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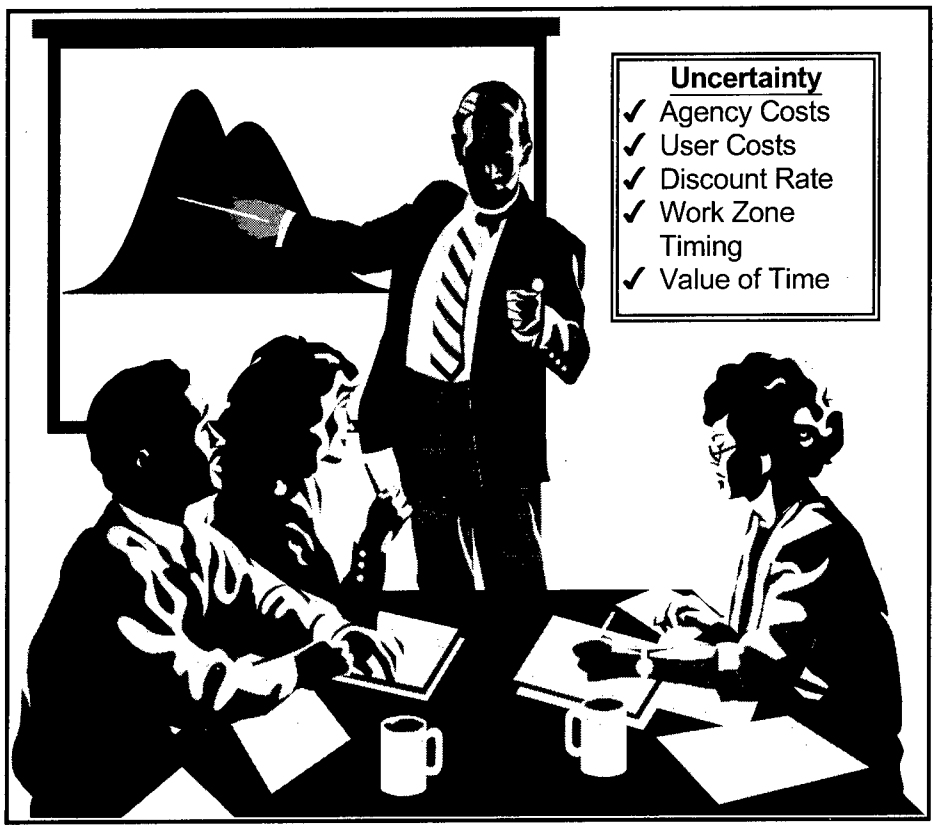
Executive Session

Life-Cycle Cost Analysis in Pavement Design

Demonstration Project No. 115



Foreword

This two-day workshop was developed by FHWA staff to facilitate the implementation of life-cycle cost analysis (LCCA) in pavement design. This workshop will be of interest to State highway agency personnel responsible for conducting and/or reviewing pavement design LCCAs.

The FHWA Office of Engineering, Pavement Division, in cooperation with the Office of Technology Applications, offers LCCA technical support through Demonstration Project No. 115 *Probabilistic LCCA in Pavement Design* (DP-115). This workshop is available free of charge, upon request, to State highway agencies.

Henry H. Rentz, Director
Office of Engineering

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Executive Summary

This free two-day workshop provides technical guidance and recommendations in conducting Life-Cycle Cost Analysis (LCCA) in pavement design. The course material, developed by Federal Highway Administration staff, provides participant's exposure to good practice in conducting LCCA. The workshop employs the use of multimedia presentations and class exercises to reinforce key principals and stimulate participation. The workshop was developed specifically for State highway agency personnel responsible for conducting or reviewing pavement design life cycle cost analysis. Class size is generally limited to 30 to 40 participants. All participants are strongly encouraged to bring calculators. Each participant is provided a Participant's Notebook that includes all presentation material and a copy of FHWA's Interim Technical Bulletin on LCCA in Pavement Design.

Purpose of LCCA

LCCA is an analysis technique that builds on the well-founded principals of economic analysis to evaluate the long-term economic efficiency between competing alternative investment options. It incorporates initial and discounted future agency and user costs over the life of alternative investments.

LCCA Requirements

The National Highway System (NHS) Designation Act of 1995 specifically required States to conduct life-cycle cost analysis on NHS projects costing $25 million or more. Implementing guidance was provided through memorandum to FHWA field offices on April 19, 1996. The implementing guidance did not recommend specific LCCA procedures, but rather specified the use of good practice.

The FHWA position on LCCA is defined in its Final Policy Statement on LCCA published in the September 18, 1996, *Federal Register*. FHWA Policy on LCCA is that it is a decision support tool, and the results of LCCA are not decisions in an of themselves. The logical analytical evaluation framework that life-cycle cost analyses fosters is as important as the LCCA results themselves. As a result, FHWA has always encouraged the use of LCCA in analyzing all major investment decisions where such analyses are likely to increase the efficiency and effectiveness of investment decisions.

The Transportation Equity Act for the 21st Century (TEA-21) has since removed the requirement for SHA's to conduct LCCA on high-cost NHS useable project segments. However, the congressional interest in LCCA is continued in the new requirement that the Secretary of Transportation develop recommended LCCA procedures for NHS projects.

Workshop Overview

The first day of the workshop focuses on traditional LCCA practice. It begins with background information supporting the need for LCCA and introduces the essential principles of the process. The workshop discusses the broad fundamental principals involved in a typical LCCA and presents widely accepted procedures used in setting up

and conducting the analysis. It also discusses input parameters and provides recommendations on acceptable ranges. It then provides a detailed, rational capacity-based approach for determining work zone user delay, vehicle operating, and crash costs associated with alternative pavement design strategies. Once this foundation is laid, the workshop moves on to several class exercises designed to stimulate participation and reinforce LCCA computational steps.

The second day of the workshop introduces a *Risk Analysis* "Probabilistic" approach to LCCA. The risk analysis approach utilizes a powerful analytical technique, known generally as the Monte Carlo Simulation, to quantify the uncertainty associated with LCCA inputs. The day begins with a refresher session on basic statistical concepts followed by an introduction to risk analysis. The fundamentals are followed by a demonstration of risk analysis software and computer simulations which is followed by a session applying the risk analysis approach to a pavement design LCCA example. The workshop concludes with a discussion of the benefits and limitations of both the traditional and risk analysis based LCCA, and a discussion of steps to implement improvements in current SHA LCCA procedures.

LCCA Procedures

LCCA should be conducted as early in the project development cycle as possible. For pavement design, the appropriate time for conducting the analysis is during project design stage. The level of detail in the analysis should be consistent with the level of investment. LCCA need only consider differential cost among alternatives. Therefore, costs common to all alternatives cancel out, are generally so noted in the text, and are not included in LCCA calculations. Inclusion of all potential LCCA factors in every analysis is counterproductive; however, all LCCA factors and assumptions should be addressed, even if only limited to an explanation of the rationale for not including eliminated factors in detail. Sunk costs, which are irrelevant to the decision at hand, should not be included.

LCCA Steps

1. Establish Strategies
2. Establish Activity Timing
3. Estimate Agency Costs
4. Estimate User Costs
5. Develop Expenditure Streams
6. Compute Net Present Value
7. Analyze Results
8. Reevaluate Strategies

Principles of Good Practice

The LCCA analysis period, or the time horizon over which alternatives are evaluated, should be sufficient to reflect long-term cost differences between alternatives. While FHWA's LCCA Policy Statement recommends an analysis period of at least 35 years for all pavement projects, including new or total reconstruction projects as well as rehabilitation, restoration, and resurfacing projects, an analysis period range of 30 to 40 years is not unreasonable.

Net Present Value (NPV) is the economic efficiency indicator of choice. The Uniform Equivalent Annual Cost (UEAC) indicator is also acceptable, but should be derived from NPV. Computation of Benefit/Cost (B/C) ratios are generally not recommended because of the difficulty in sorting out cost and benefits.

Future costs and benefits should be estimated in constant dollars and discounted to the present using a real discount rate. Although nominal dollars can be used with nominal

discount rates, use of real/constant dollars and real discount rates eliminates the need to estimate and include an inflation premium. In any given LCCA, real/constant or nominal dollars must not be mixed (i.e., all costs must be in real dollars or all costs must be in nominal dollars). Further, the discount rate selected must be consistent with the dollar type used (i.e., use real cost and real discount rates or nominal cost and nominal rates). The workshop recommends a discount rate range of 3 to 5 percent which is consistent with values reported in Appendix A of the U.S. Office of Management and Budget's (OMB) Circular A-94.

Performance periods for individual pavement designs and rehabilitation strategies may have significant impact on analysis results. For example, longer performance periods for individual pavement designs require fewer rehabilitation projects and associated agency and work zone user costs. While most analyses include traditional agency costs, some do not fully account for the SHA engineering and construction management overhead, especially on future rehabilitations. This can be a serious oversight on short-lived rehabilitations, particularly in an era of SHA downsizing.

Routine, reactive type annual maintenance costs have only a marginal effect on NPV. These costs are usually hard to obtain, generally very small in comparison to initial construction and rehabilitation costs, and differentials between competing pavement strategies are usually very small, particularly when discounted over 30-to 40-year analysis periods. Salvage value should be based on the remaining life of an alternative at the end of the analysis period as a prorated share of the last rehabilitation cost.

User Costs

User costs are the delay, vehicle operating, and crash costs incurred by the users of a facility and should be included in the LCCA. Vehicle delay and crash costs are unlikely to vary among alternative pavement designs between periods of construction, maintenance, and rehabilitation operations. Although vehicle operating costs (VOC) may vary during periods of normal operations for different pavement design strategies, existing data suggests the magnitude of such cost differentials may be small under the prevailing pavement conditions currently maintained on the NHS. This workshop therefore focuses strictly on work zone user cost differences between alternatives.

User costs are heavily influences by current and future roadway operating characteristics. They are directly related to the current and future traffic demand, facility capacity, and the timing, duration, and frequency of work zone-induced capacity restrictions, as well as any circuitous mileage caused by detours. Directional hourly traffic demand forecasts for the analysis year in question are essential for determining work zone user costs.

As long as work zone capacity exceeds vehicle demand on the facility, user costs are normally manageable and represent more of an inconvenience than a serious cost of the traveling public. When vehicle demand on the facility exceeds work zone capacity, the facility operates under forced-flow conditions and user costs can be immense. Under this latter scenario, queuing costs can account for more than 90 percent of work zone user costs with most of the costs associated with delay time of crawling through long, slow-moving queues.

Different vehicle classes have different operating characteristics and associated operating costs, and as a result, user costs should be analyzed for at least three broad vehicle classes: Passenger, Single-Unit Trucks, and Combination Trucks.

User delay cost rates are probably the most contentious of all user cost inputs. This workshop recommends the following ranges for the value of time (August 1996) shown in the table below. It is important to note that passenger vehicles, particularly pickup trucks, represent both commercial and noncommercial use.

Recommended Values of Time (Aug. 1996).

Vehicle Class	Vehicle Hour, $
Passenger Vehicle	$10 to 13
Single-Unit Truck	$17 to 20
Combination Trucks	$21 to 24

Dollar value ranges associated with fatal and nonfatal injury highway crashes are discussed in the workshop. Since user costs may dominate the analysis it is recommended *not* to combine agency and user costs. If user costs dominate the analysis it may be indicate of a capacity problem requiring the development of a new alternative.

Risk Analysis Approach

LCCA, as a minimum, should include a sensitivity analysis to address the variability of analyses input assumptions and estimates. Traditionally, sensitivity analysis evaluates a best and worst case scenario. The ultimate extension of a sensitivity analysis is a probabilistic approach, which allows all significant inputs to vary simultaneously.

This workshop advocates the use of a Risk Analysis "probabilistic" approach to LCCA that incorporates the variation of inputs into the final results. Risk Analysis is a technique that exposes areas of uncertainty, typically hidden in the more traditional deterministic approach to LCCA, and allows the decision maker to weigh the probability of the outcome actually occurring. The Risk Analysis approach combines probability descriptions of uncertain variables and a computer simulation technique, known generally as the Monte Carlo simulation, to characterize uncertainty. Monte Carlo simulations draw random samples from the individual inputs, consistent with their defined distributions to calculate hundreds, even thousands, of what if outcomes. With enough samples, the simulation can define an overall composite NPV probability distribution for each alternative – one that shows the entire range of possible outcomes and the likelihood that any particular outcome will actually occur. Given the power and sophistication of today's computers and software, the FHWA strongly endorses the use of techniques, such as the Monte Carlo simulation, for incorporating variability associated with LCCA inputs into the decision making process.

Two Day Agenda

	Time	Title
Day 1	08:00 am	Welcome
	08:15 am	Workshop Overview
	08:30 am	Background
	09:00 am	LCCA Process Overview
	09:30 am	*Break*
	09:45 am	Components & Issues
	10:45 am	*Break*
	11:00 am	Class Exercise No. 1 or 2
	12:00 am	*Lunch*
	01:00 pm	Introduction to Work Zone User Costs
	01:30 pm	Work Zone User Costs: Calculation Steps
	02:45 pm	*Break*
	03:00 pm	Class Exercise No. 3
	04:00 pm	Class Exercise No. 4
	05:00 pm	*Close for Day*
Day 2	08:00 am	Basic Statistics
	09:00 am	Risk Analysis Approach
	10:00 am	*Break*
	10:15 am	Software Demonstration
	12:00 pm	*Lunch*
	01:00 pm	Class Exercise Revisited
	02:00 pm	Presentation Techniques
	02:30 pm	*Break*
	02:45 pm	Benefits & Implementation
	03:30 pm	Workshop Summary
	04:00 pm	Question & Answers – Workshop Evaluations
	05:00 pm	*Closeout*

Note: This workshop can also be presented in a ½ day, full day, ½ day format.

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Life Cycle Cost Analysis in Pavement Design

- In Search of Better Investment Decisions -

Executive Session

Federal Highway Administration
Demonstration Project 115

2

LCCA Driving Forces

- ISTEA (91)
- Executive Order 12893 (94)
- NHS Designation Act (95)
- TEA 21 (98)

3

ISTEA (1991)

Sections: 1024 & 1025

Factors to be *considered*...

the use of life-cycle costs in the design and engineering of bridges, tunnels, or pavements.

4

Executive Order 12893 (94)

"Principles for Federal Infrastructure Investments"

- Directed at Federal Agencies
- Grant Programs
- FHWA Policy Statement

5

NHS Designation Act (95)

Section 303, "Quality Improvement" …

… required States to conduct LCCA of each NHS high cost ($25M or more) useable project segment.

6

NHS LCCA Implementation

- NHS - FHWA memo (4/96)
- LCCA Policy Statement (9/96)

7

NHS - FHWA memo (4/96)

- Federal-aid eligibility contingent on LCCA for $25 million + NHS projects
- Defines usable project segment
- LCCA procedure not prescribed
- Focus on "good" practice

8

LCCA Policy Statement (9/96)

FHWA Philosophy - LCCA

- Is a decision support tool
- Results are *not* decisions
- Logical evaluation process is as valuable as the results

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Policy Statement Cont'd

- LCCA important consideration in all highway investment decisions
- Level of detail commensurate with level of investment
- Long analysis periods
  - Pavements - min. 35 years
  - Bridges - min. 75 years

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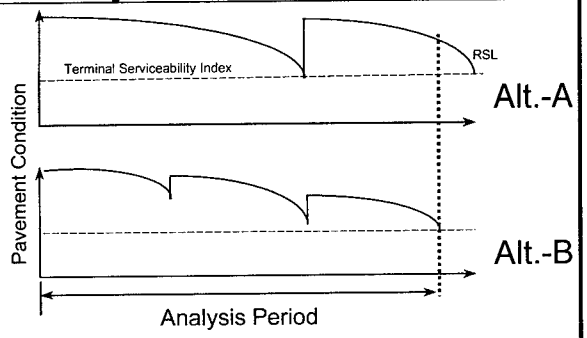
Analysis Period



Include at least one rehabilitation activity.

11

Policy Statement Cont...

- All appropriate agency and user costs should be included
- All appropriate future costs should be discounted to their *net present value (NPV)*

12

But remember...

Alternative selection has TWO components:

❶ Engineering Analysis (development of strategies)

❷ Economic Analysis (LCCA)

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TEA 21 (98)

- LCCA no longer mandated
- Adds Users Costs to LCCA def.
- Directs DOT to develop LCCA procedures based on principals contained in Exec. Order 12893
- Transportation Research Program addresses analysis period, discount rates, user costs, ...

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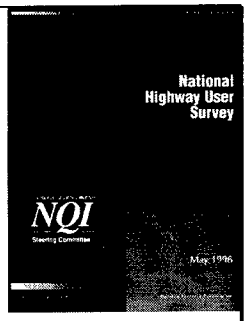
Traveling Public Expectations



National Quality Initiative (NQI):
National Highway User Survey
May 1996

Assessment of customer satisfaction

"It is clear that the top priority for improving the nation's highways is to focus on the quality of the roadway surface. This is the factor that will most significantly increase public satisfaction with the highway system."
[NQI Survey, page 14]

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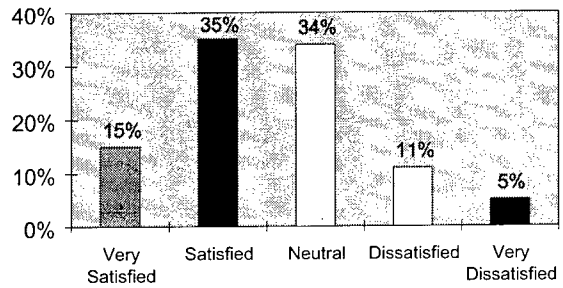
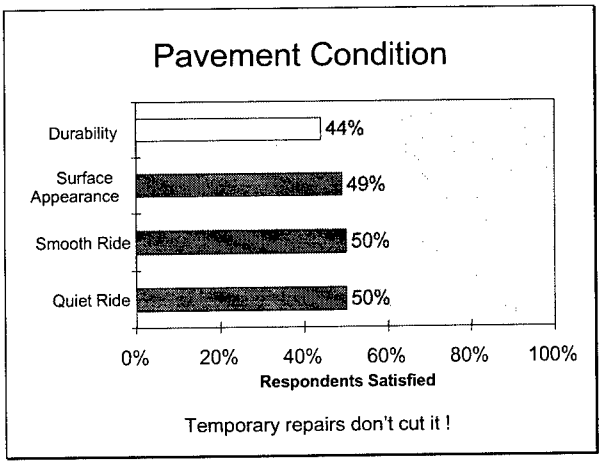
Overall Satisfaction with Highway System

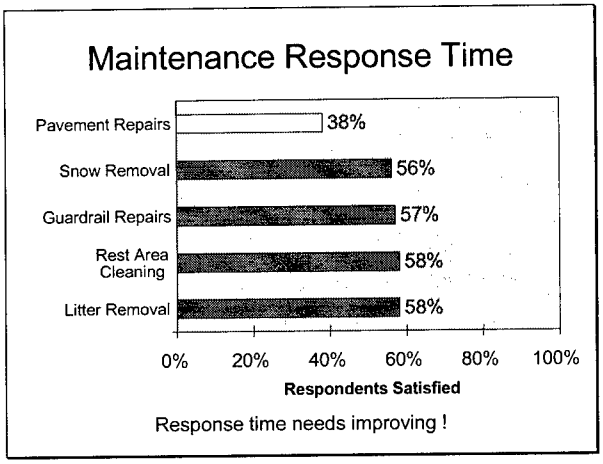


Opportunity to improve public satisfaction.

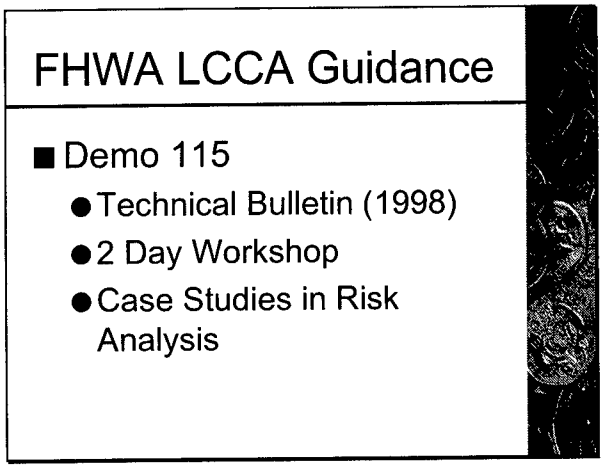
16


Pavement Condition
Durability
44%
Surface Appearance
49%
Smooth Ride
50%
Quiet Ride
50%
0%
20%
40%
60%
80%
100%
Respondents Satisfied
Temporary repairs don't cut it !

17


Maintenance Response Time
Pavement Repairs
38%
Snow Removal
56%
Guardrail Repairs
57%
Rest Area Cleaning
58%
Litter Removal
58%
0%
20%
40%
60%
80%
100%
Respondents Satisfied
Response time needs improving !

18


FHWA LCCA Guidance
Demo 115
Technical Bulletin (1998)
2 Day Workshop
Case Studies in Risk Analysis

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Technical Bulletin

- State of the practice
  - Traditional approach
- User costs (work zone)
  - VOC
  - Delay
- Introduce risk analysis (probabilistic approach)

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Workshop Training

- Length ~ 2 Days
- Presentations
- Class Exercises
- Participant's Manual
- Technical Bulletin

LCCA Process
Components & Issues
User Costs
Risk Analysis

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Workshop Outline

- Background
- Process Overview
- Components and Issues
- User Costs
- Class Exercises
- Basic Statistics
- Probabilistic Approach
- Benefits and Implementation

22

LCCA Process

1. Establish strategies for analysis period
2. Establish activity timing
3. Estimate agency costs
4. Estimate user costs
5. Develop expenditure streams
6. Compute NPV
7. Analyze results
8. Reevaluate strategies

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Recommendations

Use ...

- Long Analysis Periods
- Constant Dollars
- Real Discount Rates (3-5%)
- NPV

24

Recommendations

Agency Costs ...

- Include Overhead
- Ignore Sunk Cost
- Maintenance has Little NPV
- Salvage Value has Little NPV

25

Recommendations

Value of Time ...

Passenger Vehicle	$10 - $13
Single Unit Truck	$17 - $20
Combo Truck	$21 - $24

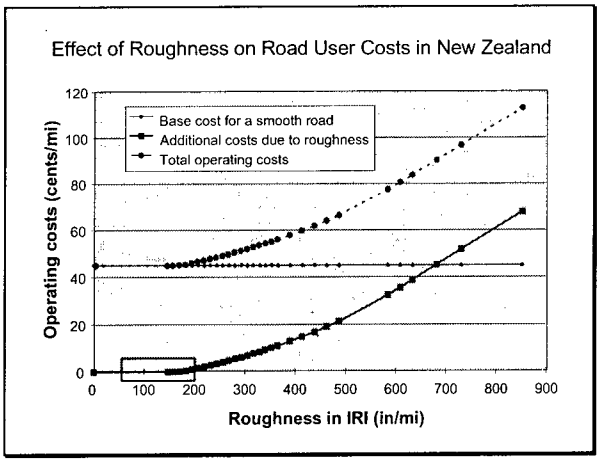
26

Observations

User Costs ...

- Traffic Grows
- Queuing Cost Dominate
- Hourly Distributions Key
- $ Value of Time Major Influence
- Circuitry Can be Major
- Normal VOC between alternatives negligible

27



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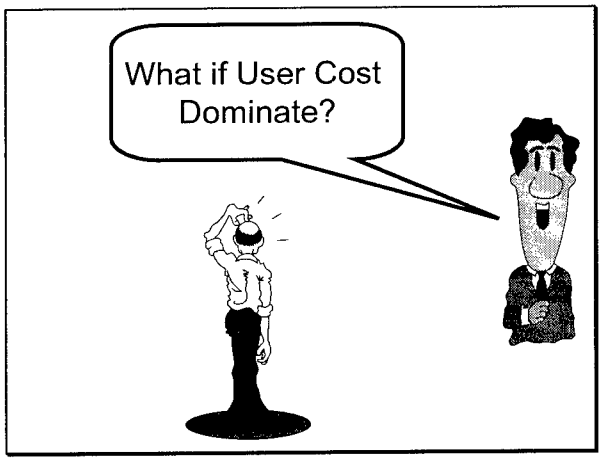

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Example

- 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

30

Thou shall not use a strategy that cannot actually occur.

31

LCCA Process

1. Establish strategies
2. Establish activity timing
3. Estimate agency costs
4. Estimate user costs
5. Develop expenditure streams
6. Compute NPV
7. Analyze results
8. Reevaluate strategies

Improved Strategy

Reevaluate the Strategy!

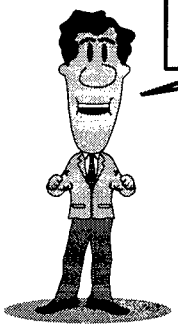
32

Deterministic Approach

- Estimate
- Best guess
- Engineering judgment

33

In the *Deterministic* approach we don't account for the variability of the inputs!



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Deterministic Approach

$ 30.1 M $ 26 M

NPV = Initial Cost +

Future Cost x $ 9 M $\left[\frac{1}{(1+i)^n}\right]$

4% 20 yrs

35

Initial Cost

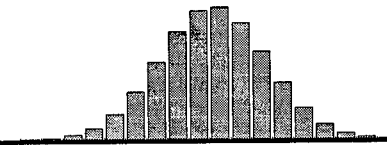
Minimum	Average	Maximum
20	26	34

Range

36

Initial Cost

Minimum	Average	Maximum
20	26	34



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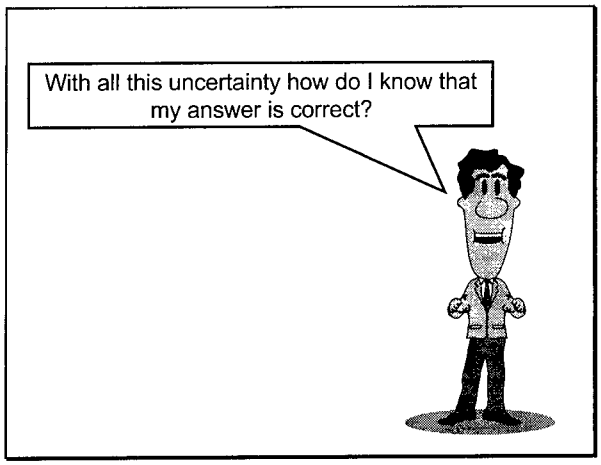

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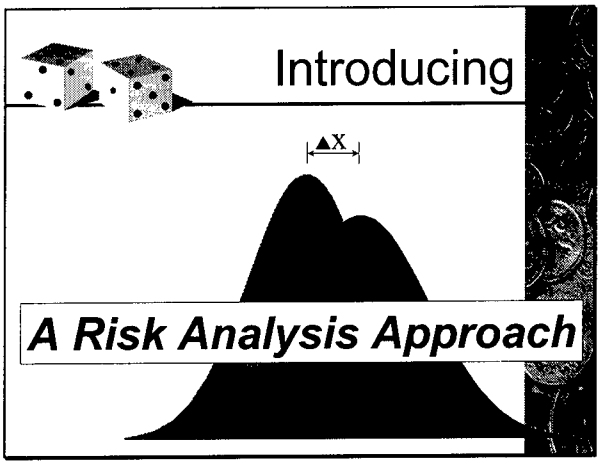

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Risk Analysis ...

- Exposes areas of uncertainty
- Provides an opportunity to take mitigating action to reduce risk exposure
- Provides those vested with appropriate authority the opportunity to make decisions about risk taking

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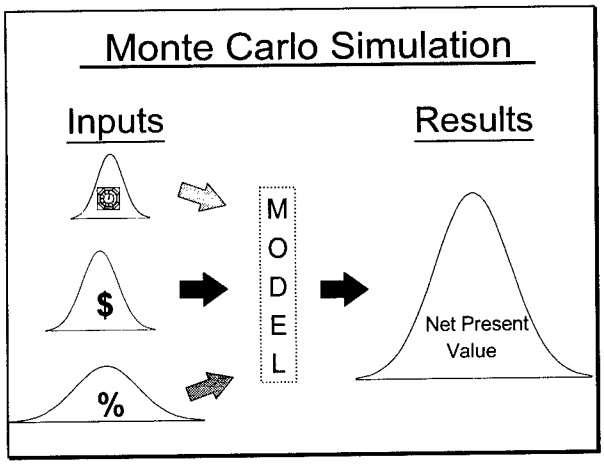
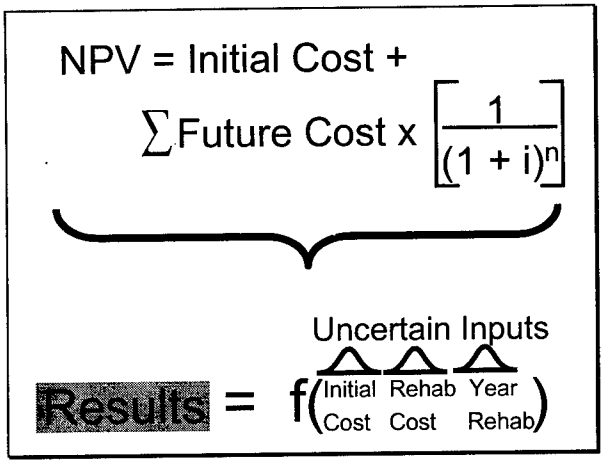
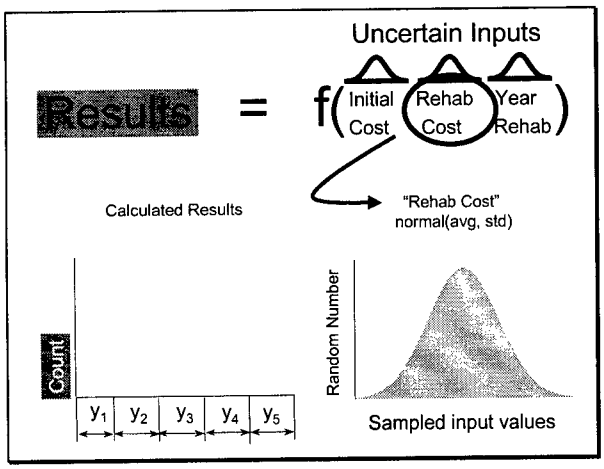

Monte Carlo Simulation
Inputs
Results
$
%
M
O
D
E
L
Net Present
Value

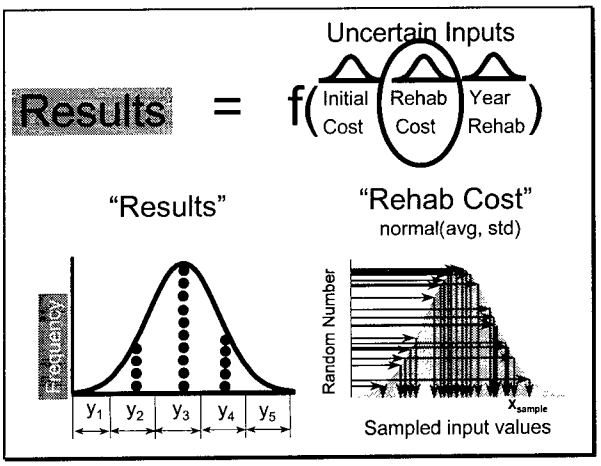
41


NPV = Initial Cost +
∑Future Cost x
1
(1 + i)n
Uncertain Inputs
Results = f(Initial Cost, Rehab Cost, Year Rehab)

42


Uncertain Inputs
Results = f(Initial Cost, Rehab Cost, Year Rehab)
Calculated Results
"Rehab Cost"
normal(avg, std)
Count
Random Number
y1 y2 y3 y4 y5
Sampled input values

43



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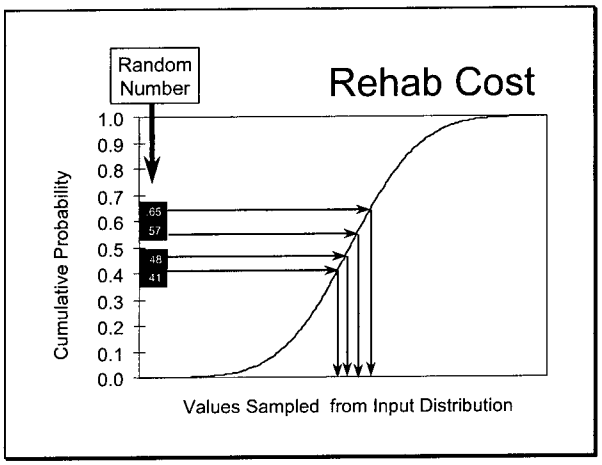

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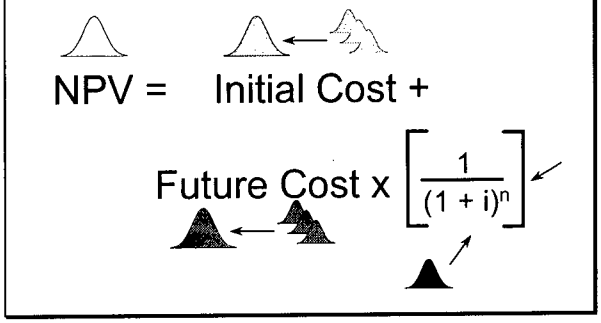
Combine variability of inputs to generate probability distribution for results



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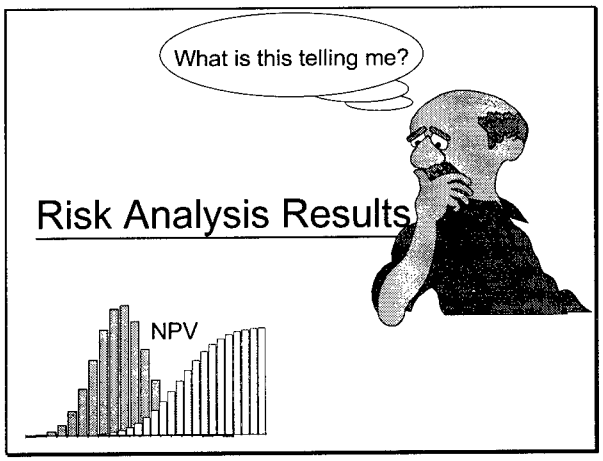
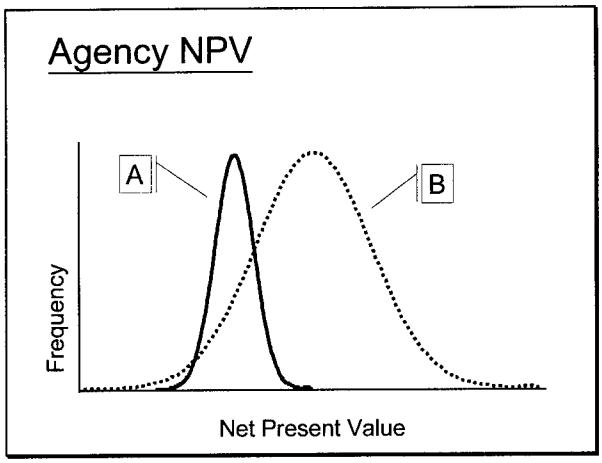
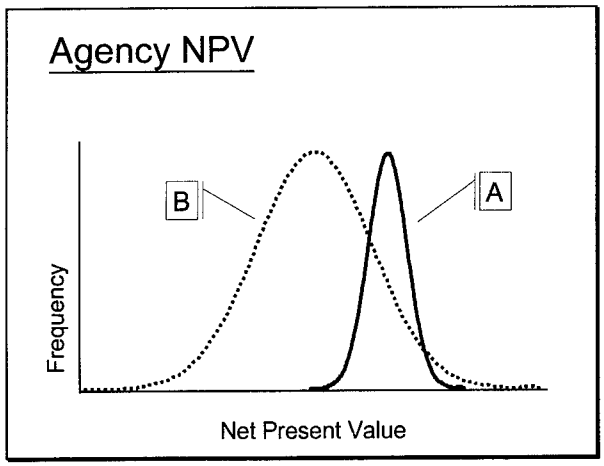

What is this telling me?
Risk Analysis Results
NPV

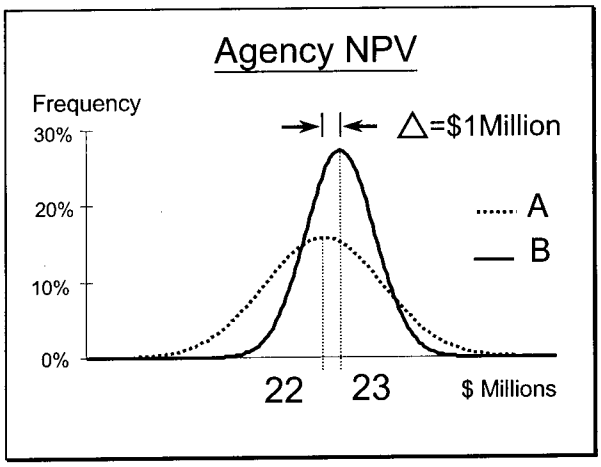
47


Agency NPV
A
B
Frequency
Net Present Value

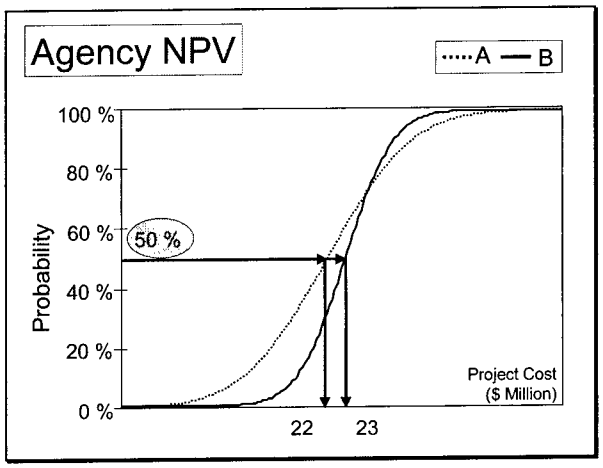
48


Agency NPV
B
A
Frequency
Net Present Value

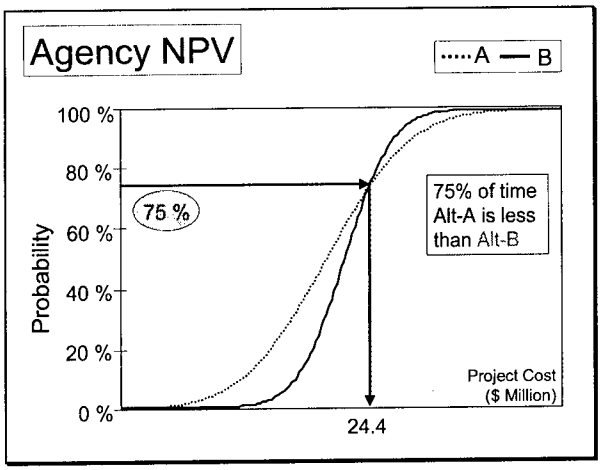
49


Agency NPV
Frequency
30%
20%
10%
0%
→| |← △=$1Million
..... A
— B
22
23
$ Millions

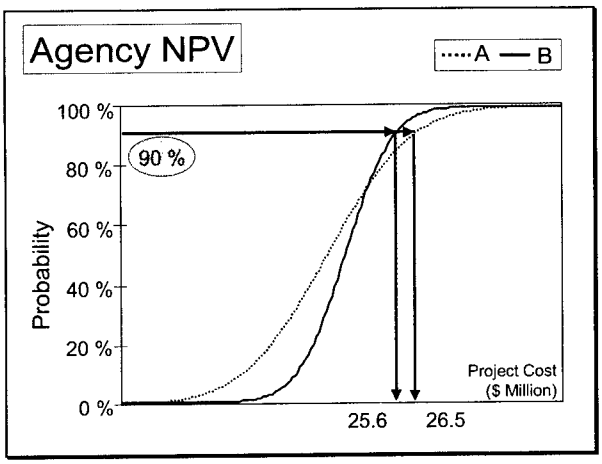
50


Agency NPV
.....A — B
100 %
80 %
60 %
40 %
20 %
0 %
Probability
50 %
Project Cost
($ Million)
22
23

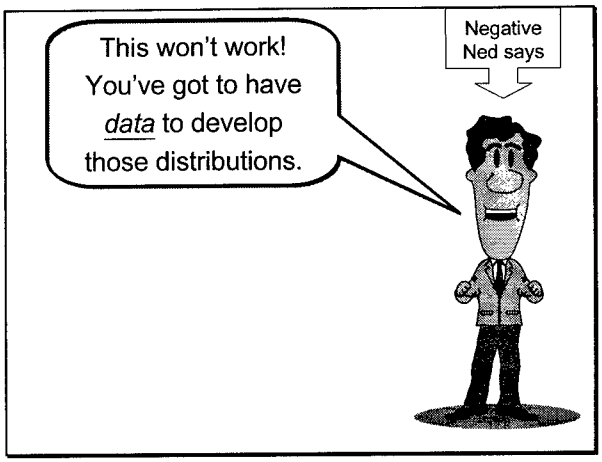
51


Agency NPV
.....A — B
100 %
80 %
60 %
40 %
20 %
0 %
Probability
75 %
75% of time
Alt-A is less
than Alt-B
Project Cost
($ Million)
24.4

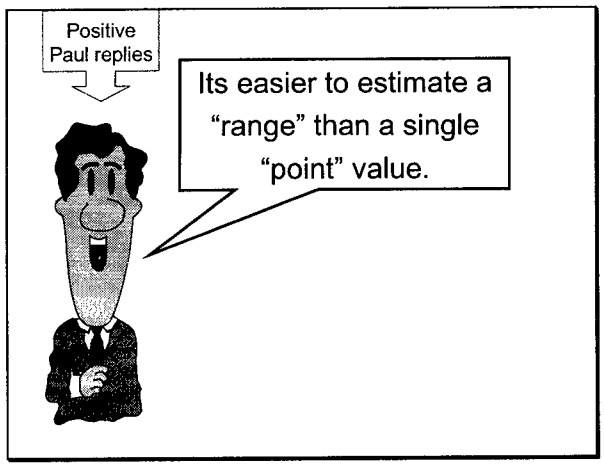
52


Agency NPV
·····A — B
100 %
80 %
60 %
40 %
20 %
0 %
Probability
90 %
Project Cost
($ Million)
25.6
26.5

53


This won't work! You've got to have *data* to develop those distributions.
Negative Ned says

54


Positive Paul replies
Its easier to estimate a "range" than a single "point" value.

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Advantages

- More Informed Decisions
  - Evaluate all possible outcomes
  - Quantify risk
  - Determine significance of difference between alternatives
  - Examine influence of underlying variables on final results
- Applications beyond pavements

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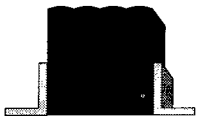
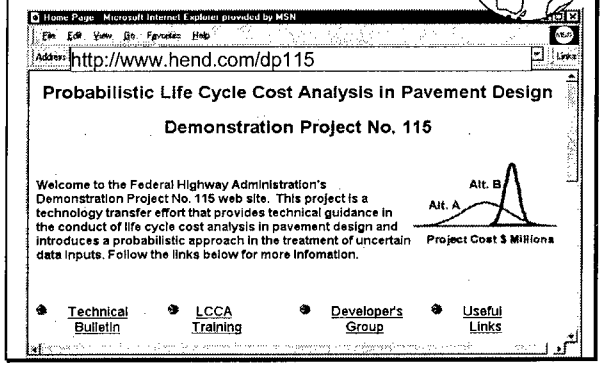
Additional Resources



57

DP-115 Web Site



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Case Studies in Risk Analysis

- Case studies
  - Probabilistic LCCA models
  - Other Applications
- Participants
  - 10 State highway agencies
  - American Concrete Pavement Association
  - National Asphalt Pavement Association

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Thank you...

...any questions?

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End Session