42
1977-1986	3.16	4.62	5.57
1967-1976	-0.93	-0.45	0.81
1957-1966	2.81	3.44	3.78
41-yr Avg.	2.21	3.14	3.93
Use Discount Rate:	2.25%	3.00%	4.00%

* 11 year Avg

OMB Circular a-94

Real Discount Rates. A forecast of real interest rates from which the inflation premium has been removed and based on the economic assumptions from the 2017 Budget is presented below. These real rates are to be used for discounting constant-dollar flows, as is often required in cost-effectiveness analysis.

Real Interest Rates on Treasury Notes and Bonds of Specified Maturities (in percent)

3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
0.3	0.6	0.8	1.0	1.2	1.5

Analyses of programs with terms different from those presented above may use a linear interpolation. For example, a four-year project can be evaluated with a rate equal to the average of the three-year and five-year rates. Programs with durations longer than 30 years may use the 30-year interest rate.

Life-Cycle Cost Analysis

Selecting the Discount Rate:

- What was just given is the traditional "business" application of LCCA
  - Assumes that that the price difference between the two alternates is invested at the discount rate.
  - Assumes the the discount rate is the minimum *Rate of Return* on the money in order to do the future work.

Life-Cycle Cost Analysis

Problems with applying traditional “business” LCCA to governmental expenditures:

- Government agencies cannot invest money to gain interest
  - Government money is spent each year
- All government money is invested in depreciating assets (trucks, computers, buildings, labor, roads)
  - Anything not bought this year is costs more next year.
- Political Powers will not allow money to be saved for future maintenance

LCCA Process

- Design equivalent pavement sections
- Establish strategies for analysis period
  - Estimate agency costs
  - Establish activity timing
  - Develop expenditure streams
- Estimate user costs
- Compute NPV
- Analyze results
- Reevaluate strategies

Life-Cycle Cost Analysis

Some basic insights:

- Initial Costs
  - Account for about 65-90% of Life Cycle Cost.
  - Selection of features plays an important role
  - Need to account for added features on the pavement performance.
- Performance must be related to current designs
  - Many PCCP designs now contain a lot of “Belts and Suspenders” but are being compared to the performance to pavements built in the 1960’s and 1970’s.

Life-Cycle Cost Analysis

Some basic insights:

- Timing of Activities.
  - After initial costs and discount rate, the next most important factor.
  - The longer an activity is delayed, the greater it is discounted and the less impact it has on present worth.
    - Most important for early rehabilitation activities.
- Traffic between rehabilitation activities.
  - Most states do not account for traffic increase between activities.
    - Must account for increased traffic or decreased performance period

Life-Cycle Cost Analysis

Some basic insights:

- Late rehabilitation activities can cause very high User's Cost
  - Traffic in later years is often near congestion
- Yearly Maintenance is not significant
  - Typically very small in comparison to initial construction and rehabilitation costs.
- What happens in the past does not matter ?
  - Most never go back, look at what was in the LCCA, and do it.
  - Every rehabilitation is determined by doing a new LCCA.

    Early failures are not penalized.

Life-Cycle Cost Analysis

Deterministic Approach

- Single Value of Inputs

  Initial, future, discount rate, etc.

- Single Value of Output

  Present Value.

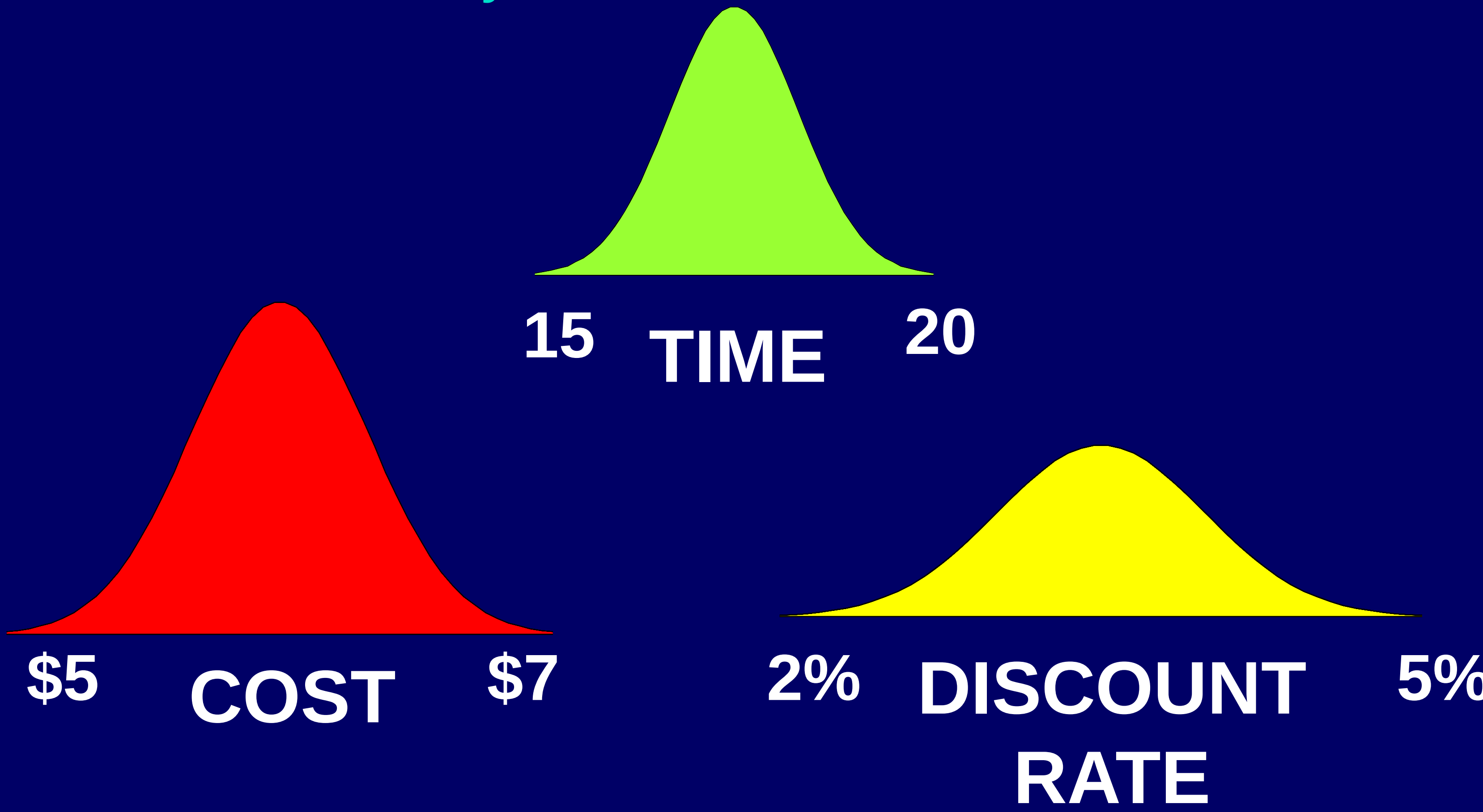
Probabilistic Approach

- Range of Inputs
- Range of Output

  A Probability Distribution of all possible outcomes

Life-Cycle Cost Analysis

Sources of Variability



Probabilistic
Life Cycle Cost Analysis

$$\text{NPV} = \text{Initial Cost} + \text{Future Cost} \times \left[\frac{1}{(1 + i)^n} \right]$$

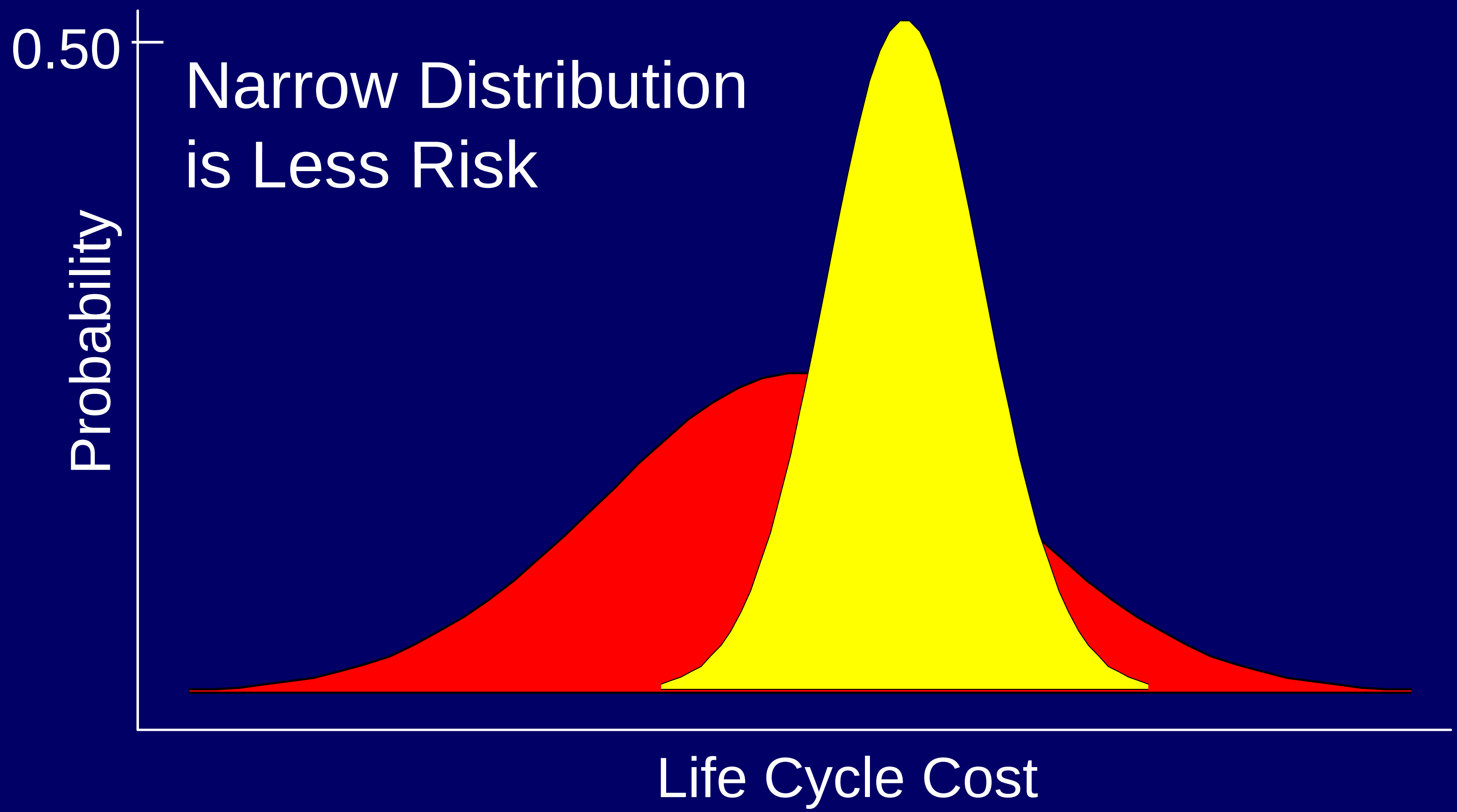
Life-Cycle Cost Analysis

Monte Carlo Simulation

- A numerical procedure for generating a probability forecast of an outcome (life cycle cost) using the probability distributions of the input variables
- Uses sampling as the basis for hundreds or thousands of “what-if” scenarios

Life-Cycle Cost Analysis

Estimating Risk



LCCA Example

Project Information			
Project Description	East Third Street		
Engineer			
Date			
Length (ft)	3300		
Width (ft)	36		
Area (sy)	13200		

Discount Rates			
	Normal	Concrete	Asphalt
Interest Rate	5.00%	5.00%	5.00%
Inflation Rate	3.00%	3.00%	3.00%
Discount Rate	1.94%	1.94%	1.94%

LCCA Example

Project: East Third Street
Run Date: 10/24/2016

Asphalt Pavement Life Cycle Costs

Analysis Period: 40

PROJECT INFO | PCCP COSTS | ASPHALT COSTS | LCCA SUMMARY

Construction Costs

Layer or Activity	Material	Thickness	Unit Weight	Units	Quantity	Unit Price	Cost
Surface	Hot Mix Asphalt	6.00	150.00	Tons	4,455.00	$90.00	$400,950.00
Base	Base Course	10.00	140.00	Tons	6,930.00	$21.31	$147,678.30
Subbase							
Excavation							

Total Initial Cost: $548,628.30
Equivalent Uniform Annual Cos: $19,851.19

Maintenance & Rehabilitation Costs

Activity	Year	Units	Thickness	Quantity	Unit Price	Cost	Base Inflation Costs: Inflated Cost	Base Inflation Costs: Present Worth	Base Inflation Costs: EUAC	Material Specific Inflation Costs: Inflated Cost	Material Specific Inflation Costs: Present Worth	Material Specific Inflation Costs: EUAC
Annual Maintenance	N/A	Lump Sum	—	1.00	$5,000.00	$200,000.00	$377,006.30	$134,160.40	$4,854.37	$377,006.30	$134,160.40	$4,854.37
Rotomilling	15	Square Yards	2	13,200.00	$2.00	$26,400.00	$41,130.34	$19,784.40	$715.87	$41,130.34	$19,784.40	$715.87
Asphalt Overlay	15	Tons	2	1,485.00	$90.00	$133,650.00	$208,222.35	$100,158.51	$3,624.07	$208,222.35	$100,158.51	$3,624.07
Rotomilling	30	Square Yards	2	13,200.00	$2.00	$26,400.00	$64,079.73	$14,826.60	$536.48	$64,079.73	$14,826.60	$536.48
Asphalt Overlay	30	Tons	2	1,485.00	$90.00	$133,650.00	$324,403.63	$75,059.68	$2,715.91	$324,403.63	$75,059.68	$2,715.91
					Total	$520,100.00	$1,014,842.34	$343,989.60	$12,446.69	$1,014,842.34	$343,989.60	$12,446.69

LCCA Example

Project: East Third Street
Run Date: 10/24/2016

Concrete Pavement Life Cycle Costs

Longitudinal Joint Spacing	12
Transverse Joint Spacing	12
Analysis Period	40

PROJECT INFO | PCCP COSTS | ASPHALT COSTS | LCCA SUMMARY

Construction Costs

Layer or Activity	Material	Thickness	Unit Weight	Units	Quantity	Unit Price	Cost
Surface	Portland Cement Concrete Pavement	8.00		Square Yards	13,200.00	$40.00	$528,000.00
Base	Base Course	4.00	140.00	Tons	2,772.00	$21.31	$59,071.32
Sub Base							
Excavation							
						Total Initial Cost	$587,071.32
						Equivalent Uniform Annual Cost	$21,242.19

Maintenance & Rehabilitation Costs

Activity	Year	Units	Quantity	Unit Price	Cost	Base Inflation Costs			Material Specific Inflation Costs		
						Inflated Cost	Present Worth	EUAC	Inflated Cost	Present Worth	EUAC
Annual Maintenance	N/A	Lump Sum	1.00	$1,000.00	$40,000.00	$75,401.26	$26,832.08	$970.87	$75,401.26	$26,832.08	$970.87
Diamond Grinding	25	Square Yards	14,080.00	$6.00	$84,480.00	$176,882.36	$52,233.85	$1,889.99	$176,882.36	$52,233.85	$1,889.99
Full Depth Repairs	25	Square Yards	132.00	$250.00	$33,000.00	$69,094.67	$20,403.85	$738.28	$69,094.67	$20,403.85	$738.28
				Total	$157,480.00	$321,378.29	$99,469.78	$3,599.15	$321,378.29	$99,469.78	$3,599.15

LCCA Example

Project Information

Project Description	East Third Street		
Engineer			
Date	10/24/2016		
Length (ft)	3300		
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Area (sy)	13200		
	Interest, Inflation, and Discount Rates		
	Normal	Concrete	Asphalt
Interest Rate	5.00%	5.00%	5.00%
Inflation Rate	3.00%	3.00%	3.00%
Discount Rate	1.94%	1.94%	1.94%

Life Cycle Costs

	Base Costs				Costs with Normal Inflation			
	Initial Cost	M&R Costs	Total Cost	EUAC	Inflated M&R	Total Inflated Cost	Present Worth	EUAC
Concrete Pavement	$587,071.32	$157,480.00	$744,551.32	$26,940.34	$321,378.29	$908,449.61	$686,541.10	$24,841.34
Asphalt Pavement	$548,628.30	$520,100.00	$1,068,728.30	$38,670.14	$1,014,842.34	$1,563,470.64	$892,617.90	$32,297.88
Difference	**$38,443.02**	**-$362,620.00**	**-$324,176.98**	**-$11,729.80**	**-$693,464.05**	**-$655,021.03**	**-$206,076.80**	**-$7,456.54**

PROJECT INFO | PCCP COSTS | ASPHALT COSTS | LCCA SUMMARY | GRAPHS

QUESTIONS ?