U. S. Department
of Transportation
**Federal Highway
Administration**

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August 1998

Life-Cycle Cost Analysis in Pavement Design Participant's Notebook

Demonstration Project No. 115

Foreword

This participant's notebook was developed by FHWA staff to compliment a 2-day workshop on life cycle cost analysis 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). DP-115 is a free 2-day workshop that demonstrates best practices in performing life-cycle cost analyses for pavement design. This workshop is available, upon request, to State highway agencies.

Henry H. Rentz, Director
Office of Engineering

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Life-Cycle Cost Analysis in Pavement Design
Participant's Notebook

Demonstration Project No. 115

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Participant Evaluation Form

Course Title: Life Cycle Cost Analysis in Pav't Design **Dates:** _____

Instructor(s): _____ **Location:** _____

Please help us improve the training by evaluating the training course and workshop in which you participated. Your input is appreciated and needed. You may use the back of this form for additional comments.

Please rate this workshop in the following areas:	**Excellent**	**Very Good**	**Good**	**Fair**	**Poor**
▪ Adequate coverage of subject matter	5	4	3	2	1
▪ Applicable to your current job	5	4	3	2	1
▪ Meeting room location	5	4	3	2	1
▪ Course materials	5	4	3	2	1
▪ Knowledge gained from this workshop	5	4	3	2	1
▪ This workshop overall	5	4	3	2	1
Please rate the instructor(s) in the following areas:					
▪ Organization	5	4	3	2	1
▪ Presentation	5	4	3	2	1
▪ Clarity of instruction	5	4	3	2	1
▪ Encouraging participation	5	4	3	2	1

Would you recommend this training to other department employees? _____ **Yes** _____ **No**

- Comments: (Please note exceptional points and/or clarify fair or poor ratings below)

_____

_____

_____

_____

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_____

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*

Three Day Agenda

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

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Workshop Overview

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Project Team

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Arizona DOT
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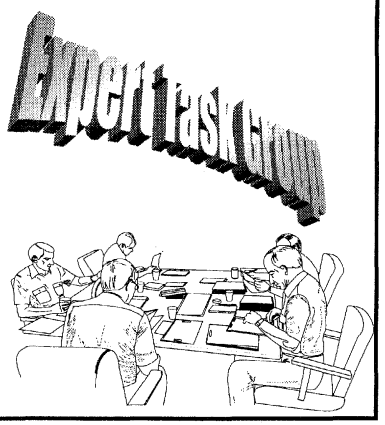
Montana DOT
Dick Clark

ACPA
James Mack

NAPA
Ken Hansen

University Washington
Joe Mahoney



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DP-115 Phases

1. Traditional approach and *Introduce* probabilistic concepts
2. SHA Case Studies
3. Application of Probabilistic Approach

5

Phase I Objective

- Provide training and practice on traditional LCCA
- Introduce probabilistic concepts

6

Workshop Outline

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

7

Major Focus ...

- LCCA process overview
- Components and issues
- User cost procedure
- *Introduce* Probabilistic approach

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End Session

1

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Session Overview

- Definitions
- Levels of Application
- Driving Forces
- Implementing Guidance
- National Pavement Design Review

3

Definitions

- Life Cycle Cost Analysis
- Agency Cost
- User Cost
- Deterministic Approach
- Risk Analysis Approach

4

LCCA Defined (NHS)

"A process for evaluating the total economic worth of a useable project segment by analyzing initial costs and discounted future costs, such as maintenance, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment. "

5

Useable Project Segment

A portion of a highway that when completed could be opened to traffic independent of some larger overall project.

6

TEA 21 (98) LCCA Defined

Life-cycle cost analysis is a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user costs, reconstruction, rehabilitation, restoration, and resurfacing costs, over the life of the project segment.

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Agency Costs

- Design and Engineering
- Initial Construction
- Maintenance of Traffic
- Maintenance
- Rehabilitation

8

User Costs

Costs incurred by users of a highway facility including excess costs to those who cannot use the facility because of agency or self-imposed detour requirements.

9

Deterministic Approach

The application of accepted LCCA procedures and techniques without regard for the variability of input factors.

10

Risk Analysis Approach

A technique which identifies the variability associated with LCCA input factors and carries this variability through the computation process to generate results in the form of a probability distribution.

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Session Overview

- Definitions
- Levels of Application
- Driving Forces
- Implementing Guidance
- National Pavement Design Review

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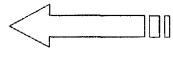
Levels of Application

- Funding levels
- Program allocation
- Project selection
- Design selection 

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Session Overview

- Definitions
- Levels of Applications
- Driving Forces
  - ISTEA (91)
  - FHWA-AASHTO Symposium (93)
  - Executive Order 12893 (94)
  - NHS Designation Act (95)
  - TEA 21 (98)
  - NQI Survey (95)

14

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.

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LCCA Symposium (93)

- AASHTO Survey
- Focused attention on LCCA
- Spotlighted issues
- No Resolutions

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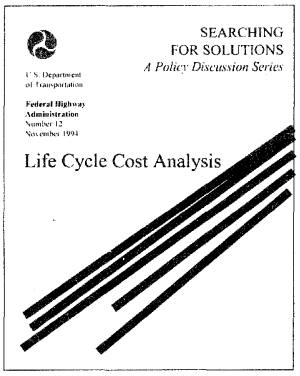

Publication No. FHWA-PL-94-025

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Executive Order 12893 (94)

"Principles for Federal Infrastructure Investments"

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

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NHS Designation Act (95)

Section 303, "Quality Improvement,"

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

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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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National Quality Initiative

- National Policy on Quality of Highways (92)
- Survey conducted (11/95)

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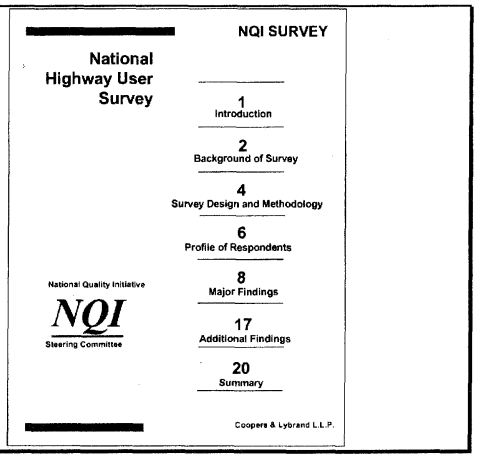

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Survey Highlights

- Overall satisfaction
- Pavement condition
- Maintenance response time
- Traffic flow

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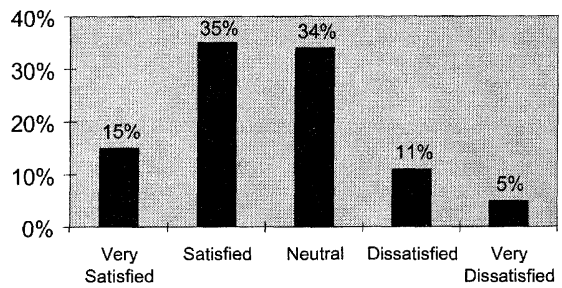
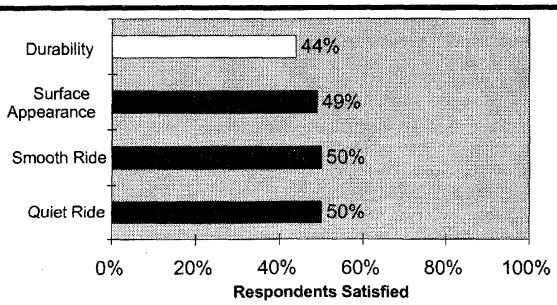
Overall Satisfaction with Highway System



Opportunity to improve public satisfaction.

24

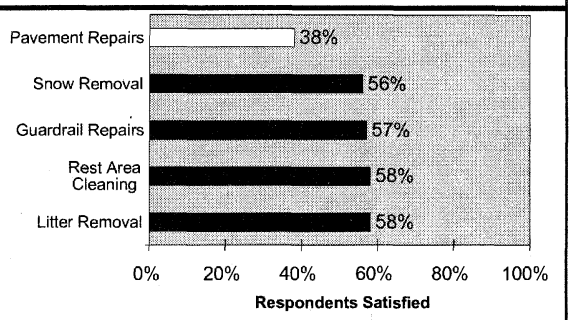
Pavement Condition



Temporary repairs don't cut it !

25

Maintenance Response Time



Response time needs improving !

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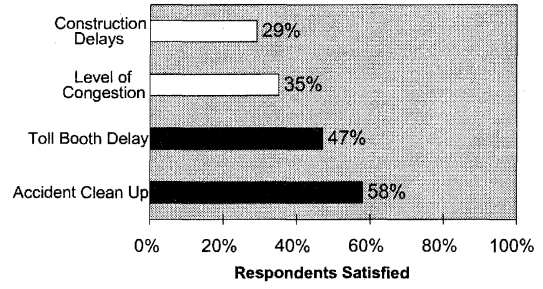
Traffic Flow



Get in, fix it, and get out !

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NQI Survey Priorities ...

1. Pavement Condition
2. Safety
3. Traffic Flow

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Session Overview

- Definitions
- Levels of Applications
- Driving Forces
- Implementing Guidance
  - NHS - FHWA memo (4/96)
  - LCCA Policy Statement (9/96)
  - Technical Bulletin (97)
  - DP 115

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FHWA Memo (4/19/96)

- Federal-aid eligibility contingent on LCCA for $25 Million + NHS projects
- Defines useable project segment
- LCCA procedures not prescribed
- Focus on "good" practice

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LCCA Policy Statement (9/96)

FHWA Philosophy ...

- Decision support tool
- Results are not decisions
- Use process to improve maintenance and rehabilitation strategies
- Logical evaluation process is as important as results

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LCCA Policy Statement (9/96)

- 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

(More)

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Policy Statement Con't ...

- Agency and user costs should be included
- Future costs should be discounted to their *net present value (NPV)*

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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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DP 115

- Workshop
- Case studies
- Future activities

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Additional Resources

- NCHRP
  - Synthesis reports
  - MicroBencost software
- AASHTO
  - Red Book
  - Pavement Design Guide
  - Darwin

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Session Overview

- Definitions
- Levels of Application
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- Implementing Guidance
- National Pavement Design Review

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National Pavement Design Review

- Background
- Purpose
- General Findings (LCCA)

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Background

- OIG/GAO reviews
- FHWA reviews 1995 - 1997
- 52 SHAs
- Areas addressed:
  - ✓ LCCA
  - ✓ Design procedures
  - ✓ Traffic

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LCCA General Findings

- Procedures
- Analysis Periods
- Performance Periods
- Discount Rates
- User Costs

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LCCA Procedures

- Number Reporting 52
- Documented Procedures 33
  - New Location 33
  - Reconstruction 33
  - Major Rehabilitation 22

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LCCA Procedures Cont.'d

- Not Documented 19
  - Informal Procedures 11
  - Plan to Develop Procedure 7
  - Has no Plan to Develop Procedure 1

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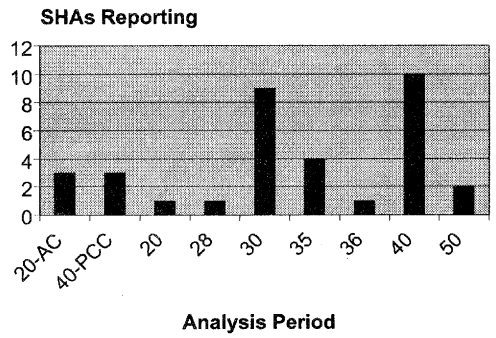

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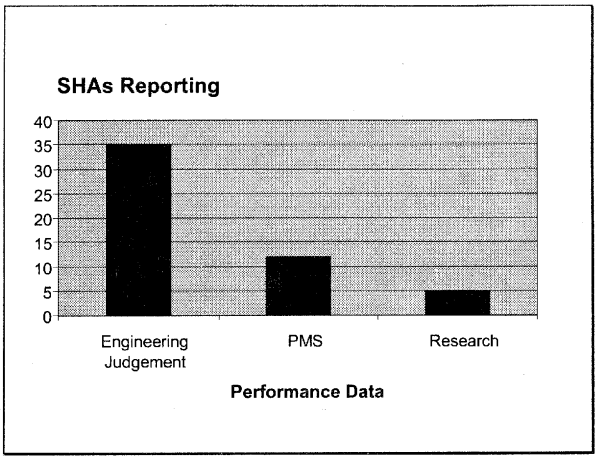
SHAs Reporting
40
35
30
25
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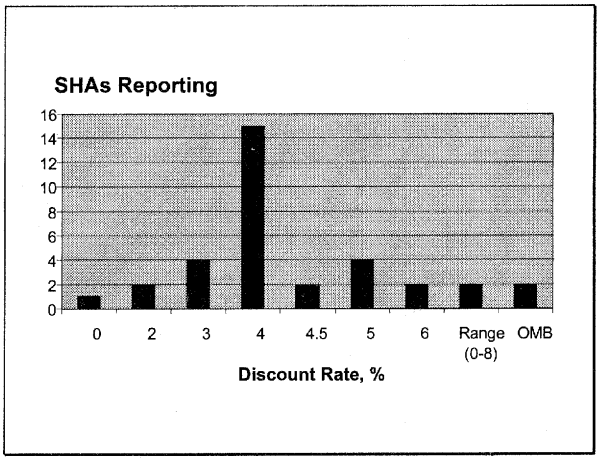
15
10
5
0
Engineering Judgement
PMS
Research
Performance Data

44


SHAs Reporting
16
14
12
10
8
6
4
2
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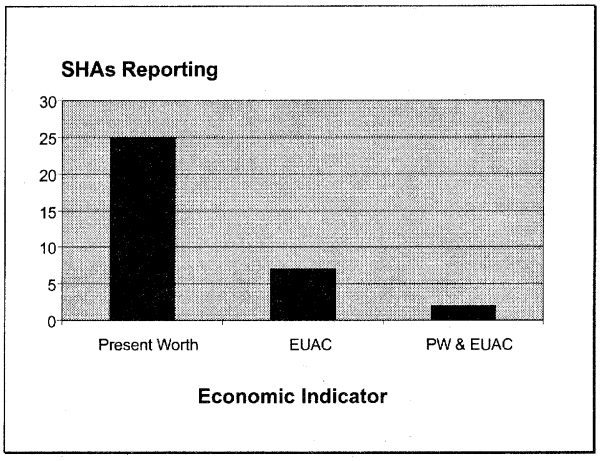
4.5
5
6
Range (0-8)
OMB
Discount Rate, %

45


SHAs Reporting
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25
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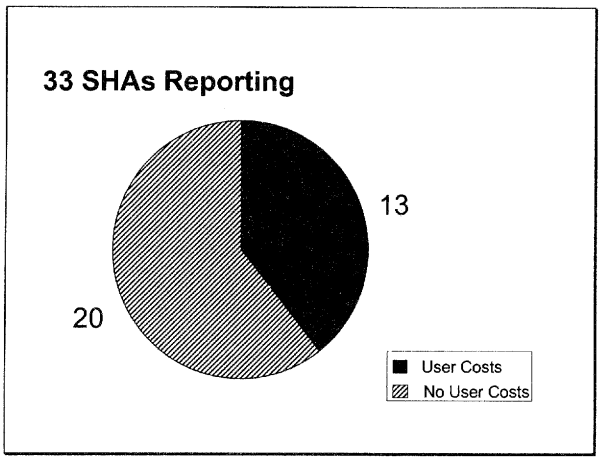
15
10
5
0
Present Worth
EUAC
PW & EUAC
Economic Indicator

46



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Session Summary

- Definitions
- Driving Forces
- Implementing Guidance
- National Pavement Design Review

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End Session

1

LCCA Process Overview

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LCCA Process Steps

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

3

Thou shall not use a strategy that cannot actually occur.

10

Example

- Initial Construction
- Single Future Construction

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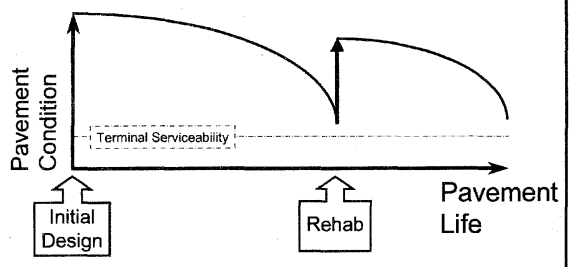
Performance Curves



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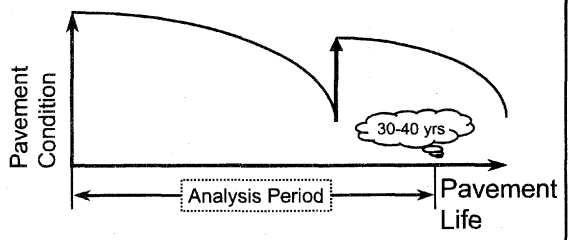
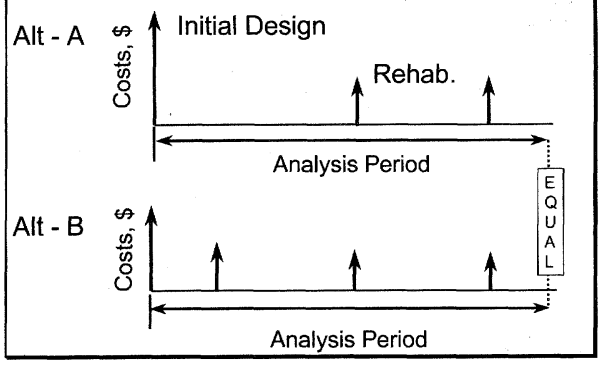
Analysis Period



Include at least one Rehab.

13

Use Same Analysis Period



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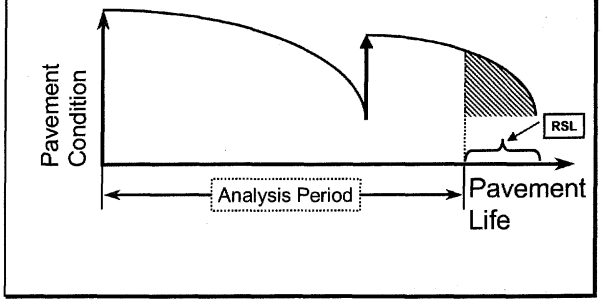
Remaining Service Life (RSL)



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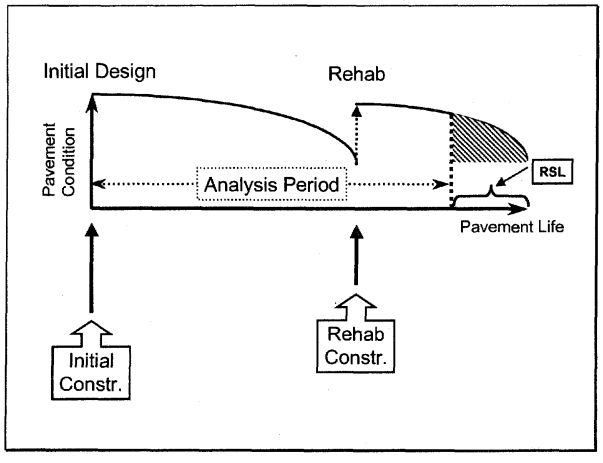

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LCCA Process Steps

1. Establish strategies for analysis period
2. Establish activity timing
3. Estimate agency costs

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3. Estimate Agency Costs

Agency Costs Defined ...

- Costs associated with roadway improvements
- Born by Agency

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Agency Cost Include ...

- Initial Construction Cost
- Future Rehab and Preventive Maint.
- Project Overhead ...
  - Preliminary Engineering,
  - Contract Administration,
  - Construction Supervision and Inspection
- Traffic Control

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Data Sources ...

- SHA historical bid data
- Bid Analysis Management System (BAMS)

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LCCA Process Steps

1. Establish strategies for analysis period
2. Establish activity timing
3. Estimate agency costs
4. Estimate user costs

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4. Estimate User Costs

User Costs Defined ...

- Costs incurred by users of a highway facility including excess costs to those who do not use the facility because of agency or self-imposed detour requirements.

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User Costs Include ...

- Vehicle operating
- User delay
- Crash

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User Costs

Can occur during ...

- Normal operations
- Work Zone

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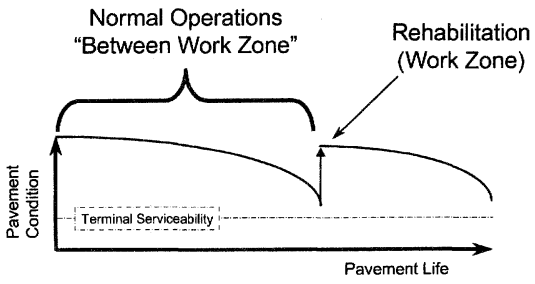

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User Costs (Normal Operations)

- Difficult to quantify
- Data suggest may be minimal if roughness is "small"

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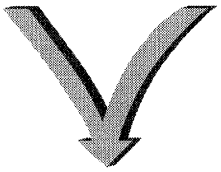
Our Primary Focus ...

Vehicle Operating

User Delay



Crash Costs

Work Zone

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Work Zone User Cost

Defined ...

- Excess VOC and delay costs to users of the facility during work zone operations.
- Additional VOC and delay costs to users who do not use the facility because of agency or self imposed detours.

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LCCA Process Steps

1. Establish strategies for analysis period
2. Establish activity timing
3. Estimate agency costs
4. Estimate user costs
5. Develop expenditure streams

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5. Develop Expenditure Streams

- Agency Costs
- User Costs

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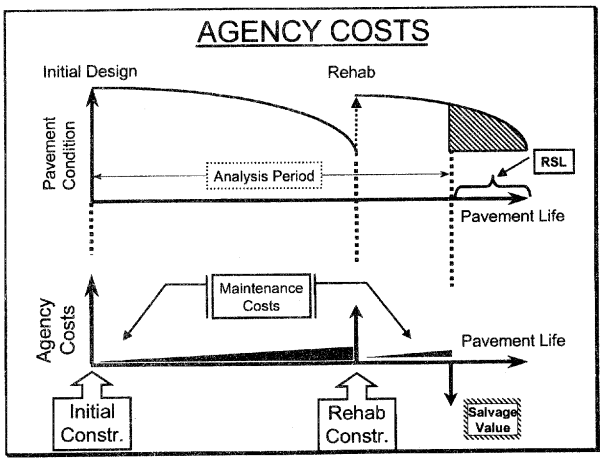

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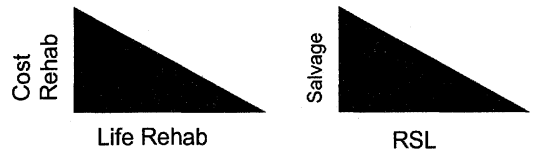
Salvage Value



$$\text{Salvage Value} = \left(\frac{\text{RSL}}{\text{Life Rehab}}\right) \text{Rehab Cost}$$

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Routine Reactive Maintenance

- Usually small
- When discounted its even smaller
- Can be ignored in the analysis

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Inflation

- Use constant dollars
- Use real discount rate

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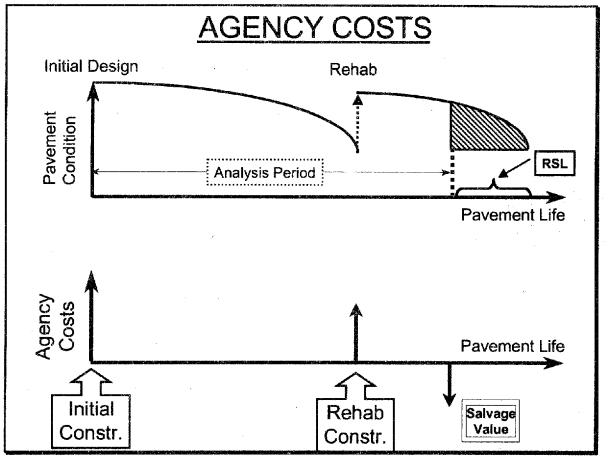

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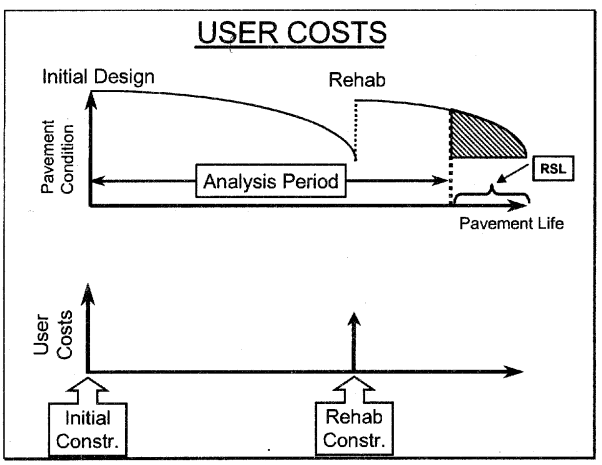

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LCCA Process Steps

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

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Definition

Discounted present value of benefits less discounted present value of costs.

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6. NPV Equation

$$NPV = \text{Initial Cost} + \sum_{k=1}^{N} \text{Future Cost}_k \times \underbrace{\left[\frac{1}{(1+i)^{n_k}}\right]}_{\text{Present Value Factor}}$$

i = discount rate
n = year of expenditure

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Present Value Factors

	Discount Rate (I)				
Year	4.0%	4.5%	5.0%	5.5%	6%
0	1.0000	1.0000	1.0000	1.0000	1.0000
1	0.9615	0.9569	0.9524	0.9479	0.9434
2	0.9246	0.9157	0.9070	0.8985	0.8900
3	0.8890	0.8763	0.8638	0.8516	0.8396
4	0.8548	0.8386	0.8227	0.8072	0.7921
5	0.8219	0.8025	0.7835	0.7651	0.7473
⋮	⋮		⋮		⋮

NPV = (Future Cost) x (Present Value Factor)

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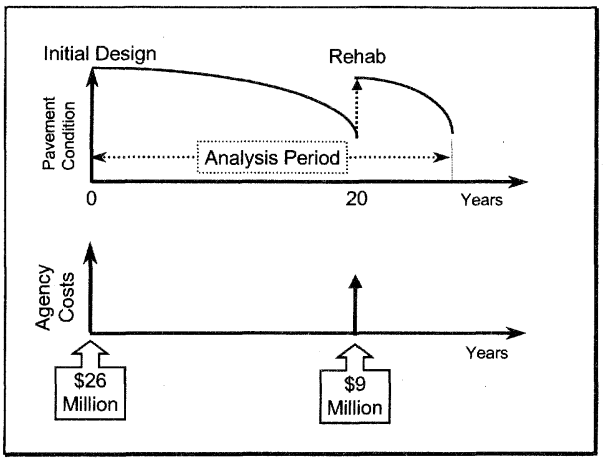

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Deterministic Approach

$ 30.1 M $ 26 M

NPV = Initial Cost +

Future Cost x $ 9 M

$$\left[\frac{1}{(1+i)^n}\right]$$

4% 20 yrs

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❶ Agency NPV

❷ User NPV

Since User Costs May Dominate
Separate Agency and User Costs

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LCCA Process Steps

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

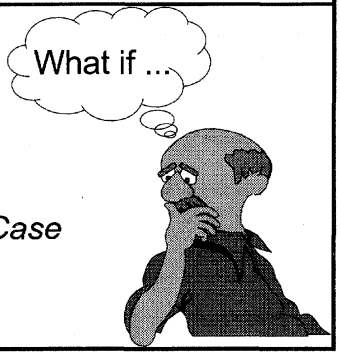
44

7. Analyze Results

- Weigh qualitative advantages and disadvantages of alternatives
- Determine and explain LCCA implications

45

Sensitivity Analysis



✓*Best Case*

✓*Most Likely Case*

✓*Worst Case*

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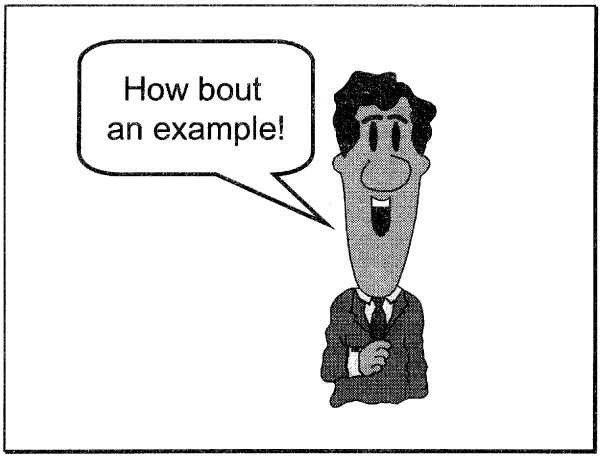

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Example

Sensitivity Analysis

Alternative - A

Activity	Year	Cost	Discounted Cost 1%	2%	3%	4%	5%
Constr.	0	$177.0	$177.0	$177.0	$177.0	$177.0	$177.0
Rehab.	10	$ 10.0	$ 9.1	$ 8.2	$ 7.4	$ 6.8	$ 6.1
Rehab.	20	$ 15.0	$ 12.3	$ 10.1	$ 8.3	$ 6.8	$ 5.7
Rehab.	30	$ 15.0	$ 11.1	$ 8.3	$ 6.2	$ 4.6	$ 3.5
Salvage	35	$(7.5)	$(5.29)	$(3.75)	$(2.67)	$(1.90)	$(1.36)
		NPV	$204.2	$199.8	$196.3	$193.3	$190.9

Alternative - B

Activity	Year	Cost	Discounted Cost 1%	2%	3%	4%	5%
Constr.	0	$125.0	$125.0	$125.0	$125.0	$125.0	$125.0
Rehab.	15	$ 80.0	$ 68.9	$ 59.4	$ 51.3	$ 44.4	$ 38.5
Rehab.	30	$ 80.0	$ 59.4	$ 44.2	$ 33.0	$ 24.7	$ 18.5
Salvage	35	$(53.3)	$ (37.6)	$ (26.7)	$ (18.9)	$ (13.5)	$ (9.7)
		NPV	$215.6	$202.0	$190.4	$180.6	$172.3

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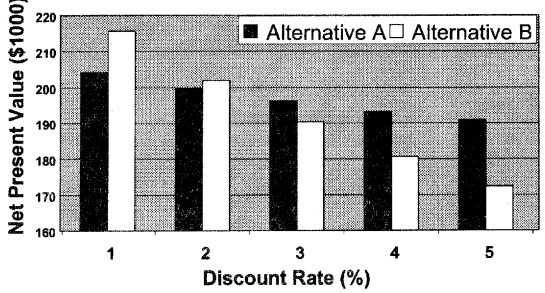
Sensitivity to Discount Rate



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Sensitivity Analysis

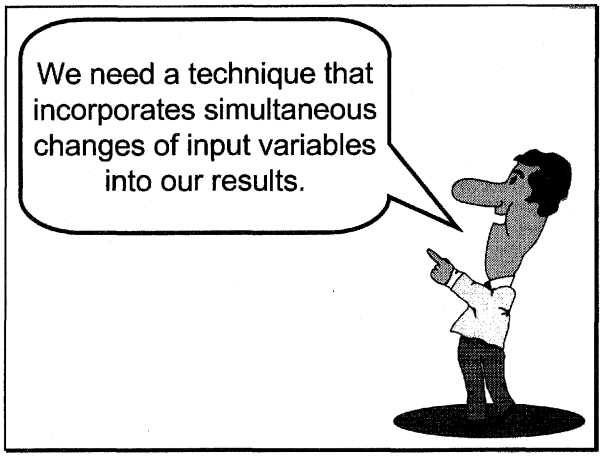
- Advantages
  - Shows effect of changing input variable on outcome
  - Easy to perform

50

Sensitivity Analysis

- Disadvantages
  - One input variable changes (others held constant)
  - Limited analysis
  - Does not ...
    - ➡ account for simultaneous change of *ALL* inputs on outcome
    - ➡ account for likelihood of input value actually occurring
    - ➡ reflect reality

51



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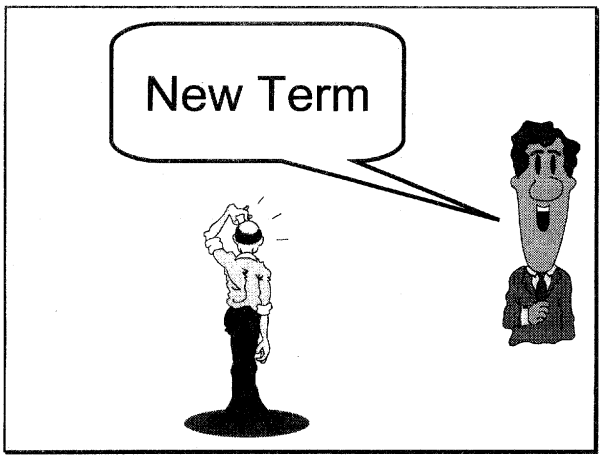

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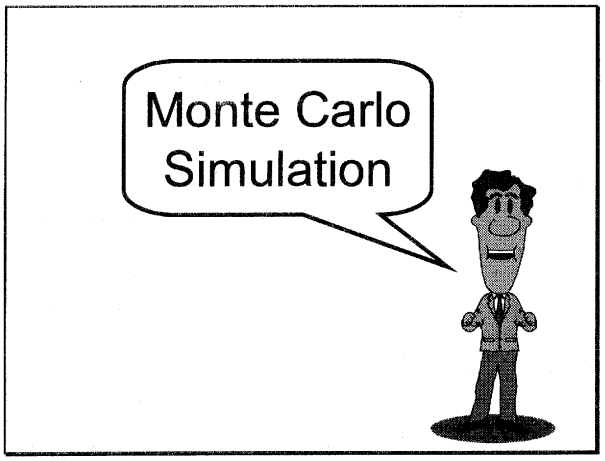

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Monte Carlo Simulation

- Input variables described using probability distribution
- Samples randomly drawn from input distributions to calculate results
- Hundreds, even thousands, of samples may be drawn to form a distribution of results

55

Monte Carlo Con't

- Rigorous extension of ...
  - Best Case
  - Most Likely
  - Worst Case
- Data Input values based on likelihood of occurrence

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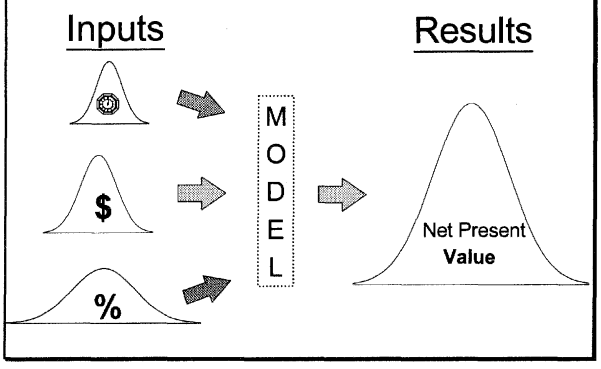
Monte Carlo Simulation



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LCCA Process Steps

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

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8. Re-evaluate Strategies

- Modify alternatives
  - ✓Design lives
  - ✓Strengthen shoulders
  - ✓New technologies
- Revise maintenance of traffic plan
  - ✓Reduce construction period
  - ✓Restrict contractor work hours
  - ✓Examine alternative modes of travel

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Implications

- Lengths and times of queues
- Agency versus user costs
- Reliability of LCCA outcome
- Practical Realities .....

60

Practical Realities ...

- Local politics
- Availability of funding
- Industry support to perform the required construction
- Agency experience with a particular strategy
- Accuracy of pavement design and rehabilitation models

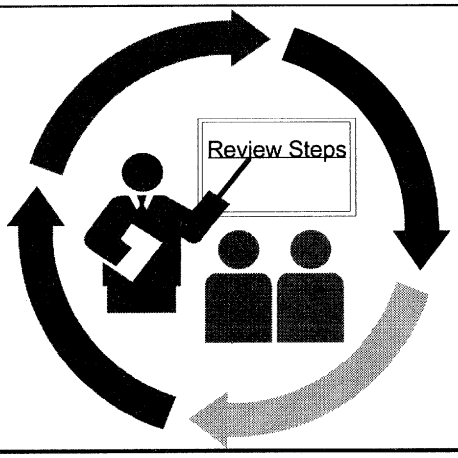
61

In Closing

LCCA ...

- Decision support tool
- Results are not decisions
- Use process to improve maintenance and rehabilitation strategies
- Logical evaluation process is as important as results

62



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LCCA Process Steps

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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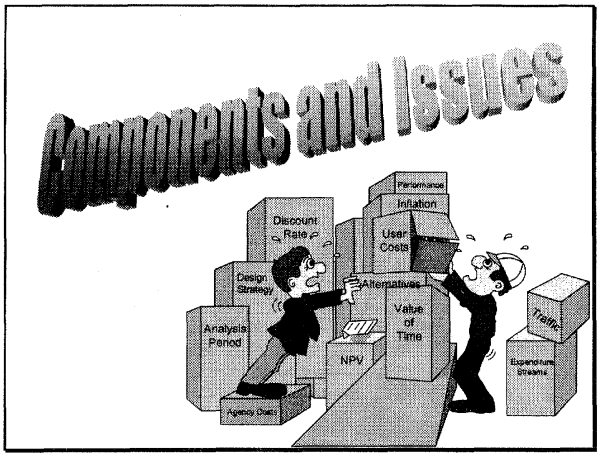
End Session

1



2

Session Overview

- Analysis periods
- Traffic
- Design strategy
- Performance estimates
- Expenditure streams

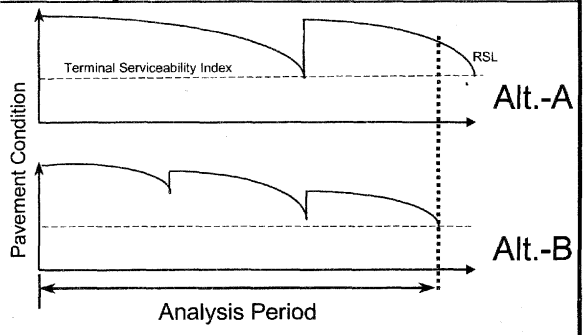
3

Session Overview Cont'd

- Costing
- Discounting
- Economic indicators
- Agency cost
- User cost

4

Analysis Period



Include at least one rehabilitation activity.

5

Analysis Period

- Capture alternative differences
- Include one rehabilitation
- FHWA LCCA Policy
  - Pavements ..... 35 Yrs
  - Bridges..... 75 Yrs

6

Traffic - Characteristics

- AADT
- Traffic mix
- Growth rates
- Directional hourly volume

7

Traffic - Projections

- Volumes - User costs
- Classification - User costs
- Load factors - Design
- ESALs - Design

8

Traffic - Hourly Demand

Sources:

- Traffic data
- Typical default values
  - PennDOT
  - MicroBencost

9

Example

PennDOT AADT Distribution - Hourly Percentages

	Traffic Pattern Group					
	Interstate		Prin. Arterial		Min. Arterial	
Hour	Urban	Rural	Urban	Rural	Urban	Rural
0 - 1	1.3	1.7	0.9	0.9	0.8	0.7
1 - 2	0.9	1.4	0.5	0.5	0.4	0.4
2 - 3	0.8	1.3	0.4	0.5	0.3	0.3
3 - 4	0.8	1.3	0.4	0.5	0.3	0.4
4 - 5	1.1	1.4	0.6	0.9	0.4	0.8
5 - 6	2.1	2.1	1.8	2.3	1.3	2.2
6 - 7	4.7	3.7	4.4	4.9	4.0	4.5
7 - 8	6.4	4.9	6.2	6.2	6.4	5.5
8 - 9	5.6	4.9	5.7	5.5	5.7	5.3
9 - 10	5.1	5.2	5.1	5.3	4.8	5.4
10 - 11	5.2	5.5	5.2	5.4	4.9	5.8
11 - 12	5.4	5.8	5.6	5.6	5.5	6.0
⋮	⋮	⋮	⋮	⋮	⋮	⋮
23 - 24	2.0	2.4	1.7	1.5	1.6	1.4

10

Performance Estimates

- Performance periods affect timing of rehabilitation
  - Frequency
  - Expenditure timing
  - Traffic levels
  - User costs

11

Design Strategy

- Initial design
- Identify supporting rehabs
- Viable and competitive

12

PCC Design Strategy

	Year						
Activity	5	10	15	20	25	30	35
■ Clean and Seal Joints	X	X	X	X	X	X	
■ Seal Coat Shoulders	X	X	X	X	X		X
■ CPR - Patch				X		X	
- Spall Repair				X			
- Slab Stabilization				X			
- Diamond Grinding				X			
■ Overlay						X	
■ Saw and Seal Joints						X	
■ Pave Shoulders						X	
■ Adjust Guard Rail and Drainage Structures						X	

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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

14

Options ....

- Plan to add capacity in the outyears
- Strengthen shoulders
- Examine use of alternative routes, modes of transportation

15

Options Cont'd

- Use materials with greater performance lives thereby reducing number of rehabs
- Initiate programs, such as preventive maintenance, that preserve pavement life

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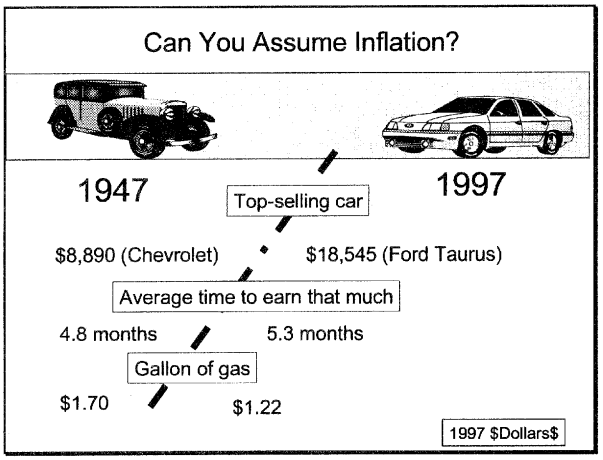
Costing and Discounting

- Costing - Type of Dollars
  - Constant (real)
  - Inflated (nominal)

17



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Example: Deflation

Computer Cost:

- 1989 - $2,500
- 1998 - $1,200

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Costing and Discounting

- Costing - Type of Dollars
  - Constant (real)
  - Inflated (nominal)
- Discounting - Type of Rates
  - Real
  - Nominal

20

Discounting - Rate Factors

- 4.0% - Real
- 3.5% - Inflation
- 4.0% - Risk premium

- 11.5% - Nominal

21

Discounting - Matching Dollars & Rates

- Real dollars and rates
- Nominal dollars and rates
- Never mix nominal and real

22

Discounting "True-isms"

- Present costs valued higher
- Out year costs worth less

23

Discounting "True-isms"

- Low Rates -

  Favor alternatives with higher initial costs and lower future costs

- High Rates -

  Favor alternatives with lower initial costs and higher future costs

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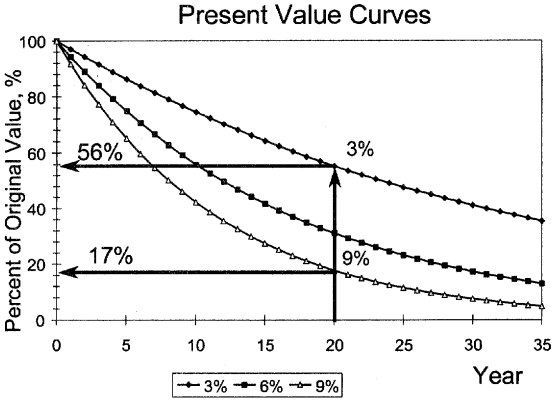

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Discount Rate Selection

- Opportunity Cost
- Office of Management and Budget Circular A-94

26

Opportunity Cost - Personal

401K - IRA	28% - 35%+
Credit Cards	15% - 22%
Signature Loans	12% - 15%
Car Loans	8% - 12%
Home Equity	7% - 11%
Mortgage	5% - 8%
Savings/Checking	0% - 3%

Nominal rates of return

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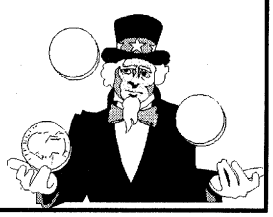
Opportunity Cost - Gov't

- J. "Queue" Public
- Other Investments
- Old Bonds
- New Bonds



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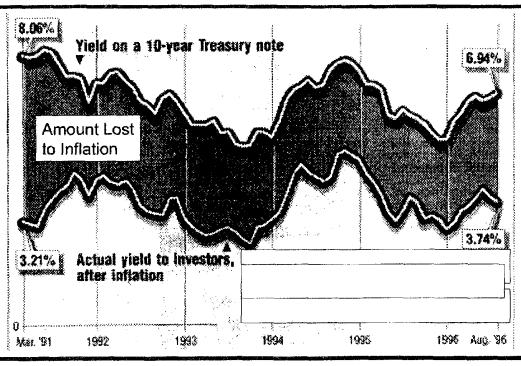
Real Discount Rate



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Real Discount Rates
Source: OMB Circular A-94

	Investment Maturity				
YEAR	3	5	7	10	30
Nov 92	2.7	3.1	3.3	3.6	3.8
Feb 93	3.1	3.6	4.0	4.3	4.5
Feb 94	2.1	2.3	2.5	2.7	2.8
Feb 95	4.2	4.5	4.6	4.8	4.9
Feb 96	2.7	2.7	2.8	2.8	3.0
Feb 97	3.2	3.3	3.4	3.5	3.6
Jan 98	3.4	3.5	3.5	3.6	3.8
Avg	3.1	3.3	3.4	3.6	3.8
Std	0.6	0.7	0.7	0.7	0.7

(No Inflation Premium)

30

Circular A-94

Discount Rates Web Address:

http://www.whitehouse.gov/WH/EOP/OMB/html/circulars/

Select A-94 and see appendix C.

31

Recommend

- 3 to 5 %
- Real rates with real dollars

32

Economic Indicators

- Internal rate of return
- Benefit cost ratio
- Equivalent uniform annual costs
- Net present value

33

Economic Indicator of Choice

Net
Present
Value

34

Agency Costs

- Design and Engineering
- Initial Construction
- Maintenance of Traffic
- Preventive Maintenance
- Rehabilitation
- Reactive Maintenance/Operating Cost

Salvage Value Sunk Costs

35

Salvage Value

- Remaining service life
  - % of last rehab cost
- Residual value
  - Value of recycled material

36

Sunk Costs

... costs that are not relevant to the decision at hand

37

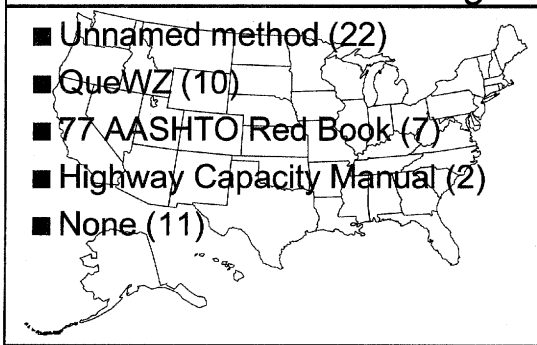
User Costs: 2B or not 2B

- Pro - User costs drive transportation investments.
  - User fees collected for public investment
- Con - Can't recoup costs
  - "Not in my budget"

38

AASHTO User Cost Survey for Innovative Contracting

- Unnamed method (22)
- QueWZ (10)
- 77 AASHTO Red Book (7)
- Highway Capacity Manual (2)
- None (11)



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User Cost Components

- Vehicle crash cost
- Vehicle operating cost
- User delay

40

User Cost Components

- Vehicle crash cost
  - Property damage only - $
  - Injury - $$
  - Fatality - $$$$$
- Data sources

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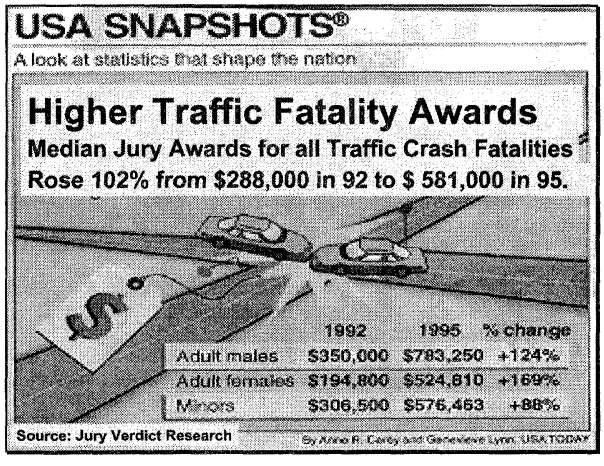

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User Cost Components

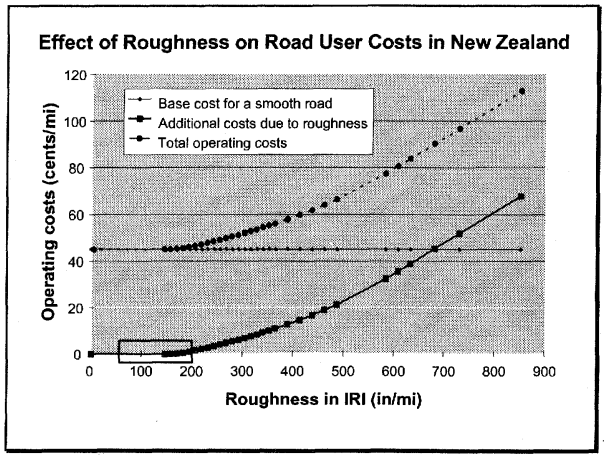
- Vehicle crash cost
- Vehicle operating cost
  - Normal operations
  - Work zone

43

VOC Normal Operations

- Function of ...
  - Pavement performance
  - VOC - IRI relationship
- May be significant but ...
  ..Not quantifiable at this time

44



45

VOC in Work Zones

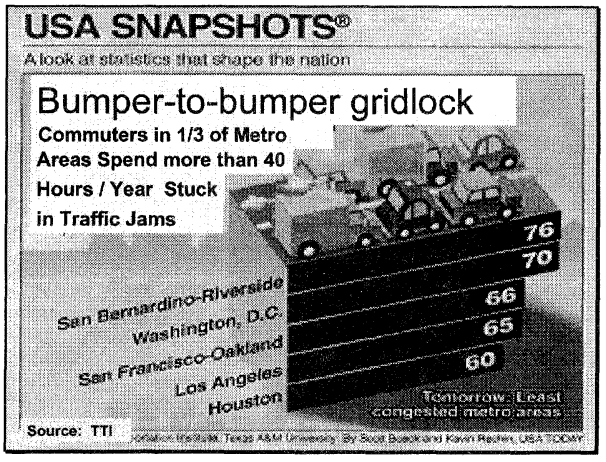
- Speed change cost
- Stopping cost
- Idling cost

46

User Cost Components

- Vehicle crash cost
- Vehicle operating cost
- User delay
  - WZ reduced speed delay
  - Congestion delay

47



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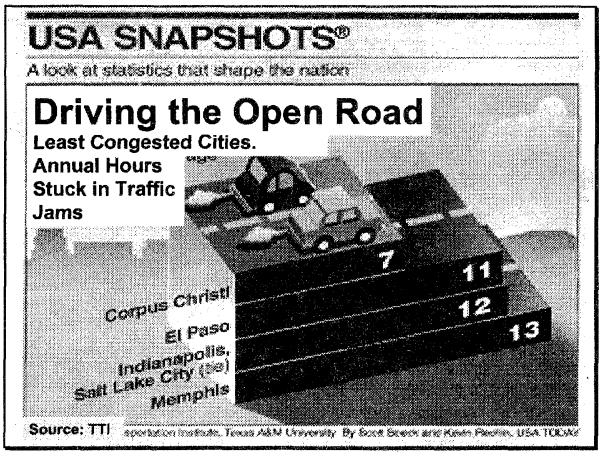

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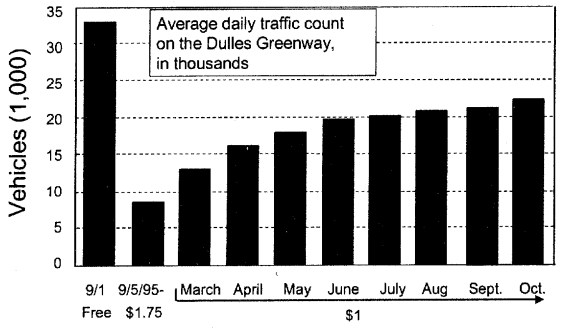
Value of Time: Sources

- A + B Bidding - Lane rentals
- Toll facilities
- Congestion pricing
- High Occupancy Toll (HOT)
- US DOT - FHWA HERS
- Research studies

50

Toll Facilities



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Congestion Pricing

- Houston 1990
- Hardy toll road experiment
- $1.00 peak - $.50 off peak
- Too successful
- Lost $500,000 in 90 days

58

Further Information ...

LCCA Tech Bulletin ...

- Fundamental principles
- Good practice
- LCCA issues
- Case studies
- Uncertainty and variability
- Computer software

59

Parting Caveat

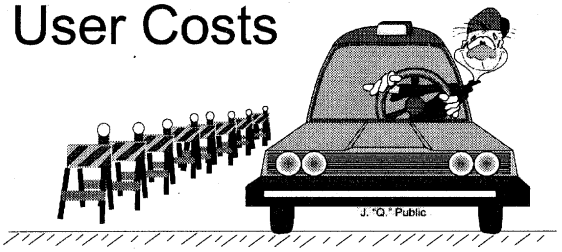
- Defending LCCA results
  - Justify all assumptions
  - Address all issues (even if not relevant to the analysis at hand)

60

End Session

1

Introduction to Project Level User Costs



2

Session Overview

- Components
- Operating Conditions
- Work zone

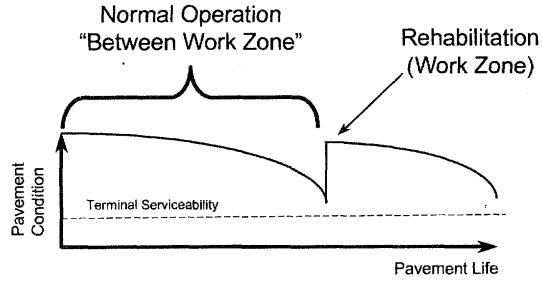
3

User Cost Components

- Vehicle operating
- User delay
- Circuity
- Crash

4

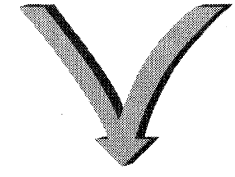
Operating Conditions



5

Our Primary Focus ...

Vehicle Operating User Delay



Crash Costs

Work Zone

6

WZ User Costs Function of ...

- Type
- Characteristics
- Duration
- Frequency
- Timing
- Traffic Operations

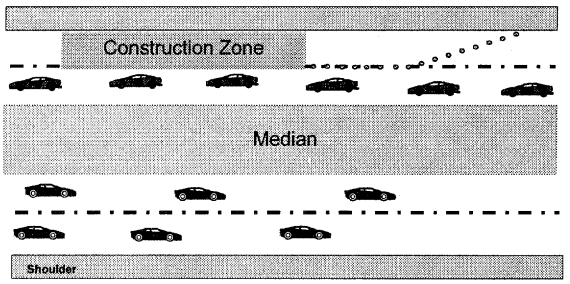
7

Work Zone Types

- Road closures
- Single lane closure
- Two lane two way operation

8

Single Lane Closure (SLC)



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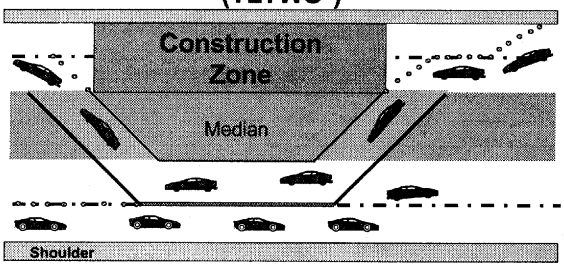
Two Lane Two Way Operation (TLTWO*)



*Also called "Crossover" or "Head to Head"

10

WZ Characteristics

- Length
- Posted Speed
- Hours of Operation
- Capacity
- Alternate Routes/Detours

11

Work Zone Duration

Includes:

- Hours per day
- Number of days

12

Work Zone Frequency

- Number of times rehab work zones need to be established over the analysis period
- The more rehabilitations the more work zones

13

Work Zone Timing

- Refers to the year the work zone is in place
- Impacts user cost NPV
  - Out-year traffic levels
  - Discount factor

14

Net Present Value (NPV)

$$NPV = \text{Initial Cost} + \sum_{k=1}^{N} \text{Future Cost}_k \times \underbrace{\left[\frac{1}{(1+I)^{n_k}}\right]}_{\text{Present Value Factor}}$$

I = discount rate
n = year of expenditure

15

Work Zone Analysis

- Different work zone types must be analyzed separately.
- Work zones with different characteristics, including traffic demand, must also be analyzed separately.

16

Work Zone Analysis Con't

- Manual approach
  - Capacity analysis
  - AASHTO Red Book
- Automated programs
  - MicroBenCost
  - QueWZ

17

McTrans Ph: **1-800-226-1013**

- MicroBenCost: ~ $110
- QueWZ: ~ $20

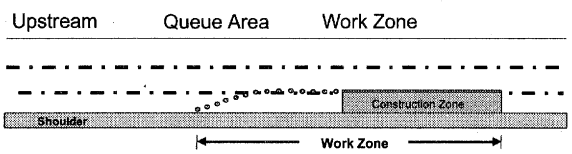
Includes: software, documentation, and shipping

18

Work Zone Traffic Operations

19

Work Zone Layout



20

WZ Operations

- Free Flow (Base Case)
  WZ Capacity Exceeds Demand
- Forced Flow (Congestion)
  Demand Exceeds WZ Capacity

21

Free Flow Cost Components

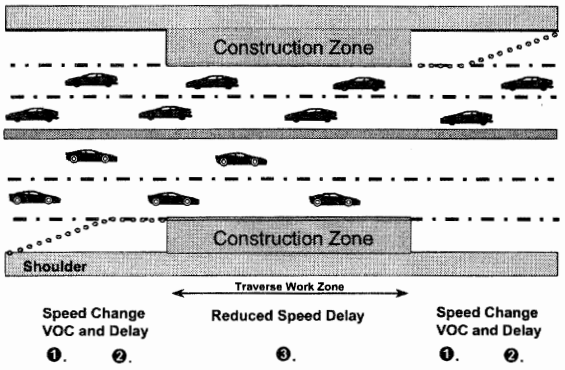
WZ capacity not exceeded ...

➡ Speed change costs
- ❶ VOC
- ❷ Delay

➡ Reduced speed costs
- ❸ Delay

22

Free Flow



23

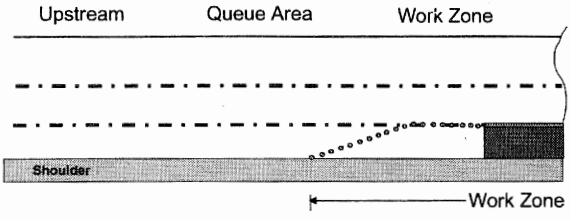
Forced Flow Cost Components

WZ capacity exceeded ...

- Stopping cost
  - ❹ VOC
  - ❺ Delay
- Queuing costs
  - ❻ Idling
  - ❼ Delay

24

Forced Flow



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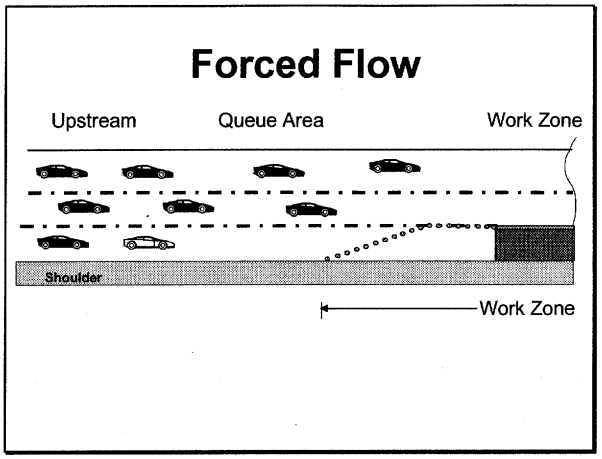
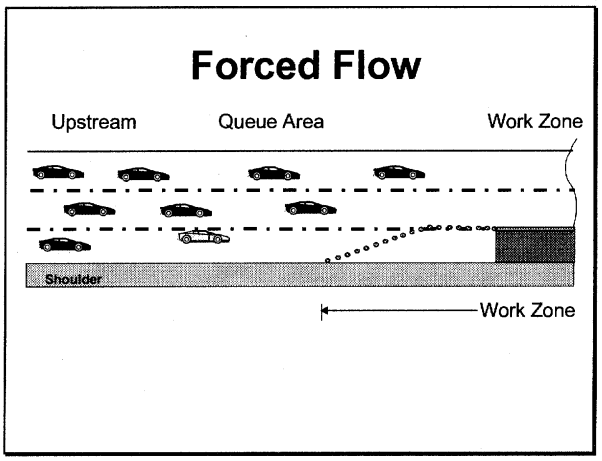
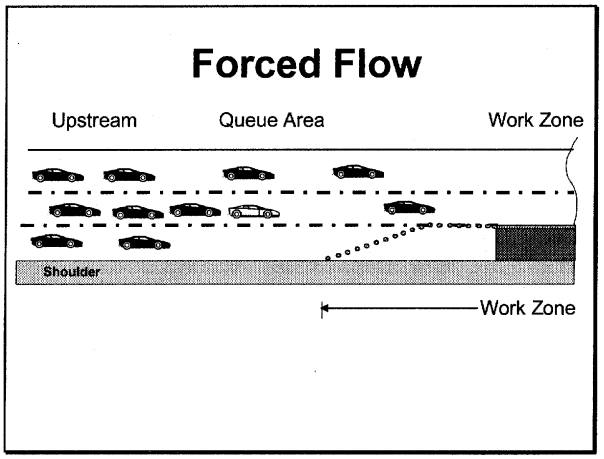

Forced Flow
Upstream
Queue Area
Work Zone
Shoulder
Work Zone

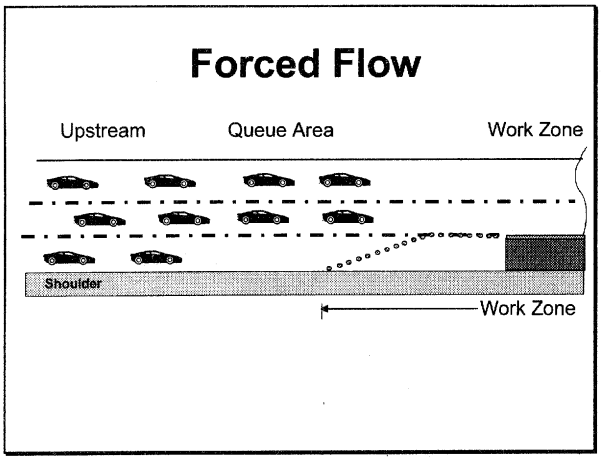
26


Forced Flow
Upstream
Queue Area
Work Zone
Shoulder
Work Zone

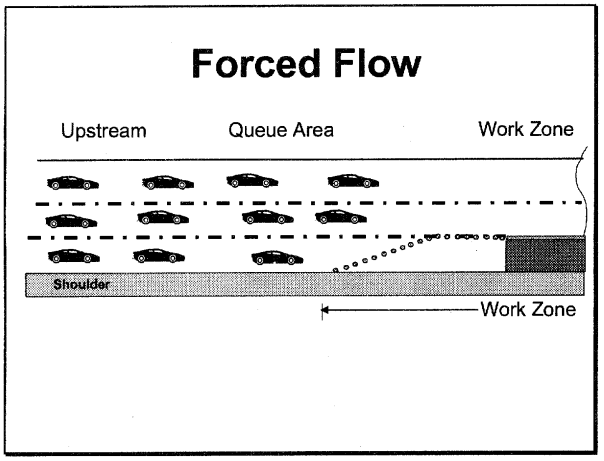
27


Forced Flow
Upstream
Queue Area
Work Zone
Shoulder
Work Zone

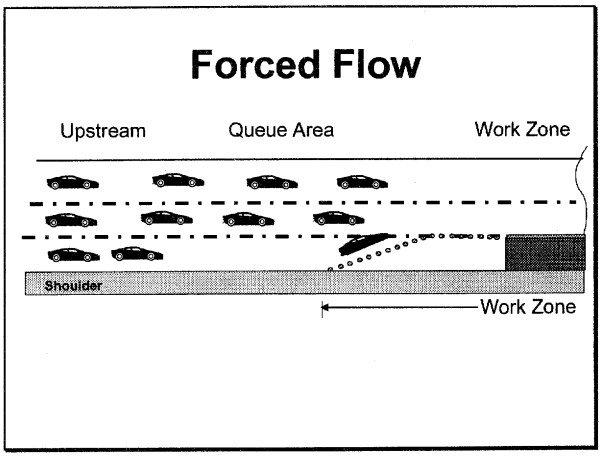
28


Forced Flow
Upstream
Queue Area
Work Zone
Shoulder
Work Zone

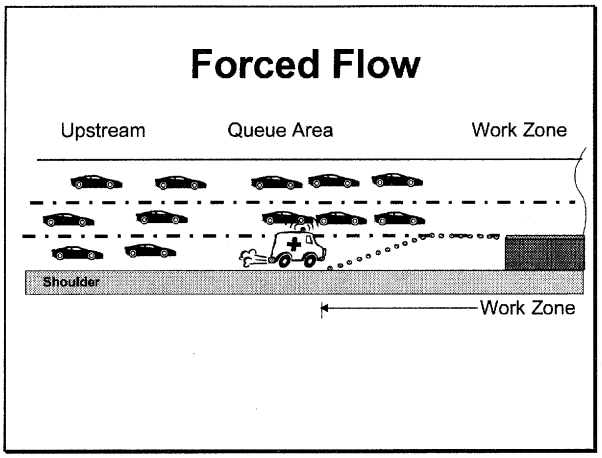
29


Forced Flow
Upstream
Queue Area
Work Zone
Shoulder
Work Zone

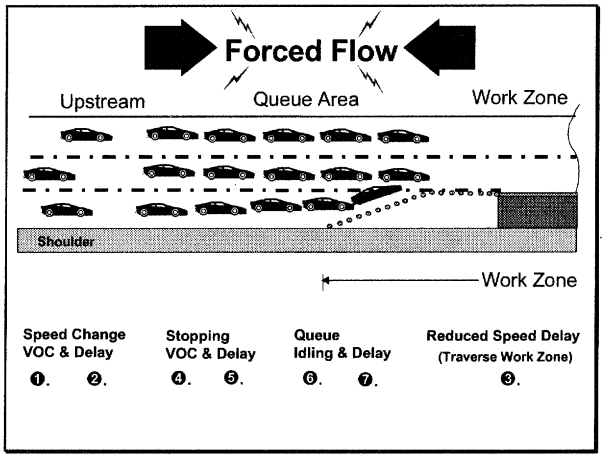
30


Forced Flow
Upstream
Queue Area
Work Zone
Shoulder
Work Zone

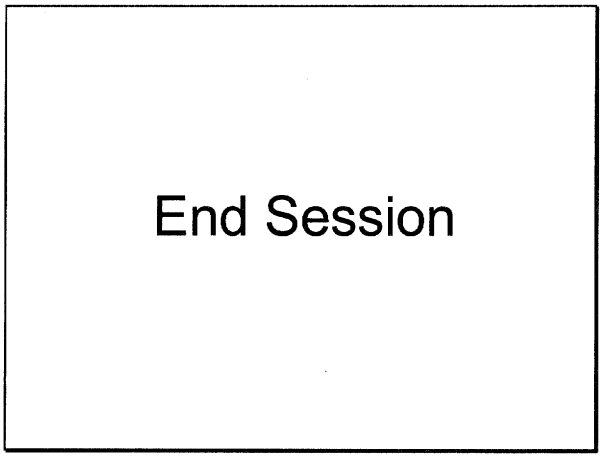
31


Forced Flow
Upstream
Queue Area
Work Zone
Shoulder
Work Zone

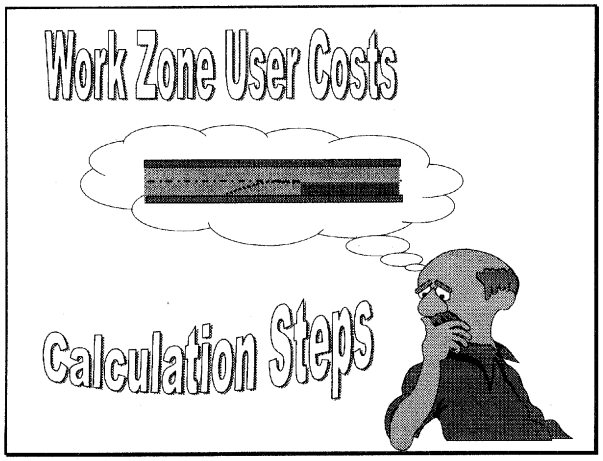
32


Forced Flow
Upstream
Queue Area
Work Zone
Shoulder
Work Zone
Speed Change
VOC & Delay
❶. ❷.
Stopping
VOC & Delay
❹. ❺.
Queue
Idling & Delay
❻. ❼.
Reduced Speed Delay
(Traverse Work Zone)
❸.

33


End Session

1



2

WZ User Costs Steps

1. Determine Capacity
2. Calculate Directional Hourly Demand
3. Identify User Cost Components
4. Quantify Traffic Affected by each Component
5. Compute Reduced Speed Delay
6. Assign VOC Cost Rates

(More)

3

WZ User Costs Steps (Cont'd)

7. Assign Delay Cost Rates
8. Assign Traffic to Vehicle Classes
9. Compute User Costs by Vehicle Class
10. Determine Circuity
11. Compute Crash Costs
12. Sum Total User Costs

4

1. Determine Capacity

- With and without WZ
- Resources:
  - Research Studies
  - Highway Capacity Manual

5

Free Flow Capacity

- Ideal
  - 2200 to 2300 pvplph
- Mixed flow reductions
  - Trucks present
  - Lane width
  - Hazard offset
  - Recreational drivers

6

Mixed Traffic Capacity

1000 - 2300 vplph

See Table 3.4-3.6 of Technical Bulletin

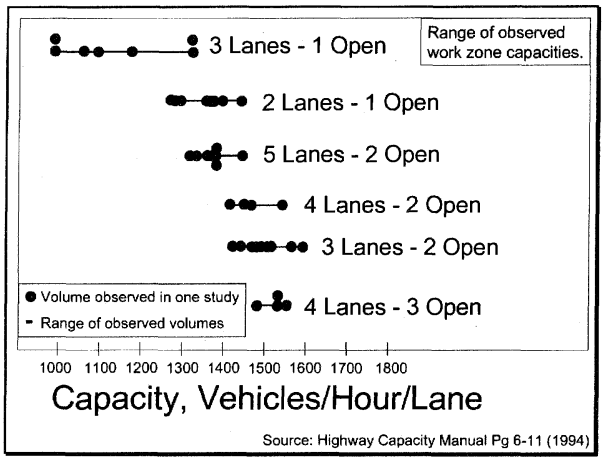
7

Work Zone Capacity

Directional Lanes				
Normal Operations	WorkZone Operations	No of Studies	Capacity (vph)	Capacity (Veh/Ln-Hr.)
3	1 Open	7	1170	1170
2	1 Open	8	1340	1340
5	2 Open	8	2740	1370
4	2 Open	4	2960	1480
3	2 Open	9	2980	1490
4	3 Open	4	4560	1520

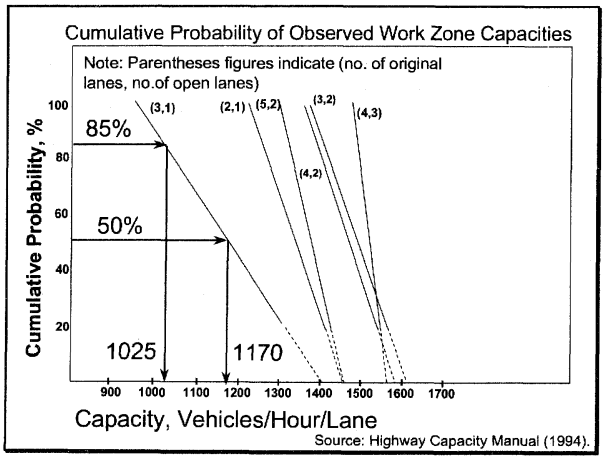
Source: 1994 Highway Capacity Manual - Table 6.1

8



Source: Highway Capacity Manual Pg 6-11 (1994)

9



Source: Highway Capacity Manual (1994).

10

Queue Dissipation Cap.

- Has significant impact on time to clear queue
- Ranges from 1500 to 2000 vphpl
- See HCM Page 2-32

11

2. Calculate Directional Hrly Demand

Directional Hourly Demand =

- (AADT) x
- (% Hourly Demand) x
- (Directional Factor)

12

Sources

- AADT & directional factor
  - Traffic counts
- Hourly distributions
  - MicroBENCOST
  - Traffic counts

13

Rural Default Hourly Distributions, MicroBenCost

	Interstate			Principal Arterials			Minor Arterials			Major Collectors		
	%	Direction		%	Direction		%	Direction		%	Direction	
Hour	ADT	In	Out	ADT	In	Out	ADT	In	Out	ADT	In	Out
0 - 1	1.8	48	52									
1 - 2	1.5	48	52									
2 - 3	1.3	45	55									
3 - 4	1.3	53	47									
4 - 5	1.5	53	47									
5 - 6	1.8	53	47									
6 - 7	2.5	57	43	**Same**			**Same**			**Same**		
7 - 8	3.5	56	44									
8 - 9	4.2	56	44									
9 - 10	5.0	54	46									
10 - 11	5.4	51	49									
11 - 12	5.6	51	49									
⋮		⋮										

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Rural Default Hourly Distributions Con't, MicroBenCost

	Interstate			Principal Arterials			Minor Arterials			Major Collectors		
	%	Direction		%	Direction		%	Direction		%	Direction	
Hour	ADT	In	Out	ADT	In	Out	ADT	In	Out	ADT	In	Out
12 - 13	5.7	50	50									
13 - 14	6.4	52	48									
14 - 15	6.8	51	49									
15 - 16	7.3	53	47									
16 - 17	9.3	49	51									
17 - 18	7.0	43	57									
18 - 19	5.5	47	53	**Same**			**Same**			**Same**		
19 - 20	4.7	47	53									
20 - 21	3.8	46	54									
21 - 22	3.2	48	52									
22 - 23	2.6	48	52									
23 - 24	2.3	47	53									

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Example

PennDOT AADT Distribution - Hourly Percentages

	Traffic Pattern Group					
	Interstate		Prin. Arterial		Min. Arterial	
Hour	Urban	Rural	Urban	Rural	Urban	Rural
0 - 1	1.3	1.7	0.9	0.9	0.8	0.7
1 - 2	0.9	1.4	0.5	0.5	0.4	0.4
2 - 3	0.8	1.3	0.4	0.5	0.3	0.3
3 - 4	0.8	1.3	0.4	0.5	0.3	0.4
4 - 5	1.1	1.4	0.6	0.9	0.4	0.8
5 - 6	2.1	2.1	1.8	2.3	1.3	2.2
6 - 7	4.7	3.7	4.4	4.9	4.0	4.5
7 - 8	6.4	4.9	6.2	6.2	6.4	5.5
8 - 9	5.6	4.9	5.7	5.5	5.7	5.3
9 - 10	5.1	5.2	5.1	5.3	4.8	5.4
10 - 11	5.2	5.5	5.2	5.4	4.9	5.8
11 - 12	5.4	5.8	5.6	5.6	5.5	6.0
⋮		⋮		⋮		⋮

16

Example

PennDOT AADT Distribution - Hourly Percentages

	Traffic Pattern Group					
	Interstate		Prin. Arterial		Minor Arterial	
Hour	Urban	Rural	Urban	Rural	Urban	Rural
12 - 13	5.5	5.7	6.0	5.7	6.0	6.2
13 - 14	5.5	5.9	5.9	5.9	5.7	6.4
14 - 15	6.1	6.3	6.4	6.6	6.3	7.2
15 - 16	7.3	6.9	7.4	7.7	7.6	8.1
16 - 17	7.8	7.2	7.8	8.0	8.3	8.0
17 - 18	7.2	6.6	7.5	7.4	8.0	7.1
18 - 19	5.4	5.3	5.9	5.5	6.2	5.4
19 - 20	4.3	4.4	4.8	4.3	5.1	4.4
20 - 21	3.7	3.8	4.0	3.6	4.3	3.6
21 - 22	3.2	3.4	3.3	3.0	3.4	2.9
22 - 23	2.6	2.9	2.4	2.3	2.4	2.1
23 - 24	2.0	2.4	1.7	1.5	1.6	1.4

17

3. Identify User Cost Components

- Free Flow
  - Speed Change
  - Reduced Speed

- Forced Flow
  - Stopping
  - Queuing

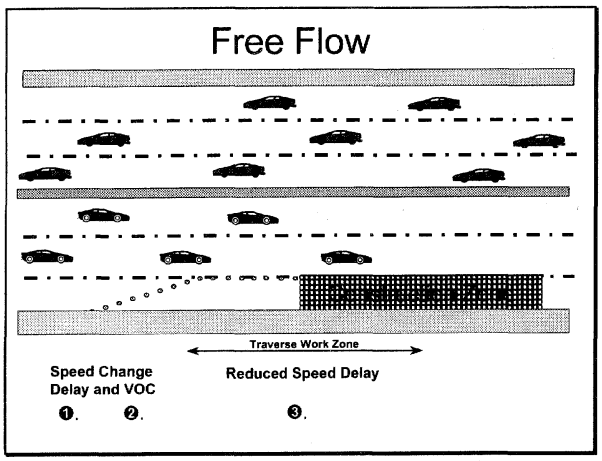
18

Free Flow Cost Components

WZ capacity not exceeded ...

- Speed change costs
  1. Delay
  2. VOC
- Reduced speed costs
  3. Delay

19



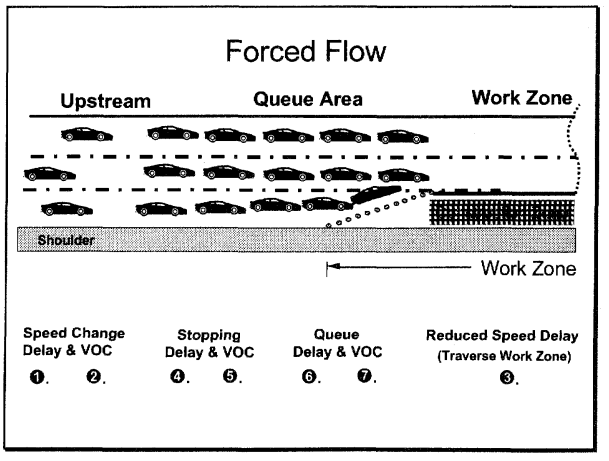
20

Forced Flow Cost Components

WZ capacity exceeded ...

- ➡ Stopping cost
  - ❹ Delay
  - ❺ VOC
- ➡ Queuing costs
  - ❻ Delay
  - ❼ Idle

21



22

4. Quantify Traffic Affected by Each Component

- Lane closure hours
- 24 Hours analysis period

23

Example

- AADT = 67,406 veh per day. (SouthBound)
- Traff. Mix 90% Auto, 5.4% SU, 4.6% Combo
- 3 Lane Open Non Work Zone (Cap. 6285 vph)
- 2 Lane Open - 1 Lane Closed for Work Zone (Cap. 3027 vph)
- Work Zone Hours 8 pm - 5 am, 9 am - 3 pm
- Length = 5.25 miles
- Approach Speed = 55 mph
- Work Zone Speed = 40 mph
- Work Zone In Place 60 Days

24

Twenty Four Hour Analysis Period - SouthBound

Hour	Hourly Distr. (%)	**Demand** (vph)	Cap. (vph)	Queue Rate (vph)	Queued Veh.	Vehicles that ... Stop 55-0-55	Traverse WZ @40 mph	Slowdown 55-40-55
		(AADT)(b)		(c-d)	(e_i+f_{i-1})	IF f > 0,c,0	See Note**	IF g=0, h,0
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
0 - 1	0.9	607	3,027	(2,420)	0	0	607	607
1 - 2	0.5	337	3,027	(2,690)	0	0	337	337
2 - 3	0.4	270	3,027	(2,757)	0	0	270	270
3 - 4	0.4	270	3,027	(2,757)	0	0	270	270
4 - 5	0.6	404	3,027	(2,623)	0	0	404	404
5 - 6	1.8	1,213	6,285	(5,072)	0	0	0	0
6 - 7	4.4	2,966	6,285	(3,319)	0	0	0	0
7 - 8	6.2	4,179	6,285	(2,106)	0	0	0	0
8 - 9	5.7	3,842	6,285	(2,443)	0	0	0	0
9 - 10	5.1	3,438	3,027	411	411	3,438	3,027	0
10 - 11	5.2	3,505	3,027	478	889	3,505	3,027	0
11 - 12	5.6	3,775	3,027	748	1,637	3,775	3,027	0
°	°	°	°	°	°	°	°	°
°	°	°	°	°	°	°	°	°
°	°	°	°	°	°	°	°	°

** If(d=3027,If (c>d,d,c),0)

25

Table Continued

Hour	Hourly Distr. (%)	**Demand** (vph)	Cap. (vph)	Queue Rate (vph)	Queued Veh.	Vehicles that ... Stop 55-0-55	Traverse WZ at 40 mph	Slowdown 55-40-55
		(AADT)(b)		(c-d)	(e_i+f_{i-1})	IF f > 0,c,0	See Note**	IF g=0, h,0
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
12 - 13	6.0	4,044	3,027	1,017	2,654	4,044	3,027	0
13 - 14	5.9	3,977	3,027	950	3,604	3,977	3,027	0
14 - 15	6.4	4,314	3,027	1,287	4,891	4,314	3,027	0
15 - 16	7.4	4,988	5,454	(466)	4,425	4,988	0	0
16 - 17	7.8	5,258	5,454	(196)	4,229	5,258	0	0
17 - 18	7.5	5,055	5,454	(399)	3,830	5,055	0	0
18 - 19	5.9	3,977	5,454	(1,477)	2,353	3,977	0	0
19 - 20	4.9	3,303	5,454	(2,151)	202	3,303	0	0
20 - 21	4.0	2,696	3,027	(331)	0	**1,646** *	2,898	**1,051**
21 - 22	3.3	2,224	3,027	(803)	0	0	2,224	2,224
22 - 23	2.4	1,618	3,027	(1,409)	0	0	1,618	1,618
23 - 24	1.7	1,146	3,027	(,1881)	0	0	1,146	1,146
					Total	**47,279**	**27,936**	**7,926**

*Prorated based on portion of hour required to clear queue.

26

Traffic Affected - Free Flow

- Speed Change (55-40-55)
  - 7,926 vpd (60 days) = 475,569 veh.
- Traverse Workzone
  (at reduced speed of 40 mph)
  - 27,936 vpd (60 days) = 1,676,152 veh.

27

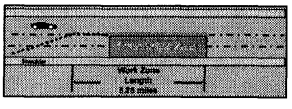
Traffic Affected - Forced Flow

- Stopping (55-0-55)
  - 47,279 vpd (60 day) = 2,836,762 veh.
- Queuing
  - Same as above

28

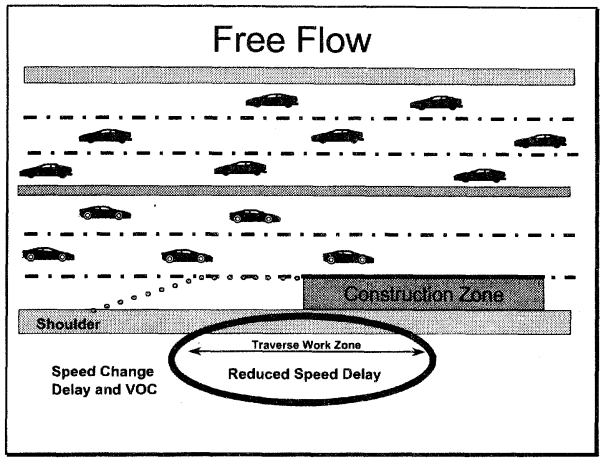
5. Compute Reduced Speed Delay

✓ Traverse Work Zone



✓ Que

29



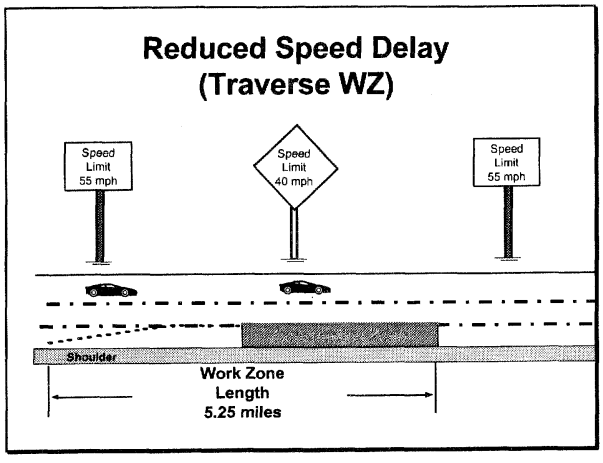
30

Reduced Speed Delay (Traverse WZ)

- Reduced speed delay is ...

  increased travel time necessary to traverse the work zone at the posted speed compared to the up stream posted speed

31



32

Reduced Speed Delay (WZ)

Reduced Speed Delay =

$$\frac{\text{WZ Length}}{\text{WZ Speed}} - \frac{\text{WZ Length}}{\text{Upstream Speed}}$$

33

Reduced Speed Delay (WZ)

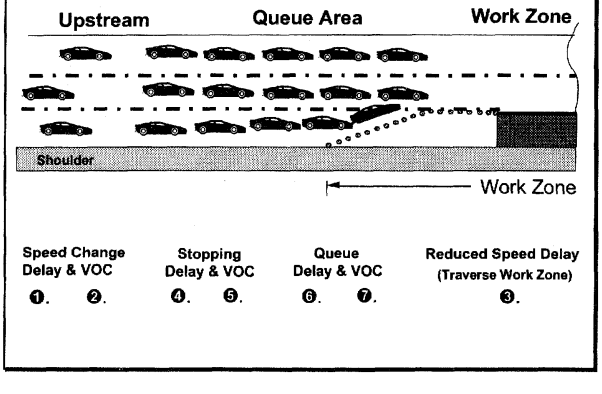
$$\frac{\text{WZ Length}}{\text{WZ Speed}} - \frac{\text{WZ Length}}{\text{Upstream Speed}}$$

$$\frac{5.25 \text{ Miles}}{40 \text{ mph}} - \frac{5.25 \text{ Miles}}{55 \text{ mph}}$$

➡ Delay / Vehicle = 0. 0358 Hours

34

Forced Flow



35

Reduced Speed Delay (Queue)

Reduced Speed Delay =

$$\frac{\text{Queue Length}}{\text{Queue Speed}} - \frac{\text{Queue Length}}{\text{Upstream Speed}}$$

36

Reduced Speed Delay (Queue)

Reduced Speed Delay =

$$\frac{\textbf{Queue Length}}{\textbf{Queue Speed}} - \frac{\textbf{Queue Length}}{\textbf{Upstream Speed}}$$

$$\frac{\text{? Miles}}{\text{? Mph}} - \frac{\text{? Miles}}{\text{55 mph}}$$

37

Reduced Speed Delay (Queue)

- Determine queue speed
- Determine average queue length

38

Reduced Speed Delay (Queue)

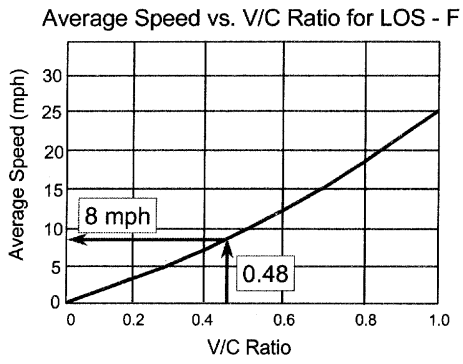
- Determine queue speed

$V/C = Vol_{Queue}/Capacity$

WZ Capacity Upstream

$V/C = 3,027/6,285 = 0.48$

39



Source: NCHRP 133 (1972)

40

Reduced Speed Delay

Queue

$$\frac{\text{Queue Length}}{\text{Queue Speed}} - \frac{\text{Queue Length}}{\text{Upstream Speed}}$$

$$\frac{\text{? Miles}}{\text{8 Mph}} - \frac{\text{? Miles}}{\text{55 mph}}$$

41

Reduced Speed Delay (Queue)

- ✓ Determine queue speed
- ■ Determine average queue length

42

Reduced Speed Delay (Queue)

Average Queue Length =

Maximum Queue Length / 2

43

Twenty Four Hour Analysis Period - SouthBound

Hour	Hourly Distr. (%)	Demand (vph)	Cap. (vph)	Queue Rate (vph)	Queued Veh.	Vehicles that ... Stop 55-0-55	Traverse WZ @40 mph	Slowdown 55-40-55
		⟨AADT⟩(b)		(c-d)	(e_i+f_{i-1})	IF f > 0,c,0	See Note**	IF g=0, h,0
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
0 - 1	0.9	607	3,027	(2,420)	0	0	607	607
1 - 2	0.5	337	3,027	(2,690)	0	0	337	337
2 - 3	0.4	270	3,027	(2,757)	0	0	270	270
3 - 4	0.4	270	3,027	(2,757)	0	0	270	270
4 - 5	0.6	404	3,027	(2,623)	0	0	404	404
5 - 6	1.8	1,213	6,285	(5,072)	0	0	0	0
6 - 7	4.4	2,966	6,285	(3,319)	0	0	0	0
7 - 8	6.2	4,179	6,285	(2,106)	0	0	0	0
8 - 9	5.7	3,842	6,285	(2,443)	0	0	0	0
9 - 10	5.1	3,438	3,027	411	411	3,438	3,027	0
10 - 11	5.2	3,505	3,027	478	889	3,505	3,027	0
11 - 12	5.6	3,775	3,027	748	1,637	3,775	3,027	0
°	°	°	°	°	°	°	°	°
°	°	°	°	°	°	°	°	°
°	°	°	°	°	°	°	°	°

** If(d=3027,If (c>d,d,c),0)

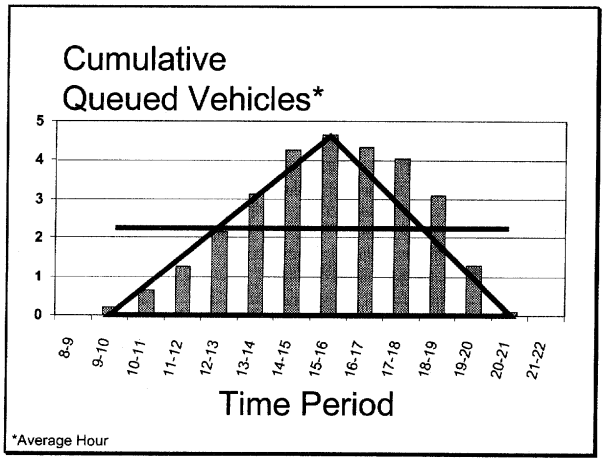
44

Table Continued

Hour	Hourly Distr. (%)	Demand (vph)	Cap. (vph)	Queue Rate (vph)	Queued Veh.	Vehicles that ... Stop 55-0-55	Traverse WZ at 40 mph	Slowdown 55-40-55
		(AADT)(b)		(c-d)	$(e+f_{t-1})$	IF f > 0,c,0	See Note**	IF g=0, h,0
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
12 - 13	6.0	4,044	3,027	1,017	2,654	4,044	3,027	0
13 - 14	5.9	3,977	3,027	950	3,604	3,977	3,027	0
14 - 15	6.4	4,314	3,027	1,287	4,891	4,314	3,027	0
15 - 16	7.4	4,988	5,454	(466)	4,425	4,988	0	0
16 - 17	7.8	5,258	5,454	(196)	4,229	5,258	0	0
17 - 18	7.5	5,055	5,454	(399)	3,830	5,055	0	0
18 - 19	5.9	3,977	5,454	(1,477)	2,353	3,977	0	0
19 - 20	4.9	3,303	5,454	(2,151)	202	3,303	0	0
20 - 21	4.0	2,696	3,027	(331)	0	**1,646** *	2,898	1,051
21 - 22	3.3	2,224	3,027	(803)	0	0	2,224	2,224
22 - 23	2.4	1,618	3,027	(1,409)	0	0	1,618	1,618
23 - 24	1.7	1,146	3,027	(,1881)	0	0	1,146	1,146
					Total	**47,279**	**27,936**	**7,926**

*Prorated based on portion of hour required to clear queue. ** If(d=3027,If (c>d,d,c),0)

45



46

Reduced Speed Delay (Queue)

Caution:

- Queue could grow and stabilize for a period of time and then dissipate.
- This would support calculating queue length on a per hour basis.

47

Reduced Speed Delay (Queue)

Average Queue Length =

Maximum Queue Length / 2

48

Reduced Speed Delay (Queue)

Maximum Queue Length =

$$\frac{\text{Maximum No. of Queued Vehicles}}{\text{Change in Traffic Density}}$$

49

Traffic Density (veh./mi.)

- The number of vehicles on a mile of road.
- Computed by ...
- Volume / Speed (vph/mph)

50

Change in Traffic Density

WZ Capacity at max. no. queued veh. = Demand at max. no. queued veh.

$$\frac{\text{Queue Volume}}{\text{Queue Speed}} - \frac{\text{Upstream Volume}}{\text{Upstream Speed}}$$

51

Change in Traffic Density

=

$$\frac{\text{Queue Volume}}{\text{Queue Speed}} - \frac{\text{Upstream Volume}}{\text{Upstream Speed}}$$

$$\frac{\text{? Vph}}{\text{8 mph}} - \frac{\text{? Vph}}{\text{55 mph}}$$

52

Twenty Four Hour Analysis Period - SouthBound

Hour	Hourly Distr. (%)	Demand (vph)	Cap. (vph)	Queue Rate (vph)	Queued Veh.	Vehicles that ... Stop 55-0-55	Traverse WZ @40 mph	Slowdown 55-40-55
		(AADT)(b)		(c-d)	$(e+f_{t-1})$	IF f > 0,c,0	IF d=3027,c,0	IF g=0, h,0
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
0 - 1	0.9	607	3,027	(2,420)	0	0	607	607
1 - 2	0.5	337	3,027	(2,690)	0	0	337	337
2 - 3	0.4	270	3,027	(2,757)	0	0	270	270
3 - 4	0.4	270	3,027	(2,757)	0	0	270	270
4 - 5	0.6	404	3,027	(2,623)	0	0	404	404
5 - 6	1.8	1,213	6,285	(5,072)	0	0	0	0
6 - 7	4.4	2,966	6,285	(3,319)	0	0	0	0
7 - 8	6.2	4,179	6,285	(2,106)	0	0	0	0
8 - 9	5.7	3,842	6,285	(2,443)	0	0	0	0
9 - 10	5.1	3,438	3,027	411	411	3,438	3,027	0
10 - 11	5.2	3,505	3,027	478	889	3,505	3,027	0
11 - 12	5.6	3,775	3,027	748	1,637	3,775	3,027	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

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Table Continued

Hour	Hourly Distr. (%)	Demand (vph)	Cap. (vph)	Queue Rate (vph)	Queued Veh.	Vehicles that ... Stop 55-0-55	Traverse WZ at 40 mph	Slowdown 55-40-55
		(AADT)(b)		(c-d)	$(e+f_{-1})$	IF f > 0,c,0	IF d=3027,c,0	IF g=0, h,0
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
12 - 13	6.0	4,044	3,027	1,017	2,654	4,044	3,027	0
13 - 14	5.9	3,977	3,027	950	3,604	3,977	3,027	0
14 - 15	6.4	4,314	3,027	1,287	4,891	4,314	3,027	0
15 - 16	7.4	4,988	5,454	(466)	4,425	4,988	0	0
16 - 17	7.8	5,258	5,454	(196)	4,229	5,258	0	0
17 - 18	7.5	5,055	5,454	(399)	3,830	5,055	0	0
18 - 19	5.9	3,977	5,454	(1,477)	2,353	3,977	0	0
19 - 20	4.9	3,303	5,454	(2,151)	202	3,303	0	0
20 - 21	4.0	2,696	3,027	(331)	0	**1,646** *	2,898	1,051
21 - 22	3.3	2,224	3,027	(803)	0	0	2,224	2,224
22 - 23	2.4	1,618	3,027	(1,409)	0	0	1,618	1,618
23 - 24	1.7	1,146	3,027	(,1881)	0	0	1,146	1,146
					Total	**47,279**	**27,936**	**7,926**

*Prorated based on portion of hour required to clear queue.

54

Change in Traffic Density

=

$$\frac{\text{Queue Volume}}{\text{Queue Speed}} - \frac{\text{Upstream Volume}}{\text{Upstream Speed}}$$

$$\frac{(3027 \text{ vph})}{(8 \text{ mph})} - \frac{(4314 \text{ vph})}{(55 \text{ mph})}$$

55

Change in Traffic Density

=

$$\frac{\text{Queue Volume}}{\text{Queue Speed}} - \frac{\text{Upstream Volume}}{\text{Upstream Speed}}$$

$$\frac{(3027 \text{ vph})}{(8 \text{ mph})} - \frac{(4314 \text{ vph})}{(55 \text{ mph})}$$

= 300 veh./mi.

56

Reduced Speed Delay (Queue)

Maximum Queue Length =

$$\frac{\text{Maximum no. of Queued Vehicles}}{\text{Change in traffic density}}$$

$$\frac{4{,}891 \text{ vehicles}}{300 \text{ vehicles/mile}} = 16.3 \text{ Miles}$$

57

Reduced Speed Delay (Queue)

Average Queue Length =

Maximum Queue Length / 2

$$= \frac{16.3 \text{ Miles}}{2} = 8.15 \text{ Miles}$$

58

Reduced Speed Delay

Queue

$$\frac{\text{Queue Length}}{\text{Queue Speed}} - \frac{\text{Queue Length}}{\text{Upstream Speed}}$$

$$\frac{8.15 \text{ Miles}}{8 \text{ Mph}} - \frac{8.15 \text{ Miles}}{55 \text{ mph}}$$

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Reduced Speed Delay

Queue

Queue Length / Queue Speed - Queue Length / Upstream Speed

8.15 Miles / 8 Mph - 8.15 Miles / 55 mph

1.02 Hours - 0.15 Hours

➡ Delay / Vehicle = 0. 87 Hours

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6. Assign VOC Cost Rates

Sources:

- NCHRP 133 Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects, 1972
- Economic Analysis for Highways, Winfrey 1969

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Added Time & Veh. Running Cost / 1000 Stops and Idling Costs (Aug. 1996 values)

Initial Speed (mph)	Added Time (Hr/1000 Stops) (Excludes Idling Time)			Added Cost ($/1000 Stops) (Excludes Idling Cost)		
	Pass Cars	Single Unit Trk	Comb. Truck	Pass Cars	Single Unit Trk	Comb. Truck
5	1.02	0.73	1.10	2.70	9.25	33.62
10	1.51	1.47	2.27	8.83	20.72	77.49
15	2.00	2.20	3.48	15.16	33.89	129.97
20	2.49	2.93	4.76	21.74	48.40	190.06
25	2.98	3.67	6.10	28.67	63.97	256.54
30	3.46	4.40	7.56	36.10	80.23	328.21
35	3.94	5.13	9.19	44.06	96.88	403.84
40	4.42	5.87	11.09	52.70	113.97	482.21
45	4.90	6.60	13.39	62.07	130.08	562.14
50	5.37	7.33	16.37	72.31	145.96	642.41
55	5.84	8.07	20.72	83.47	160.89	721.77
60	6.31	8.80	27.94	95.70	178.98	798.99
65	6.78	9.53	NA	109.02	195.84	NA
70	7.25	NA	NA	123.61	NA	NA
75	7.71	NA	NA	139.53	NA	NA
80	8.17	NA	NA	156.85	NA	NA
Idling Cost ($ / Veh-Hr.)				0.6927	0.7681	0.8248

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Example

55 mph → 40 mph → 55 mph

Initial Speed (mph)	Added Time (Hr/1000 Stops) (Excludes Idling Time) Pass Cars	Single Unit Trk	Comb. Truck	Added Cost ($/1000 Stops) (Excludes Idling Cost) Pass Cars	Single Unit Trk	Comb. Truck
5	1.02	0.73	1.10	2.70	9.25	33.62
10	1.51	1.47	2.27	8.83	20.72	77.49
15	2.00	2.20	3.48	15.16	33.89	129.97
20	2.49	2.93	4.76	21.74	48.40	190.06
25	2.98	3.67	6.10	28.67	63.97	256.54
30	3.46	4.40	7.56	36.10	80.23	328.21
35	3.94	5.13	9.19	44.06	96.88	403.84
40	4.42	5.87	11.09	52.70	113.97	482.21
45	4.90	6.60	13.39	62.07	130.08	562.14
50	5.37	7.33	16.37	72.31	145.96	642.41
55	5.84	8.07	20.72	83.47	160.89	721.77
60	6.31	8.80	27.94	95.70	178.98	798.99
65	6.78	9.53	NA	109.02	195.84	NA
70	7.25	NA	NA	123.61	NA	NA
75	7.71	NA	NA	139.53	NA	NA
80	8.17	NA	NA	156.85	NA	NA
Idling Cost ($ / Veh-Hr.)				0.6927	0.7681	0.8248

63

Example

Added Time & Veh. Running Cost / 1000 Stops and Idling Costs (Aug. 1996 values)

Initial Speed (mph)	Added Time (Hr/1000 Stops) (Excludes Idling Time) Pass Cars	Single Unit Trk	Comb. Truck	Added Cost ($/1000 Stops) (Excludes Idling Cost) Pass Cars	Single Unit Trk	Comb. Truck
55	5.84	8.07	20.72	83.47	160.89	721.77
40	4.42	5.87	11.09	52.70	113.97	482.21
55-40-55	1.42	2.20	9.63	30.77	46.92	239.56

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Note:

Update tables to current year

- Value of time
  - Overall current CPI to base year overall CPI
- VOC
  - Current year transportation component CPI to base year transportation component

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7. Assign Delay Cost Rates

Value of Time

Vehicle Class	$ / Vehicle Hour	
	Value	Range
Passenger Vehicles	11.58	10 - 13
Single Unit Trucks	18.54	17 - 19
Combination Trucks	22.31	21 - 24

Aug. 1996 Dollars

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8. Assign Traffic to Vehicle Classes

Vehicle classification:

- Passenger vehicles
  - Personal
  - Commercial
- Single unit trucks
- Combination trucks

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		Cost Component	Vehicle Class	No. Vehicles
Free Flow	❶	WZ Speed Change Delay	Pass	428,012
		(55-40-55)	SU	25,681
		(475,569)(%Class)=	Comb	21,786
	❷	WZ Speed Change VOC	Pass	428,012
		(55-40-55)	SU	25,681
		(475,569)(%Class)=	Comb	21,786
	❸	WZ Reduced Speed Delay	Pass	1,508,537
		(Traverse WZ at 40 mph)	SU	90,512
		(1,676,152)(%Class)=	Comb	77,103
Forced Flow	❹	Queue Stopping Delay	Pass	2,553,086
		(55-0-55)	SU	153,185
		(2,836,762)(%Class)=	Comb	130,491
	❺	Queue Stopping VOC	Pass	2,553,086
		(55-0-55)	SU	153,185
		(2,836,762)(%Class)=	Comb	130,491
	❻	Queue Added Travel Delay	Pass	2,553,086
		(Traverse Queue at 8 mph)	SU	153,185
		(2,836,762)(%Class)	Comb	130,491
	❼	Queue Idle VOC	Pass	2,553,086
			SU	153,185
		(2,836,762)(%Class)	Comb	130,491

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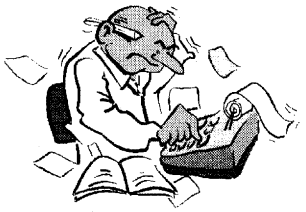
9. Compute User Costs by Vehicle Class



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Cost Component	Vehicle Class	No. Vehicles	Added Time (hpv)	Cost Factor	Cost ($)	%of Total
❶WZ Speed Change Delay 55 ➡.40 ➡.55 mph	Pass	428,012	0.00142	11.58	7,038	0.02
	SU	25,681	0.00220	18.54	1,047	0.00
	Comb	21,876	0.00963	22.31	4,700	0.01
❷WZ Speed Change VOC 55 ➡.40 ➡.55 mph	Pass	428,012		0.03077	13,170	0.04
	SU	25,681		0.04692	1,205	0.00
	Comb	21,876		0.23956	5,241	0.02
❸WZ Reduced Speed Delay 40 vs 55 mph	Pass	1,508,537	0.0358	11.58	625,385	1.85
	SU	90,512	0.0358	18.54	60,076	0.18
	Comb	77,103	0.0358	22.31	61,582	0.18
❹Queue Stopping Delay 55 ➡.0 ➡.55 mph	Pass	2,553,086	0.00584	11.58	172,658	0.51
	SU	153,185	0.00807	18.54	22,919	0.07
	Comb	130,491	0.02072	22.31	60,321	0.18
❺Queue Stopping VOC 55 ➡.0 ➡.55 mph	Pass	2,553,086		0.08347	213,106	0.63
	SU	153,185		0.16089	24,646	0.07
	Comb	130,491		0.72177	94,185	0.28
❻Queue Added Travel Delay 8 vs 55 mph	Pass	2,553,086	0.87	11.58	25,721,320	76.04
	SU	153,185	0.87	18.54	2,470,846	7.30
	Comb	130,491	0.87	22.31	2,532,792	7.49
❼Queue Idle VOC	Pass	2,553,086	0.87	0.6927	1,538,615	4.55
	SU	153,185	0.87	0.7681	102,366	0.30
	Comb	130,491	0.87	0.8248	93,637	0.28

Total WZ User Cost = $33,826,855

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Queue Added Travel Time Delay 8 vs 55 mph

Vehicle Class	No. Vehicles	Added Time (hpv)	Cost Factor	Cost	% of Total
Pass	2,553,086	0.87	11.58	25,721,320	76.04
SU	153,185	0.87	18.54	2,470,846	7.30
Combo	130,491	0.87	22.31	2,532,792	7.49

71

10. Determine Circuity

- Detours - 31cents per mile
  - Road closures
  - Self-imposed diversions
- Driver type

72

Driver Types

- Hang Toughers
- Time Shifters
- Detourees
- Trip Swappers
- Trip Avoiders

73

11. Compute Crash Cost

Crash Cost = (Crash Rate) (Exposure) (Crash Cost)
[units] [crash/100 M VMT] [VMT] [$/crash]

Crash rate: Studies, MicroBENCOST
Exposure: Traffic data
Crash cost: MicroBENCOST defaults, Insurance, SHA

Note:
Crash rate and cost is determined by type of crash.

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Crash Costs

- Commonly assumed that Crashes triple in work zone compared to normal operation of facility
- Not much statistical data to support rule
- WZ Crash rates?

75

Crash Injury Rates Computed From *1995 Highway Statistics*

Persons Injured per 100 Million VMT

	Rural		Urban	
Functional Class	Fatalities	Non-Fatal Injury	Fatalities	Non-Fatal Injury
Interstate	1.0	25.0	0.6	74.3
Other Freeways	-	-	0.9	57.2
Other Principal Arter	2.1	55.8	1.6	208.8
Minor Arterial	2.8	108.6	1.3	175.8
Major Collector	2.7	100.8	-	-
Minor Collector	3.1	120.4	-	-
Collectors	-	-	2.0	172.4
Local	3.7	224.8	2.2	292.1

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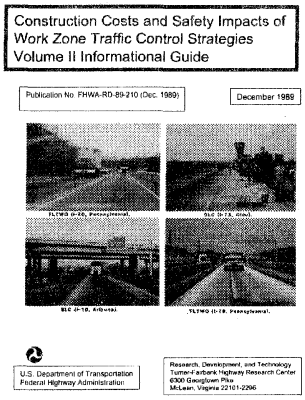

"Construction Cost and Safety Impacts of Work Zone Traffic Control Strategies"

Publication No. FHWA-RD-89-210 (Dec. 1989)

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Constraints of Study

- Single lane closure (SLC) versus two-lane two-way operation (TLTWO) Rural, 4-lane divided highways
- ADT: 10,000 to 30,000
- 51 projects in 11 states
- 3 had traffic delays

78

Primary Findings

- Many variables influence WZ cost control strategy
- No statistical difference in Crash rates for SLC vs. TLTWO
- Fatal + injury Crashes had a signif. increase for both SLC and TLTWO
- No significant accidents to construction workers

79

Annual Crashes / mi / 10k ADT

Single Lane Closure

	Before	During	Change
Average	2.256	3.414	1.159
StdDev	1.525	2.372	

Based on data from 26 projects.

Two Lane Two Way Oper.

	Before	During	Change
Average	3.241	3.057	-0.184
StdDev	2.191	1.384	

Based on data from 22 projects.

80

12. Sum Total Work Zone User Costs

Delay & VOC
+ Circuity
+ Crash

Total User Costs

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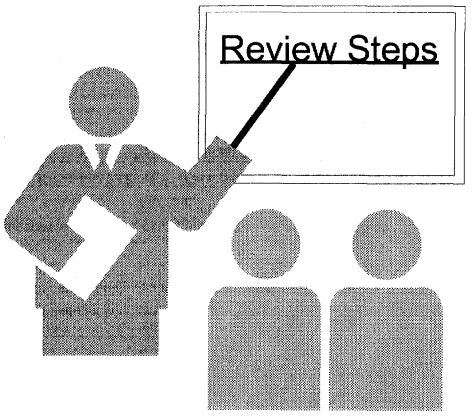

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WZ User Costs Steps

1. Determine Capacity
2. Calculate Directional Hourly Demand
3. Identify User Cost Components
4. Quantify Traffic Affected by Each Component
5. Compute Reduced Speed Delay Times
6. Assign VOC Cost Rates

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WZ User Costs Steps (Con't)

7. Assign Delay Cost Rates
8. Assign Traffic to Vehicle Classes
9. Compute User Costs by Vehicle Class
10. Circuity
11. Crash Costs
12. Sum Total User Costs

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End Session

1

Basic Statistics

2

Session Overview

- Probability Concepts
- Probability Distributions
- Measures of Central Tendency
- Measures of Variability
- Interpreting Results

3

Probability Concepts

- Probability is the likelihood of an event occurring
- Probabilities sum to 100%

4

Two Same Birthdays

$$P = 1 - \left[\frac{365!}{(365-n)!\ (365^n)}\right]$$

n = number of people

23 people ... P = 51%

30 people ... P = 71%

5

Probability Development

- Theoretical
  - Math
- Empirical
  - Experience

6

Variables

- Discrete
- Continuous

7

Discrete

- Countable
- Examples - rolling dice
  - birthday
  - # of accidents

8

DICE COMBINATIONS

Dice	1	2	3	4	5	6
1	2	3	4	5	6	7
2	3	4	5	6	7	8
3	4	5	6	7	8	9
4	5	6	7	8	9	10
5	6	7	8	9	10	11
6	7	8	9	10	11	12

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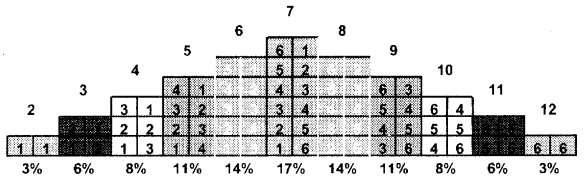
Discrete Probability of Dice



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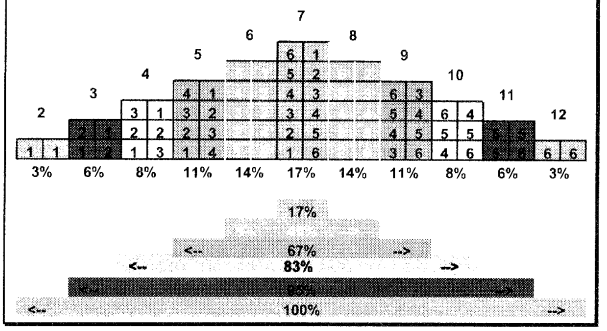
Discrete Probability of Dice



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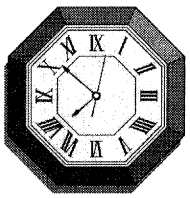
Continuous

- Uncountable



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Probability Distributions

- Common Varieties
  - Normal
  - Uniform
  - Triangular

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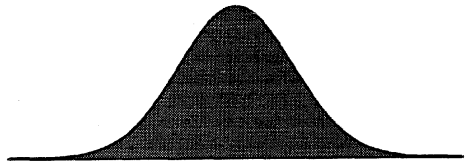
Normal Distribution

- Bell shaped curve
  - Intelligence tests
  - Defined by mean and std. dev.



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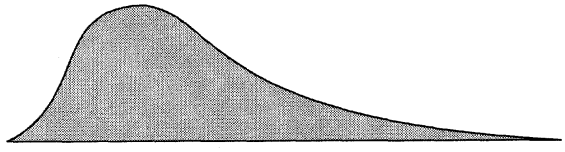
Skewed Distribution



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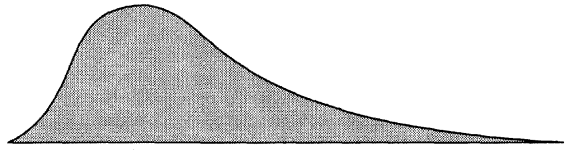
Skewed Distribution



Salaries

Michael Jordan

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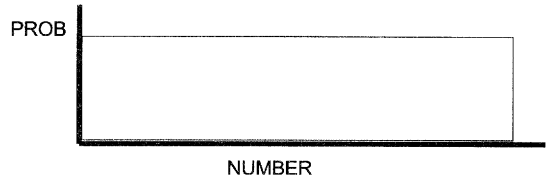
Uniform Distribution

- Equal Chance
  - Lottery Numbers



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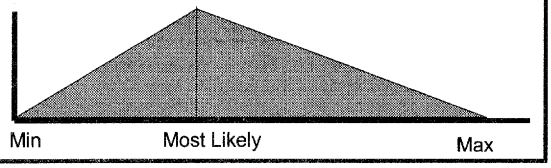
Triangular Distribution

- Defined by:
  - Min - Most Likely - Max
- Handy for estimating



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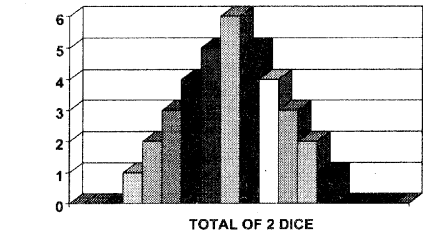
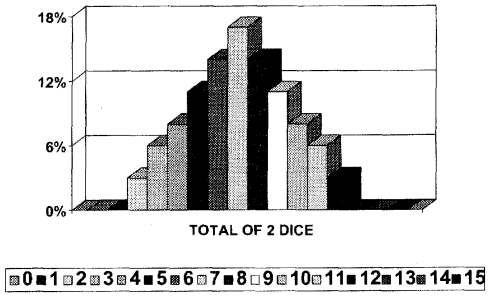
Histogram



0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

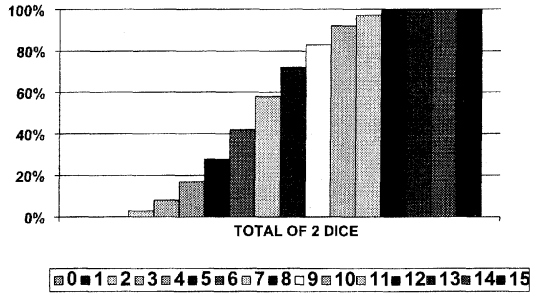
19

Histogram with %



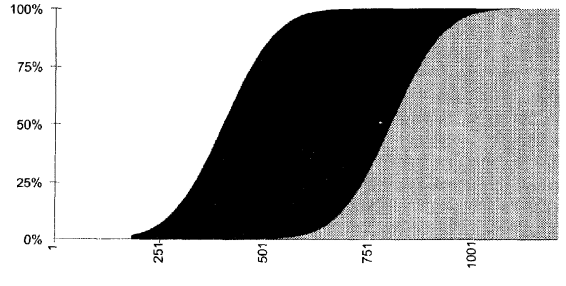
20

Cumulative Ascending



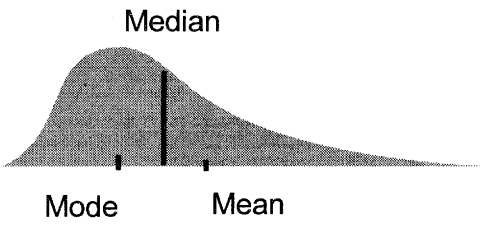
21

Multiple Cumulative



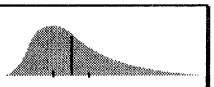
22

Measures of Central Tendency



23

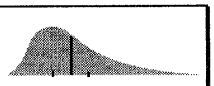
Mode



- Point with the greatest frequency
- Used for quick estimate
- Identifies most common value
- More than one possible

24

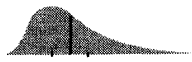
Median



- Equal number of variables on each side
- Not sensitive to extreme values

25

Mean



- Balance point of distribution
- Sensitive to all scores
- Extreme values can effect

26

Measures of Variability

- Range
- Standard Deviation
- Coefficient of Variation

27

Range

- Difference between largest and smallest measurement in a set
- In our dice example the range should be 12 - 2 = 10

28

Standard Deviation

- Root Mean Square of individual deviations from the mean
- Sensitive to all values

29

Formula

- Population

$$\sigma = \sqrt{\sum (x_i - \bar{x})^2 / n}$$

- Sample

$$s = \sqrt{\sum (x_i - \bar{x})^2 / (n-1)}$$

30

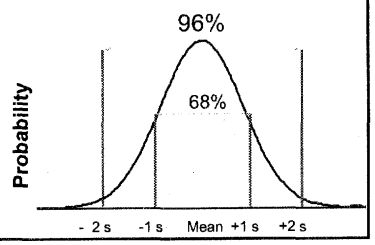
Rule of Thumb

- Standard Deviation may be estimated by dividing the range by 4 to 6

31

Applications

- 68% of data within ± 1 σ
- 96% within ± 2 σ



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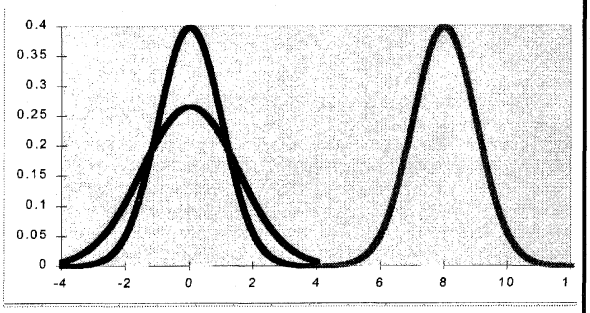
Means & Standard Deviations



33

Coefficient of Variation

- COV = Std. Dev./ Mean
  - Mean = 120
  - Std. Dev. = 30
  - COV = 25%
- Use To Normalize Variation

34

Population - Set of all measurements of interest

Sample - Subset of measurements selected from the population

35

Random Sample

- Each part of the population has an equal chance of being included in the sample

36

Confidence Intervals

- There is a 95% probability that the mean height of class members is between 63 and 73 inches

37

Difference Between Means

- Significance levels
- Statistical versus practical significance

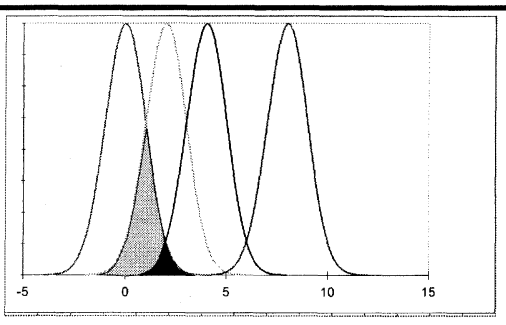
38

Interpreting Results

- Percentiles
- Distributions
  - Overlapping
  - Cumulative

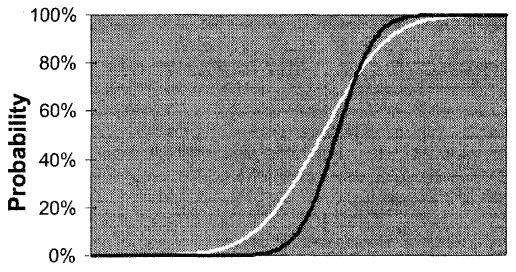
39

Overlapping Normals



40

Overlapping Cumulative



41

Correlation

- How well does a regression equation describe the data
- $R^2 = 1.0$ Perfect
- $R^2 = 0.0$ None
- Percentage of variation described by equation

42

Interpreting R

- R>0
  - Positive correlation
- R<0
  - Negative correlation

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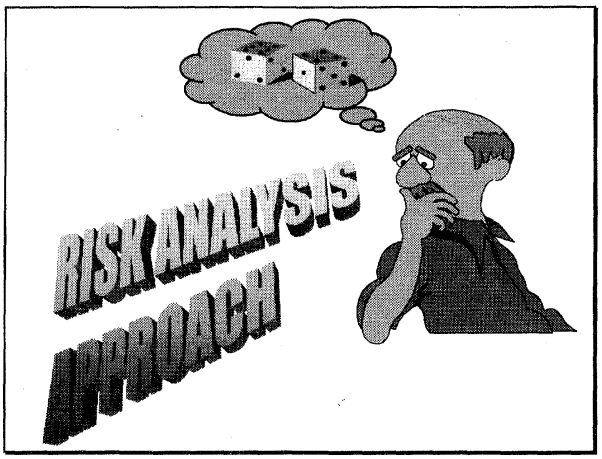
End Session

1



2

Session Overview

- Deterministic Approach
- Sources of Variability
- Risk Analysis Approach
- Applications
- Advantages/Disadvantages

3

Deterministic Approach

- Select discrete point values
  - Initial cost
  - Future cost
  - Timing of future cost
  - Value of time
  - Discount rate
- Compute discrete alternative NPV

4

Deterministic Approach

$ 29.4 M $ 26 M

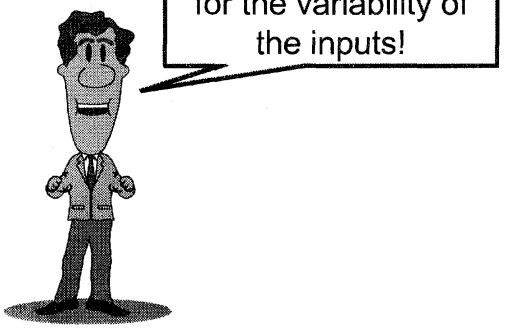
NPV = Initial Cost +

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

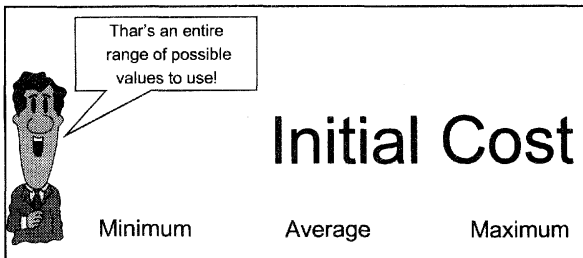
$ 9 M

5% 20 yrs

5



6



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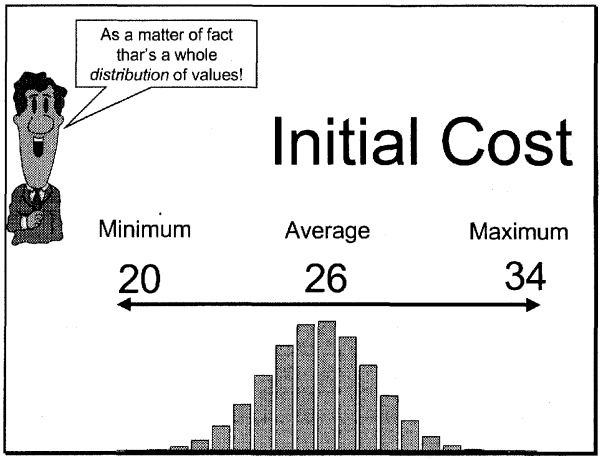

8

Sources of Variability

Assumptions and estimates in ...

➡Agency Costs

- initial, rehab. construction, and maintenance activities --->materials, labor, overhead

➡User Costs

- Daily delay (traffic --> initial & growth rate, daily distribution), construction work days, value of time, ...

9

Sources of Variability Con't

➡Discount Rate

➡Performance

- Environment, traffic loading, subgrade properties, materials design and construction ...

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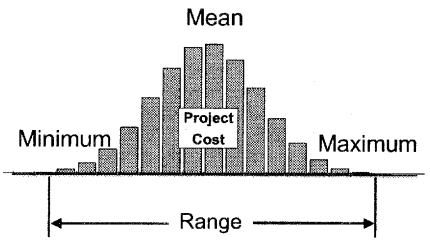
Probability Distributions



❶ Range of Outcomes

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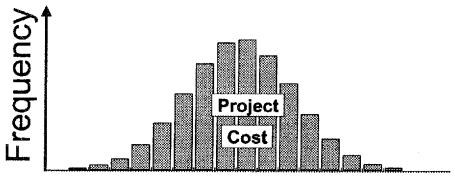
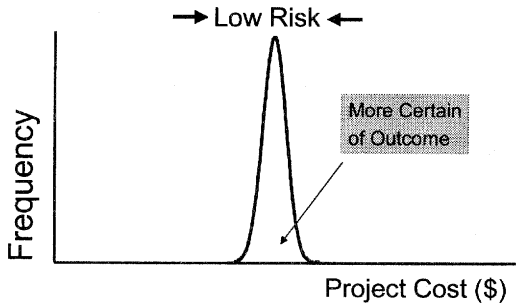
Probability Distributions



❷ Likelihood of Occurrence

18

Probability and Risk



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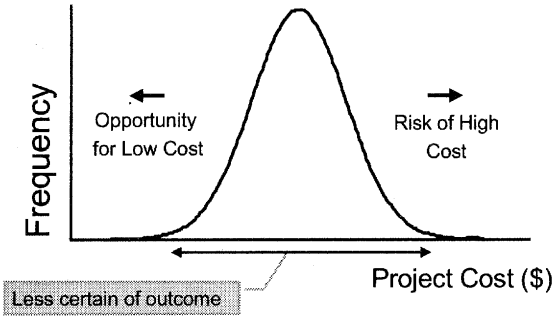
Probability and Risk



20

Five Step Approach to Risk Analysis

1. Identify structure and logic of problem
2. Quantify assumptions w/ probabilistic descriptions of uncertain variables
3. Simulate problem to obtain results
4. Analyze and interpret results
5. Make consensus decision

21

1. Identify Structure and Logic of Problem

$$NPV = \text{Initial Cost} + \sum_{k=1}^{N} \text{Future Cost}_k \times \left[\frac{1}{(1+i)^{n_k}}\right]$$

i = discount rate
n = year of expenditure

22

2. Quantify Assumptions Using Probability

- Identify variables to include
- Describe uncertainty

23

Variables to Include ...

- Agency costs
- User costs
- Timing of costs
- Discount rate

24

Agency Costs

- Preliminary engineering
- Construction management
- Construction costs
- Maintenance costs

25

User Costs

- Current traffic
- Future traffic
- Hourly demand
- Vehicle distributions
- Dollar value of delay time
- Work zone configuration
- Work zone hours of operation
- Work zone duration
- Work zone activity years
- Accident rates

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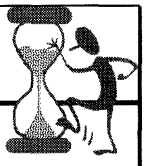
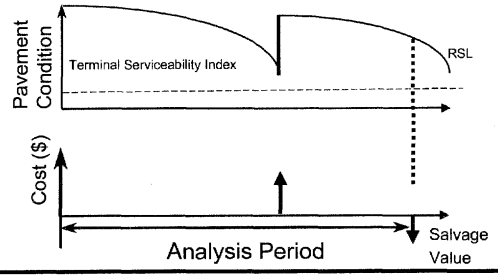
Timing of Costs



- Pavement performance



27

Discount Rate

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

28

Describe Uncertainty

- Objective Method
- Subjective Method

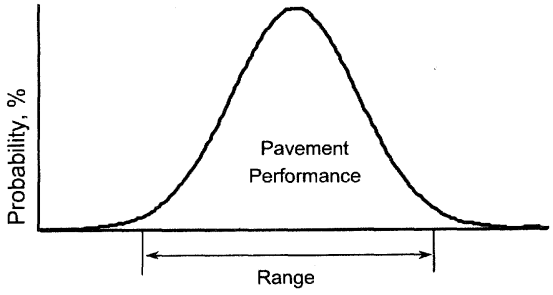
29

Objective Method

- Historical data
  - BAMS
  - PMS
  - Research studies
  - Other
- Statistical analysis software
  - BestFit, ...

30

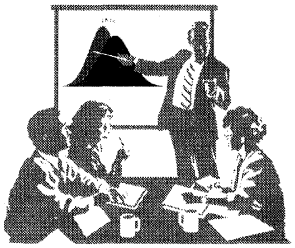
Objective Method - Ideal



31

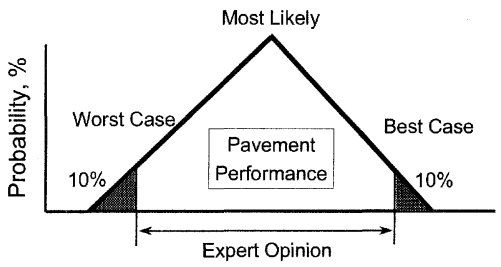
Subjective Method

- Interviews
- Group discussion
  - Facilitated
  - Consensus Building
- Surveys



32

Subjective Method



33

3. Simulate Problem to Obtain Results

Monte Carlo Simulation ...

- Values are randomly selected from input probability distributions
- Each randomly selected set is used to determine an outcome
- Combination of all outcomes form a probability distribution of results

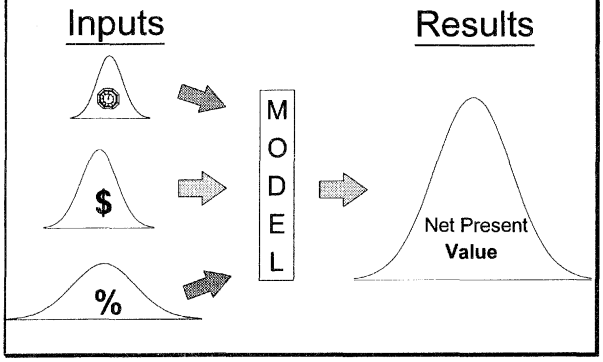
34

Monte Carlo Simulation

- Rigorous extension of ...
  - best case
  - most likely
  - worst case
- Use empirical or theoretical equations
- Calculation intensive

35

Monte Carlo Simulation



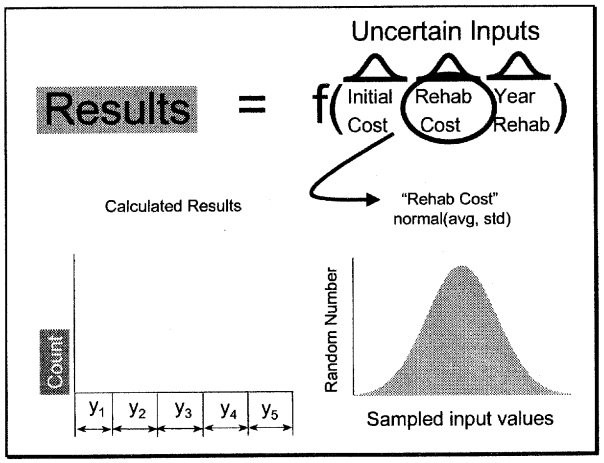
36

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

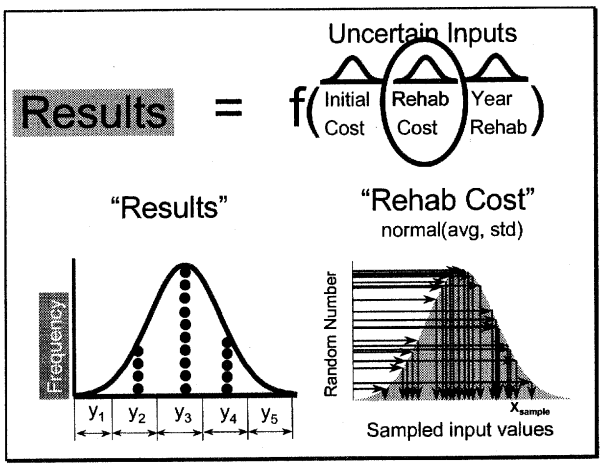
Uncertain Inputs

$$\text{Results} = f(\text{Initial Cost}, \text{Rehab Cost}, \text{Year Rehab})$$

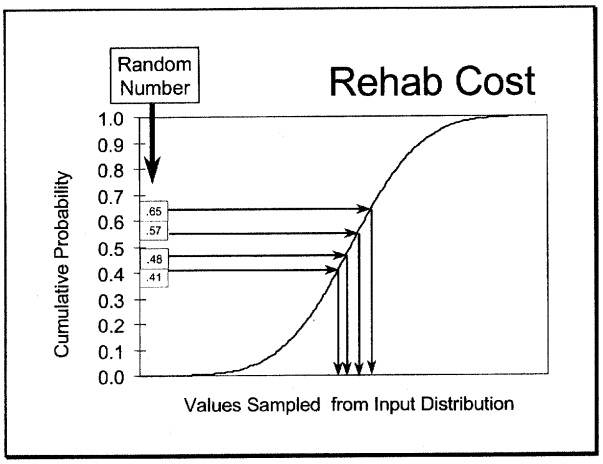
37


Uncertain Inputs
Results
=
f(
Initial Cost
Rehab Cost
Year Rehab
)
Calculated Results
"Rehab Cost"
normal(avg, std)
Count
y_1 y_2 y_3 y_4 y_5
Random Number
Sampled input values

38

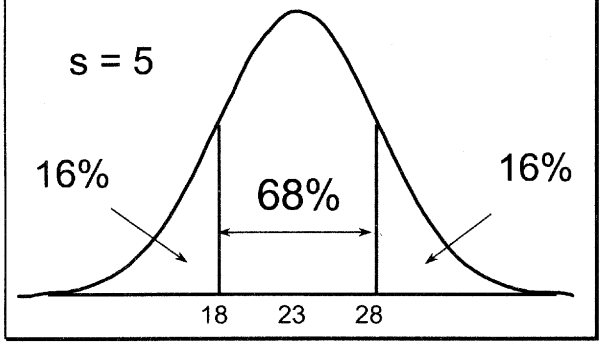

Uncertain Inputs
Results
=
f(
Initial Cost
Rehab Cost
Year Rehab
)
"Results"
"Rehab Cost"
normal(avg, std)
Frequency
y_1 y_2 y_3 y_4 y_5
Random Number
x_{sample}
Sampled input values

39


Random Number
Rehab Cost
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
.65
.57
.48
.41
Cumulative Probability
Values Sampled from Input Distribution

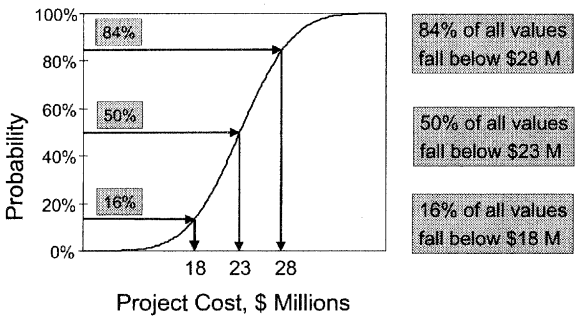
46

Presenting Results: Histogram



47

Presenting Results: Cumulative



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Examples

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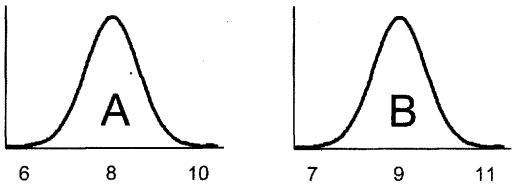
Agency NPV

$s_A = s_B$

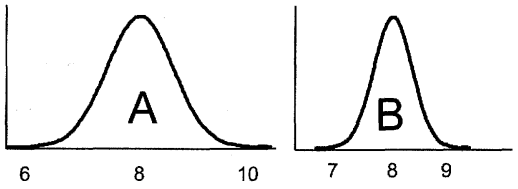


Which alternative do you select?

50

Agency NPV

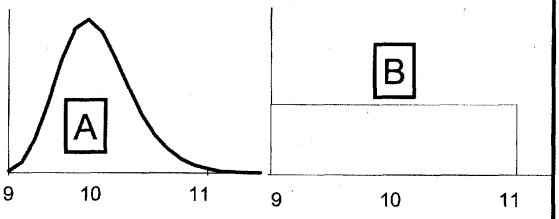
$s_B = 1/2\ s_A$



Which alternative do you select?

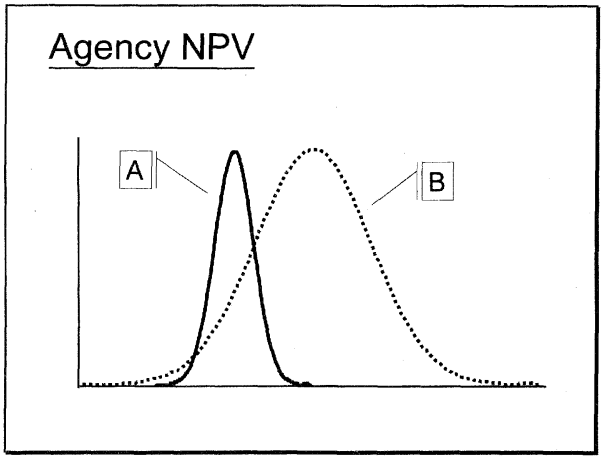
51

Agency NPV

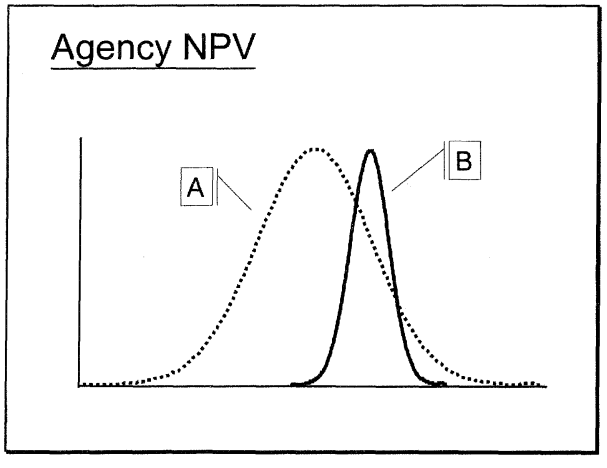


Which outcome has greater risk?

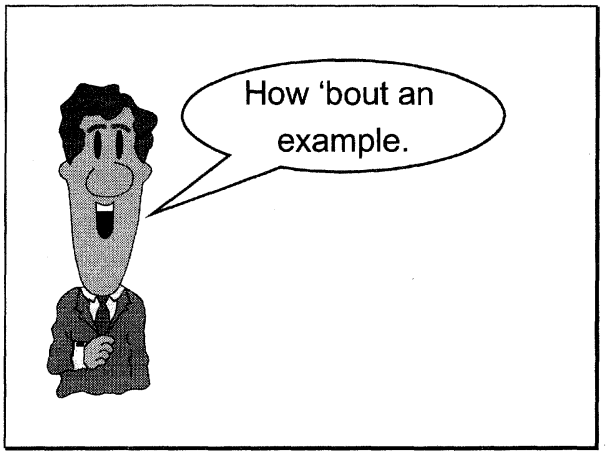
52



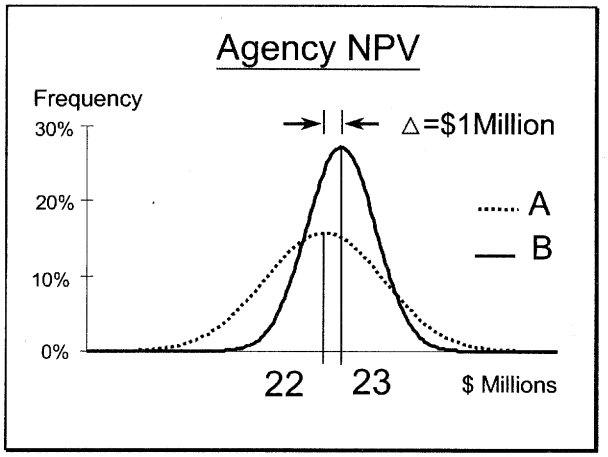
53



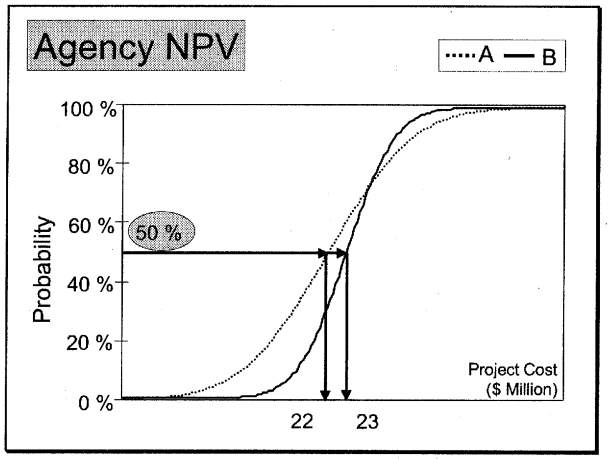
54



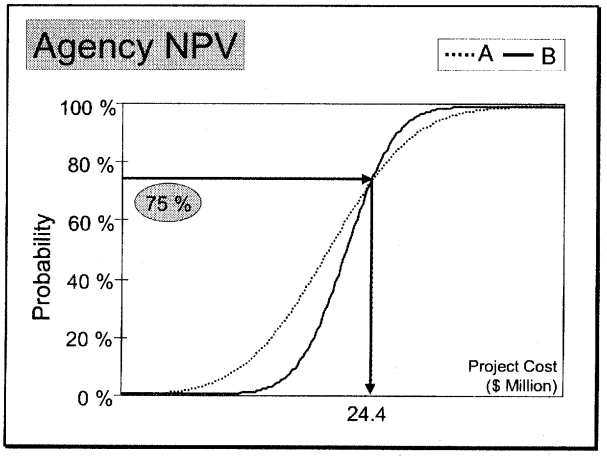
55


Agency NPV
Frequency
30%
20%
10%
0%
△=$1Million
A
B
22
23
$ Millions

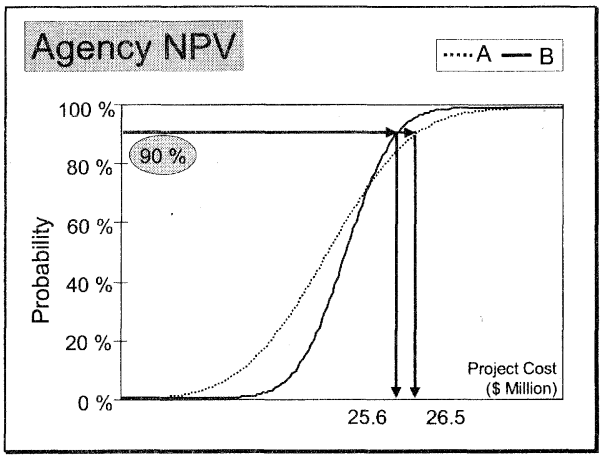
56


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

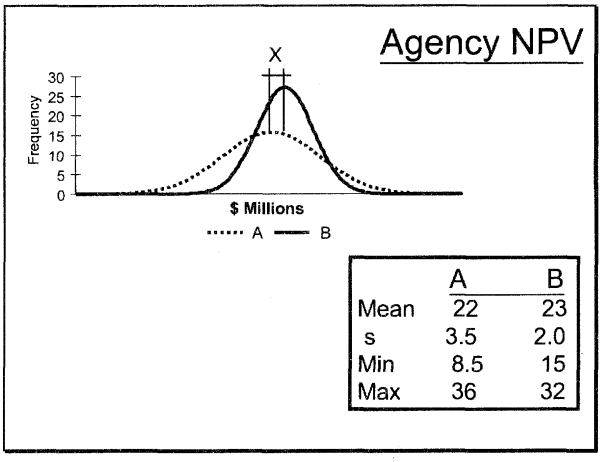
57


Agency NPV
A
B
100 %
80 %
60 %
40 %
20 %
0 %
Probability
75 %
Project Cost
($ Million)
24.4

58

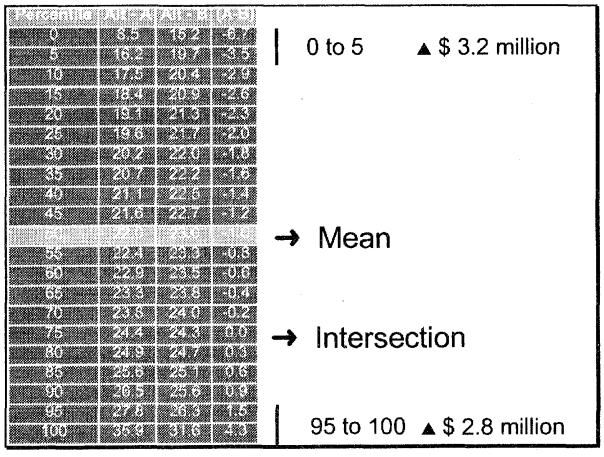


59



	A	B
Mean	22	23
s	3.5	2.0
Min	8.5	15
Max	36	32

60



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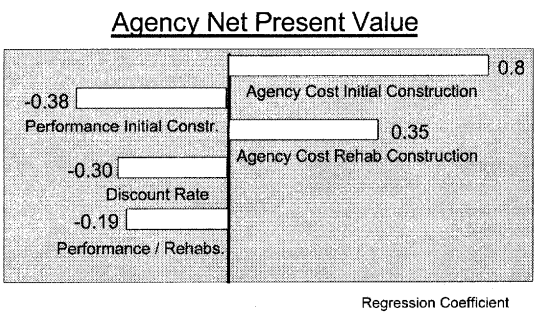
Regression Sensitivity (Tornado Graphs)



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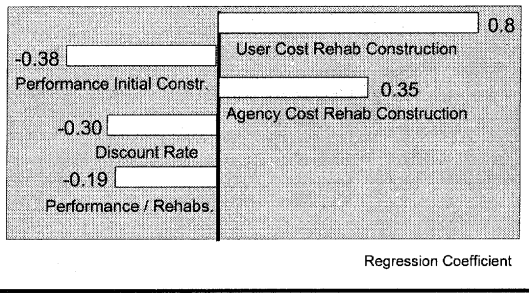
Regression Sensitivity (Tornado Graphs)



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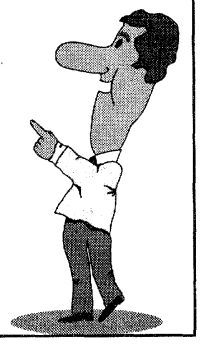
Scenario Analysis

- Examine changes in policy variables
- Example:
  - Closing down a lane of traffic
    versus
  - Keeping traffic lane open
- Develop better alternatives

64

5. Make Consensus Decision

- Decisions about ...
  - Strategic Planning
  - Resource Allocation
  - Timing of Investments



65

Risk Analysis Approach (Review)

1. Identify structure and logic of problem
2. Quantify assumptions w/ probabilistic descriptions of uncertain variables
3. Simulate problem to obtain results
4. Analyze and interpret results
5. Make consensus decision

66

Applications

- Investment & new product analysis

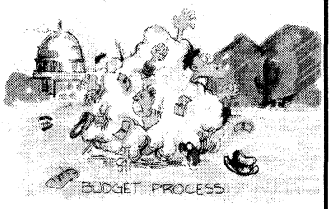
New Drug Research

American Stock Exchange

67

Applications

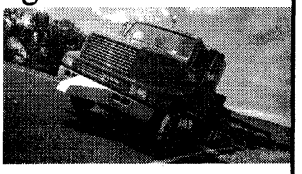
- Investment & new product analysis
- Capital budgeting



68

Applications

- Investment & new product analysis
- Capital budgeting
- Performance specifications



WesTrack

69

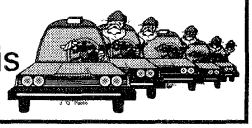
Applications

- Investment & new product analysis
- Capital budgeting
- Performance specifications
- Quality control

70

Applications

- Investment & new product analysis
- Capital budgeting
- Performance specifications
- Quality control
- Traffic flow analysis



71

Applications

- Investment & new product analysis
- Capital budgeting
- Perf. spec. & quality control
- Traffic flow analysis
- Engineering design

Performance Database

Future Pavement Condition

72

Example: Flexible Pavement Design

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN + 1) - 0.2$$

$$+ \frac{\log_{10}\left(\frac{\Delta PSI}{4.2 - 1.5}\right)}{0.40 + \frac{1094}{(SN + 1)^{5.19}}}$$

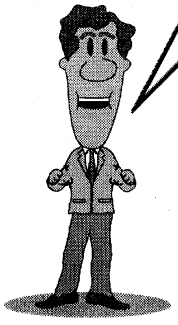
$$+ 2.32 \times \log_{10}(M_R) - 8.07$$

73

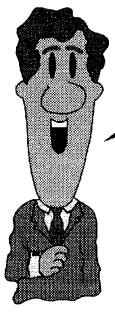
Disadvantages

- Computer intensive
  - Proprietary software
  - Complex models
- Requires some statistical background
- Requires "buy-in" of risk management by senior executives

74



75



76

Advantages

- Quantify risk
- Provide decisionmaker the opportunity to take mitigating action
- Justify budget requests, pavement structural designs, …
- Scenario analysis to create better alternatives

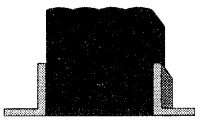
77

Advantages Con't

- Elevates the LCCA debate ...
  - From validity of results
  - To what is "our" best policy

78

Additional Resources



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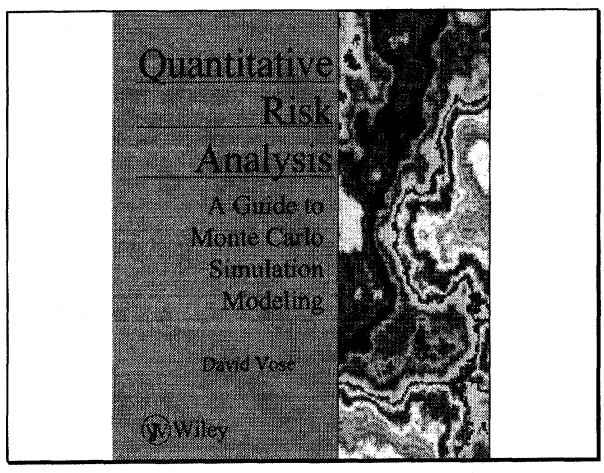
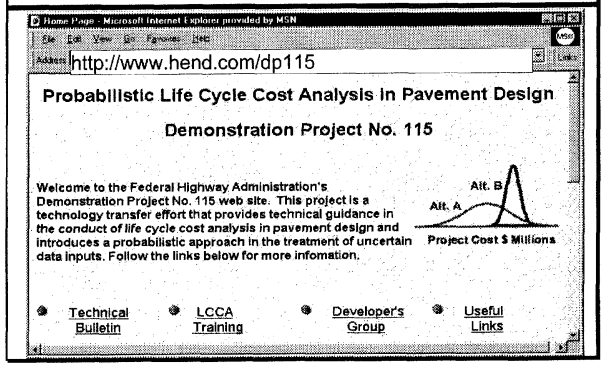


80

DP 115 Web Site

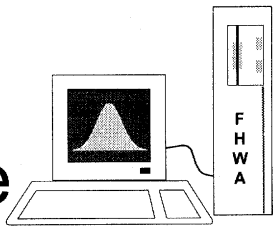


81

End Session

1

Software Demonstration



2

Session Overview

Part 1

- Adding Uncertainty to Models

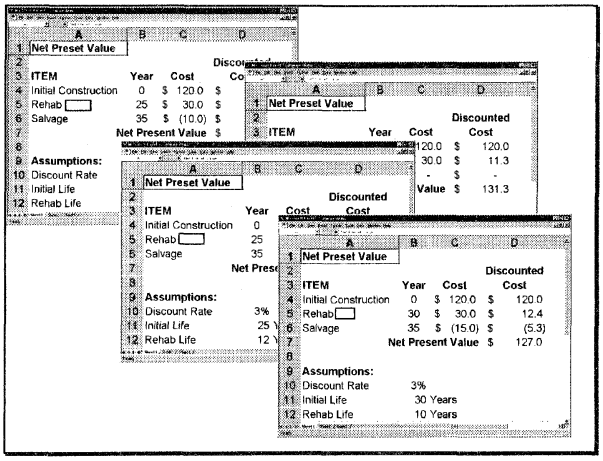
Part 2

- Running a Risk Analysis
- @Risk Results

3

	A	B	C	D
1	**Net Preset Value**			
2				**Discounted**
3	**ITEM**	**Year**	**Cost**	**Cost**
4	Initial Construction	0	$ 120.0	$ 120.0
5	Rehab	30	$ 30.0	$ 12.4
6	Salvage	35	$ (15.0)	$ (5.3)
7		**Net Present Value**		$ 127.0
8				
9	**Assumptions:**			
10	Discount Rate	3%		
11	Initial Life	30	Years	
12	Rehab Life	10	Years	

4



5

NPV = $132 NPV = $150 NPV = $97 NPV = 123 NPV = $76 NPV = $200 NPV = $156 NPV = $148 NPV = $45 NPV = $187 NPV = ($156) NPV = $286 NPV = $98 NPV = $34 NPV = $165 NPV = $ 6 NPV = $129 NPV 47 NPV = $27 NPV 175 NPV = $145 = ($94) NPV = $ 4) NPV = $190 NPV = $167 NPV = $10 NPV = $132 NPV = $88 NPV = $98 NPV = $44 NPV = $22 NPV = $50 NPV = $65 NPV =$90 NPV = $22 NPV = $50 NPV = $65 NPV =$90

Help!

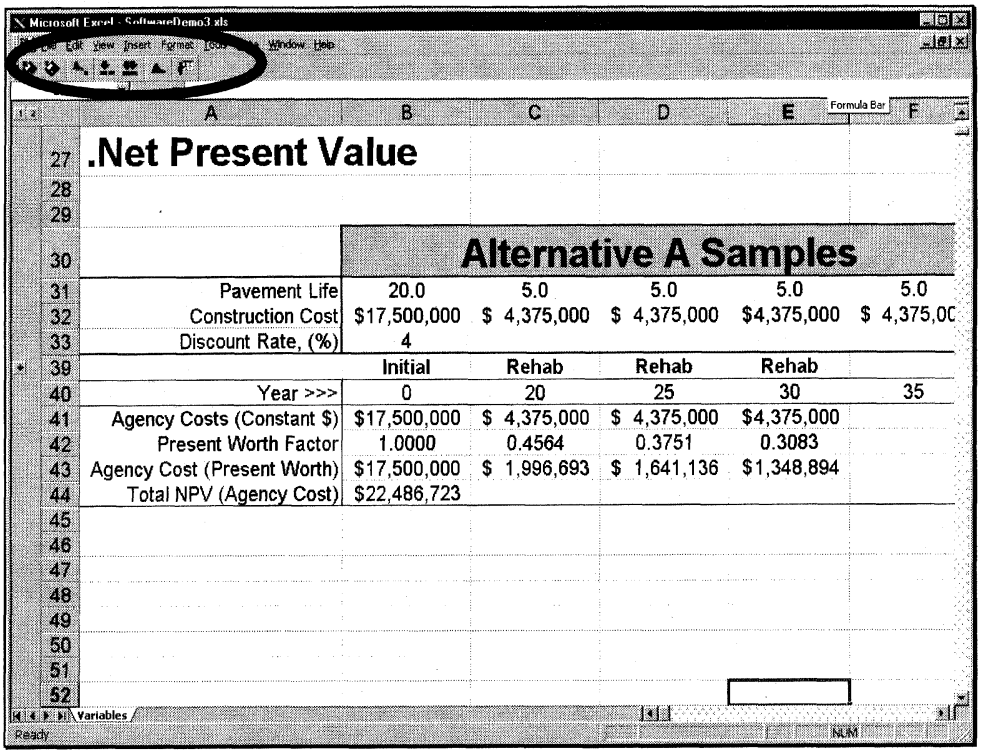
6

Solution: Modeling Uncertainty with Probability

@Risk works with Excel or Lotus

- How to add risk analysis to spreadsheet models
- How to use built-in @Risk functions

7

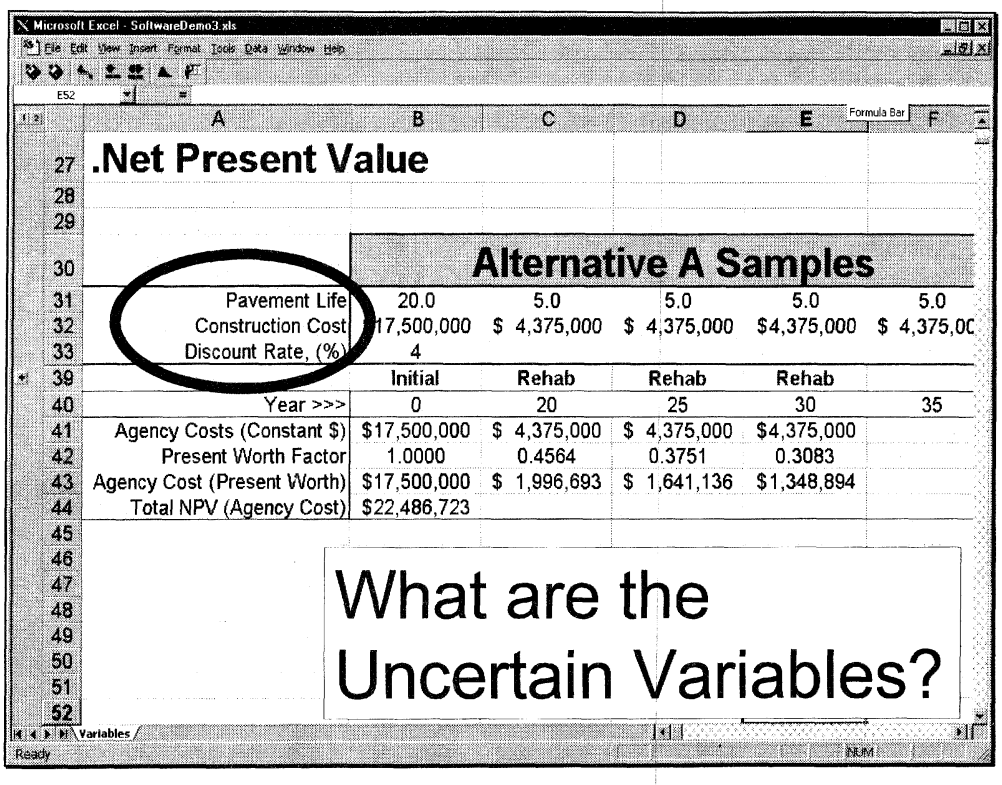


8

Adding Variability to Spreadsheet Models

- Identify uncertain variables

9



10

Adding Variability to Spreadsheet Models

- Identify uncertain variables
- Describe uncertain variables as probability distributions

11

Adding Variability to Spreadsheet Models

- Identify uncertain variables
- Describe uncertain variables as probability distributions
- @Risk provides over 30 built-in probability functions

12

@Risk Probability Functions

Beta	Gamma	**Normal**
Binomial	Geometric	Pareto
Chi-Square	General	Poisson
Cumulative	Histogram	Truncated Exponential
Dependent	Hypergeometric	Truncated Lognormal
Discrete	Independent	Truncated Normal
Discrete Uniform	Logistic	**Triangle**
Error Function	**Lognormal**	**Trigen**
Erlang	Lognormal2	**Uniform**
Exponential	Negative Binomial	Weibull

13

Functions are Similar to Excel

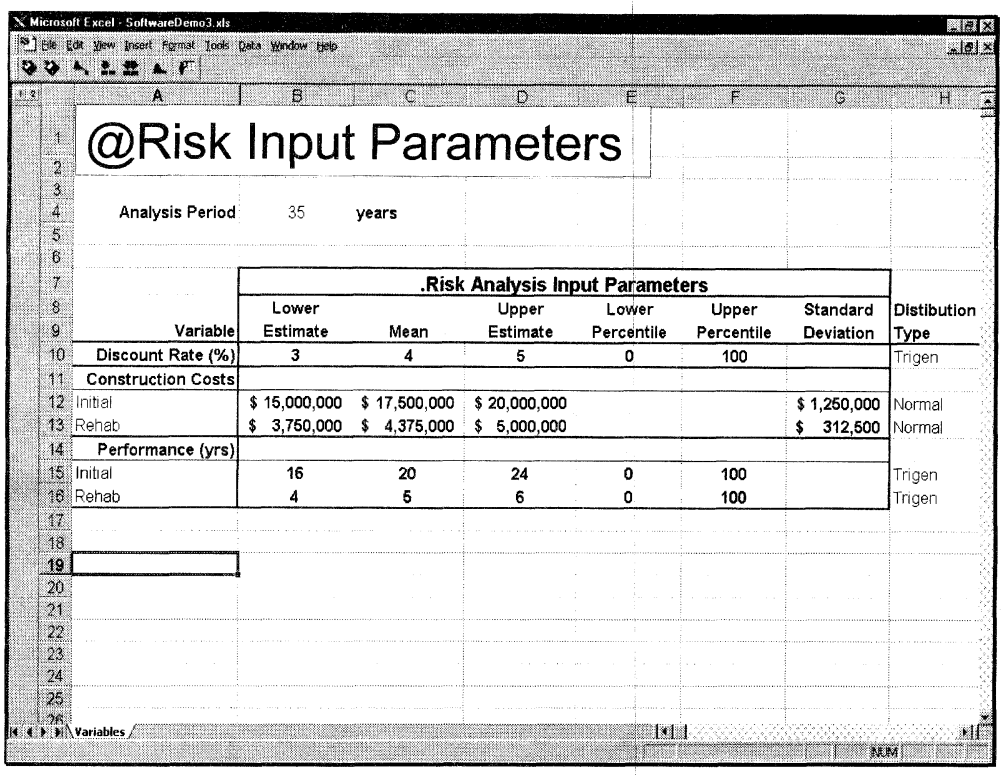
=RiskNormal(A1,A2)

=RiskNormal(3500*B7,C12/3000)

=RiskNormal(RiskLognormal(A1,A2),RiskUniform(1,5))

=If (G7>0,RiskNormal(3500,300),RiskNormal(3500,300*G8))

14



Microsoft Excel - SoftwareDemo3.xls

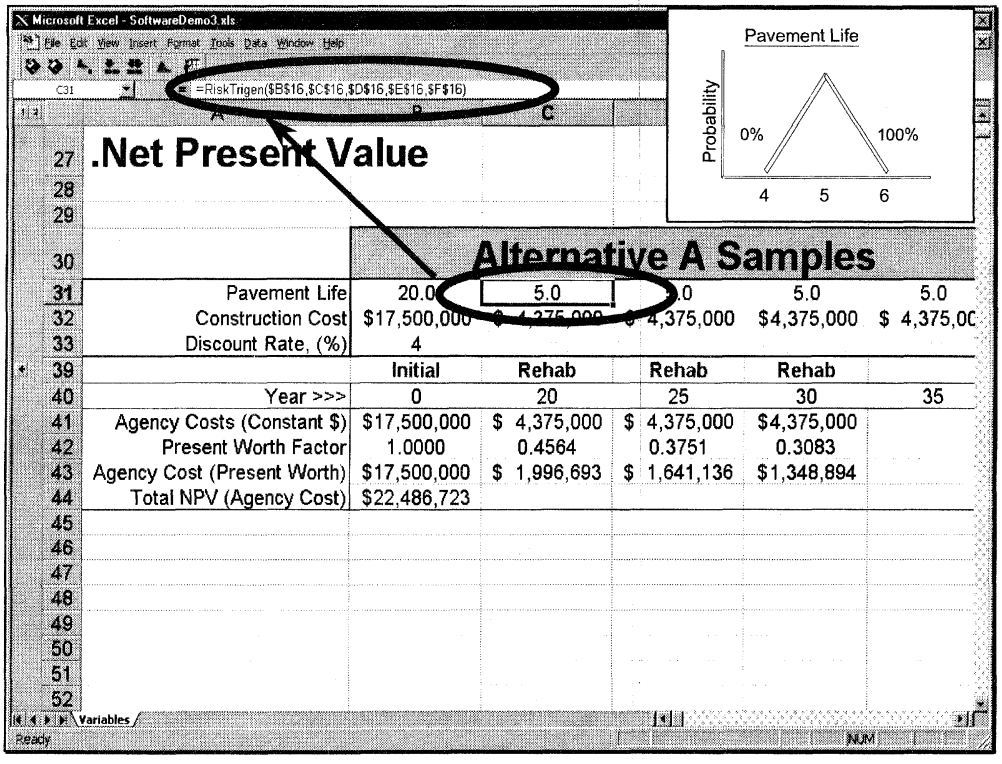
@Risk Input Parameters

Analysis Period 35 years

	.Risk Analysis Input Parameters						
Variable	Lower Estimate	Mean	Upper Estimate	Lower Percentile	Upper Percentile	Standard Deviation	Distibution Type
Discount Rate (%)	3	4	5	0	100		Trigen
Construction Costs							
Initial	$ 15,000,000	$ 17,500,000	$ 20,000,000			$ 1,250,000	Normal
Rehab	$ 3,750,000	$ 4,375,000	$ 5,000,000			$ 312,500	Normal
Performance (yrs)							
Initial	16	20	24	0	100		Trigen
Rehab	4	5	6	0	100		Trigen

Variables

15



.Net Present Value

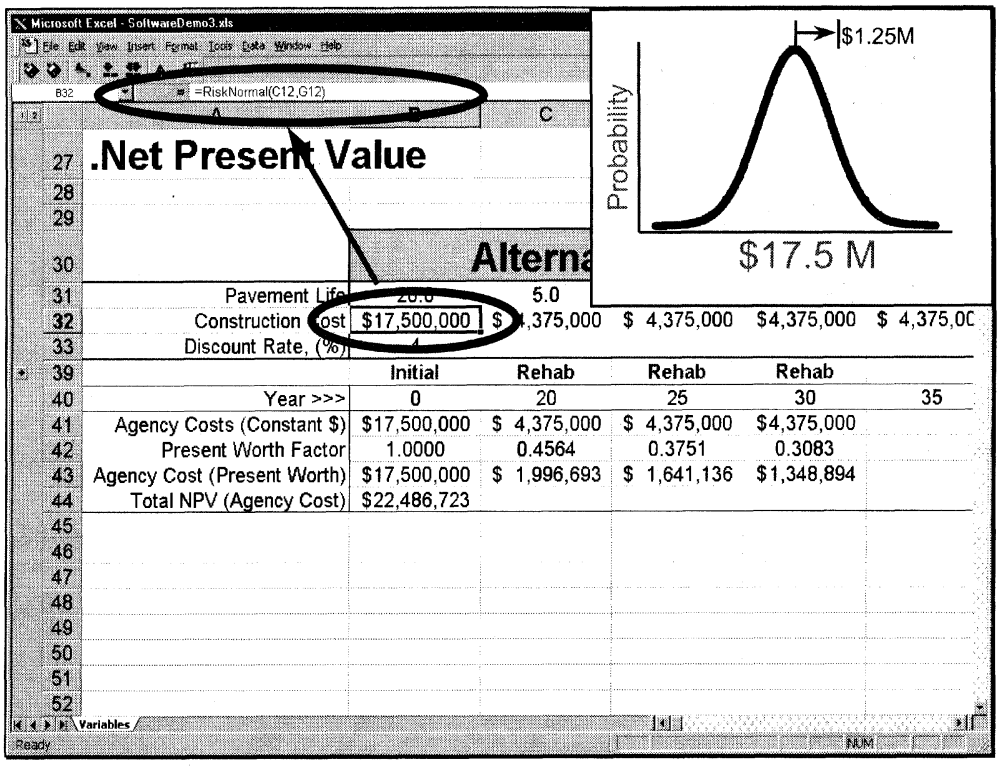
	Alternative A Samples				
Pavement Life	20.0	5.0	.0	5.0	5.0
Construction Cost	$17,500,000	$ 4,375,000	$ 4,375,000	$4,375,000	$ 4,375,00
Discount Rate, (%)	4				

	Initial	Rehab	Rehab	Rehab	
Year >>>	0	20	25	30	35
Agency Costs (Constant $)	$17,500,000	$ 4,375,000	$ 4,375,000	$4,375,000	
Present Worth Factor	1.0000	0.4564	0.3751	0.3083	
Agency Cost (Present Worth)	$17,500,000	$ 1,996,693	$ 1,641,136	$1,348,894	
Total NPV (Agency Cost)	$22,486,723				

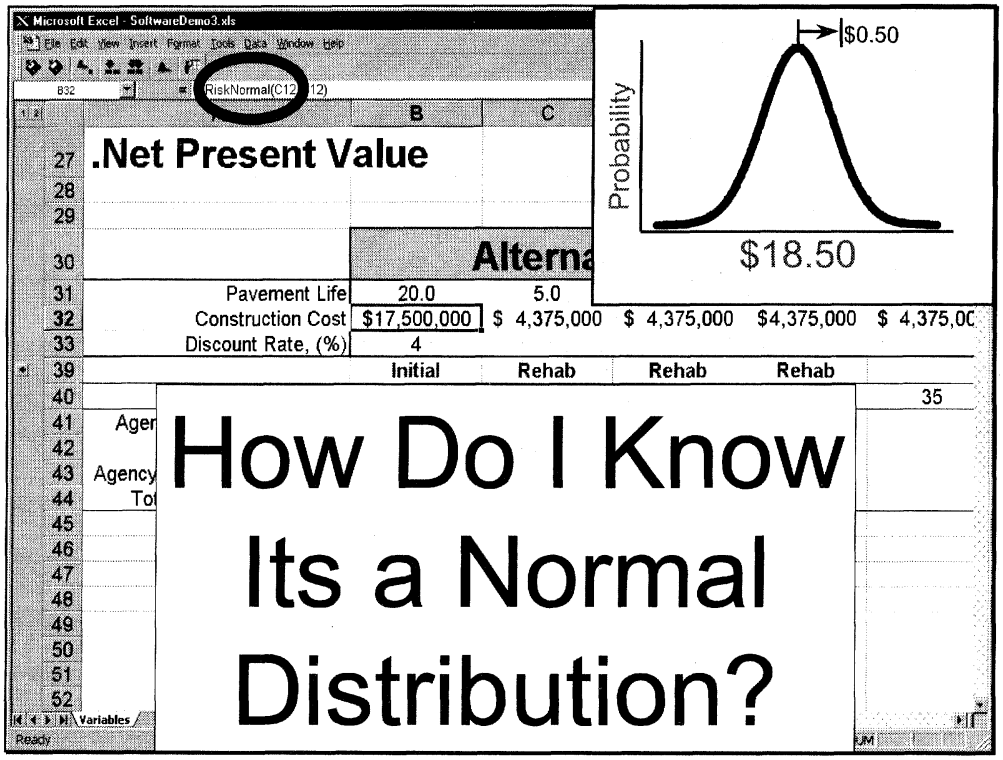
Variables

Ready

16


Microsoft Excel - SoftwareDemo3.xls
=RiskNormal(C12,G12)
.Net Present Value
Alterna
Pavement Life 20.0 5.0
Construction Cost $17,500,000 $ 4,375,000 $ 4,375,000 $4,375,000 $ 4,375,00
Discount Rate, (%) 4
Initial Rehab Rehab Rehab
Year >>> 0 20 25 30 35
Agency Costs (Constant $) $17,500,000 $ 4,375,000 $ 4,375,000 $4,375,000
Present Worth Factor 1.0000 0.4564 0.3751 0.3083
Agency Cost (Present Worth) $17,500,000 $ 1,996,693 $ 1,641,136 $1,348,894
Total NPV (Agency Cost) $22,486,723
Variables
Ready
NUM
$1.25M
Probability
$17.5 M

17


Microsoft Excel - SoftwareDemo3.xls
.Net Present Value
Alterna
Pavement Life 20.0 5.0
Construction Cost $17,500,000 $ 4,375,000 $ 4,375,000 $4,375,000 $ 4,375,00
Discount Rate, (%) 4
Initial Rehab Rehab Rehab
35
How Do I Know Its a Normal Distribution?
Variables
Ready
$0.50
Probability
$18.50

18

@Risk Probability Functions

Beta	Gamma	Normal
Binomial	Geometric	Pareto
Chi-Squa		
Cumulati		xponential
Depende		ognormal
Discrete		ormal
Discrete		
Error Function	Lognormal	Trigen
Erlang	Lognormal2	Uniform
Exponential	Negative Binomial	Weibull

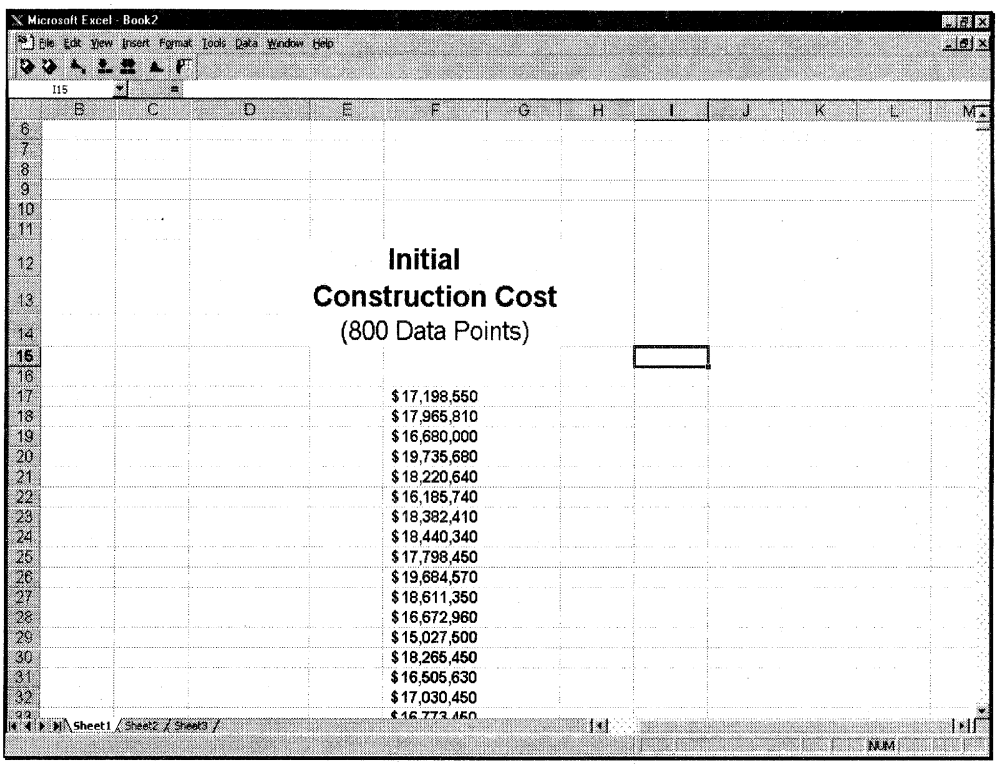
Which One Should I Use?

19

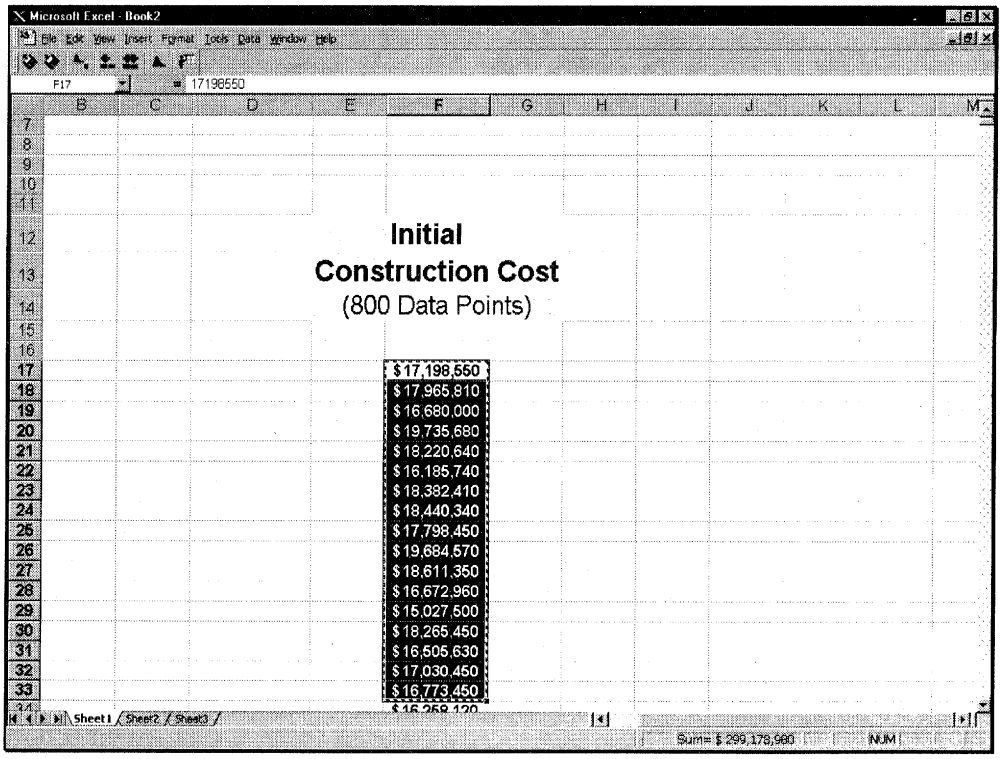
@Risk & BestFit

- Based on historical data input distribution models are developed using BestFit
- BestFit automatically determines the "bestfit" probability distribution
- Distribution model is "copied" directly into @Risk/Excel spreadsheet

20


Microsoft Excel - Book2
Initial
Construction Cost
(800 Data Points)
$17,198,550
$17,965,810
$16,680,000
$19,735,680
$18,220,640
$16,185,740
$18,382,410
$18,440,340
$17,798,450
$19,684,570
$18,611,350
$16,672,960
$15,027,500
$18,265,450
$16,505,630
$17,030,450
Sheet1 / Sheet2 / Sheet3 /
NUM

21


Microsoft Excel - Book2
F17
17198550
Initial
Construction Cost
(800 Data Points)
$17,198,550
$17,965,810
$16,680,000
$19,735,680
$18,220,640
$16,185,740
$18,382,410
$18,440,340
$17,798,450
$19,684,570
$18,611,350
$16,672,960
$15,027,500
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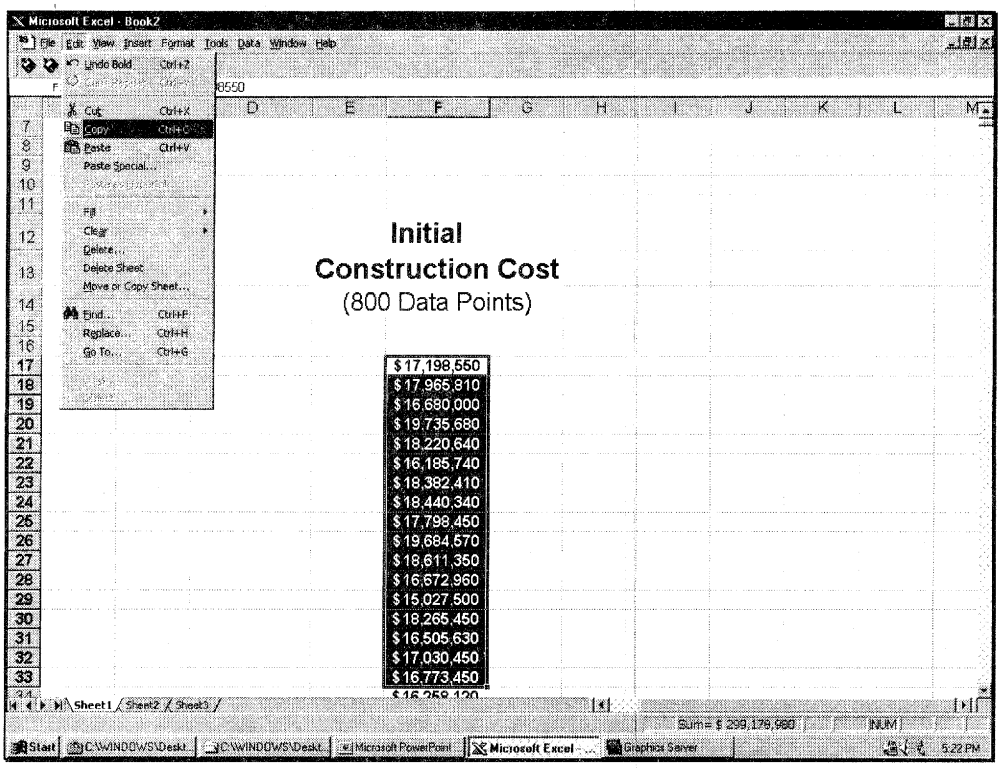
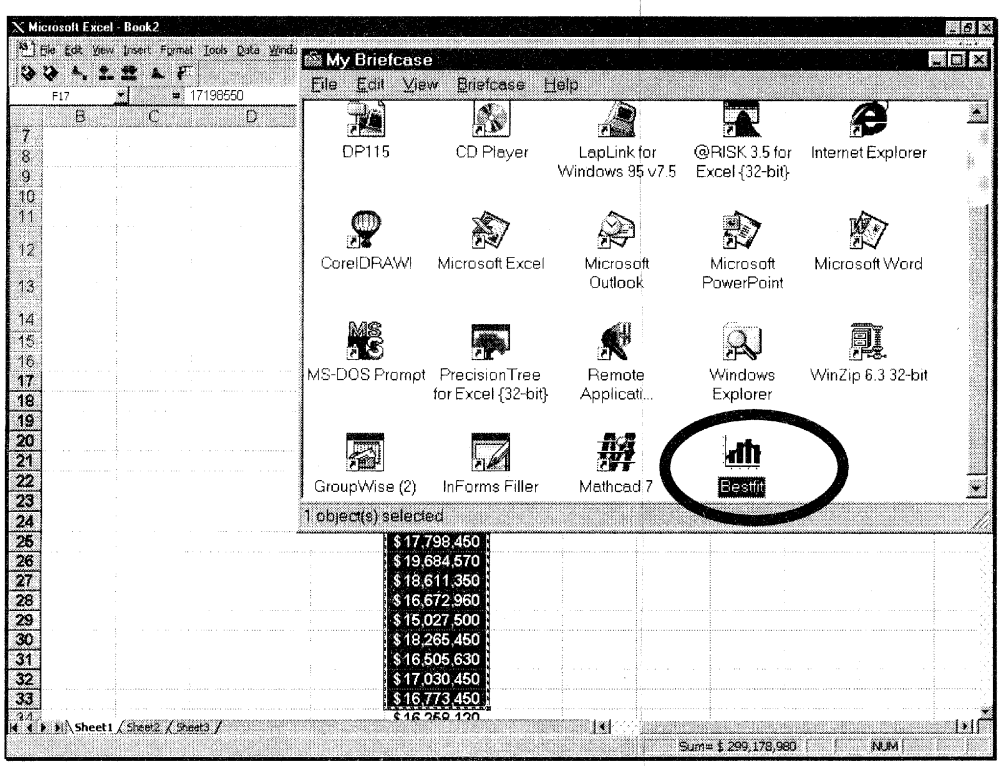
Sheet1 / Sheet2 / Sheet3 /
Sum= $ 299,178,990
NUM

22


Microsoft Excel - Book2
Initial
Construction Cost
(800 Data Points)
$17,198,550
$17,965,810
$16,680,000
$19,735,680
$18,220,640
$16,185,740
$18,382,410
$18,440,340
$17,798,450
$19,684,570
$18,611,350
$16,672,960
$15,027,500
$18,265,450
$16,505,630
$17,030,450
$16,773,450

23


Microsoft Excel - Book2
My Briefcase
File Edit View Briefcase Help
DP115
CD Player
LapLink for Windows 95 v7.5
@RISK 3.5 for Excel {32-bit}
Internet Explorer
CorelDRAW!
Microsoft Excel
Microsoft Outlook
Microsoft PowerPoint
Microsoft Word
MS-DOS Prompt
PrecisionTree for Excel {32-bit}
Remote Applicati...
Windows Explorer
WinZip 6.3 32-bit
GroupWise (2)
InForms Filler
Mathcad 7
Bestfit
1 object(s) selected
$17,798,450
$19,684,570
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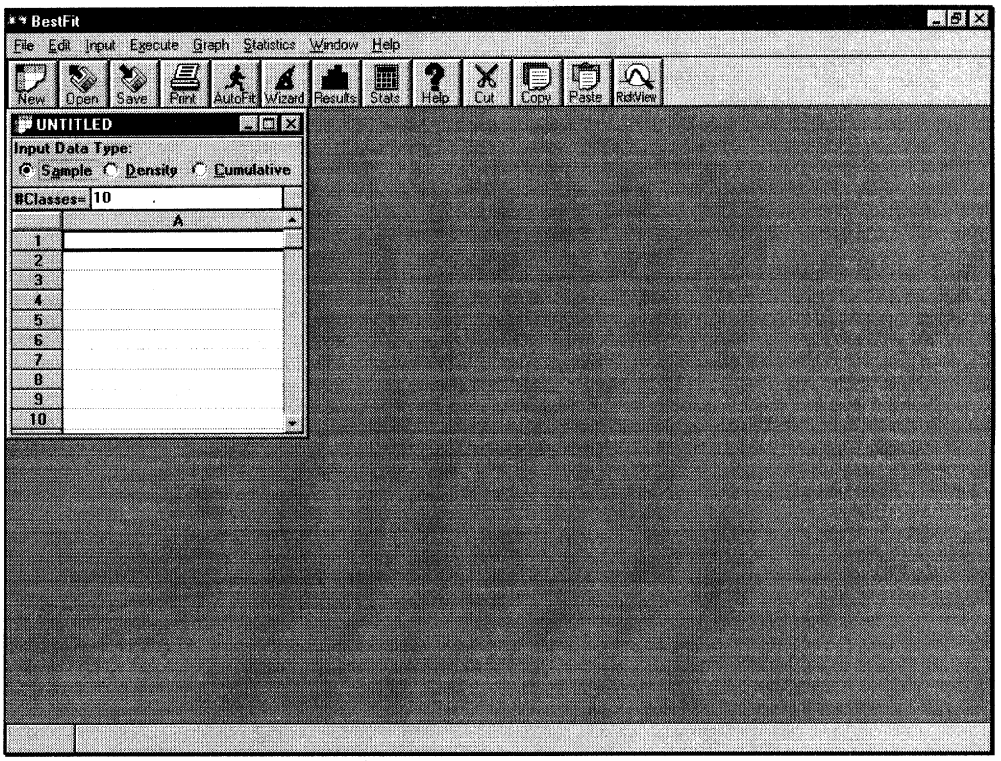
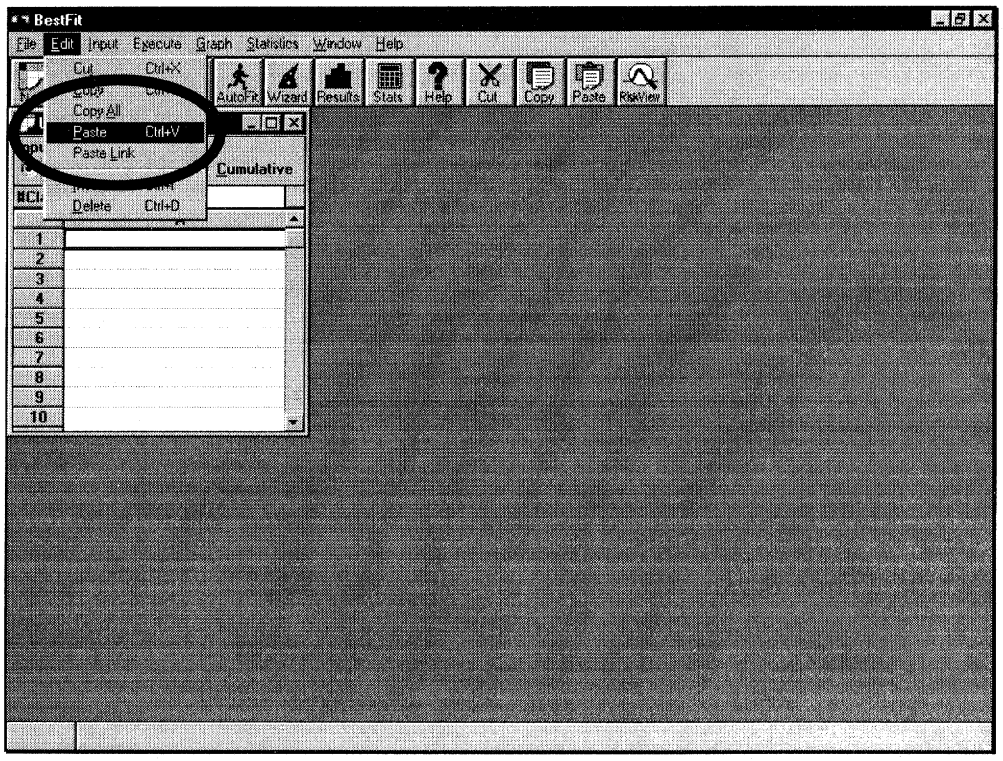
$16,505,630
$17,030,450
$16,773,450

24


BestFit
File Edit Input Execute Graph Statistics Window Help
New Open Save Print AutoFit Wizard Results Stats Help Cut Copy Paste RiskView
UNTITLED
Input Data Type:
Sample Density Cumulative
#Classes= 10
A
1 2 3 4 5 6 7 8 9 10

25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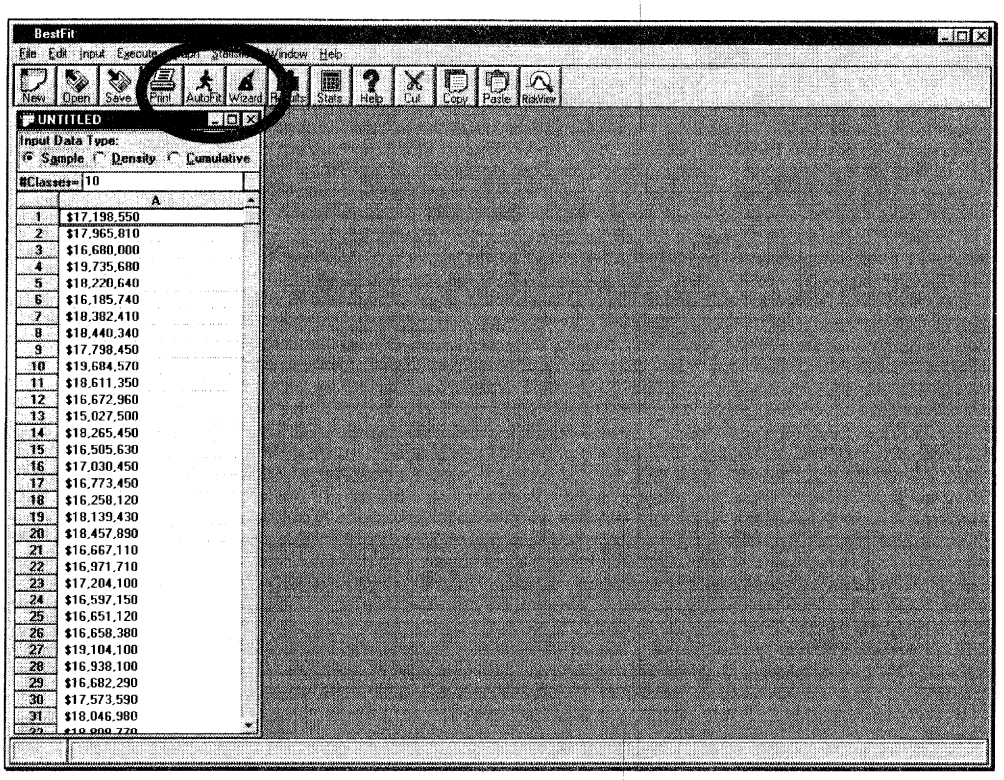
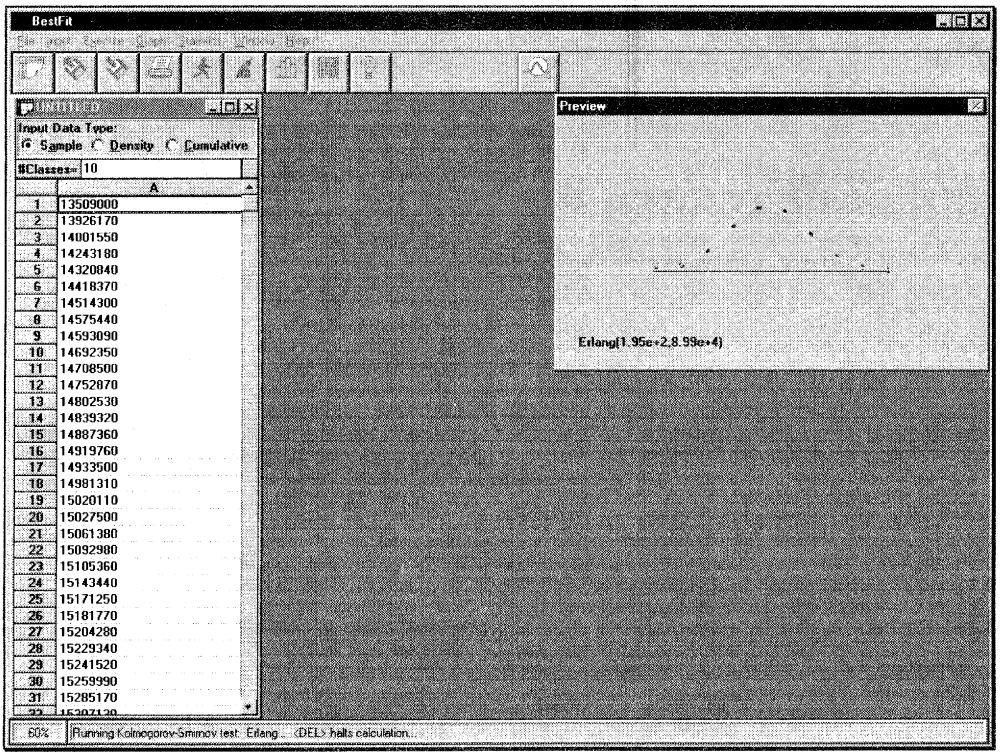
File Edit Input Execute Graph Statistics Window Help
Cut Ctrl+X
Copy All
Paste Ctrl+V
Paste Link
Delete Ctrl+D
AutoFit Wizard Results Stats Help Cut Copy Paste RiskView
Cumulative
1 2 3 4 5 6 7 8 9 10

26


BestFit
File Edit Input Execute Graph Statistics Window Help
New Open Save Print AutoFit Wizard Reports Stats Help Cut Copy Paste ReView
UNTITLED
Input Data Type:
Sample Density Cumulative
#Classes= 10
A
1 $17,198,550
2 $17,965,810
3 $16,680,000
4 $19,735,680
5 $18,220,640
6 $16,185,740
7 $18,382,410
8 $18,440,340
9 $17,798,450
10 $19,684,570
11 $18,611,350
12 $16,672,960
13 $15,027,500
14 $18,265,450
15 $16,505,630
16 $17,030,450
17 $16,773,450
18 $16,258,120
19 $18,139,430
20 $18,457,890
21 $16,667,110
22 $16,971,710
23 $17,204,100
24 $16,597,150
25 $16,651,120
26 $16,658,380
27 $19,104,100
28 $16,938,100
29 $16,682,290
30 $17,573,590
31 $18,046,980

27


BestFit
Input Data Type:
Sample Density Cumulative
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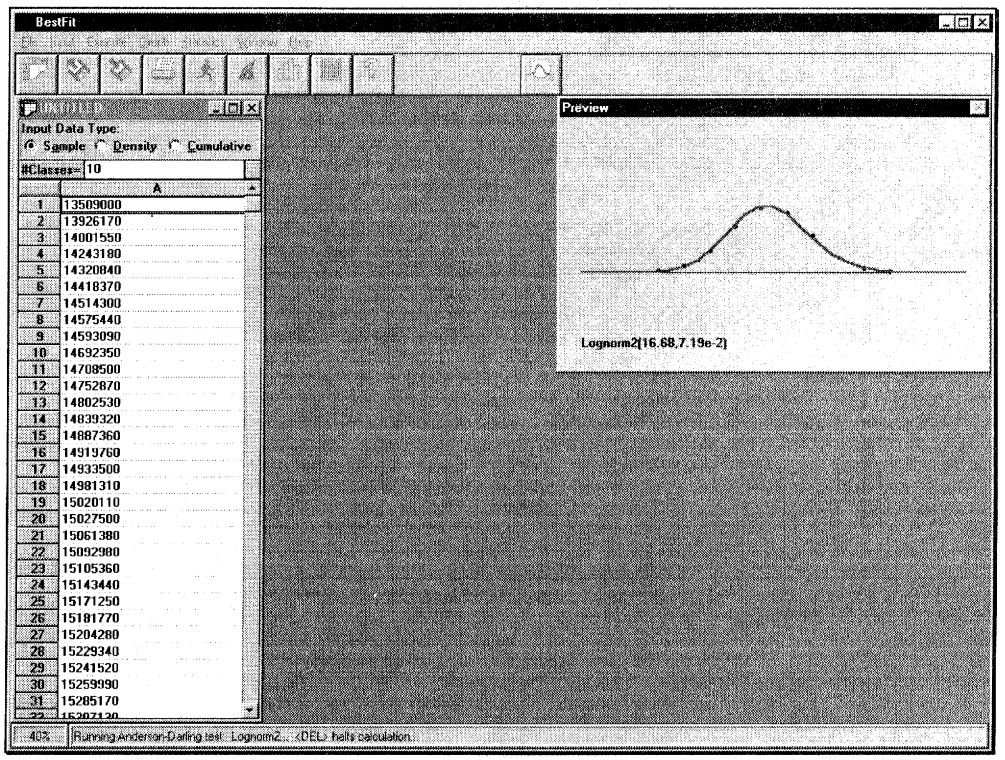
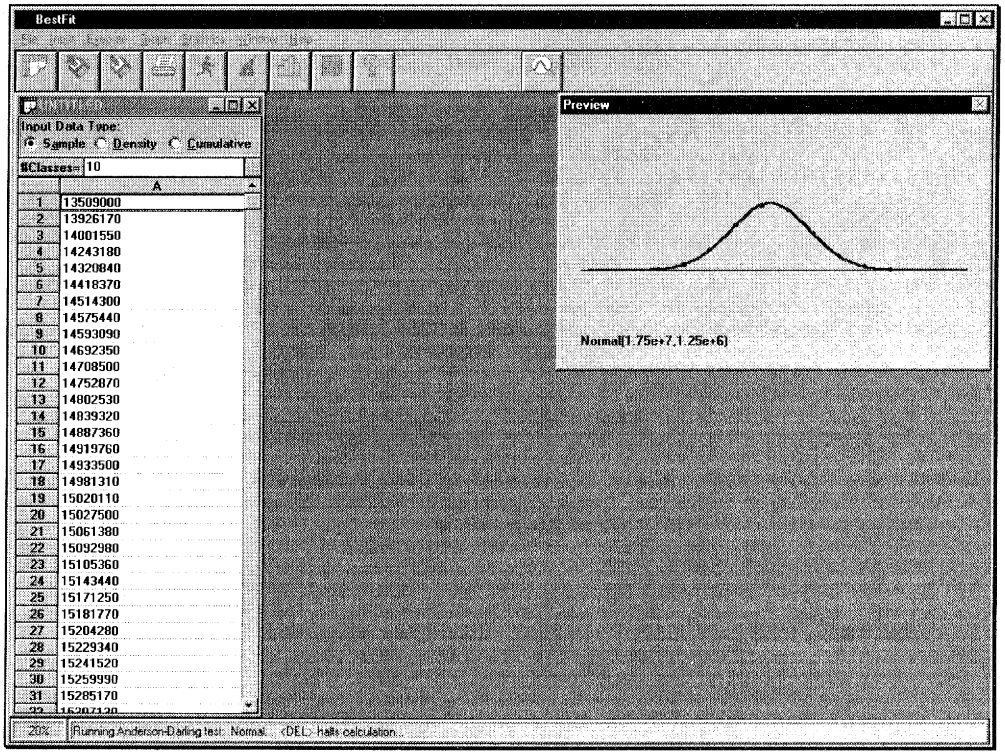
2 13926170
3 14001550
4 14243180
5 14320840
6 14418370
7 14514300
8 14575440
9 14593090
10 14692350
11 14708500
12 14752870
13 14802530
14 14839320
15 14887360
16 14919760
17 14933500
18 14981310
19 15020110
20 15027500
21 15061380
22 15092980
23 15105360
24 15143440
25 15171250
26 15181770
27 15204280
28 15229340
29 15241520
30 15259990
31 15285170
Preview
Erlang(1.95e+2,8.99e+4)
60%
Running Kolmogorov-Smirnov test: Erlang... (DEL) halts calculation.

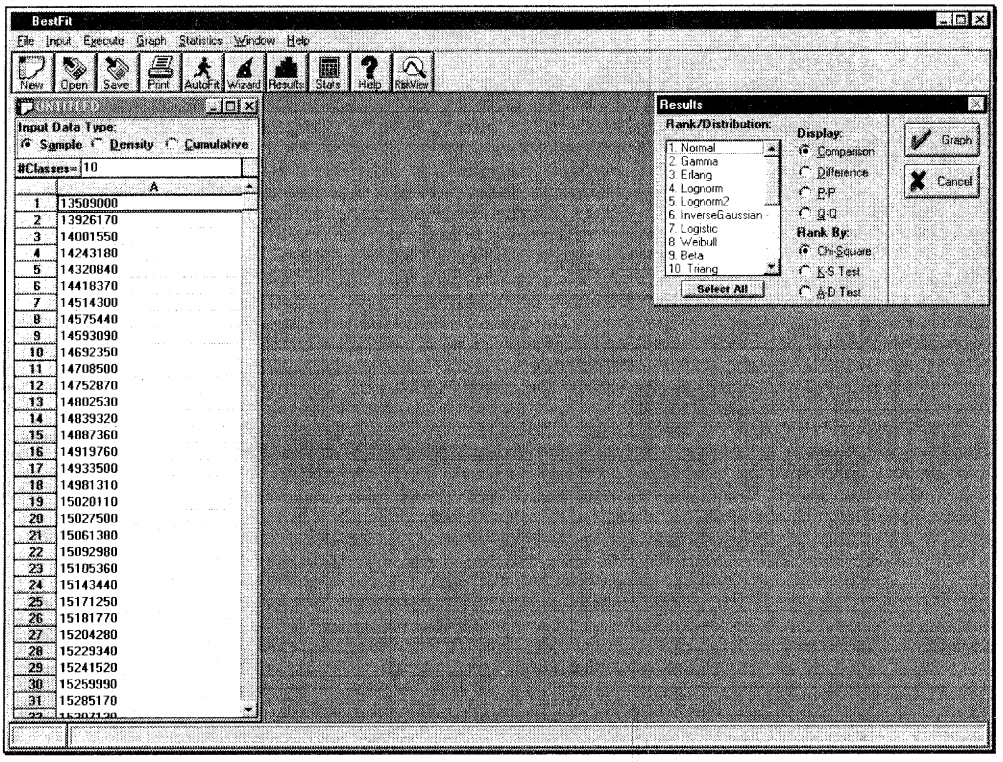
28


BestFit
Input Data Type:
Sample Density Cumulative
#Classes= 10
A
1 13509000
2 13926170
3 14001550
4 14243180
5 14320840
6 14418370
7 14514300
8 14575440
9 14593090
10 14692350
11 14708500
12 14752870
13 14802530
14 14839320
15 14887360
16 14919760
17 14933500
18 14981310
19 15020110
20 15027500
21 15061380
22 15092980
23 15105360
24 15143440
25 15171250
26 15181770
27 15204280
28 15229340
29 15241520
30 15259990
31 15285170
Preview
Lognorm2[16.68,7.19e-2]
40%
Running Anderson-Darling test: Lognorm2... <DEL> halts calculation.

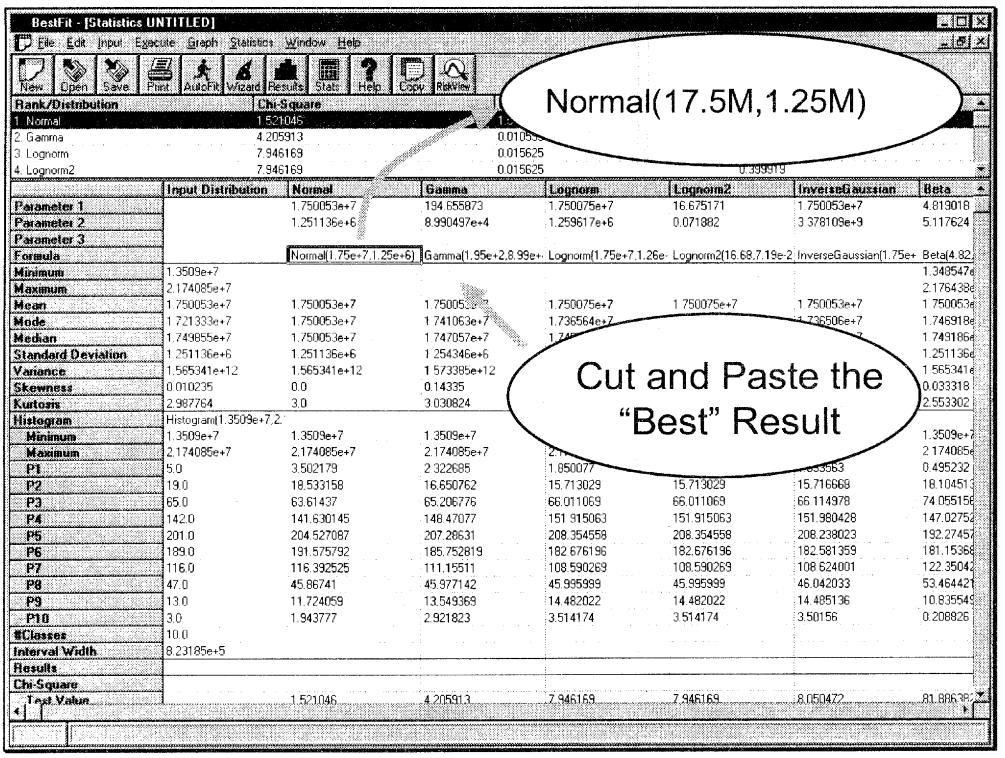
29


BestFit
Input Data Type:
Sample Density Cumulative
#Classes= 10
A
1 13509000
2 13926170
3 14001550
4 14243180
5 14320840
6 14418370
7 14514300
8 14575440
9 14593090
10 14692350
11 14708500
12 14752870
13 14802530
14 14839320
15 14887360
16 14919760
17 14933500
18 14981310
19 15020110
20 15027500
21 15061380
22 15092980
23 15105360
24 15143440
25 15171250
26 15181770
27 15204280
28 15229340
29 15241520
30 15259990
31 15285170
Preview
Normal[1.75e+7,1.25e+6]
20%
Running Anderson-Darling test: Normal... <DEL> halts calculation.

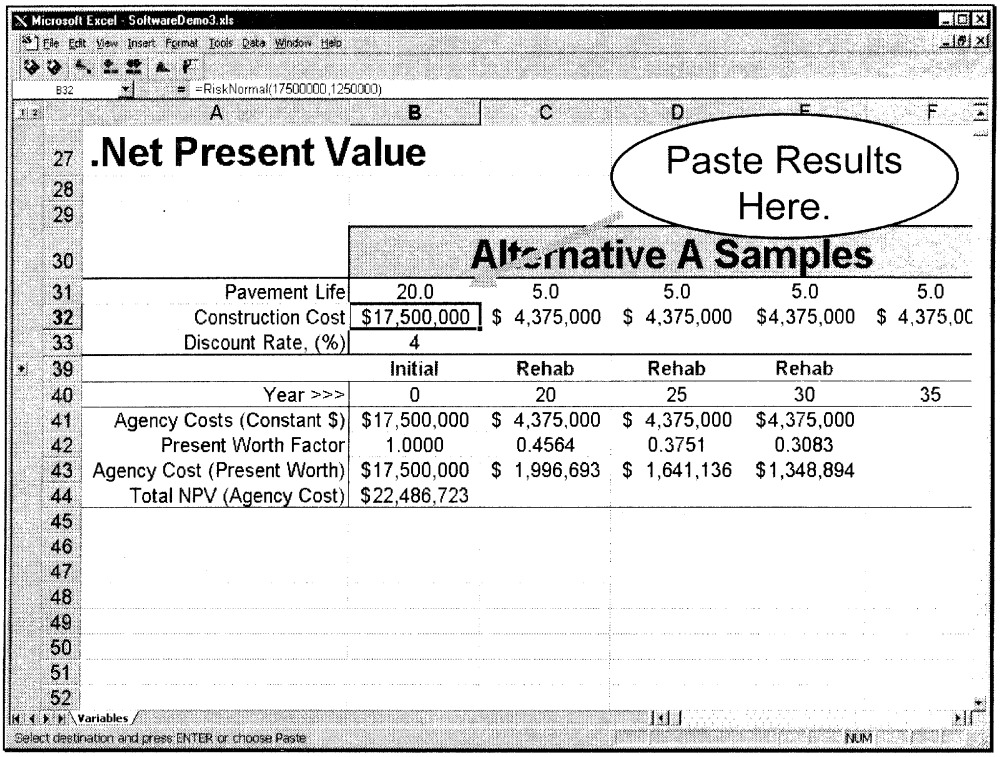
30


BestFit
File Input Execute Graph Statistics Window Help
New Open Save Print AutoFit Wizard Results Stats Help RiskView
Input Data Type:
Sample Density Cumulative
#Classes= 10
Results
Rank/Distribution:
1. Normal
2. Gamma
3. Erlang
4. Lognorm
5. Lognorm2
6. InverseGaussian
7. Logistic
8. Weibull
9. Beta
10. Triang
Select All
Display:
Comparison
Difference
P-P
Q-Q
Rank By:
Chi-Square
K-S Test
A-D Test
Graph
Cancel

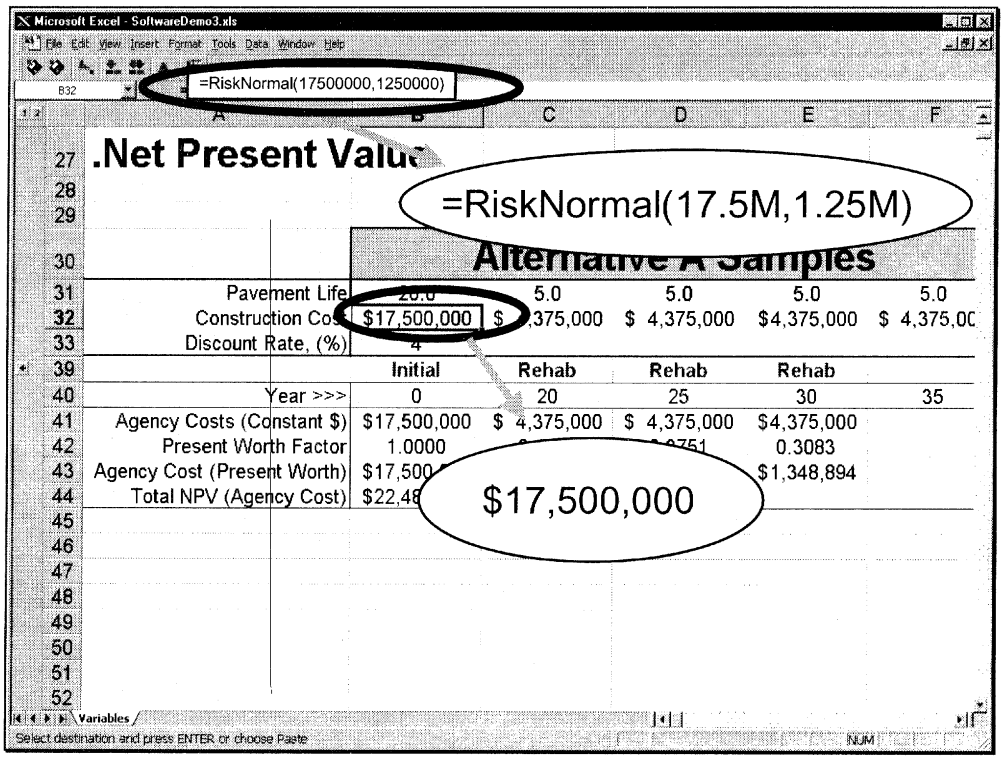
31


BestFit - [Statistics UNTITLED]
File Edit Input Execute Graph Statistics Window Help
Normal(17.5M,1.25M)
Cut and Paste the "Best" Result

32


Microsoft Excel - SoftwareDemo3.xls
=RiskNormal(17500000,1250000)
.Net Present Value
Paste Results Here.
Alternative A Samples
Pavement Life 20.0 5.0 5.0 5.0 5.0
Construction Cost $17,500,000 $ 4,375,000 $ 4,375,000 $4,375,000 $ 4,375,00
Discount Rate, (%) 4
Initial Rehab Rehab Rehab
Year >>> 0 20 25 30 35
Agency Costs (Constant $) $17,500,000 $ 4,375,000 $ 4,375,000 $4,375,000
Present Worth Factor 1.0000 0.4564 0.3751 0.3083
Agency Cost (Present Worth) $17,500,000 $ 1,996,693 $ 1,641,136 $1,348,894
Total NPV (Agency Cost) $22,486,723
Variables
Select destination and press ENTER or choose Paste
NUM

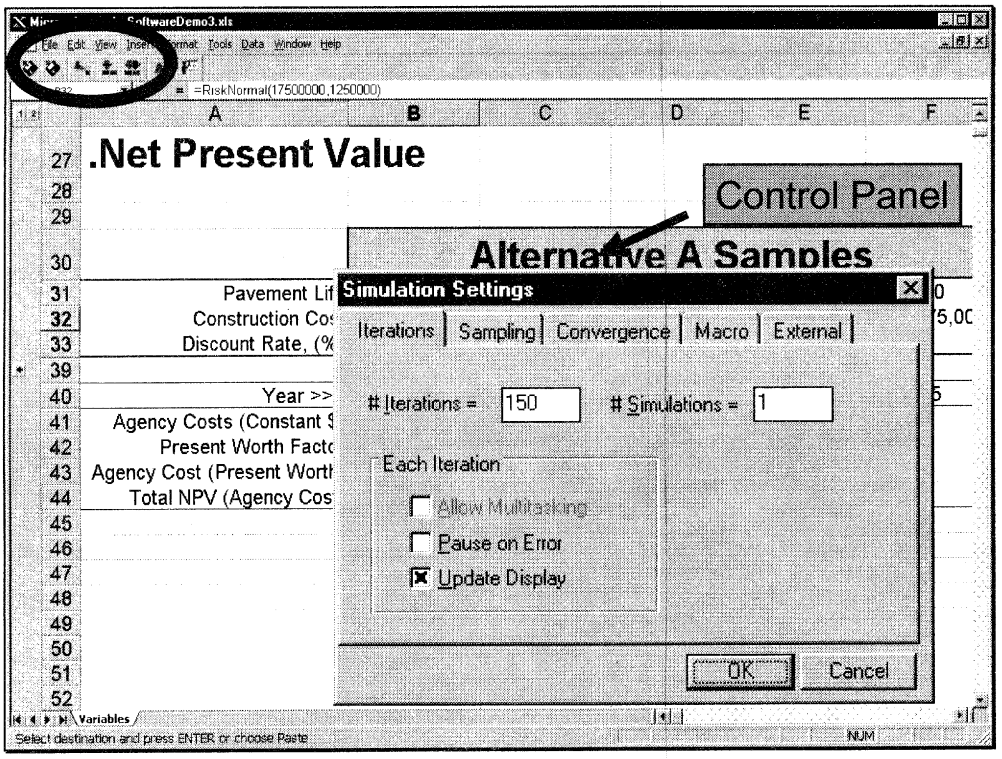
33


Microsoft Excel - SoftwareDemo3.xls
=RiskNormal(17500000,1250000)
=RiskNormal(17.5M,1.25M)
$17,500,000
Variables
Select destination and press ENTER or choose Paste
NUM

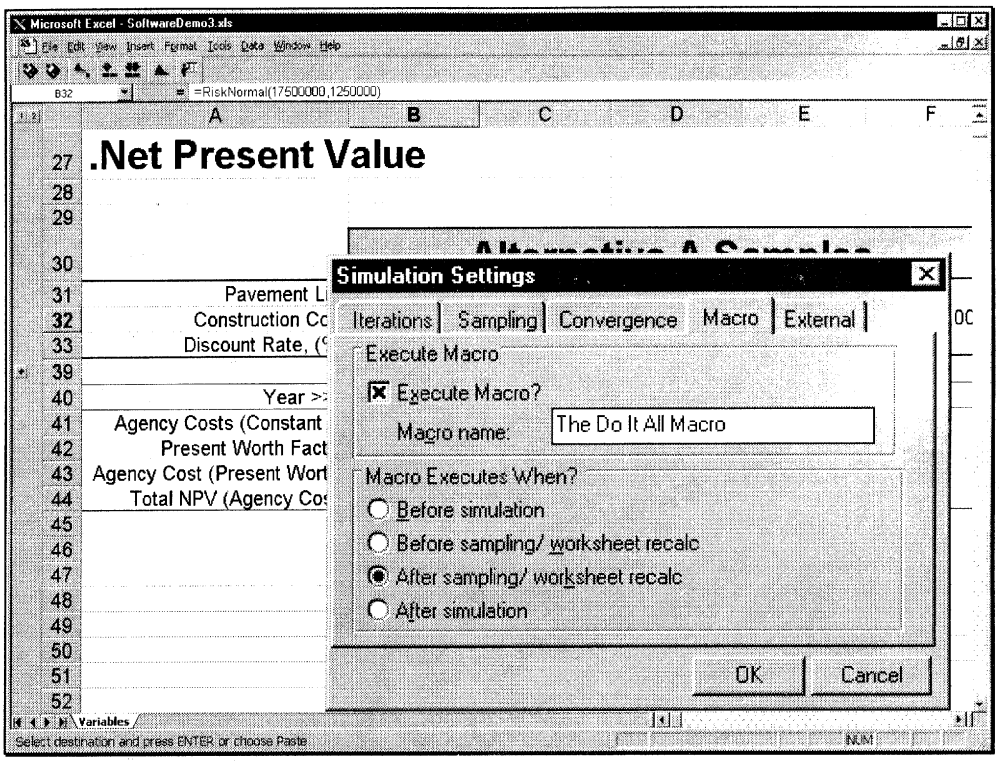
34

Running a Risk Analysis

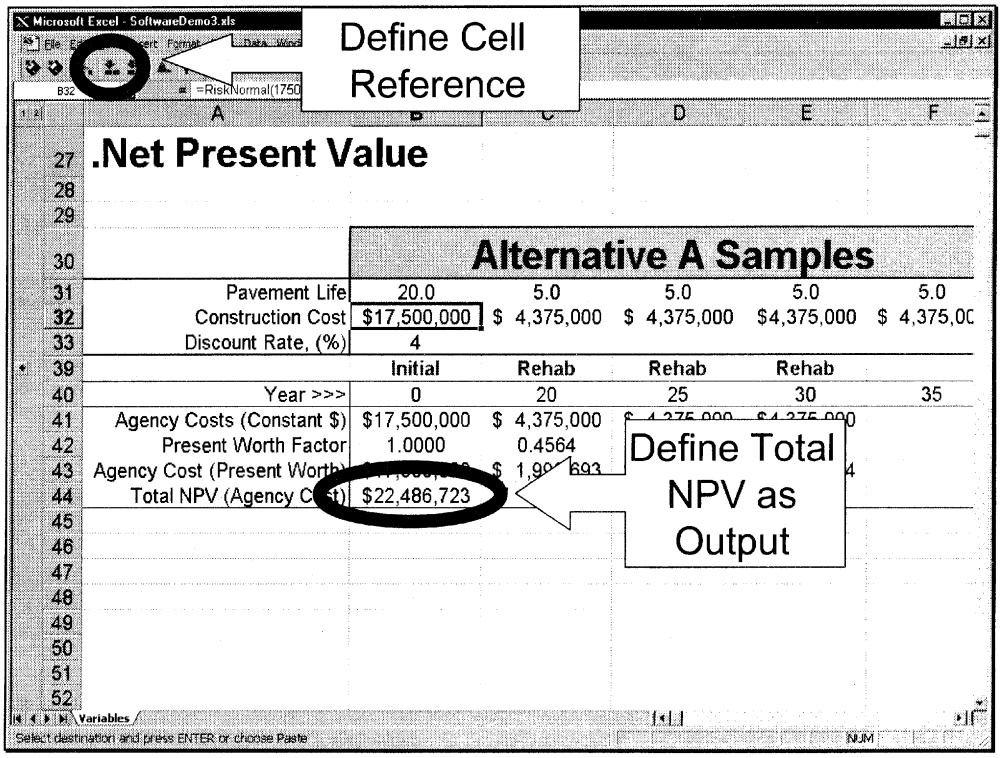
35



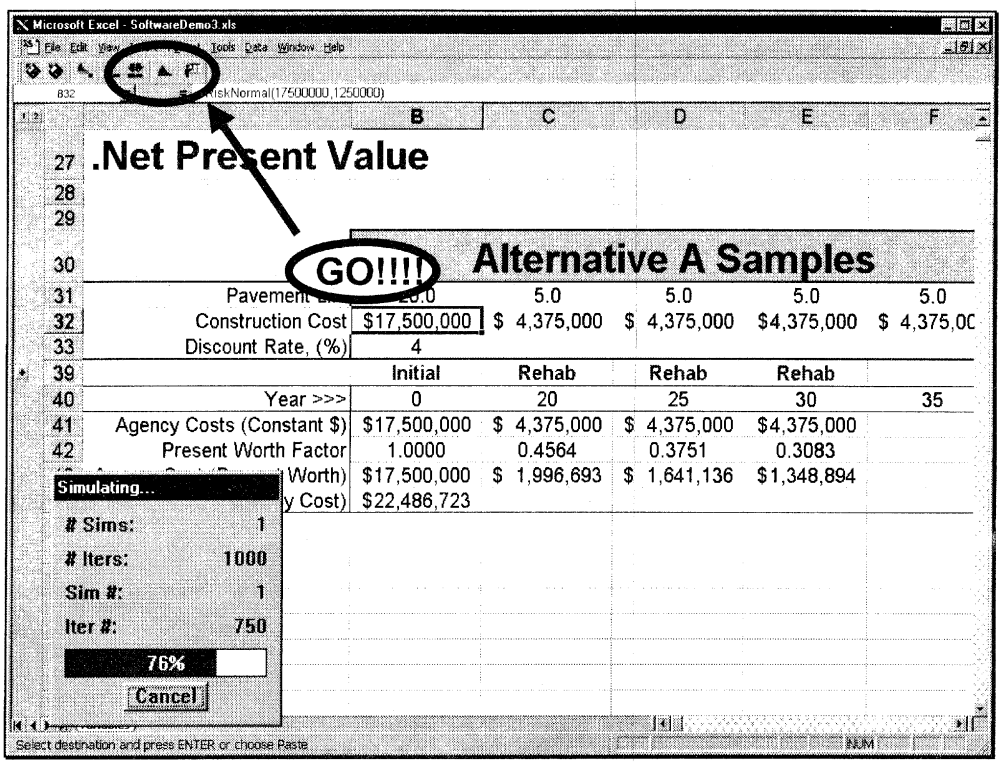
36


Microsoft Excel - SoftwareDemo3.xls
=RiskNormal(17500000,1250000)
.Net Present Value
Simulation Settings
Iterations
Sampling
Convergence
Macro
External
Execute Macro
Execute Macro?
Macro name:
The Do It All Macro
Macro Executes When?
Before simulation
Before sampling/ worksheet recalc
After sampling/ worksheet recalc
After simulation
OK
Cancel
Year >>
Agency Costs (Constant
Present Worth Fact
Agency Cost (Present Wort
Total NPV (Agency Co
Variables
Select destination and press ENTER or choose Paste
NUM

37


Define Cell Reference
.Net Present Value
Alternative A Samples
Pavement Life
Construction Cost
Discount Rate, (%)
Year >>>
Agency Costs (Constant $)
Present Worth Factor
Agency Cost (Present Worth
Total NPV (Agency Cost)
20.0
5.0
5.0
5.0
5.0
$17,500,000
$ 4,375,000
$ 4,375,000
$4,375,000
$ 4,375,000
4
Initial
Rehab
Rehab
Rehab
0
20
25
30
35
$17,500,000
$ 4,375,000
1.0000
0.4564
$22,486,723
Define Total NPV as Output
Variables
Select destination and press ENTER or choose Paste
NUM

38



39

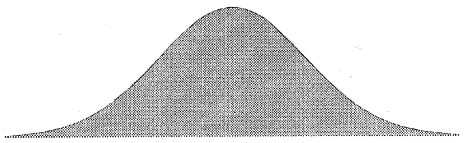
Simulation Processing

- Latin Hypercube
- 24 Input Variables
- 1 Output Variables
- 10,000 Iterations
- Run Time = 1 minute 15 seconds

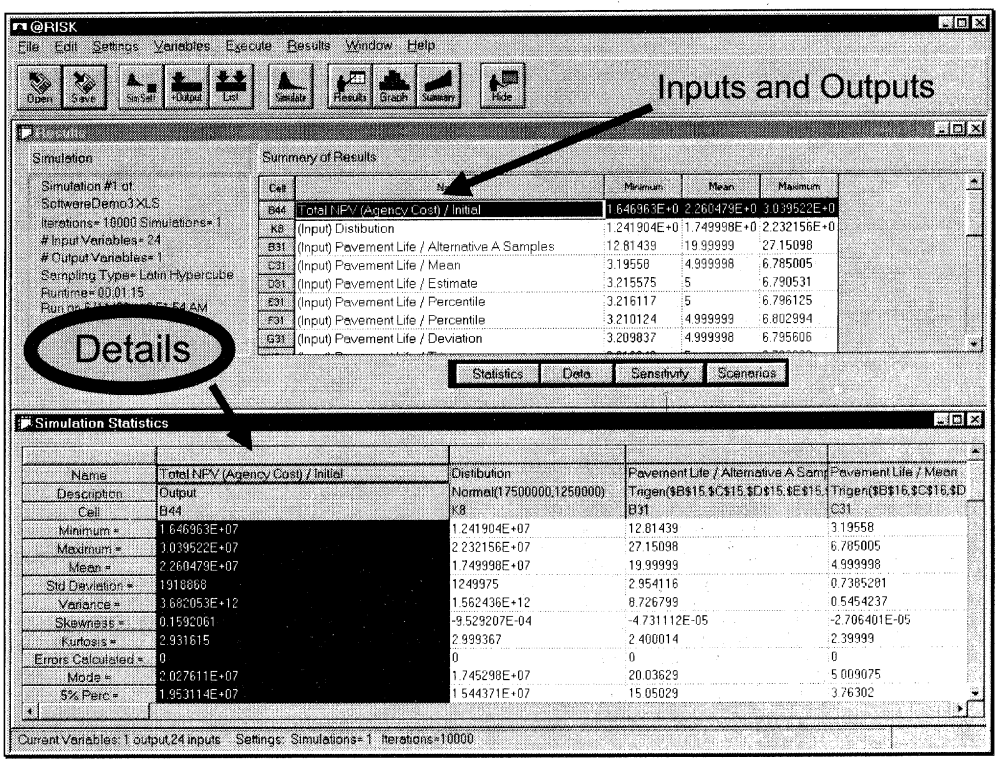
40

Simulation Results

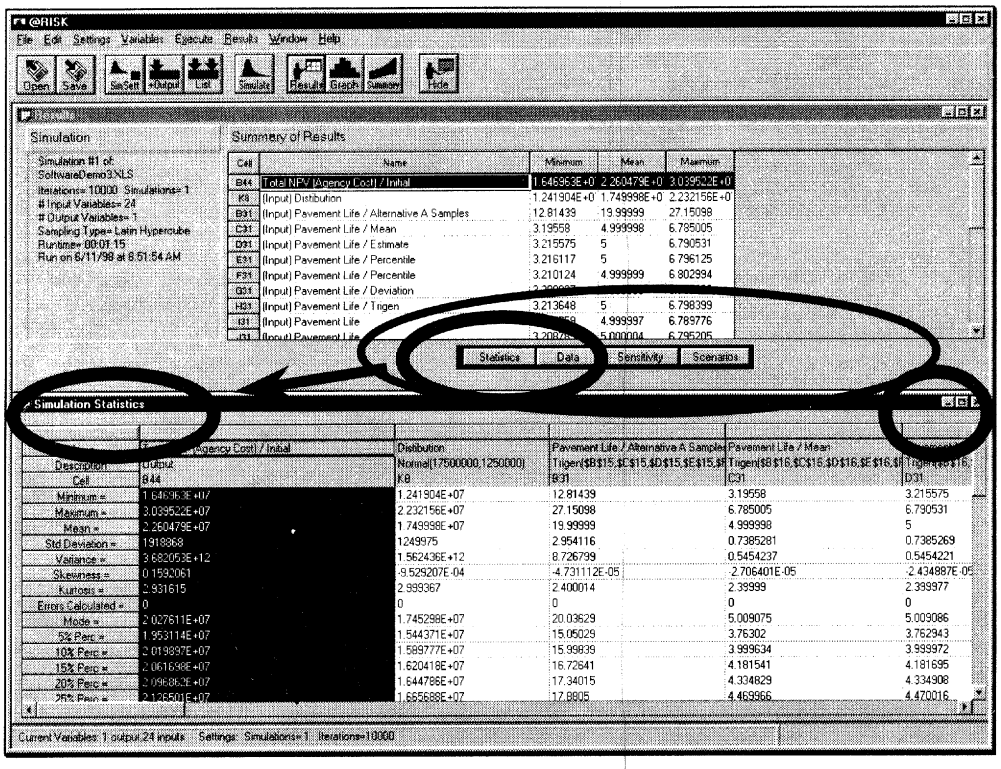
- Results from each iteration are stored and presented as probability distributions.



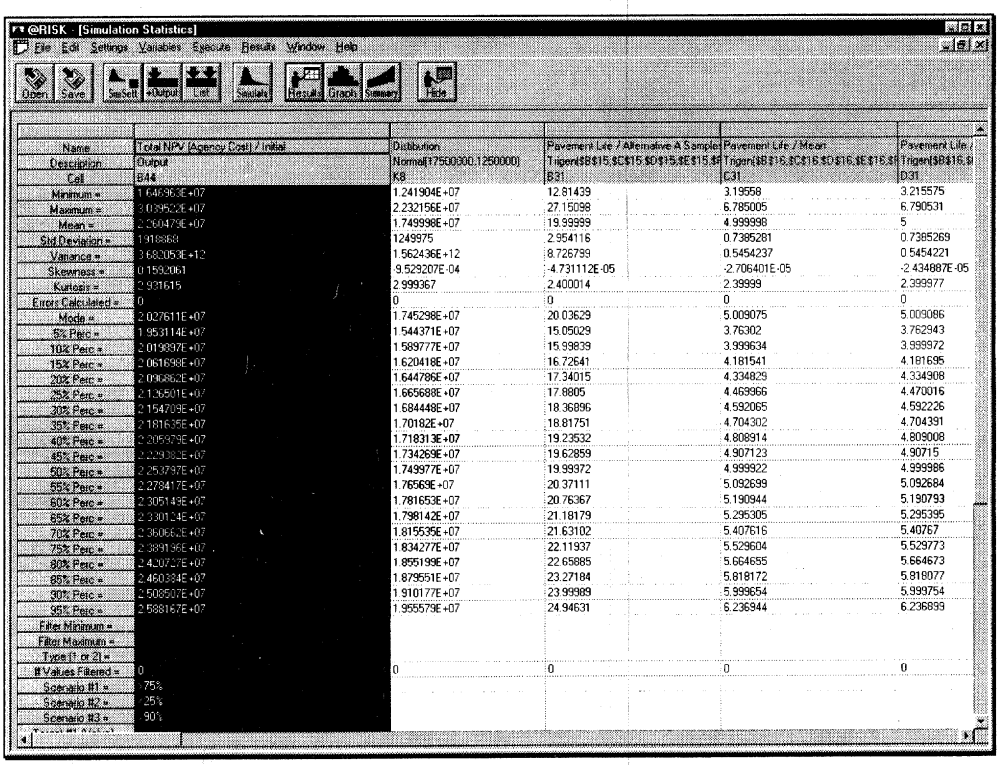
41



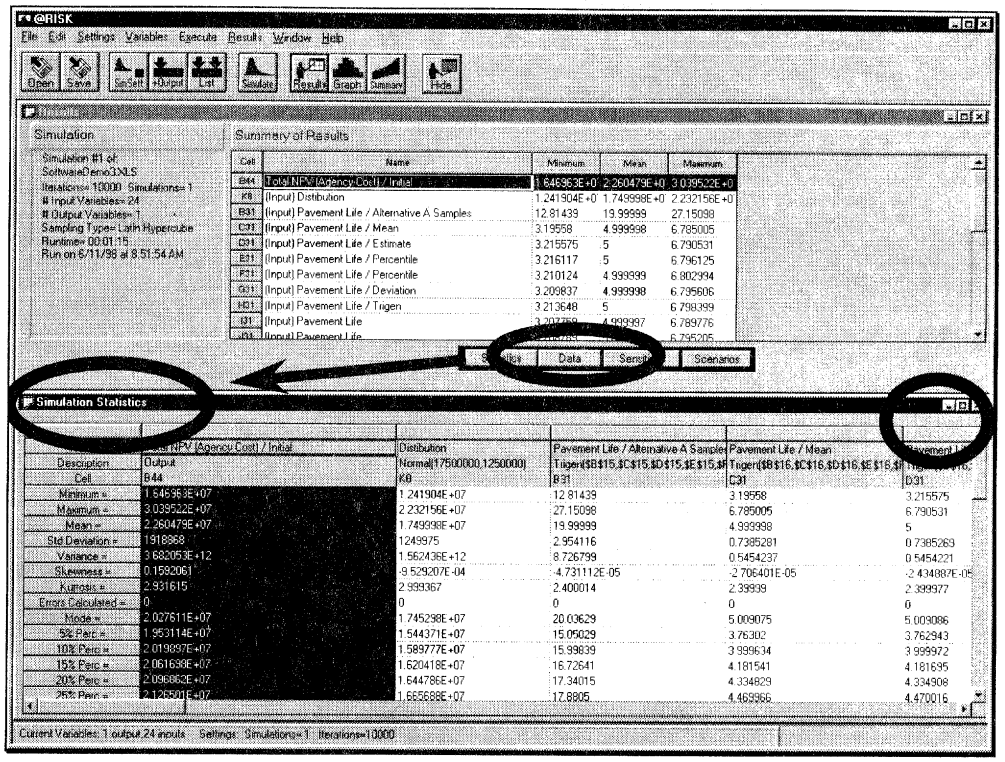
42


@RISK
File Edit Settings Variables Execute Results Window Help
Open Save SetSelt +Output List Simulate Results Graph Summary Hide
Simulation
Simulation #1 of:
SoftwareDemo3.XLS
Iterations= 10000 Simulations= 1
# Input Variables= 24
# Output Variables= 1
Sampling Type= Latin Hypercube
Runtime= 00:01:15
Run on 6/11/98 at 8:51:54 AM
Summary of Results
Cell Name Minimum Mean Maximum
B44 Total NPV [Agency Cost] / Initial 1.646963E+0 2.260479E+0 3.039522E+0
K8 [Input] Distribution 1.241904E+0 1.749998E+0 2.232156E+0
B31 [Input] Pavement Life / Alternative A Samples 12.81439 19.99999 27.15098
C31 [Input] Pavement Life / Mean 3.19558 4.999998 6.785005
D31 [Input] Pavement Life / Estimate 3.215575 5 6.790531
E31 [Input] Pavement Life / Percentile 3.216117 5 6.796125
F31 [Input] Pavement Life / Percentile 3.210124 4.999999 6.802994
G31 [Input] Pavement Life / Deviation
H31 [Input] Pavement Life / Trigen 3.213648 5 6.798399
I31 [Input] Pavement Life 4.999997 6.789776
J31 [Input] Pavement Life 5.000004 6.795205
Statistics Data Sensitivity Scenarios
Simulation Statistics
Description Output
Cell B44
Minimum = 1.646963E+07
Maximum = 3.039522E+07
Mean = 2.260479E+07
Std Deviation = 1918868
Variance = 3.682053E+12
Skewness = 0.1592061
Kurtosis = 2.931615
Errors Calculated = 0
Mode = 2.027611E+07
5% Perc = 1.953114E+07
10% Perc = 2.019897E+07
15% Perc = 2.061698E+07
20% Perc = 2.096862E+07
25% Perc = 2.126501E+07
Distribution Normal(17500000,1250000)
K8
1.241904E+07
1.749998E+07
1249975
1.562436E+12
-9.529207E-04
2.999367
0
1.745298E+07
1.544371E+07
1.589777E+07
1.620418E+07
1.644786E+07
1.665688E+07
Pavement Life / Alternative A Samples Trigen($B$15,$C$15,$D$15,$E$15,$F
B31
12.81439
19.99999
2.954116
8.726799
-4.731112E-05
2.400014
0
20.03629
15.05029
15.99839
16.72641
17.34015
17.8805
Pavement Life / Mean Trigen($B$16,$C$16,$D$16,$E$16,$F
C31
3.19558
4.999998
0.7385281
0.5454237
-2.706401E-05
2.39999
0
5.009075
3.76302
3.999634
4.181541
4.334829
4.469966
Trigen($B$16,$C$16,$D$16,$E$16,$F
D31
3.215575
6.790531
0.7385269
0.5454221
-2.434887E-05
2.399977
0
5.009086
3.762943
3.999972
4.181695
4.334908
4.470016
Current Variables: 1 output,24 inputs Settings: Simulations=1 Iterations=10000

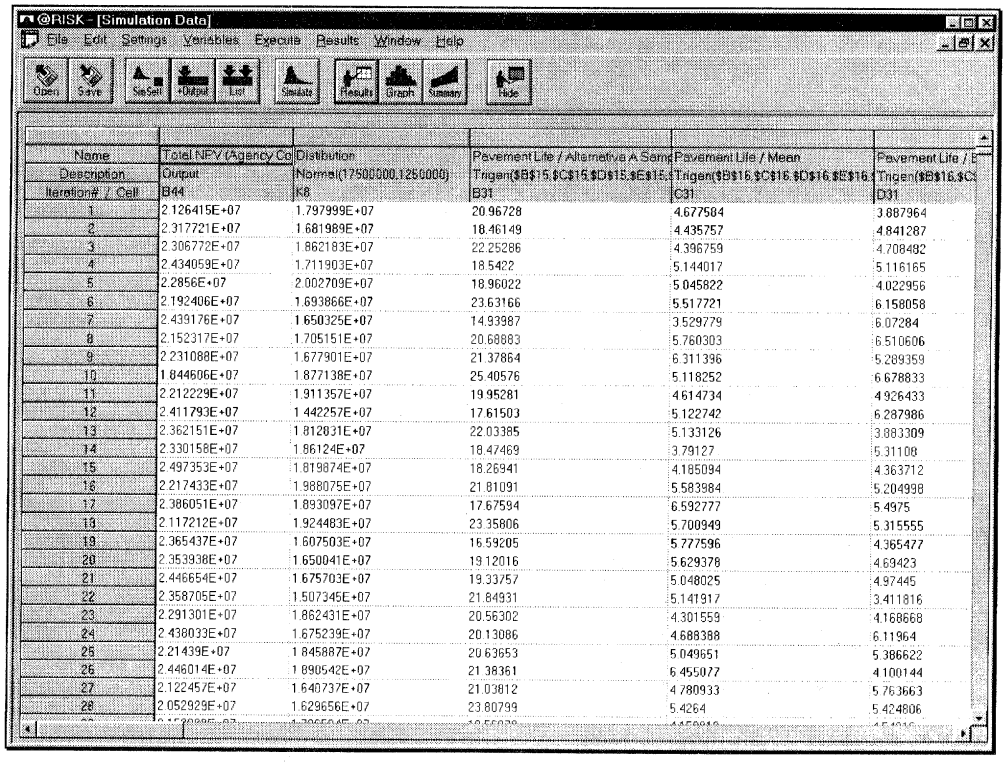
43


@RISK [Simulation Statistics]
File Edit Settings Variables Execute Results Window Help
Open Save SetSelt +Output List Simulate Results Graph Summary Hide
Name Total NPV [Agency Cost] / Initial
Description Output
Cell B44
Minimum = 1.646963E+07
Maximum = 3.039522E+07
Mean = 2.260479E+07
Std Deviation = 1918868
Variance = 3.682053E+12
Skewness = 0.1592061
Kurtosis = 2.931615
Errors Calculated = 0
Mode = 2.027611E+07
5% Perc = 1.953114E+07
10% Perc = 2.019897E+07
15% Perc = 2.061698E+07
20% Perc = 2.096862E+07
25% Perc = 2.126501E+07
30% Perc = 2.154709E+07
35% Perc = 2.181635E+07
40% Perc = 2.205979E+07
45% Perc = 2.229382E+07
50% Perc = 2.253797E+07
55% Perc = 2.278417E+07
60% Perc = 2.305148E+07
65% Perc = 2.330124E+07
70% Perc = 2.360662E+07
75% Perc = 2.389156E+07
80% Perc = 2.420737E+07
85% Perc = 2.460384E+07
90% Perc = 2.508507E+07
95% Perc = 2.588167E+07
Filter Minimum =
Filter Maximum =
Type (1 or 2) =
Values Filtered = 0
Scenario #1 = 75%
Scenario #2 = 25%
Scenario #3 = 90%
Distribution Normal(17500000,1250000)
K8
1.241904E+07
1.749998E+07
1249975
1.562436E+12
-9.529207E-04
2.999367
0
1.745298E+07
1.544371E+07
1.589777E+07
1.620418E+07
1.644786E+07
1.665688E+07
1.684448E+07
1.70182E+07
1.718313E+07
1.734269E+07
1.749977E+07
1.76569E+07
1.781653E+07
1.798142E+07
1.815535E+07
1.834277E+07
1.855199E+07
1.879551E+07
1.910177E+07
1.955579E+07
0
Pavement Life / Alternative A Samples Trigen($B$15,$C$15,$D$15,$E$15,$F
B31
12.81439
19.99999
2.954116
8.726799
-4.731112E-05
2.400014
0
20.03629
15.05029
15.99839
16.72641
17.34015
17.8805
18.36896
18.81751
19.23532
19.62859
19.99972
20.37111
20.76367
21.18179
21.63102
22.11937
22.65885
23.27184
23.99989
24.94631
0
Pavement Life / Mean Trigen($B$16,$C$16,$D$16,$E$16,$F
C31
3.19558
4.999998
0.7385281
0.5454237
-2.706401E-05
2.39999
0
5.009075
3.76302
3.999634
4.181541
4.334829
4.469966
4.592065
4.704302
4.808914
4.907123
4.999922
5.092699
5.190944
5.295305
5.407616
5.529604
5.664655
5.818172
5.999654
6.236944
0
Pavement Life / Trigen($B$16,$
D31
3.215575
6.790531
0.7385269
0.5454221
-2.434887E-05
2.399977
0
5.009086
3.762943
3.999972
4.181695
4.334908
4.470016
4.592226
4.704391
4.809008
4.90715
4.999986
5.092684
5.190793
5.295395
5.40767
5.529773
5.664673
5.818077
5.999754
6.236899
0

44


@RISK
File Edit Settings Variables Execute Results Window Help
Open Save SetSell +Output List Simulate Results Graph Summary Hide
Simulation
Summary of Results
Simulation #1 of SoftwareDemo1XLS
Iterations= 10000 Simulations= 1
# Input Variables= 24
# Output Variables= 1
Sampling Type= Latin Hypercube
Runtime= 00:01:15
Run on 6/11/98 at 8:51:54 AM
Cell Name Minimum Mean Maximum
B44 Total NPV (Agency Cost) / Initial 1.646963E+07 2.260479E+07 3.039532E+07
K8 [Input] Distribution 1.241904E+07 1.749998E+07 2.232156E+07
B31 [Input] Pavement Life / Alternative A Samples 12.81439 19.99999 27.15098
C31 [Input] Pavement Life / Mean 3.19558 4.999998 6.795005
C31 [Input] Pavement Life / Estimate 3.215575 5 6.790531
B31 [Input] Pavement Life / Percentile 3.216117 5 6.796125
B31 [Input] Pavement Life / Percentile 3.210124 4.999999 6.802994
G31 [Input] Pavement Life / Deviation 3.209837 4.999998 6.795606
H31 [Input] Pavement Life / Trigen 3.213648 5 6.798399
I31 [Input] Pavement Life 3.207759 4.999997 6.789776
D31 [Input] Pavement Life 6.795205
Graphs Data Sensitivity Scenarios
Simulation Statistics
Name Total NPV (Agency Cost) / Initial Distribution Pavement Life / Alternative A Samples Pavement Life / Mean
Description Output Normal(17500000,1250000) Trigen($B$15,$C$15,$D$15,$E$15,$F Trigen($B$16,$C$16,$D$16,$E$16,$F
Cell B44 K8 B31 C31 D31
Minimum = 1.646963E+07 1.241904E+07 12.81439 3.19558 3.215575
Maximum = 3.039532E+07 2.232156E+07 27.15098 6.795005 6.790531
Mean = 2.260479E+07 1.749998E+07 19.99999 4.999998 5
Std Deviation = 1918868 1249975 2.954116 0.7385281 0.7385269
Variance = 3.682053E+12 1.562436E+12 8.726799 0.5454237 0.5454221
Skewness = 0.1582061 -9.529207E-04 -4.731112E-05 -2.706401E-05 -2.434887E-05
Kurtosis = 2.931615 2.999367 2.400014 2.39939 2.399977
Errors Calculated = 0 0 0 0 0
Mode = 2.027611E+07 1.745298E+07 20.03629 5.009075 5.009086
5% Perc = 1.953114E+07 1.544371E+07 15.05029 3.76302 3.762943
10% Perc = 2.019897E+07 1.589777E+07 15.99839 3.999634 3.999972
15% Perc = 2.061688E+07 1.620418E+07 16.72641 4.181541 4.181695
20% Perc = 2.096862E+07 1.644788E+07 17.34015 4.334829 4.334908
25% Perc = 2.126501E+07 1.665688E+07 17.8805 4.469966 4.470016
Current Variables: 1 output,24 inputs Settings: Simulations=1 Iterations=10000

45

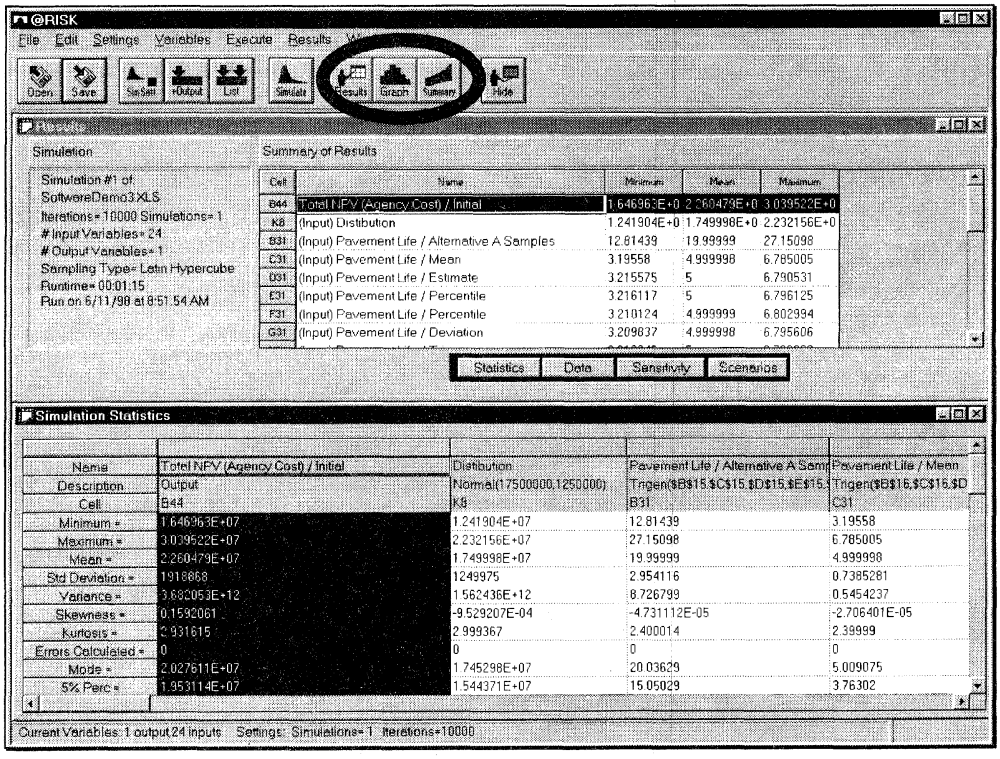

@RISK - [Simulation Data]
File Edit Settings Variables Execute Results Window Help
Open Save SetSell +Output List Simulate Results Graph Summary Hide
Name Total NPV (Agency Co Distribution Pavement Life / Alternative A Samp Pavement Life / Mean Pavement Life / E
Description Output Normal(17500000,1250000) Trigen($B$15,$C$15,$D$15,$E$15,$ Trigen($B$16,$C$16,$D$16,$E$16, Trigen($B$16,C
Iteration# / Cell B44 K8 B31 C31 D31
1 2.126415E+07 1.797999E+07 20.96728 4.677584 3.887964
2 2.317721E+07 1.681989E+07 18.46149 4.435757 4.841287
3 2.306772E+07 1.862183E+07 22.25286 4.396759 4.708482
4 2.434059E+07 1.711903E+07 18.5422 5.144017 5.116165
5 2.2856E+07 2.002709E+07 18.96022 5.045822 4.022956
6 2.192406E+07 1.693866E+07 23.63166 5.517721 6.158058
7 2.439176E+07 1.650325E+07 14.93987 3.529779 6.07284
8 2.152317E+07 1.705151E+07 20.68883 5.760303 6.510606
9 2.231088E+07 1.677901E+07 21.37864 6.311396 5.289359
10 1.844606E+07 1.877138E+07 25.40576 5.118252 6.678833
11 2.212229E+07 1.911357E+07 19.95281 4.614734 4.926433
12 2.411793E+07 1.442257E+07 17.61503 5.122742 6.287986
13 2.362151E+07 1.812031E+07 22.03385 5.133126 3.883309
14 2.330158E+07 1.86124E+07 18.47469 3.79127 5.31108
15 2.497353E+07 1.819874E+07 18.26941 4.185094 4.363712
16 2.217433E+07 1.988075E+07 21.81091 5.583984 5.204998
17 2.386051E+07 1.893097E+07 17.67594 6.592777 5.4975
18 2.117212E+07 1.924483E+07 23.35806 5.700949 5.315555
19 2.365437E+07 1.607503E+07 16.59205 5.777596 4.365477
20 2.353938E+07 1.650041E+07 19.12016 5.629378 4.69423
21 2.446654E+07 1.675703E+07 19.33757 5.048025 4.97445
22 2.358705E+07 1.507345E+07 21.84931 5.141917 3.411816
23 2.291301E+07 1.862431E+07 20.56302 4.301559 4.168668
24 2.438033E+07 1.675239E+07 20.13086 4.688388 6.11964
25 2.21439E+07 1.845887E+07 20.63653 5.049651 5.386622
26 2.446014E+07 1.890542E+07 21.38361 6.455077 4.100144
27 2.122457E+07 1.640737E+07 21.03812 4.780933 5.763663
28 2.052929E+07 1.629656E+07 23.80799 5.4264 5.424806

46

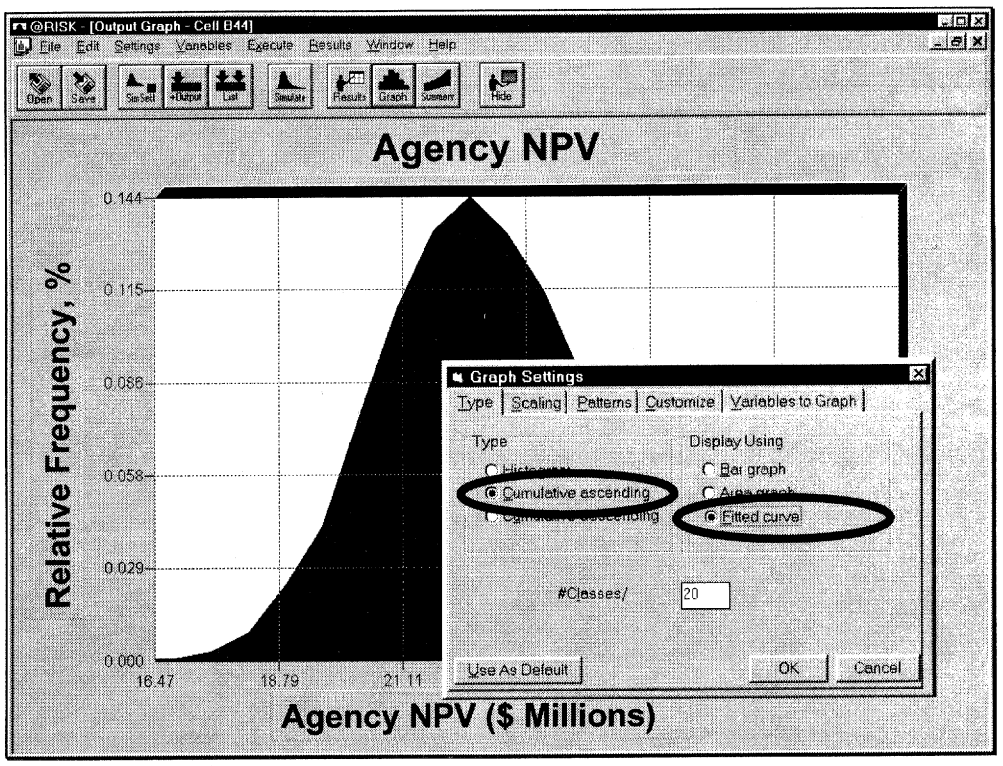
Agency NPV

- Probability
- Sensitivity
- Scenario Analysis

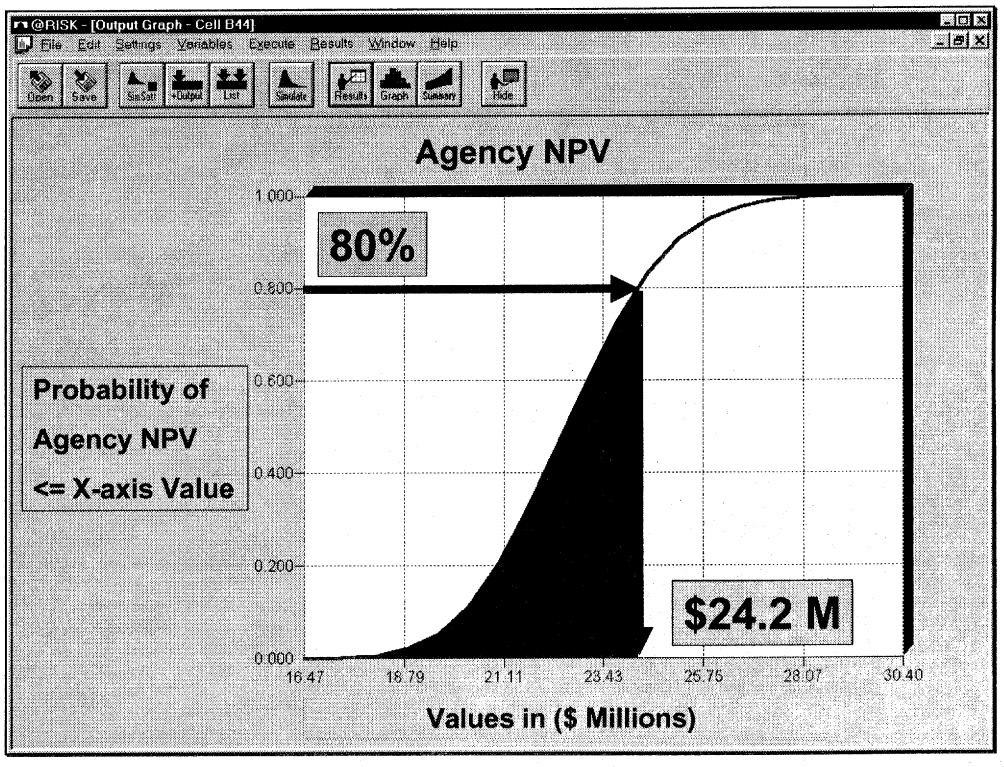
47



48


@RISK - [Output Graph - Cell B44]
File Edit Settings Variables Execute Results Window Help
Open Save SimSet +Output List Simulate Results Graph Summary Hide
Agency NPV
Relative Frequency, %
0.144
0.115
0.086
0.058
0.029
0.000
16.47
18.79
21.11
Agency NPV ($ Millions)
Graph Settings
Type Scaling Patterns Customize Variables to Graph
Type
Cumulative ascending
Display Using
Bar graph
Fitted curve
#Classes/
20
Use As Default
OK
Cancel

49

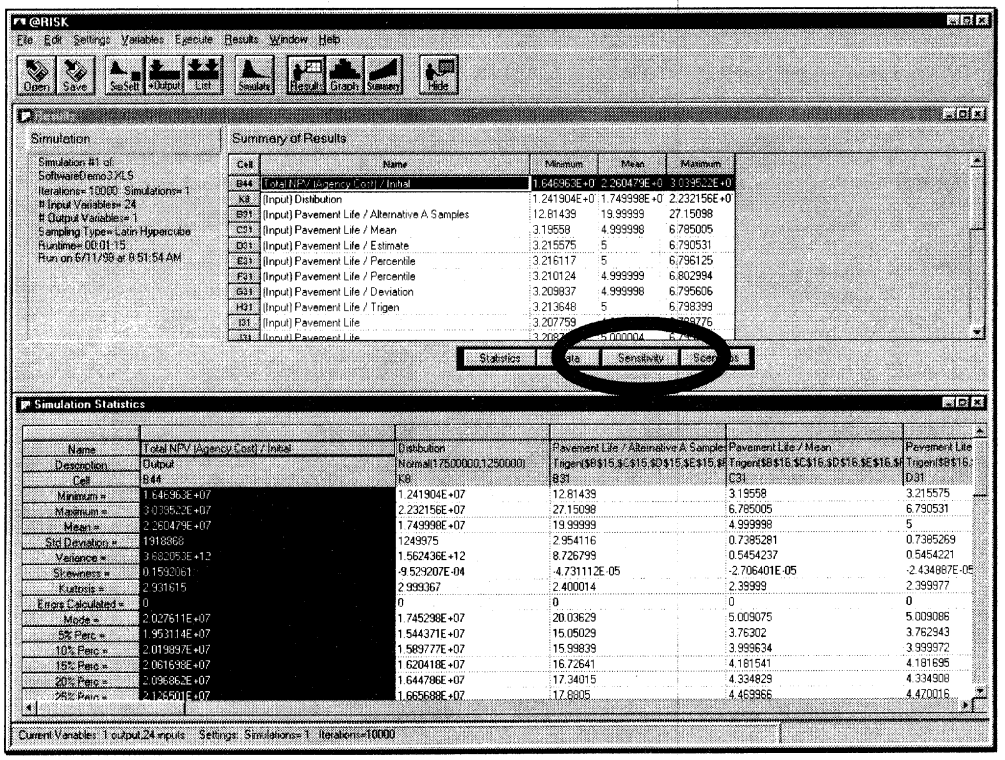

@RISK - [Output Graph - Cell B44]
File Edit Settings Variables Execute Results Window Help
Open Save SimSet +Output List Simulate Results Graph Summary Hide
Agency NPV
80%
Probability of
Agency NPV
<= X-axis Value
1.000
0.800
0.600
0.400
0.200
0.000
$24.2 M
16.47
18.79
21.11
23.43
25.75
28.07
30.40
Values in ($ Millions)

50

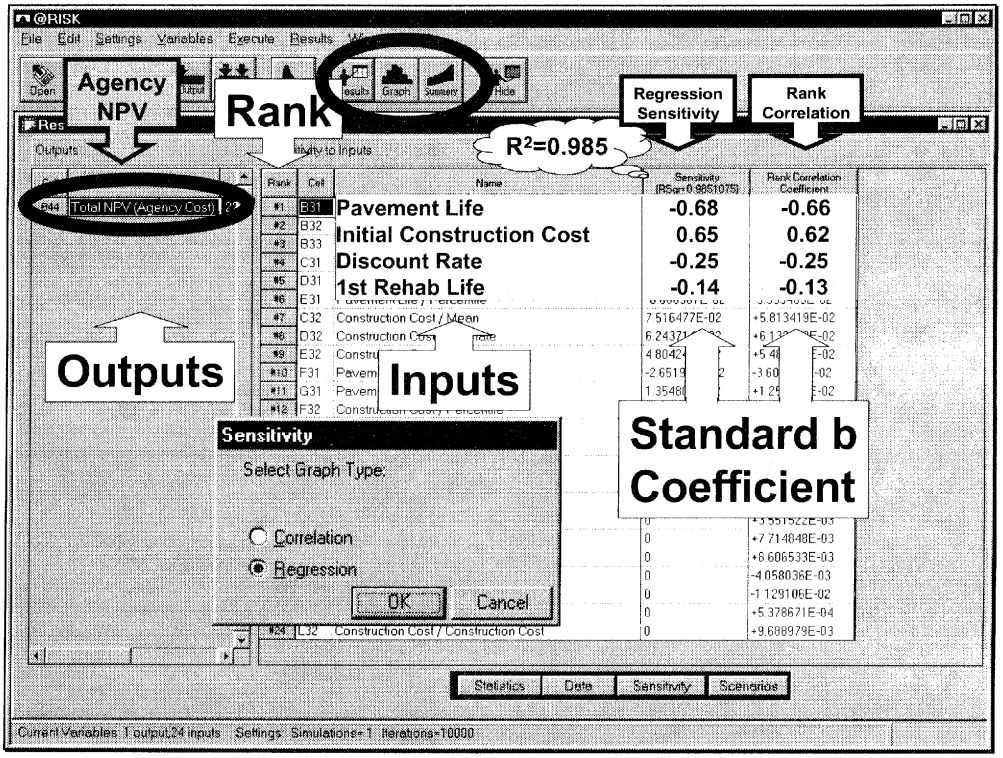
Agency Cost

- Probability
- Sensitivity

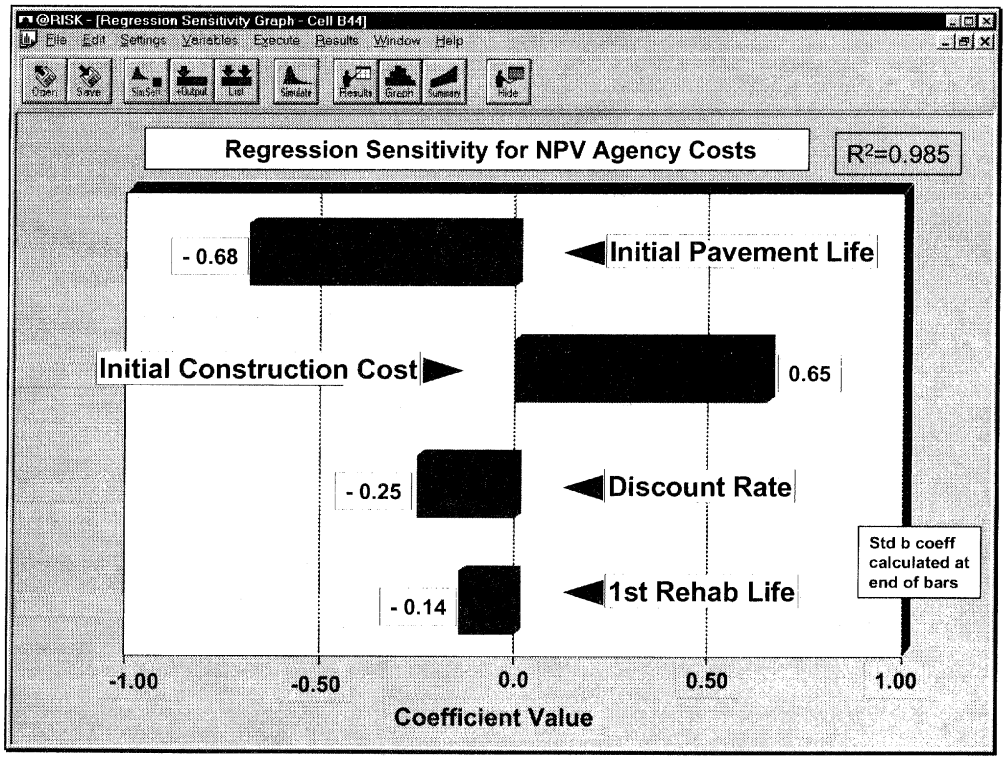
51



52


@RISK
Agency NPV
Rank
Regression Sensitivity
Rank Correlation
R²=0.985
Outputs
Inputs
Standard b Coefficient
Total NPV (Agency Cost)
Pavement Life
Initial Construction Cost
Discount Rate
1st Rehab Life
-0.68
0.65
-0.25
-0.14
-0.66
0.62
-0.25
-0.13
Sensitivity
Select Graph Type:
Correlation
Regression
OK
Cancel
Statistics
Data
Sensitivity
Scenarios

53


@RISK - [Regression Sensitivity Graph - Cell B44]
Regression Sensitivity for NPV Agency Costs
R²=0.985
- 0.68
Initial Pavement Life
Initial Construction Cost
0.65
- 0.25
Discount Rate
- 0.14
1st Rehab Life
Std b coeff calculated at end of bars
-1.00
-0.50
0.0
0.50
1.00
Coefficient Value

54

Sensitivity Analysis Observations

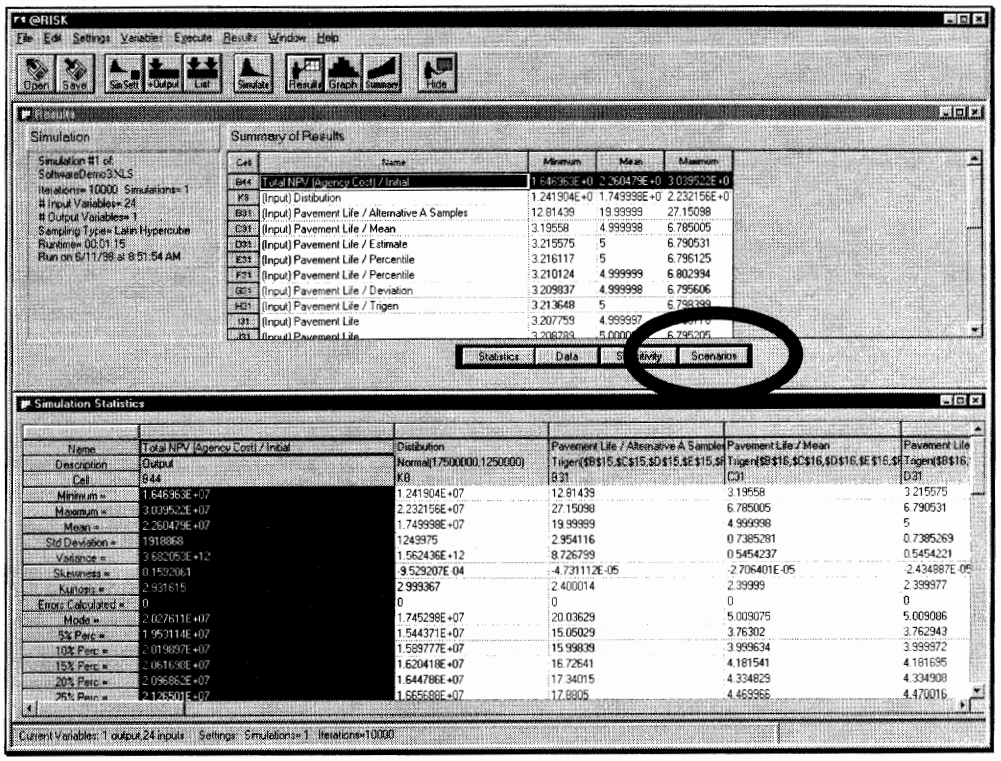
- Initial Pavement Life and Initial Construction Cost have the greatest influence on Agency NPV
- Discount Rate and 1st Rehab life have minor influence on Agency NPV

55

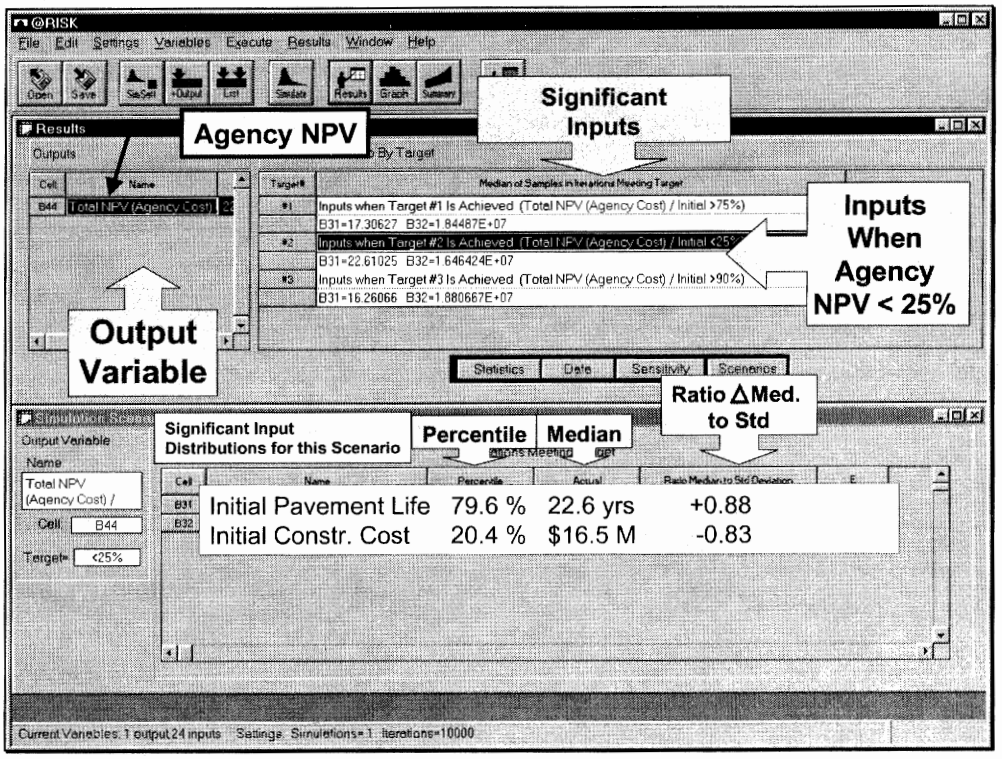
Agency Cost

- Probability
- Sensitivity
- Scenario Analysis

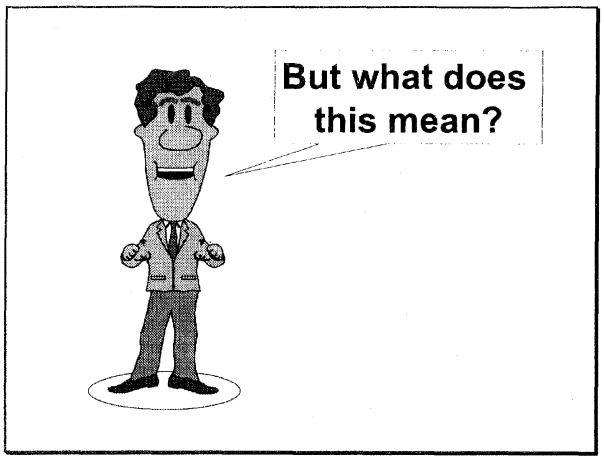
56


@RISK
Simulation
Summary of Results
Statistics
Data
Scenarios
Simulation Statistics

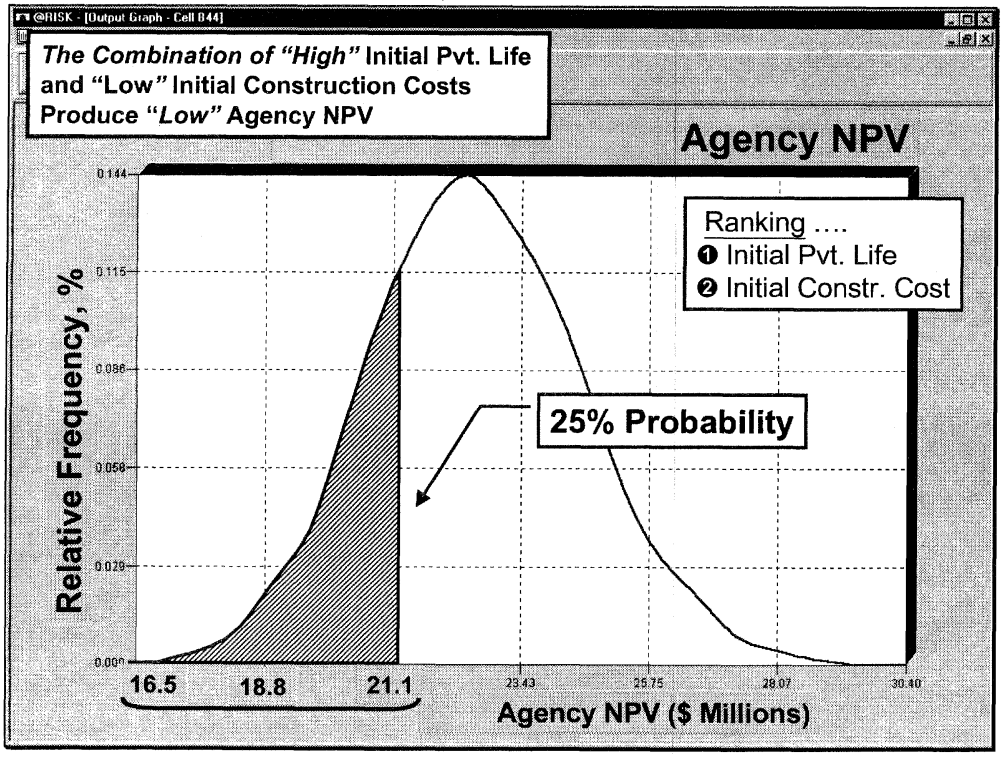
57


@RISK
Agency NPV
Significant Inputs
Inputs When Agency NPV < 25%
Output Variable
Ratio ΔMed. to Std
Significant Input Distributions for this Scenario
Percentile
Median
Initial Pavement Life 79.6 % 22.6 yrs +0.88
Initial Constr. Cost 20.4 % $16.5 M -0.83

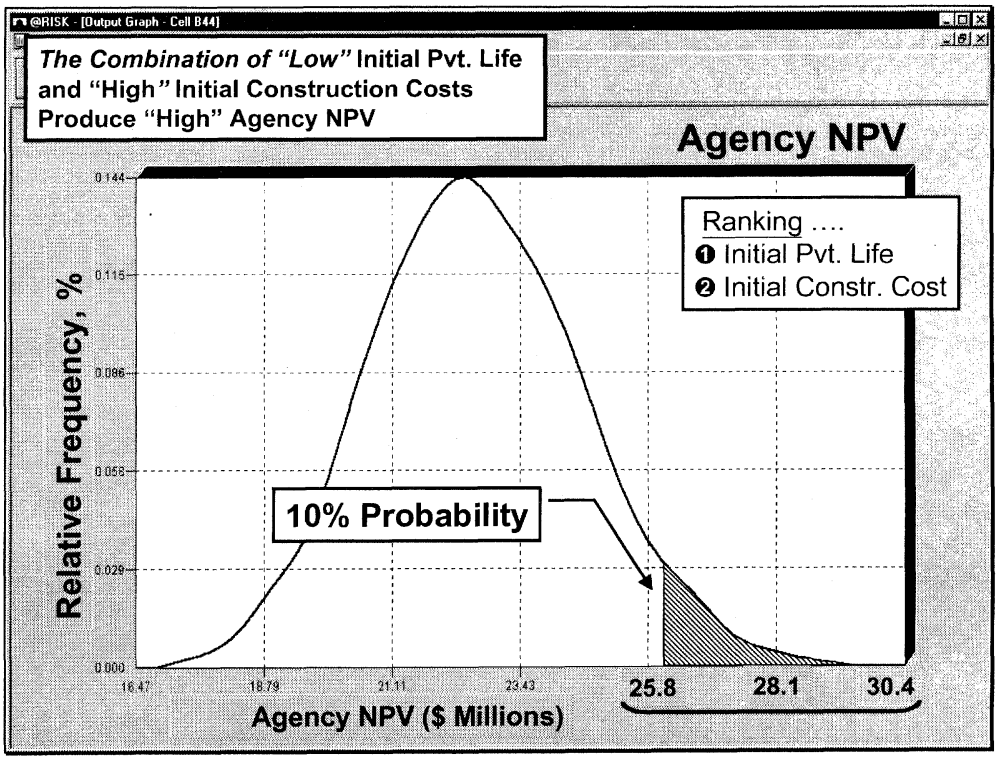
58


But what does this mean?

59


@RISK - [Output Graph - Cell B44]
The Combination of "High" Initial Pvt. Life and "Low" Initial Construction Costs Produce "Low" Agency NPV
Agency NPV
Ranking ....
❶ Initial Pvt. Life
❷ Initial Constr. Cost
25% Probability
Relative Frequency, %
0.144
0.115
0.086
0.058
0.029
0.000
16.5
18.8
21.1
23.43
25.75
28.07
30.40
Agency NPV ($ Millions)

60



61

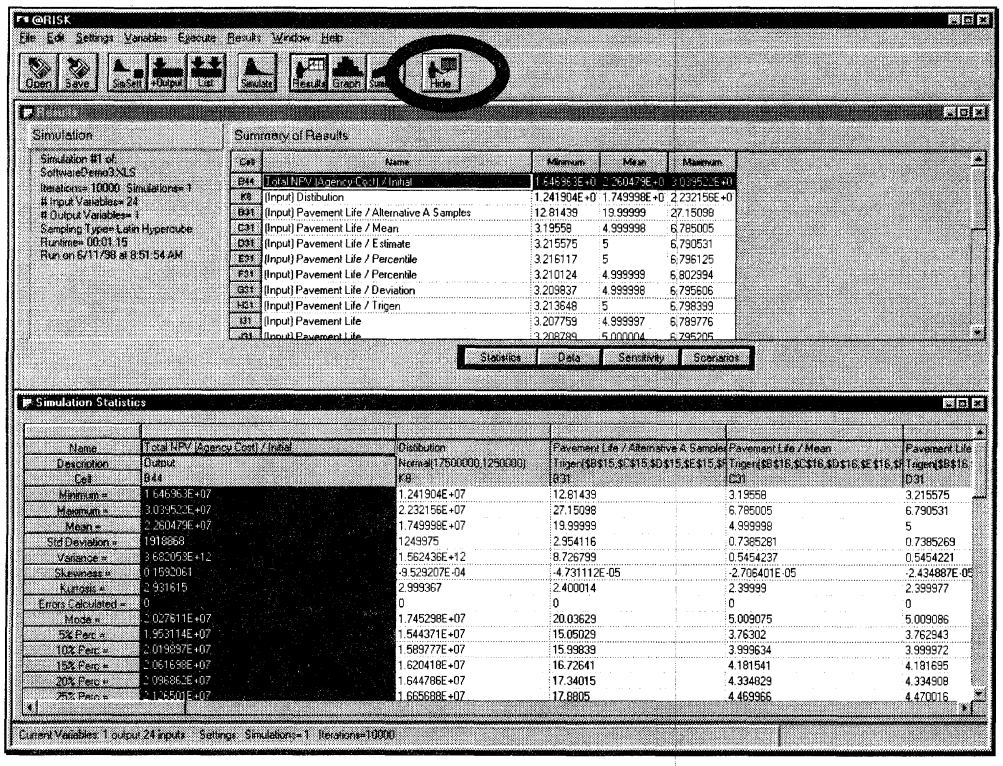
Scenario Analysis Observations

The Combination of ....

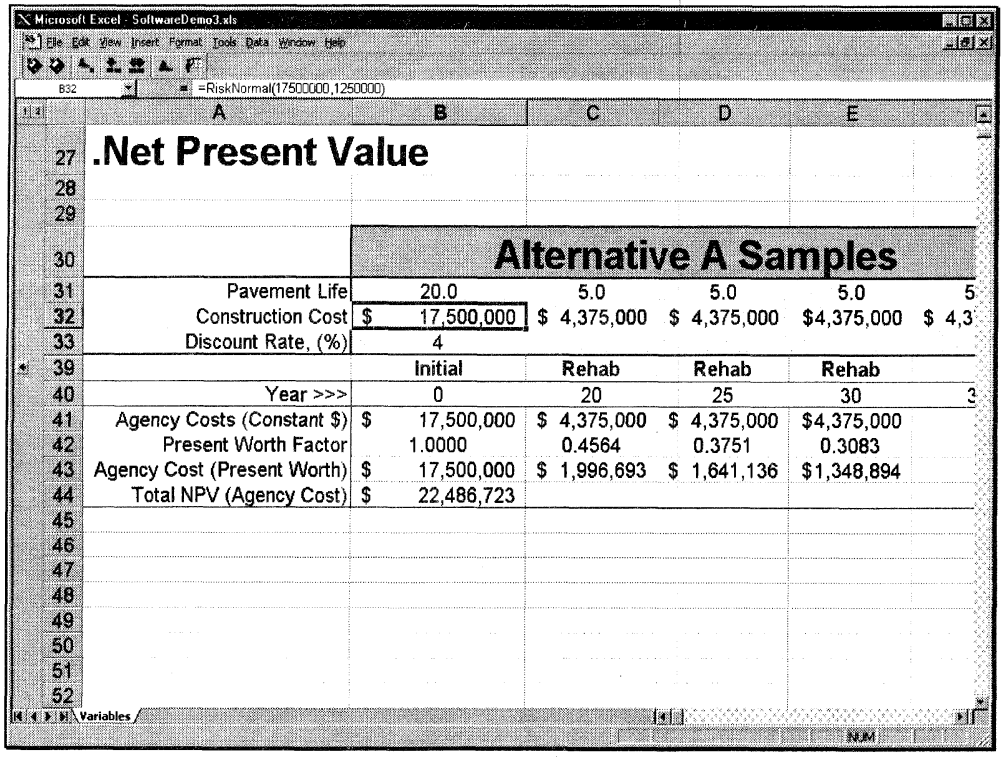
- *"High"* Initial Pvt. Life and *"Low"* Initial Construction Costs Produce *"Low"* [< 25%] Agency NPV

- *"Low"* Initial Pvt. Life and *"High"* Initial Construction Costs Produce *"High"* [>90%] Agency NPV

62


@RISK
File Edit Settings Variables Execute Results Window Help
Open Save SimSett +Output List Simulate Results Graph Sum Hide
Simulation
Summary of Results
Simulation #1 of SoftwareDemo3.XLS
Iterations= 10000 Simulations= 1
# Input Variables= 24
# Output Variables= 1
Sampling Type= Latin Hypercube
Runtime= 00:01:15
Run on 6/11/98 at 8:51:54 AM
Cell | Name | Minimum | Mean | Maximum
B44 | Total NPV (Agency Cost) / Initial | 1.646963E+07 | 2.260479E+07 | 3.039532E+07
K8 | (Input) Distribution | 1.241904E+07 | 1.749998E+07 | 2.232156E+07
B31 | (Input) Pavement Life / Alternative A Samples | 12.81439 | 19.99999 | 27.15098
C31 | (Input) Pavement Life / Mean | 3.19558 | 4.999998 | 6.785005
D31 | (Input) Pavement Life / Estimate | 3.215575 | 5 | 6.790531
E31 | (Input) Pavement Life / Percentile | 3.216117 | 5 | 6.796125
F31 | (Input) Pavement Life / Percentile | 3.210124 | 4.999999 | 6.802994
G31 | (Input) Pavement Life / Deviation | 3.209837 | 4.999998 | 6.795606
H31 | (Input) Pavement Life / Trigen | 3.213648 | 5 | 6.798399
I31 | (Input) Pavement Life | 3.207759 | 4.999997 | 6.789776
J31 | (Input) Pavement Life | 3.208789 | 5.000004 | 6.795205
Statistics Data Sensitivity Scenarios
Simulation Statistics
Name | Total NPV (Agency Cost) / Initial | Distribution | Pavement Life / Alternative A Samples | Pavement Life / Mean | Pavement Life
Description | Output | Normal(17500000,1250000) | Trigen($B$15,$C$15,$D$15,$E$15,$F | Trigen($B$16,$C$16,$D$16,$E$16,$F | Trigen($B$16,
Cell | B44 | K8 | B31 | C31 | D31
Minimum = | 1.646963E+07 | 1.241904E+07 | 12.81439 | 3.19558 | 3.215575
Maximum = | 3.039532E+07 | 2.232156E+07 | 27.15098 | 6.785005 | 6.790531
Mean = | 2.260479E+07 | 1.749998E+07 | 19.99999 | 4.999998 | 5
Std Deviation = | 1918868 | 1249975 | 2.954116 | 0.7385281 | 0.7385269
Variance = | 3.682053E+12 | 1.562436E+12 | 8.726799 | 0.5454237 | 0.5454221
Skewness = | 0.1592061 | -9.529207E-04 | -4.731112E-05 | -2.706401E-05 | -2.434887E-05
Kurtosis = | 2.931615 | 2.999367 | 2.400014 | 2.39999 | 2.399977
Errors Calculated = | 0 | 0 | 0 | 0 | 0
Mode = | 2.027611E+07 | 1.745298E+07 | 20.03629 | 5.009075 | 5.009086
5% Perc = | 1.953114E+07 | 1.544371E+07 | 15.05029 | 3.76302 | 3.762943
10% Perc = | 2.019897E+07 | 1.589777E+07 | 15.99839 | 3.999634 | 3.999972
15% Perc = | 2.061698E+07 | 1.620418E+07 | 16.72641 | 4.181541 | 4.181695
20% Perc = | 2.096862E+07 | 1.644786E+07 | 17.34015 | 4.334829 | 4.334908
25% Perc = | 2.124850E+07 | 1.665688E+07 | 17.8805 | 4.469966 | 4.470016
Current Variables: 1 output 24 inputs Settings: Simulations=1 Iterations=10000

63


Microsoft Excel - SoftwareDemo3.xls
File Edit View Insert Format Tools Data Window Help
B32 =RiskNormal(17500000,1250000)
A B C D E
27 .Net Present Value
28
29
30 Alternative A Samples
31 Pavement Life 20.0 5.0 5.0 5.0 5
32 Construction Cost $ 17,500,000 $ 4,375,000 $ 4,375,000 $4,375,000 $ 4,3
33 Discount Rate, (%) 4
39 Initial Rehab Rehab Rehab
40 Year >>> 0 20 25 30 3
41 Agency Costs (Constant $) $ 17,500,000 $ 4,375,000 $ 4,375,000 $4,375,000
42 Present Worth Factor 1.0000 0.4564 0.3751 0.3083
43 Agency Cost (Present Worth) $ 17,500,000 $ 1,996,693 $ 1,641,136 $1,348,894
44 Total NPV (Agency Cost) $ 22,486,723
45
46
47
48
49
50
51
52
Variables
NUM

64

Risk Modeling Review

- Build the traditional NPV model
- Identify and describe uncertain variables using risk functions
- Define simulation parameters and output variables
- Run the simulation
- Analyze Results

65

Parting Caveat ...

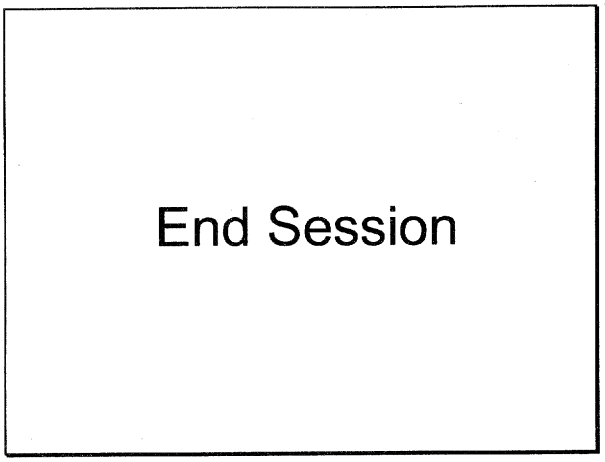
- *@Risk* and *BestFit* have been used for illustration purposes.
- Other software packages are available to do risk analysis.

66

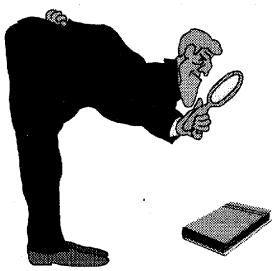
For More Information:

- @Risk and BestFit
  - Palisade Corporation
    http://www.palisade.com
    Phone: 800-432-7475
- Crystal Ball
  - Decisioneering
    http://www.decisioneering.com
    Phone: 800-289-2550

67



1



LCCA

Class Exercise Revisited

2

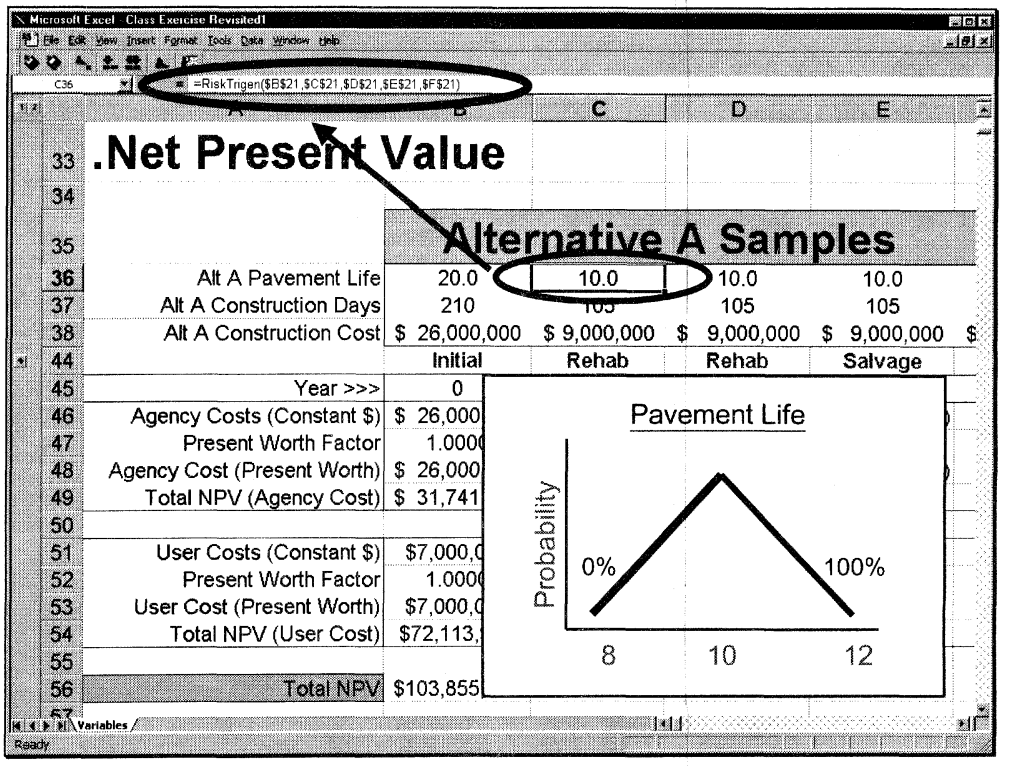
Microsoft Excel - Class Exercise Revisited1.xls

Class Exercise Revisited

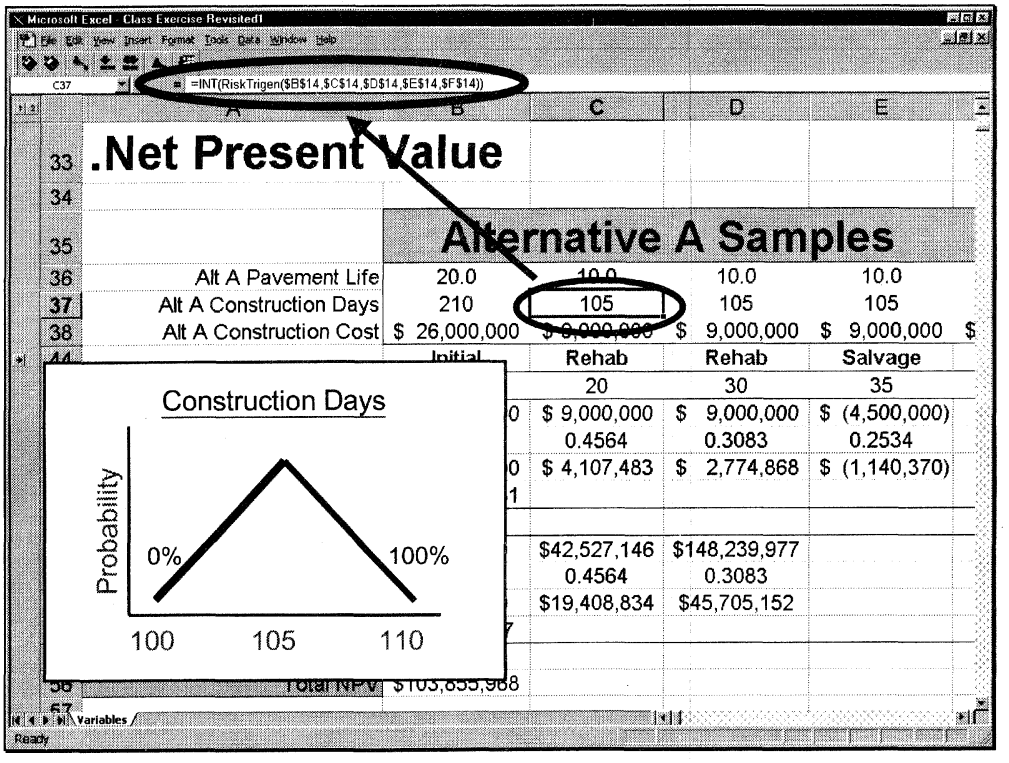
Analysis Period	35	years	
Discount Rate	4.0%		

	.Risk Analysis Input Parameters					
Variable	Lower Estimate	Most Likely	Upper Estimate	Lower Percentile	Upper Percentile	Distibution Type
Construction Days						
Alternative A						
Initial	200	210	220	0	100	Trigen
Rehab	100	105	110	0	100	Trigen
Alternative B						
Initial	150	165	180	0	100	Trigen
Rehab	70	85	100	0	100	Trigen
Performance Estimates						
Alternative A						
Initial	16	20	24	0.00	100.00	Trigen
Rehab	8	10	12	0.00	100.00	Trigen
Alternative B						
Initial	10	13	16	0.00	100.00	Trigen
Rehab	6	7	8	0.00	100.00	Trigen

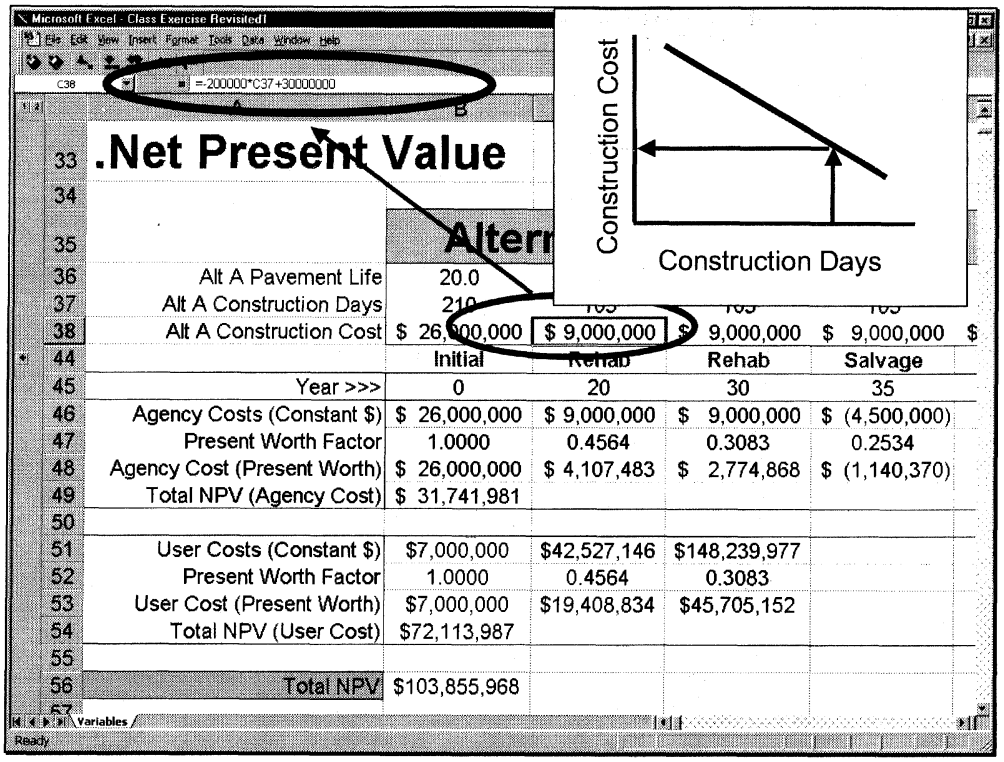
3


Microsoft Excel - Class Exercise Revisited1
=RiskTrigen($B$21,$C$21,$D$21,$E$21,$F$21)
.Net Present Value
Alternative A Samples
Alt A Pavement Life 20.0 10.0 10.0 10.0
Alt A Construction Days 210 105 105 105
Alt A Construction Cost $ 26,000,000 $ 9,000,000 $ 9,000,000 $ 9,000,000
Initial Rehab Rehab Salvage
Year >>> 0
Agency Costs (Constant $) $ 26,000
Present Worth Factor 1.000
Agency Cost (Present Worth) $ 26,000
Total NPV (Agency Cost) $ 31,741
User Costs (Constant $) $7,000,0
Present Worth Factor 1.000
User Cost (Present Worth) $7,000,0
Total NPV (User Cost) $72,113,
Total NPV $103,855
Pavement Life
Probability
0%
100%
8
10
12
Variables
Ready

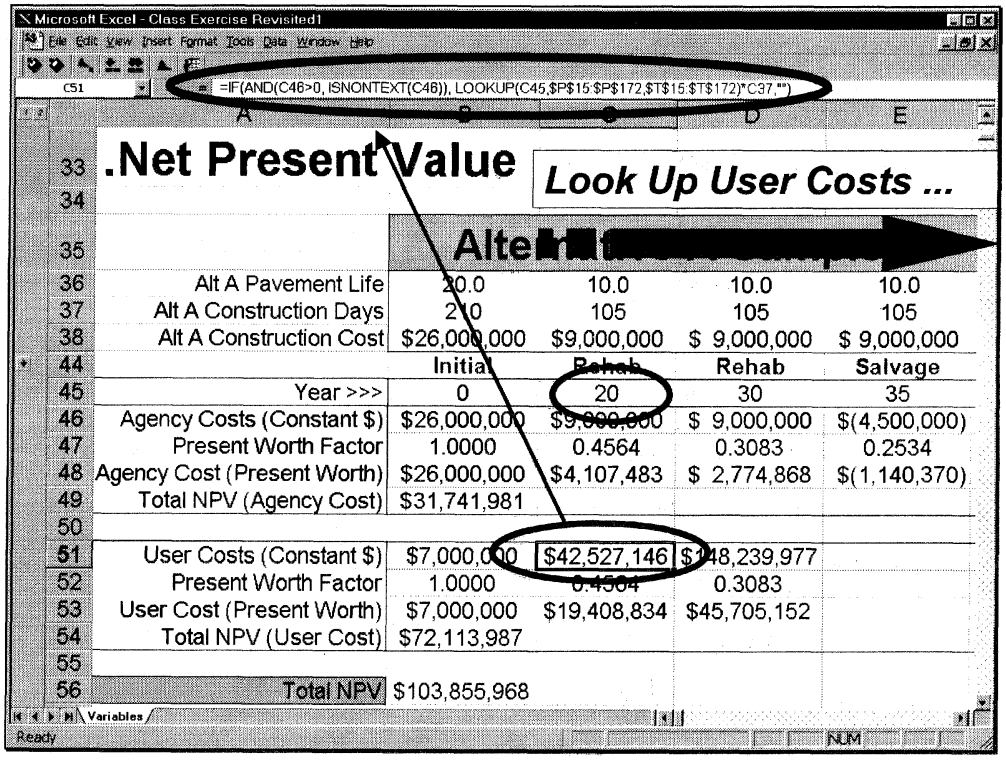
4


Microsoft Excel - Class Exercise Revisited1
=INT(RiskTrigen($B$14,$C$14,$D$14,$E$14,$F$14))
.Net Present Value
Alternative A Samples
Alt A Pavement Life 20.0 10.0 10.0 10.0
Alt A Construction Days 210 105 105 105
Alt A Construction Cost $ 26,000,000 $ 9,000,000 $ 9,000,000 $
Rehab Rehab Salvage
20 30 35
$ 9,000,000 $ 9,000,000 $ (4,500,000)
0.4564 0.3083 0.2534
$ 4,107,483 $ 2,774,868 $ (1,140,370)
$42,527,146 $148,239,977
0.4564 0.3083
$19,408,834 $45,705,152
Construction Days
Probability
0%
100%
100
105
110
Variables
Ready

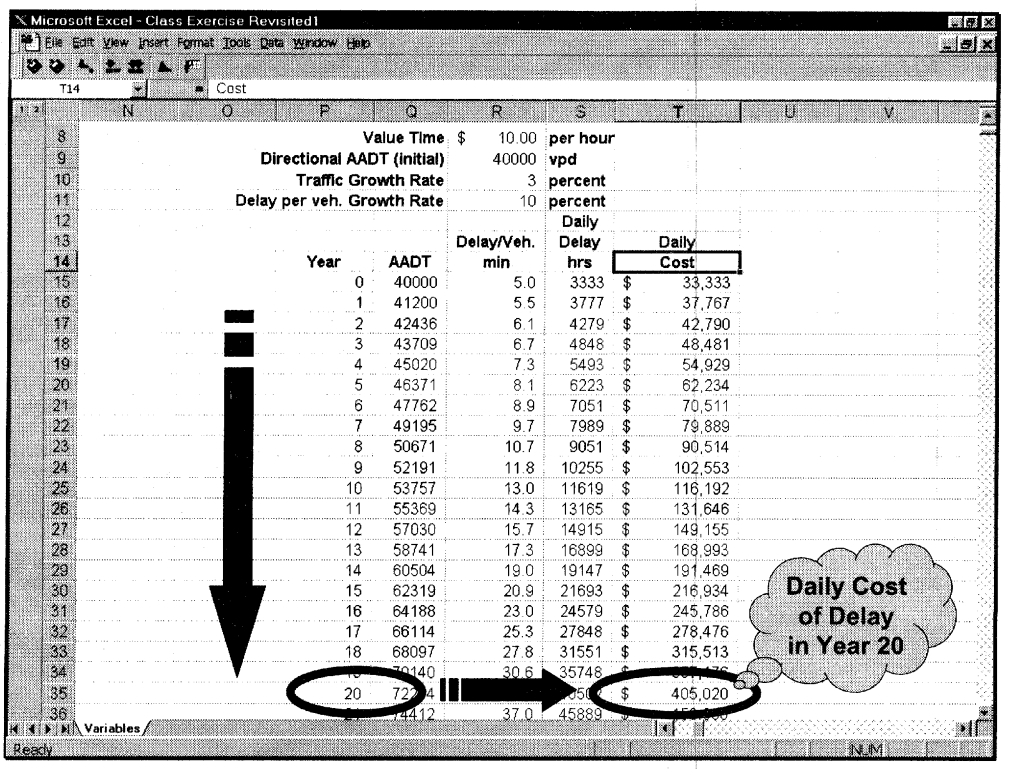
5


Microsoft Excel - Class Exercise Revisited1
=-200000*C37+30000000
.Net Present Value
Construction Cost
Construction Days
Alt A Pavement Life 20.0
Alt A Construction Days 210
Alt A Construction Cost $ 26,000,000 $ 9,000,000 $ 9,000,000 $ 9,000,000 $
Initial Rehab Rehab Salvage
Year >>> 0 20 30 35
Agency Costs (Constant $) $ 26,000,000 $ 9,000,000 $ 9,000,000 $ (4,500,000)
Present Worth Factor 1.0000 0.4564 0.3083 0.2534
Agency Cost (Present Worth) $ 26,000,000 $ 4,107,483 $ 2,774,868 $ (1,140,370)
Total NPV (Agency Cost) $ 31,741,981
User Costs (Constant $) $7,000,000 $42,527,146 $148,239,977
Present Worth Factor 1.0000 0.4564 0.3083
User Cost (Present Worth) $7,000,000 $19,408,834 $45,705,152
Total NPV (User Cost) $72,113,987
Total NPV $103,855,968
Variables
Ready

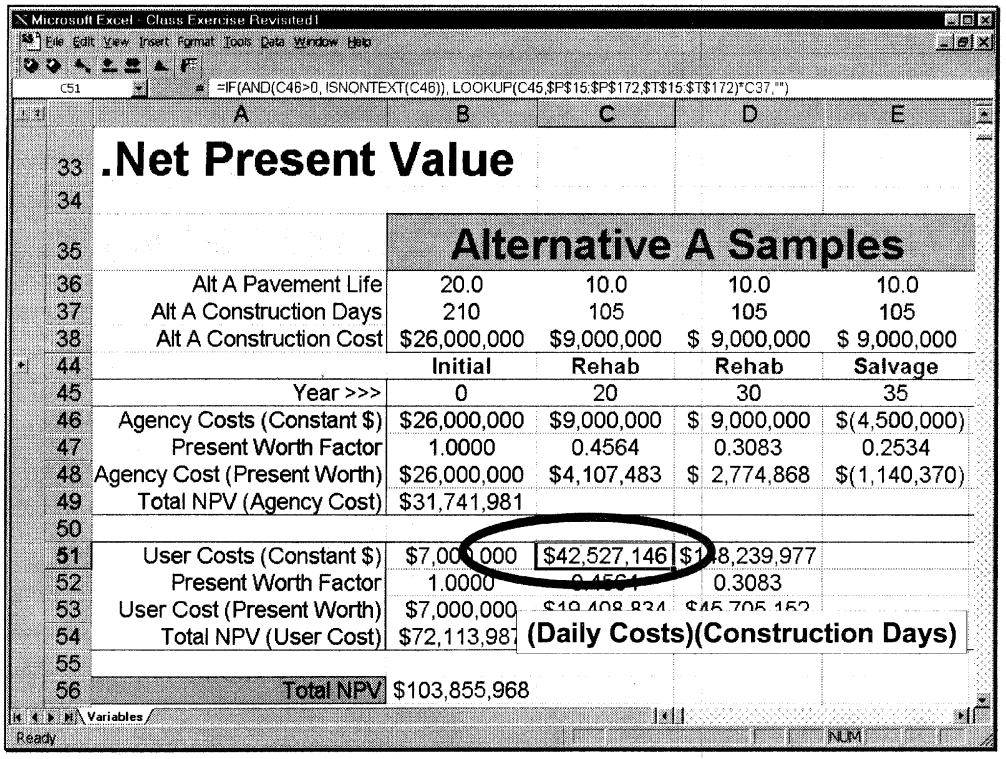
6


Microsoft Excel - Class Exercise Revisited1
=IF(AND(C46>0, ISNONTEXT(C46)), LOOKUP(C45,$P$15:$P$172,$T$15:$T$172)*C37,"")
.Net Present Value
Look Up User Costs ...
Alt A Pavement Life 20.0 10.0 10.0 10.0
Alt A Construction Days 210 105 105 105
Alt A Construction Cost $26,000,000 $9,000,000 $ 9,000,000 $ 9,000,000
Initial Rehab Rehab Salvage
Year >>> 0 20 30 35
Agency Costs (Constant $) $26,000,000 $9,000,000 $ 9,000,000 $(4,500,000)
Present Worth Factor 1.0000 0.4564 0.3083 0.2534
Agency Cost (Present Worth) $26,000,000 $4,107,483 $ 2,774,868 $(1,140,370)
Total NPV (Agency Cost) $31,741,981
User Costs (Constant $) $7,000,000 $42,527,146 $148,239,977
Present Worth Factor 1.0000 0.4564 0.3083
User Cost (Present Worth) $7,000,000 $19,408,834 $45,705,152
Total NPV (User Cost) $72,113,987
Total NPV $103,855,968
Variables
Ready
NUM

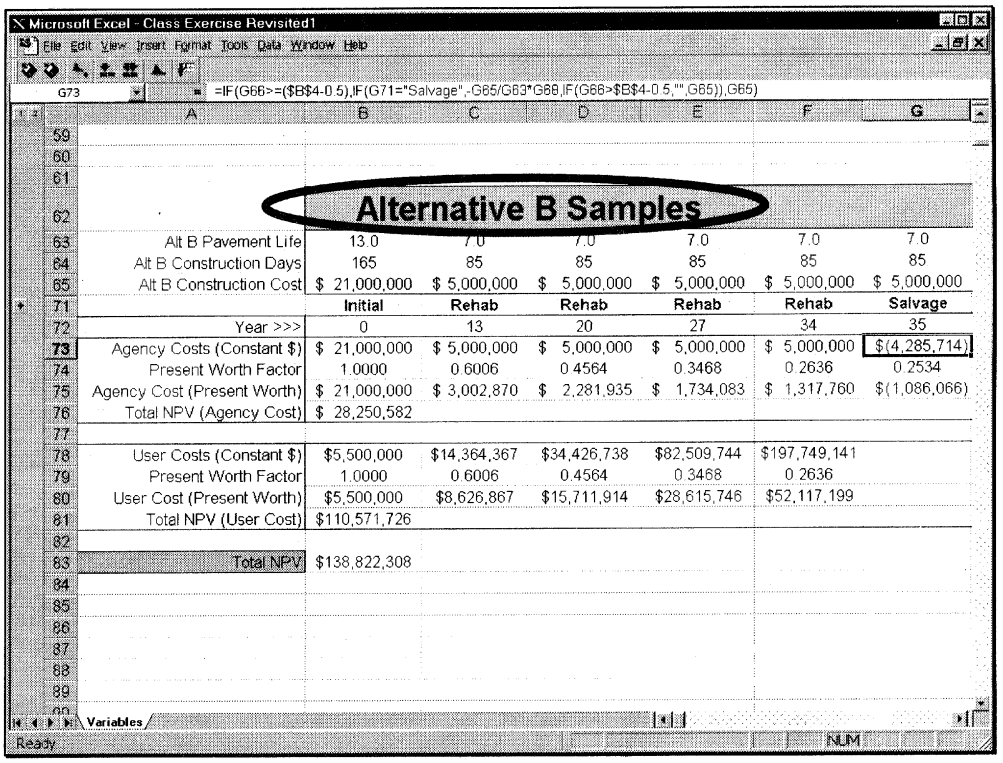
7


Microsoft Excel - Class Exercise Revisited1
Value Time $ 10.00 per hour
Directional AADT (initial) 40000 vpd
Traffic Growth Rate 3 percent
Delay per veh. Growth Rate 10 percent
Year AADT Delay/Veh. min Daily Delay hrs Daily Cost
0 40000 5.0 3333 $ 33,333
1 41200 5.5 3777 $ 37,767
2 42436 6.1 4279 $ 42,790
3 43709 6.7 4848 $ 48,481
4 45020 7.3 5493 $ 54,929
5 46371 8.1 6223 $ 62,234
6 47762 8.9 7051 $ 70,511
7 49195 9.7 7989 $ 79,889
8 50671 10.7 9051 $ 90,514
9 52191 11.8 10255 $ 102,553
10 53757 13.0 11619 $ 116,192
11 55369 14.3 13165 $ 131,646
12 57030 15.7 14915 $ 149,155
13 58741 17.3 16899 $ 168,993
14 60504 19.0 19147 $ 191,469
15 62319 20.9 21693 $ 216,934
16 64188 23.0 24579 $ 245,786
17 66114 25.3 27848 $ 278,476
18 68097 27.8 31551 $ 315,513
20 $ 405,020
Daily Cost of Delay in Year 20
Variables
Ready
NUM

8


Microsoft Excel - Class Exercise Revisited1
=IF(AND(C46>0, ISNONTEXT(C46)), LOOKUP(C45,$P$15:$P$172,$T$15:$T$172)*C37,"")
.Net Present Value
Alternative A Samples
Alt A Pavement Life 20.0 10.0 10.0 10.0
Alt A Construction Days 210 105 105 105
Alt A Construction Cost $26,000,000 $9,000,000 $ 9,000,000 $ 9,000,000
Initial Rehab Rehab Salvage
Year >>> 0 20 30 35
Agency Costs (Constant $) $26,000,000 $9,000,000 $ 9,000,000 $(4,500,000)
Present Worth Factor 1.0000 0.4564 0.3083 0.2534
Agency Cost (Present Worth) $26,000,000 $4,107,483 $ 2,774,868 $(1,140,370)
Total NPV (Agency Cost) $31,741,981
User Costs (Constant $) $7,000,000 $42,527,146 $18,239,977
Present Worth Factor 1.0000 0.4564 0.3083
User Cost (Present Worth) $7,000,000
Total NPV (User Cost) $72,113,987
(Daily Costs)(Construction Days)
Total NPV $103,855,968
Variables
Ready
NUM

9



Microsoft Excel - Class Exercise Revisited1

File Edit View Insert Format Tools Data Window Help

G73 =IF(G66>=($B$4-0.5),IF(G71="Salvage",-G65/G63*G68,IF(G66>$B$4-0.5,"",G65)),G65)

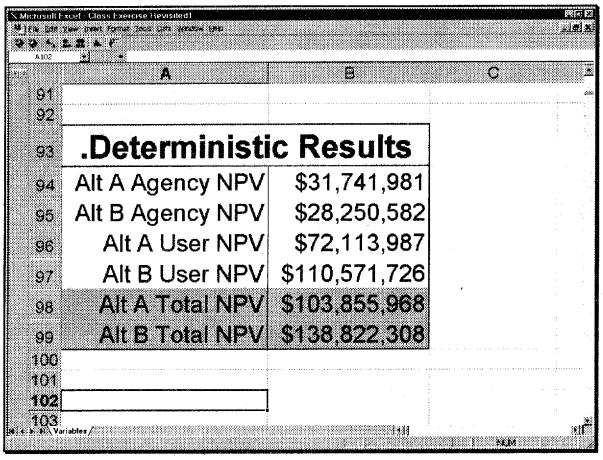
Alternative B Samples

Alt B Pavement Life	13.0	7.0	7.0	7.0	7.0	7.0
Alt B Construction Days	165	85	85	85	85	85
Alt B Construction Cost	$ 21,000,000	$ 5,000,000	$ 5,000,000	$ 5,000,000	$ 5,000,000	$ 5,000,000
	Initial	**Rehab**	**Rehab**	**Rehab**	**Rehab**	**Salvage**
Year >>>	0	13	20	27	34	35
Agency Costs (Constant $)	$ 21,000,000	$ 5,000,000	$ 5,000,000	$ 5,000,000	$ 5,000,000	$(4,285,714)
Present Worth Factor	1.0000	0.6006	0.4564	0.3468	0.2636	0.2534
Agency Cost (Present Worth)	$ 21,000,000	$ 3,002,870	$ 2,281,935	$ 1,734,083	$ 1,317,760	$(1,086,066)
Total NPV (Agency Cost)	$ 28,250,582					
User Costs (Constant $)	$5,500,000	$14,364,367	$34,426,738	$82,509,744	$197,749,141	
Present Worth Factor	1.0000	0.6006	0.4564	0.3468	0.2636	
User Cost (Present Worth)	$5,500,000	$8,626,867	$15,711,914	$28,615,746	$52,117,199	
Total NPV (User Cost)	$110,571,726					
Total NPV	$138,822,308					

Variables

Ready NUM

10



.Deterministic Results

Alt A Agency NPV	$31,741,981
Alt B Agency NPV	$28,250,582
Alt A User NPV	$72,113,987
Alt B User NPV	$110,571,726
Alt A Total NPV	$103,855,968
Alt B Total NPV	$138,822,308

11

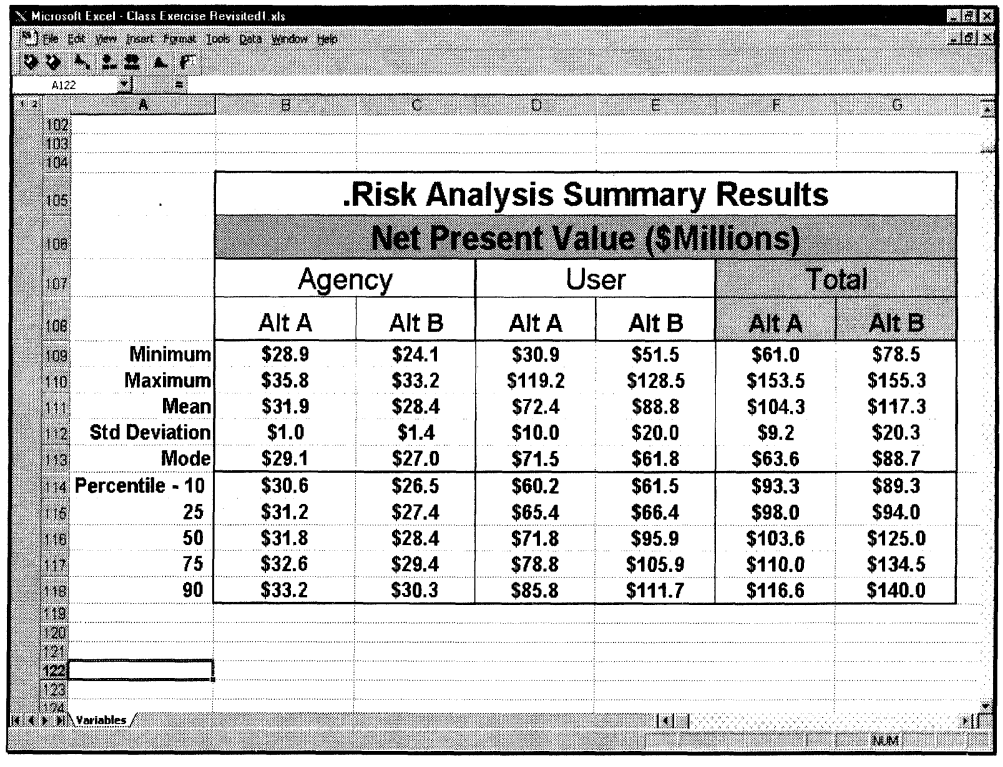
Simulation Processing

- Latin Hypercube
- 44 Input Variables
- 6 Output Variables
- 10,000 Iterations
- Run Time = 3 min 51 sec

12

Simulation Results

13



.Risk Analysis Summary Results						
Net Present Value ($Millions)						
	Agency		User		Total	
	Alt A	Alt B	Alt A	Alt B	Alt A	Alt B
Minimum	$28.9	$24.1	$30.9	$51.5	$61.0	$78.5
Maximum	$35.8	$33.2	$119.2	$128.5	$153.5	$155.3
Mean	$31.9	$28.4	$72.4	$88.8	$104.3	$117.3
Std Deviation	$1.0	$1.4	$10.0	$20.0	$9.2	$20.3
Mode	$29.1	$27.0	$71.5	$61.8	$63.6	$88.7
Percentile - 10	$30.6	$26.5	$60.2	$61.5	$93.3	$89.3
25	$31.2	$27.4	$65.4	$66.4	$98.0	$94.0
50	$31.8	$28.4	$71.8	$95.9	$103.6	$125.0
75	$32.6	$29.4	$78.8	$105.9	$110.0	$134.5
90	$33.2	$30.3	$85.8	$111.7	$116.6	$140.0

14

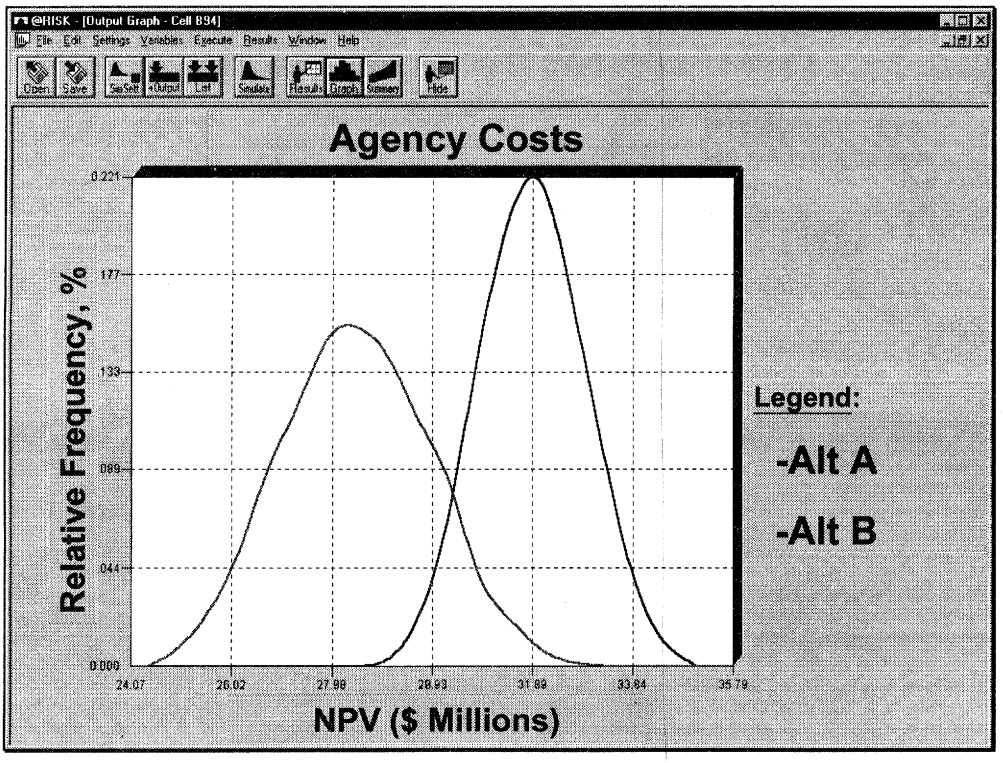
Agency Costs

15

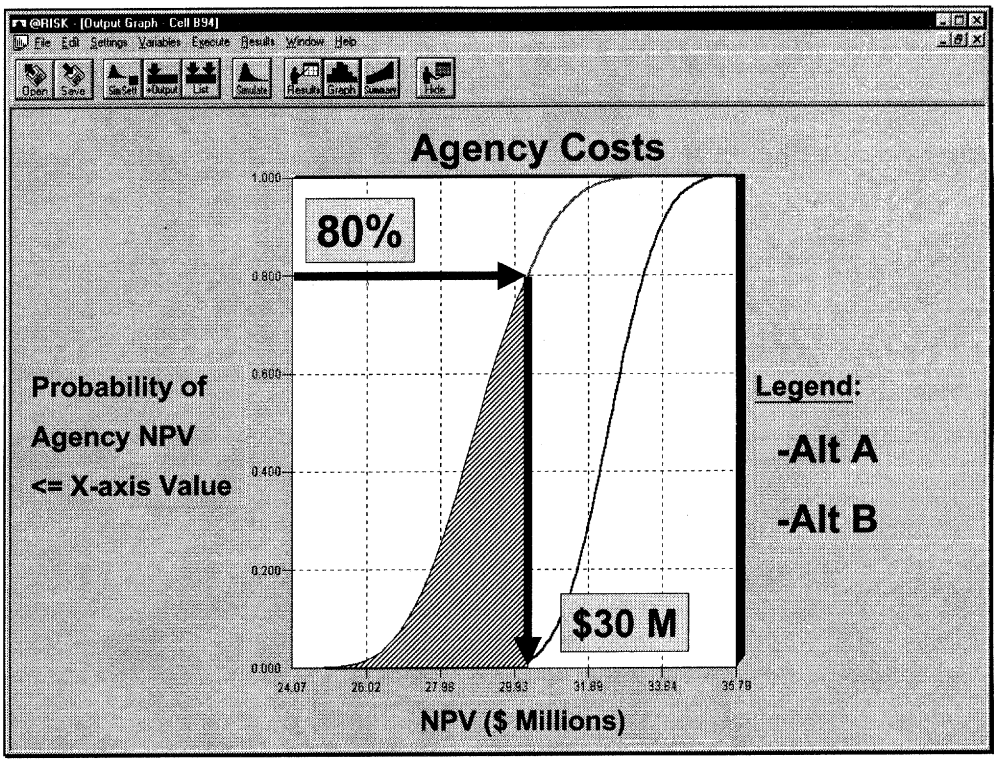
Agency Cost

- Probability
- Sensitivity
- Scenario Analysis

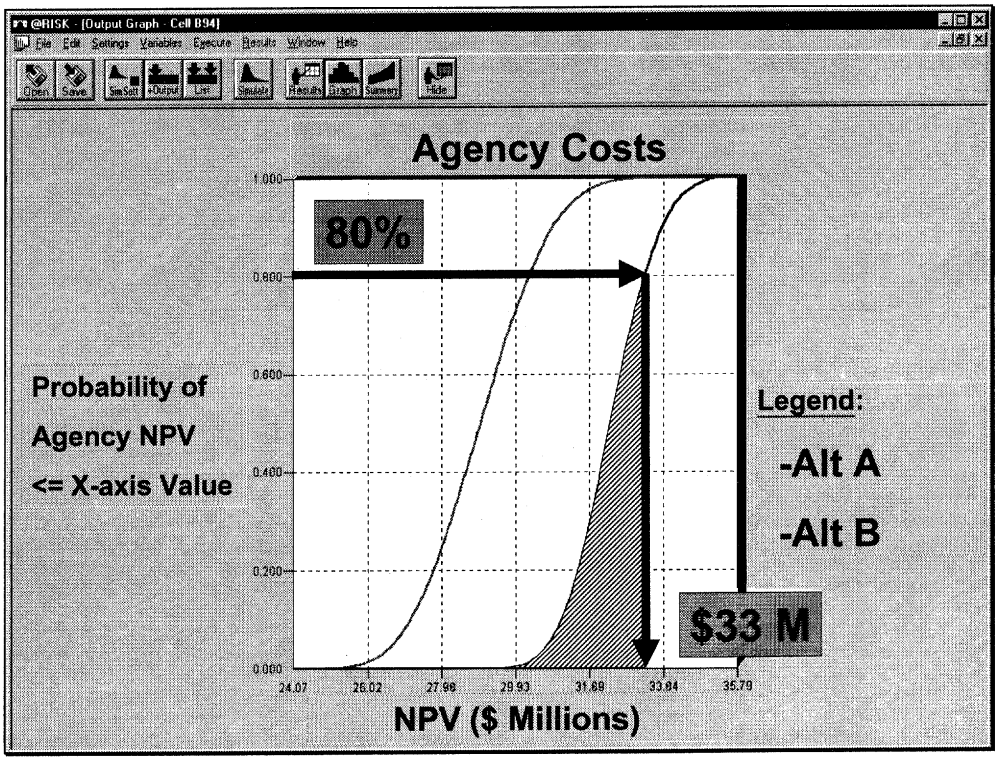
16



17


@RISK - [Output Graph - Cell B94]
File Edit Settings Variables Execute Results Window Help
Agency Costs
80%
$30 M
Probability of
Agency NPV
<= X-axis Value
Legend:
-Alt A
-Alt B
1.000
0.800
0.600
0.400
0.200
0.000
24.07
26.02
27.98
29.93
31.89
33.84
35.79
NPV ($ Millions)

18


@RISK - [Output Graph - Cell B94]
File Edit Settings Variables Execute Results Window Help
Agency Costs
80%
$33 M
Probability of
Agency NPV
<= X-axis Value
Legend:
-Alt A
-Alt B
1.000
0.800
0.600
0.400
0.200
0.000
24.07
26.02
27.98
29.93
31.89
33.84
35.79
NPV ($ Millions)

19

Probability Observations

Agency Costs …

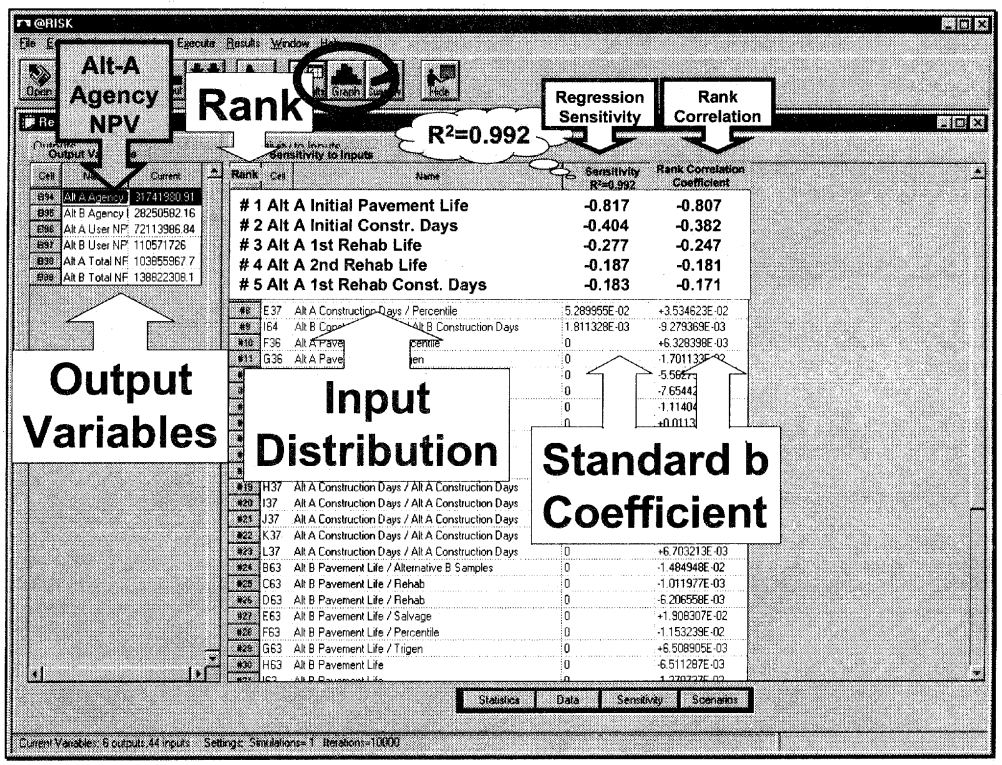
- Alt-B is 42% *more* variable than Alt-A
- At *any* given level of reliability Alt-B is *less* expensive than Alt-A.

20

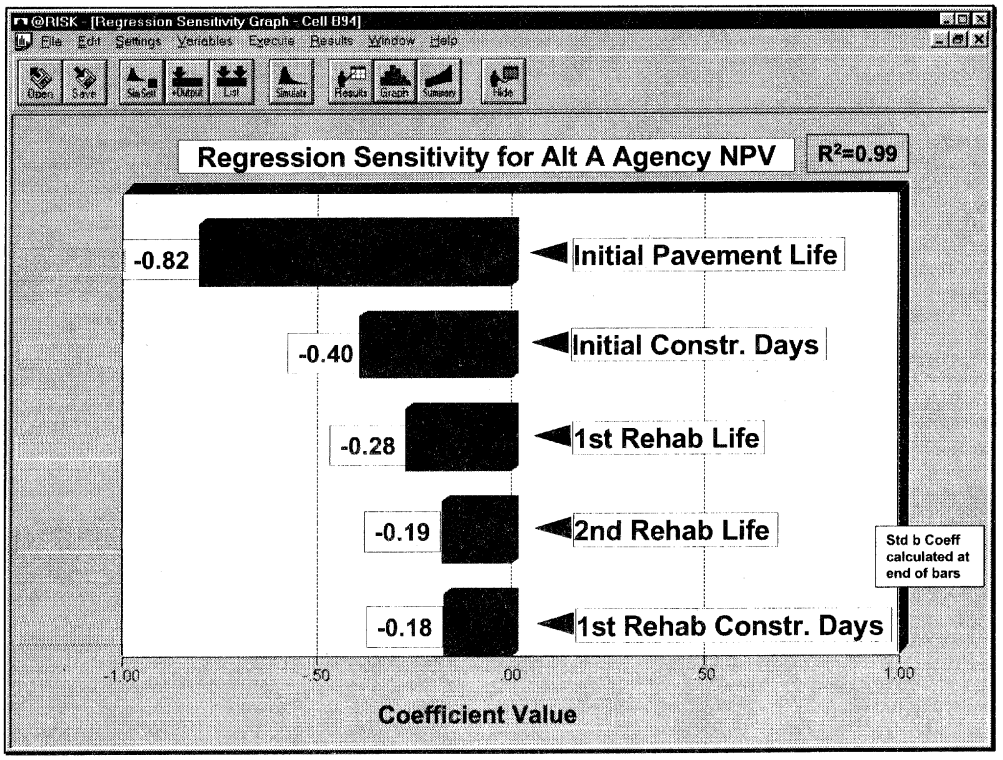
Agency Cost

- Probability
- Sensitivity

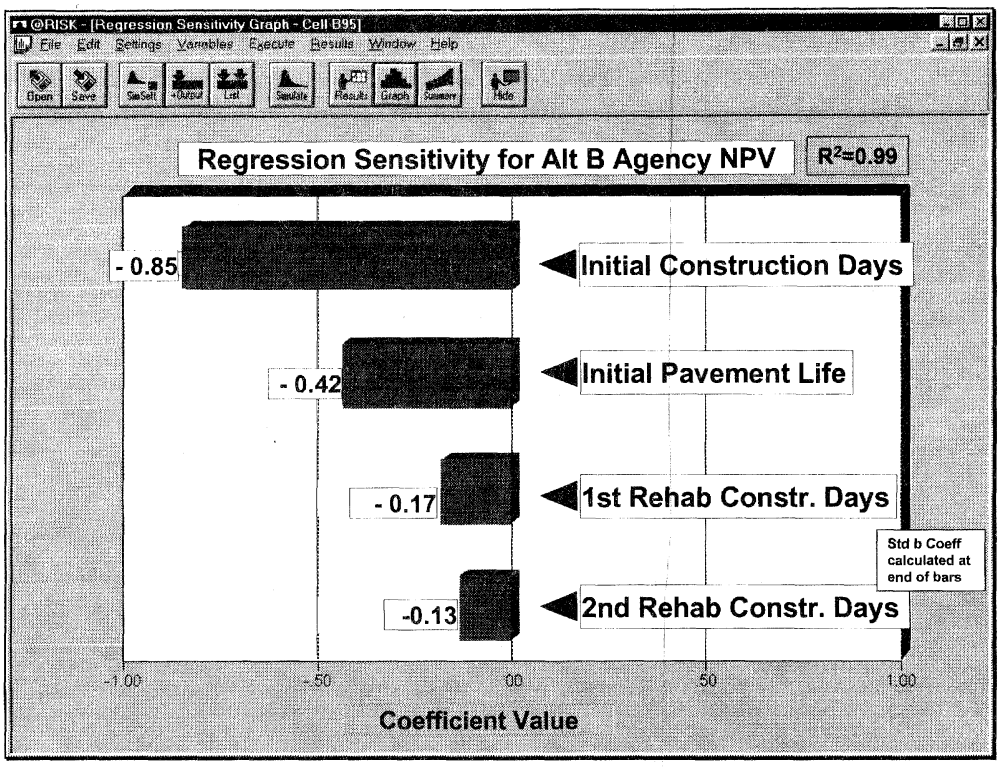
21


Alt-A Agency NPV
Rank
R²=0.992
Regression Sensitivity
Rank Correlation
1 Alt A Initial Pavement Life -0.817 -0.807
2 Alt A Initial Constr. Days -0.404 -0.382
3 Alt A 1st Rehab Life -0.277 -0.247
4 Alt A 2nd Rehab Life -0.187 -0.181
5 Alt A 1st Rehab Const. Days -0.183 -0.171
Output Variables
Input Distribution
Standard b Coefficient

22


Regression Sensitivity for Alt A Agency NPV
R²=0.99
-0.82 Initial Pavement Life
-0.40 Initial Constr. Days
-0.28 1st Rehab Life
-0.19 2nd Rehab Life
-0.18 1st Rehab Constr. Days
Std b Coeff calculated at end of bars
-1.00
-.50
.00
.50
1.00
Coefficient Value

23



24

Sensitivity Observations

Agency Costs ...

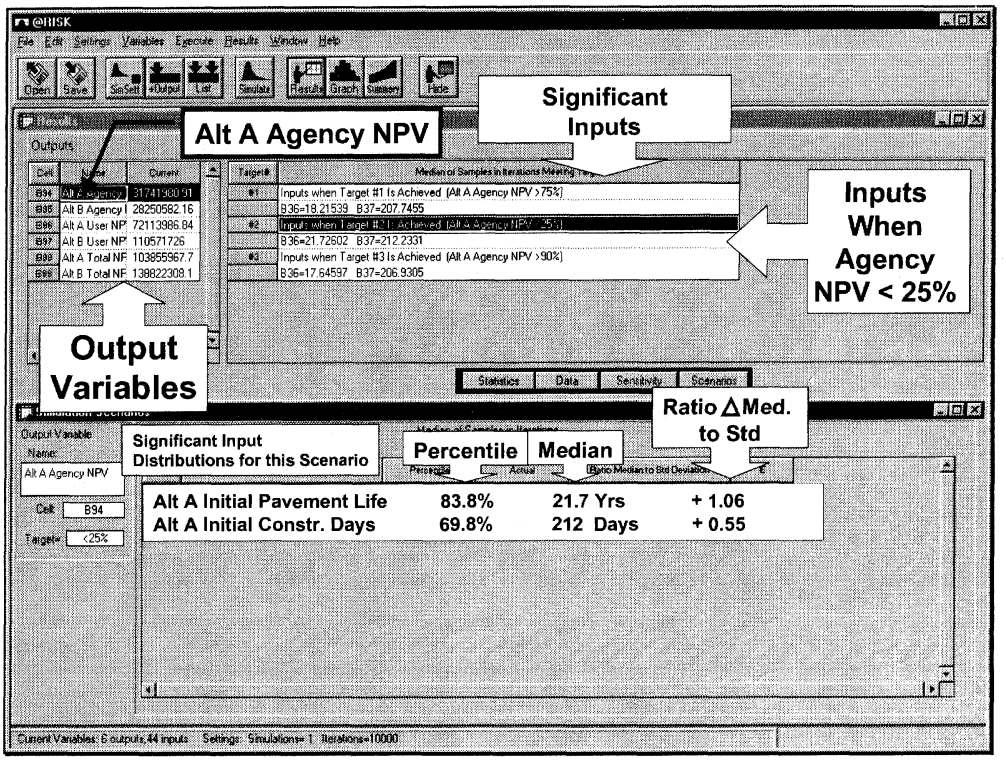
- Alternative A
  - Initial Pavement Life has the greatest influence on Agency NPV
- Alternative B
  - Initial Construction Days has the greatest influence on Agency NPV

25

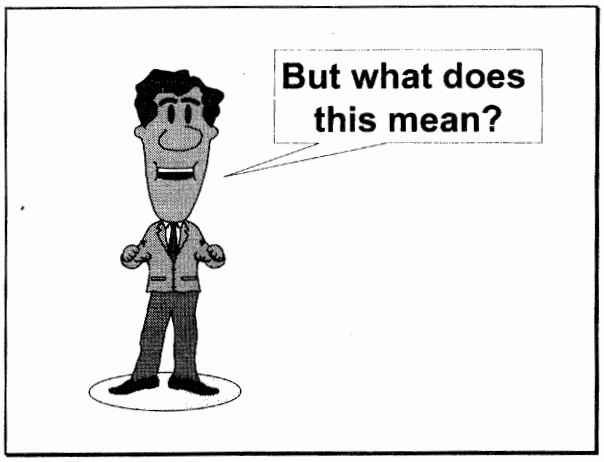
Agency Cost

- Probability
- Sensitivity
- Scenario Analysis

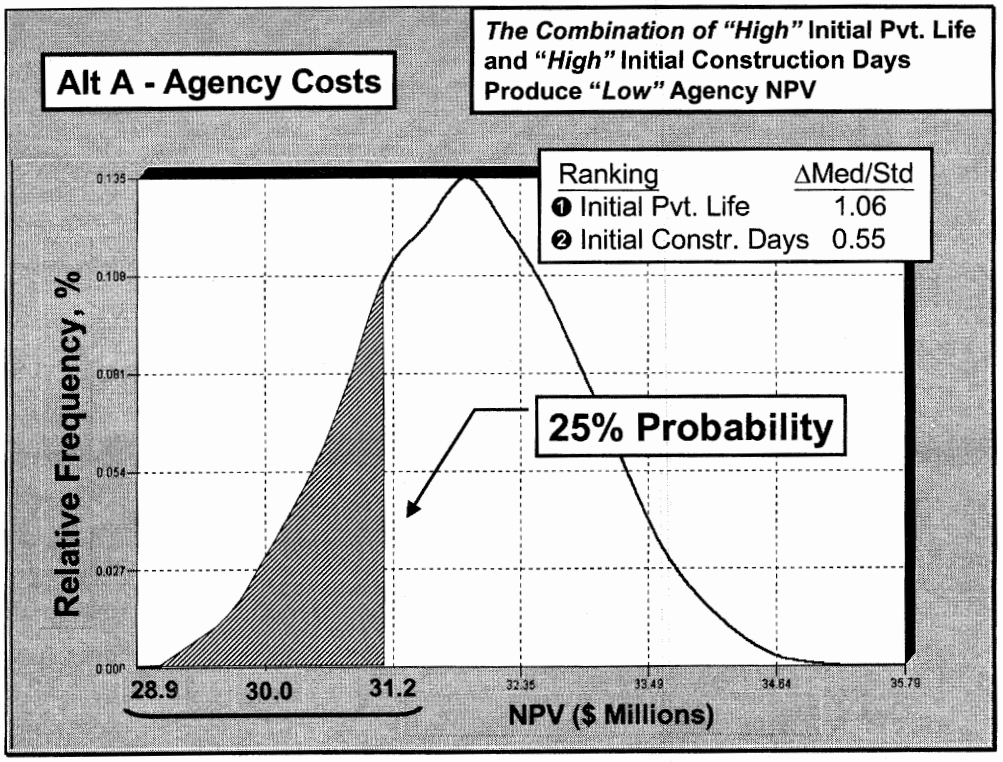
26



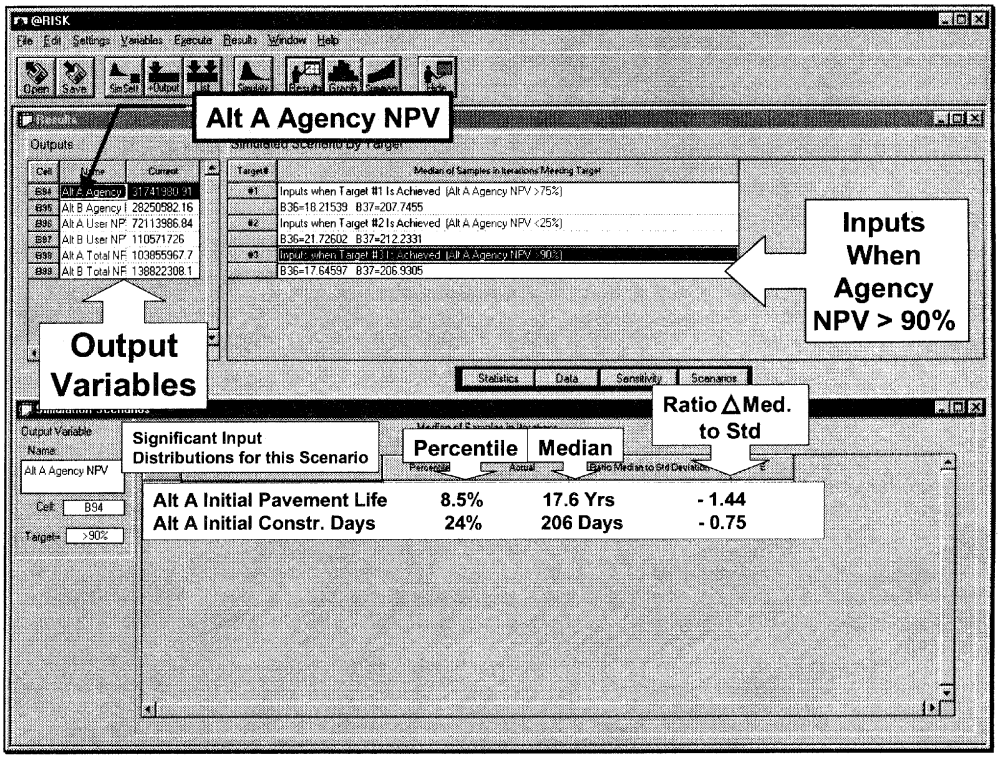
27


But what does this mean?

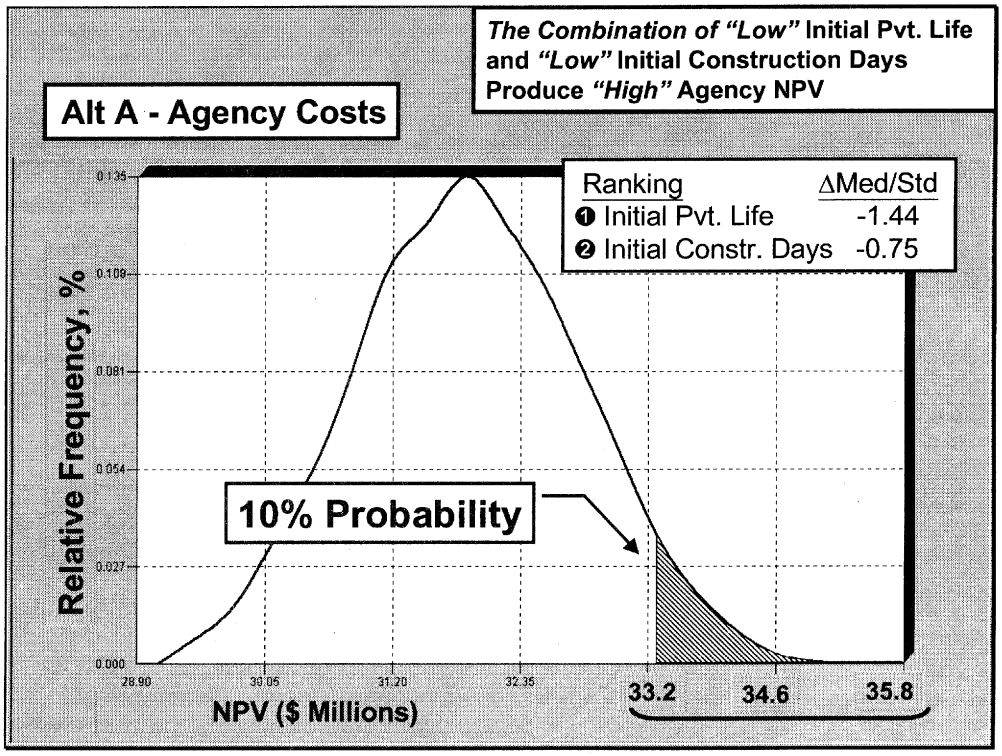
28


Alt A - Agency Costs
The Combination of "High" Initial Pvt. Life and "High" Initial Construction Days Produce "Low" Agency NPV
Ranking ΔMed/Std
❶ Initial Pvt. Life 1.06
❷ Initial Constr. Days 0.55
25% Probability
Relative Frequency, %
0.135
0.108
0.081
0.054
0.027
0.000
28.9
30.0
31.2
32.35
33.49
34.64
35.79
NPV ($ Millions)

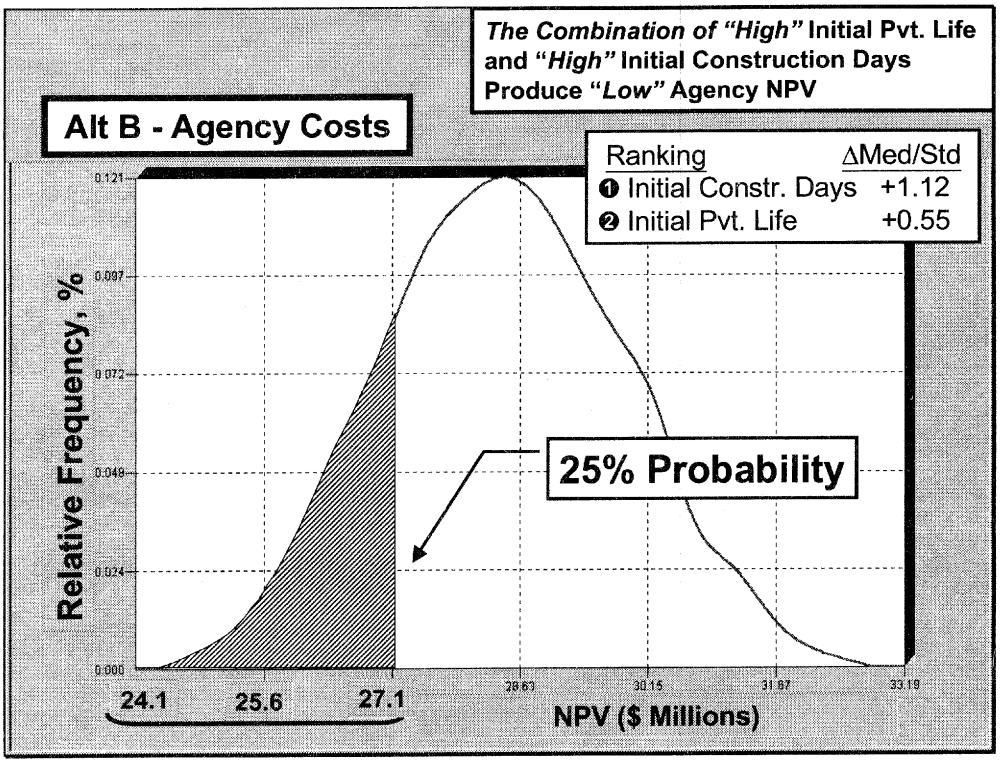
29


Alt A Agency NPV
Output Variables
Inputs When Agency NPV > 90%
Ratio ΔMed. to Std
Significant Input Distributions for this Scenario
Percentile
Median
Alt A Initial Pavement Life 8.5% 17.6 Yrs - 1.44
Alt A Initial Constr. Days 24% 206 Days - 0.75

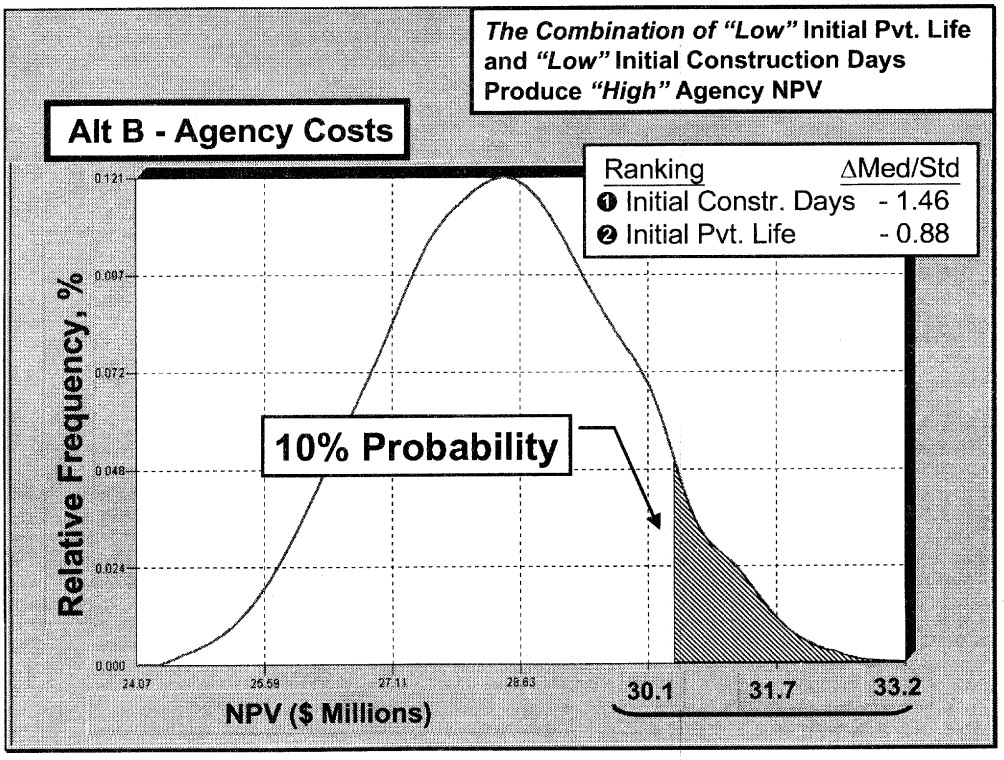
30


The Combination of "Low" Initial Pvt. Life and "Low" Initial Construction Days Produce "High" Agency NPV
Alt A - Agency Costs
Ranking ΔMed/Std
❶ Initial Pvt. Life -1.44
❷ Initial Constr. Days -0.75
Relative Frequency, %
10% Probability
NPV ($ Millions)
33.2
34.6
35.8

31


The Combination of "High" Initial Pvt. Life and "High" Initial Construction Days Produce "Low" Agency NPV
Alt B - Agency Costs
Ranking ΔMed/Std
❶ Initial Constr. Days +1.12
❷ Initial Pvt. Life +0.55
Relative Frequency, %
0.121
0.097
0.072
0.048
0.024
0.000
25% Probability
24.1
25.6
27.1
28.63
30.15
31.67
33.19
NPV ($ Millions)

32


The Combination of "Low" Initial Pvt. Life and "Low" Initial Construction Days Produce "High" Agency NPV
Alt B - Agency Costs
Ranking ΔMed/Std
❶ Initial Constr. Days - 1.46
❷ Initial Pvt. Life - 0.88
Relative Frequency, %
0.121
0.097
0.072
0.048
0.024
0.000
10% Probability
24.07
25.59
27.11
28.63
30.1
31.7
33.2
NPV ($ Millions)

33

Scenario Analysis Observations

For Alt A & B The Combination of ....

- *"High"* Initial Pvt. Life and "High" Initial Construction Days Produce "Low" [< 25%] Agency Costs
- *"Low"* Initial Pvt. Life and "Low" Initial Construction Costs Produce "High" [>90%] Agency Costs

34

Scenario Analysis Observations Cont'd.

Alternative A ...

- Initial Pavement Life is more significant than Initial Constr. days in both scenarios.

35

Scenario Analysis Observations Cont'd.

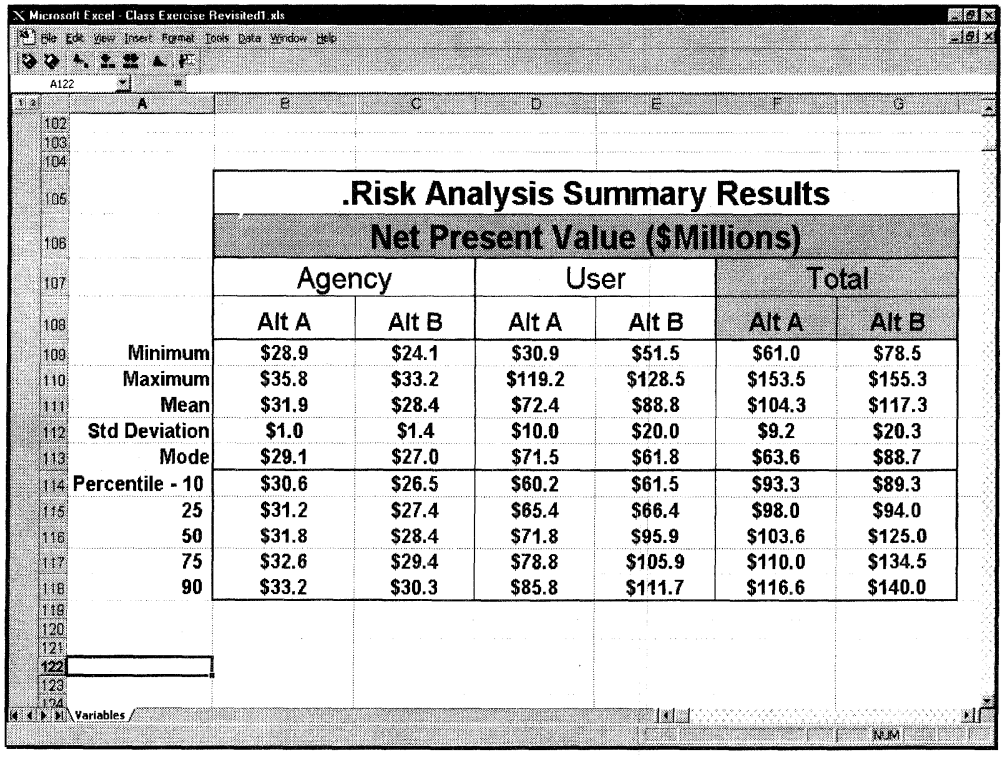
Alternative B ...

- Initial Constr. Days is more significant than Initial Pavement Life in both scenarios.

36

User Costs

37



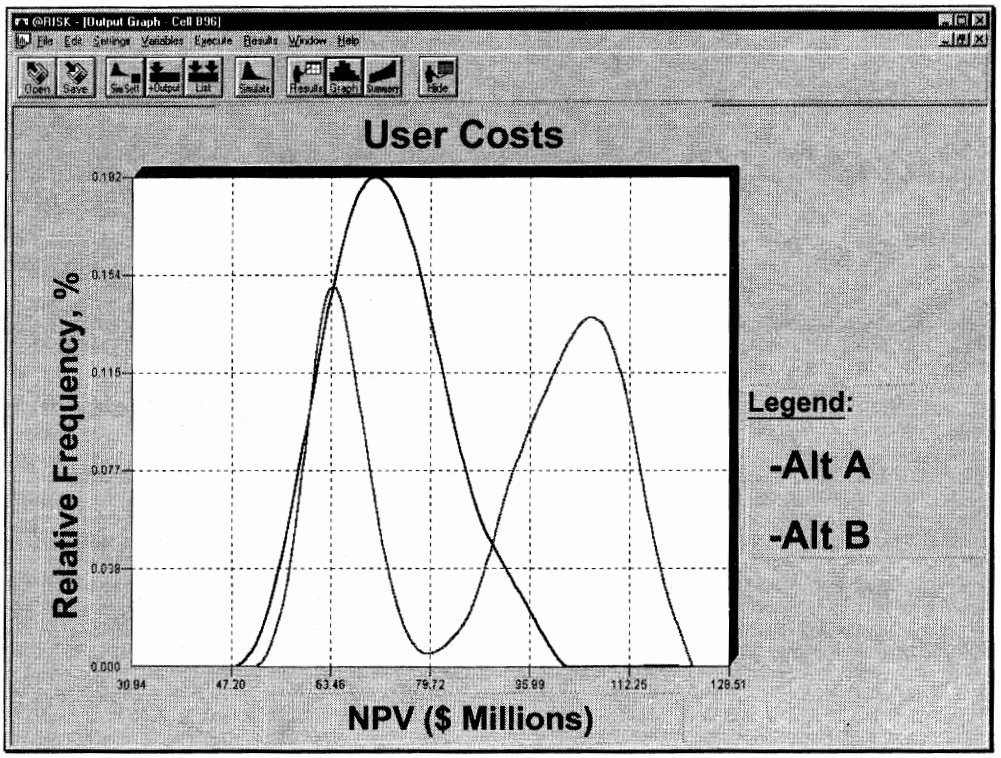
.Risk Analysis Summary Results						
Net Present Value ($Millions)						
	Agency		User		Total	
	Alt A	Alt B	Alt A	Alt B	Alt A	Alt B
Minimum	$28.9	$24.1	$30.9	$51.5	$61.0	$78.5
Maximum	$35.8	$33.2	$119.2	$128.5	$153.5	$155.3
Mean	$31.9	$28.4	$72.4	$88.8	$104.3	$117.3
Std Deviation	$1.0	$1.4	$10.0	$20.0	$9.2	$20.3
Mode	$29.1	$27.0	$71.5	$61.8	$63.6	$88.7
Percentile - 10	$30.6	$26.5	$60.2	$61.5	$93.3	$89.3
25	$31.2	$27.4	$65.4	$66.4	$98.0	$94.0
50	$31.8	$28.4	$71.8	$95.9	$103.6	$125.0
75	$32.6	$29.4	$78.8	$105.9	$110.0	$134.5
90	$33.2	$30.3	$85.8	$111.7	$116.6	$140.0

38

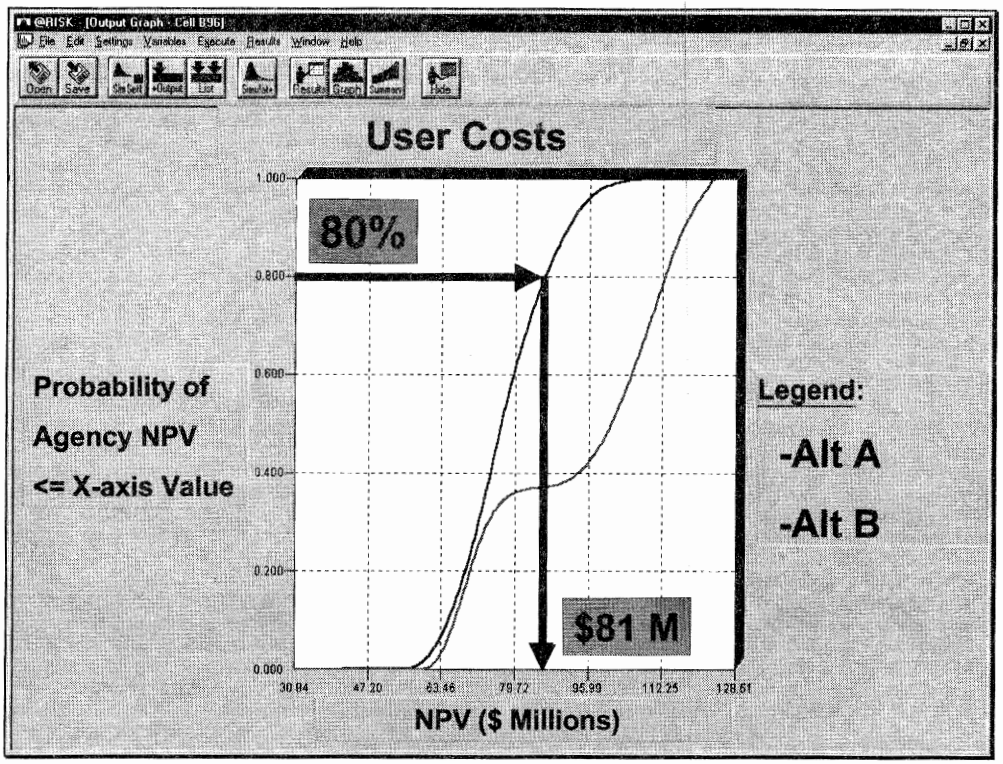
User Costs

- Probability
- Sensitivity
- Scenario Analysis

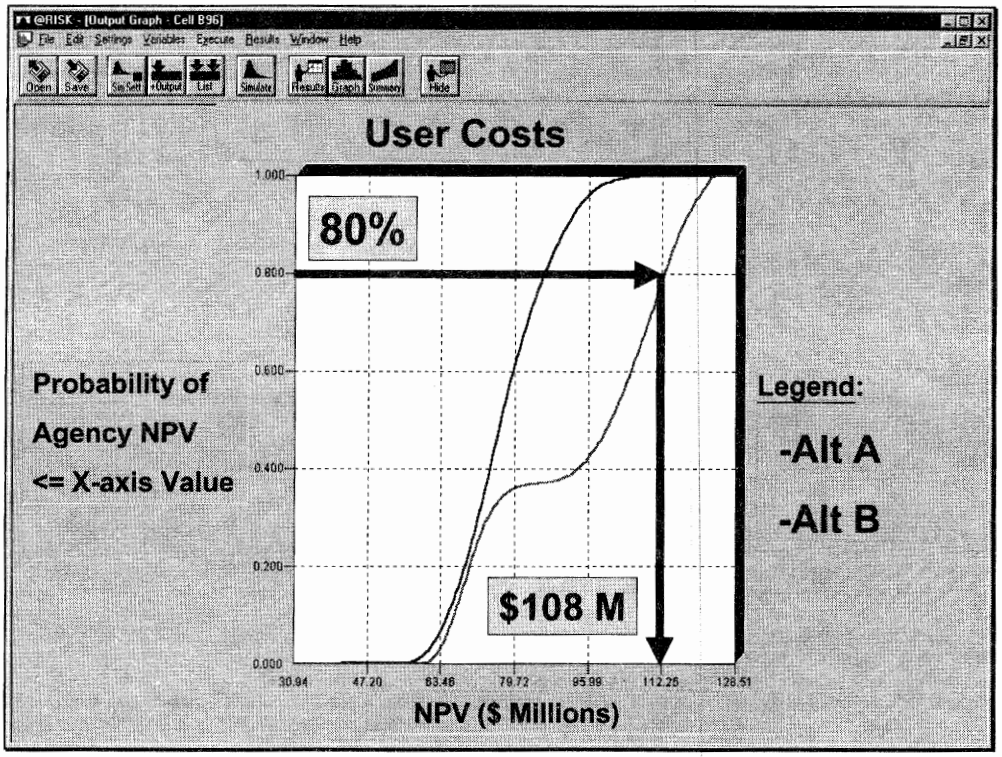
39



40


@RISK - [Output Graph - Cell B96]
File Edit Settings Variables Execute Results Window Help
User Costs
80%
$81 M
Probability of
Agency NPV
<= X-axis Value
Legend:
-Alt A
-Alt B
1.000
0.800
0.600
0.400
0.200
0.000
30.94
47.20
63.46
79.72
95.99
112.25
128.51
NPV ($ Millions)

41


@RISK - [Output Graph - Cell B96]
File Edit Settings Variables Execute Results Window Help
User Costs
80%
$108 M
Probability of
Agency NPV
<= X-axis Value
Legend:
-Alt A
-Alt B
1.000
0.800
0.600
0.400
0.200
0.000
30.94
47.20
63.46
79.72
95.99
112.25
128.51
NPV ($ Millions)

42

Probability Observations

User Costs …

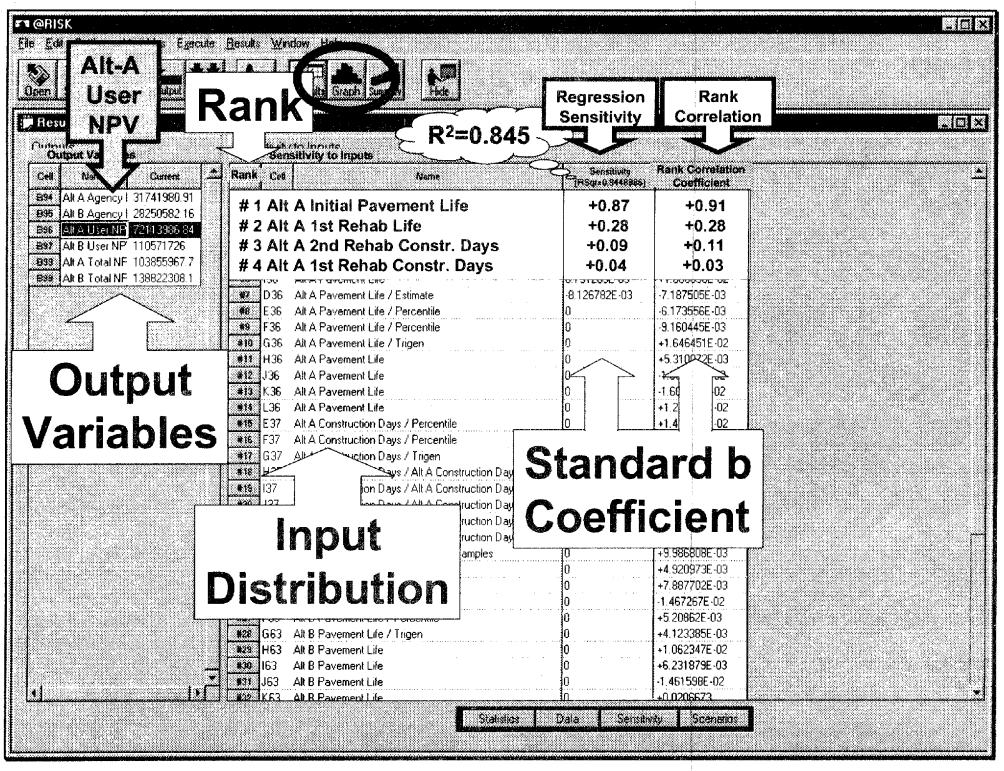
- At *any* given level of reliability Alt-A is *less* expensive than Alt-B.
- Alt-B is a *Bi-modal* Distribution
- Alt-B is *twice* as variable as Alt-A

43

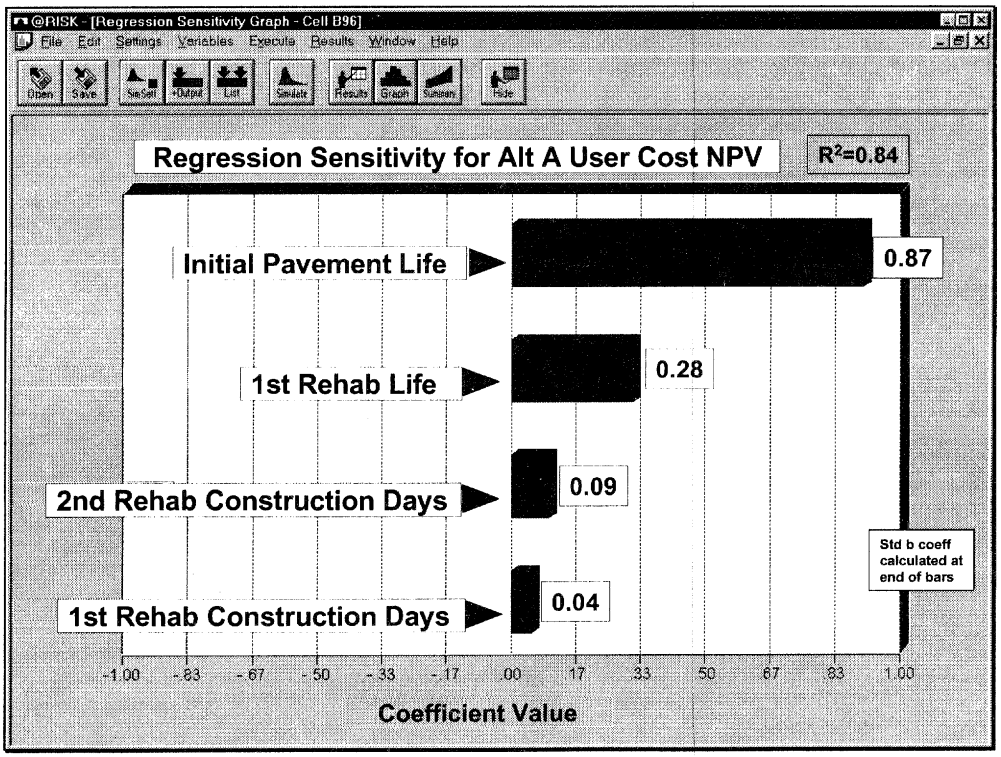
User Costs

- Probability
- Sensitivity

44


Alt-A User NPV
Rank
R²=0.845
Regression Sensitivity
Rank Correlation
Output Variables
Input Distribution
Standard b Coefficient
1 Alt A Initial Pavement Life +0.87 +0.91
2 Alt A 1st Rehab Life +0.28 +0.28
3 Alt A 2nd Rehab Constr. Days +0.09 +0.11
4 Alt A 1st Rehab Constr. Days +0.04 +0.03

45


@RISK - [Regression Sensitivity Graph - Cell B96]
Regression Sensitivity for Alt A User Cost NPV
R²=0.84
Initial Pavement Life
0.87
1st Rehab Life
0.28
2nd Rehab Construction Days
0.09
1st Rehab Construction Days
0.04
Std b coeff calculated at end of bars
-1.00 -.83 -.67 -.50 -.33 -.17 .00 .17 .33 .50 .67 .83 1.00
Coefficient Value

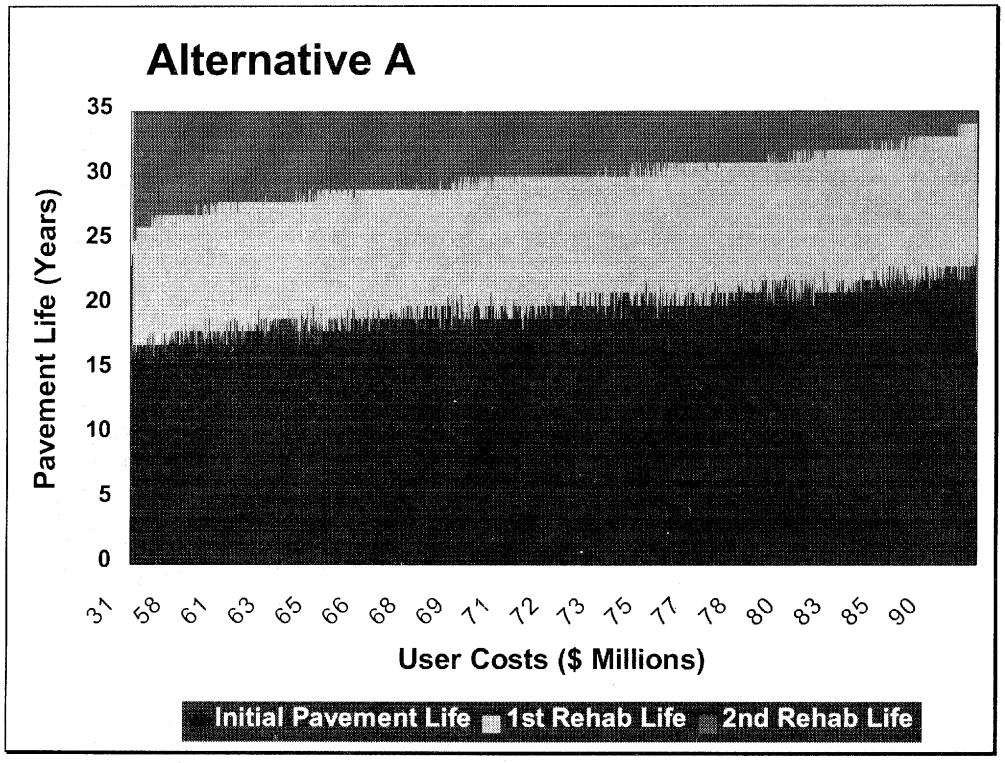
46

The Graph says ...
When Initial Pavement Life Samples High ...

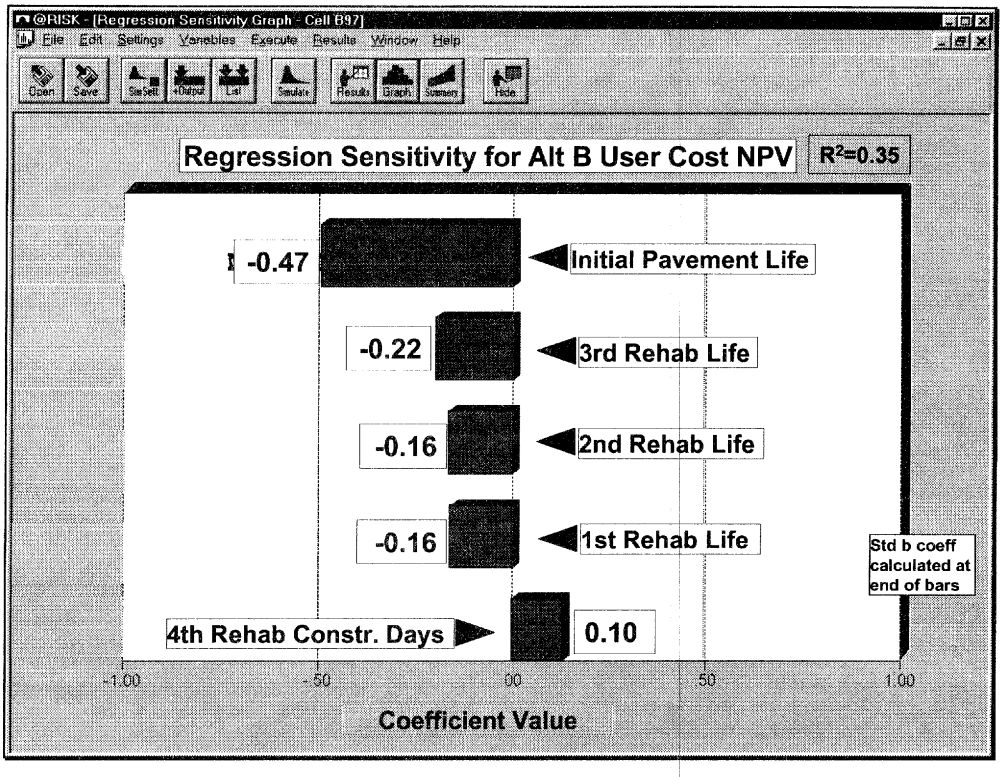
High User Costs are Produced.

Does this make sense?

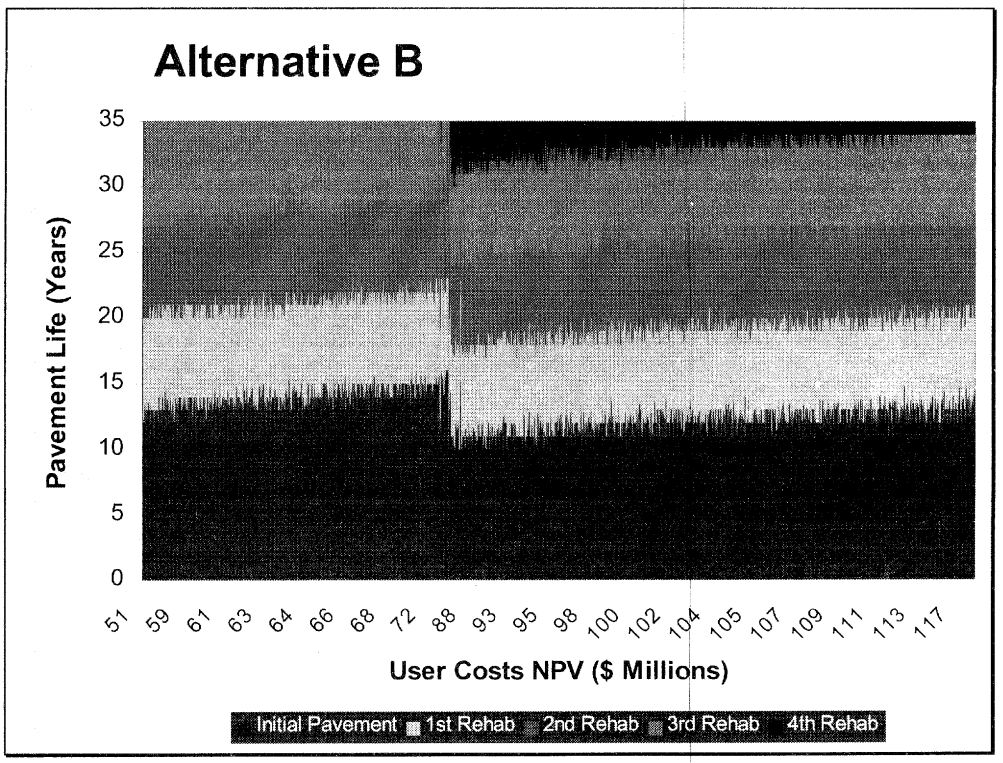
47



48


@RISK - [Regression Sensitivity Graph - Cell B97]
File Edit Settings Variables Execute Results Window Help
Regression Sensitivity for Alt B User Cost NPV
R²=0.35
-0.47
Initial Pavement Life
-0.22
3rd Rehab Life
-0.16
2nd Rehab Life
-0.16
1st Rehab Life
4th Rehab Constr. Days
0.10
Std b coeff calculated at end of bars
-1.00
-.50
.00
.50
1.00
Coefficient Value

49


Alternative B
Pavement Life (Years)
35
30
25
20
15
10
5
0
51 59 61 63 64 66 68 72 88 93 95 98 100 102 104 105 107 109 111 113 117
User Costs NPV ($ Millions)
Initial Pavement
1st Rehab
2nd Rehab
3rd Rehab
4th Rehab

50

Sensitivity Observations

For both Alt A & B User Costs ...

- Initial Pavement Life has the greatest influence

51

Sensitivity Observations Cont'd

Alternative A

- The variability of pavement life was such that two rehabs *always* occurred during analysis period
- As a result lower pavement lives produced lower user costs.

52

Sensitivity Observations Cont'd

Alternative B

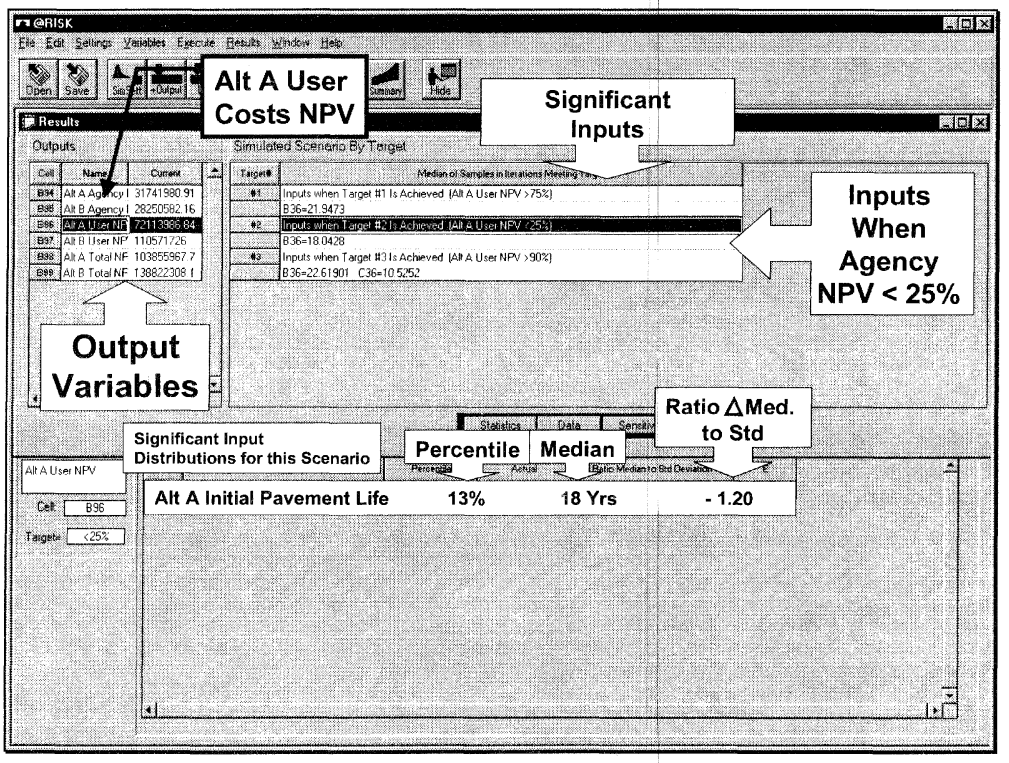
- The variability of pavement life was such that 3 and 4 rehabs occurred during analysis period
- This caused a Bi-modal Distribution
- As a result lower pavement lives produced higher user costs.

53

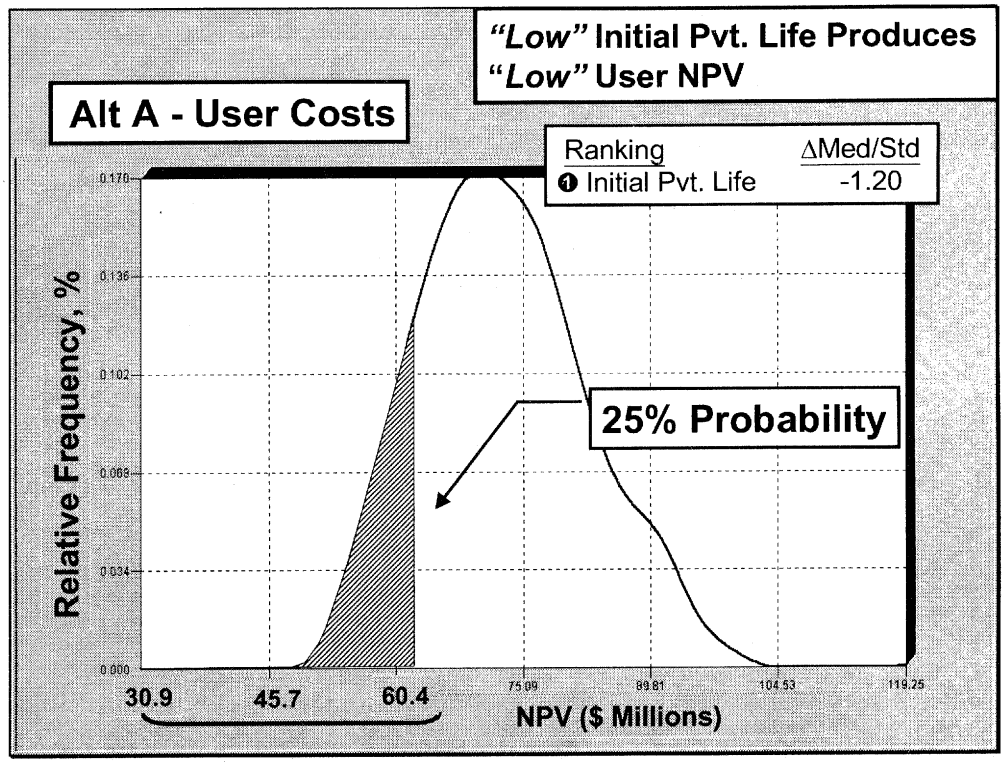
User Costs

- Probability
- Sensitivity
- Scenario Analysis

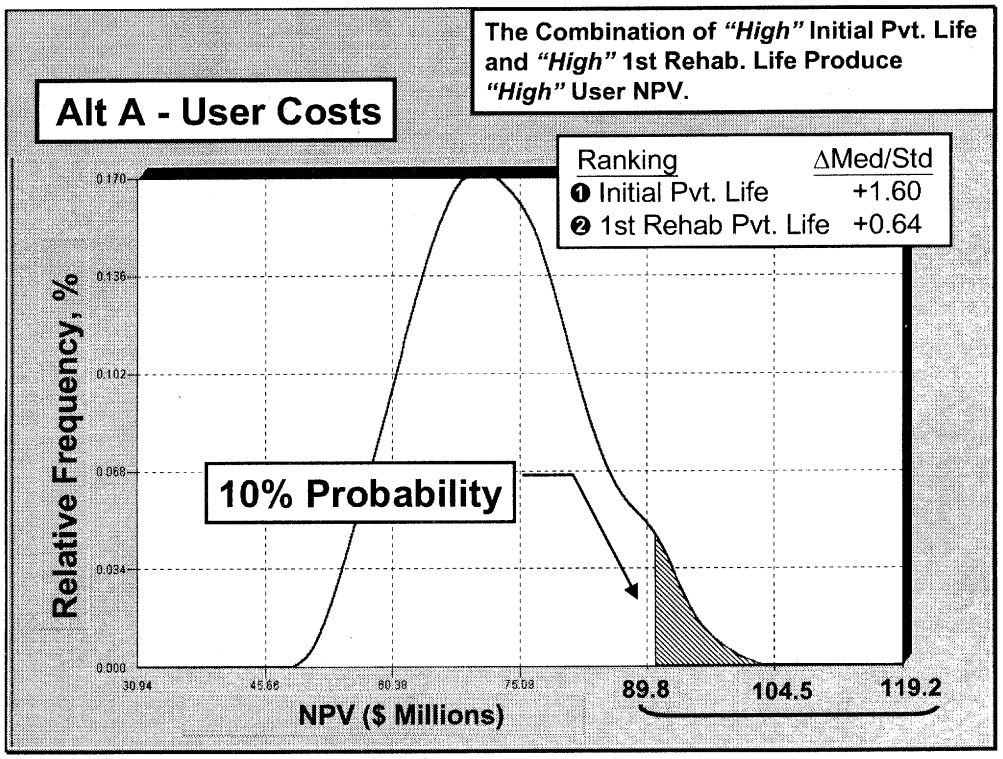
54



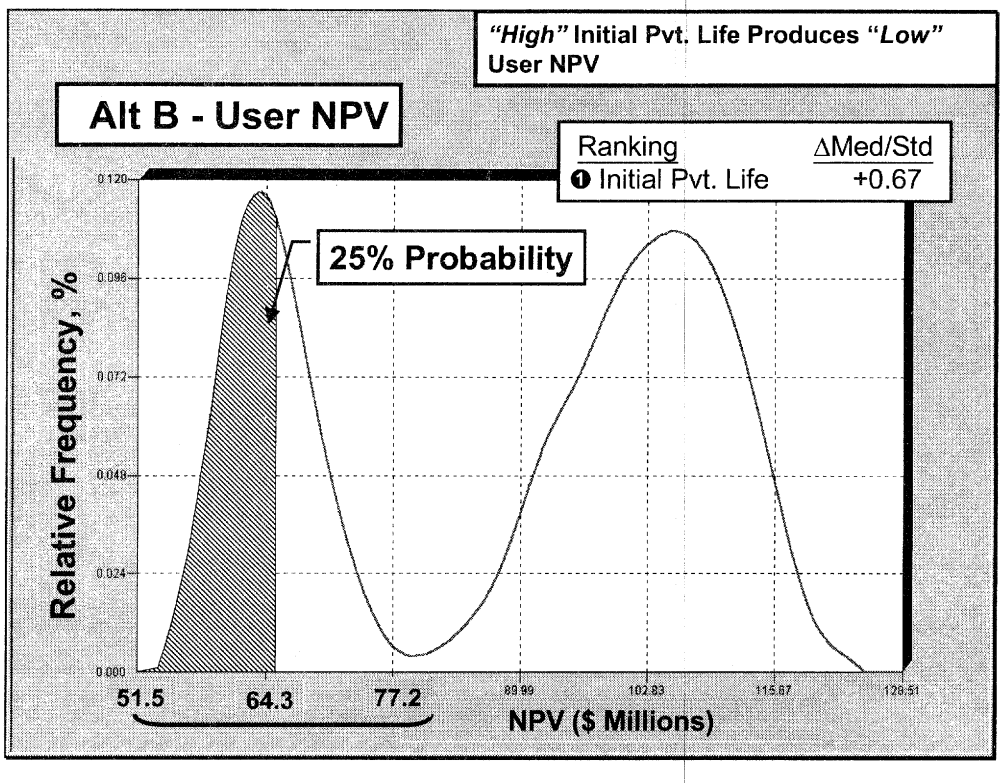
55


"Low" Initial Pvt. Life Produces "Low" User NPV
Alt A - User Costs
Ranking
ΔMed/Std
❶ Initial Pvt. Life
-1.20
25% Probability
Relative Frequency, %
0.170
0.136
0.102
0.068
0.034
0.000
30.9
45.7
60.4
75.09
89.81
104.53
119.25
NPV ($ Millions)

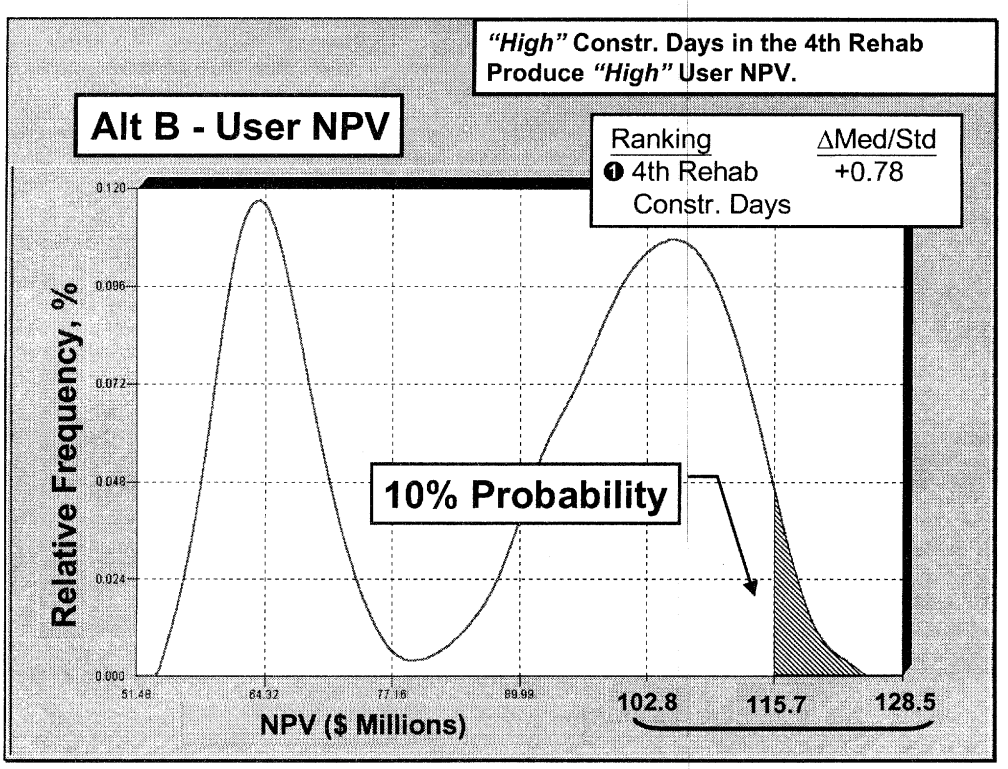
56


The Combination of "High" Initial Pvt. Life and "High" 1st Rehab. Life Produce "High" User NPV.
Alt A - User Costs
Ranking
ΔMed/Std
❶ Initial Pvt. Life
+1.60
❷ 1st Rehab Pvt. Life
+0.64
10% Probability
Relative Frequency, %
0.170
0.136
0.102
0.068
0.034
0.000
30.94
45.66
60.38
75.08
89.8
104.5
119.2
NPV ($ Millions)

57


"High" Initial Pvt. Life Produces "Low" User NPV
Alt B - User NPV
Ranking
ΔMed/Std
❶ Initial Pvt. Life
+0.67
25% Probability
Relative Frequency, %
0.120
0.096
0.072
0.048
0.024
0.000
51.5
64.3
77.2
89.99
102.83
115.67
128.51
NPV ($ Millions)

58


"High" Constr. Days in the 4th Rehab Produce "High" User NPV.
Alt B - User NPV
Ranking
ΔMed/Std
❶ 4th Rehab Constr. Days
+0.78
10% Probability
Relative Frequency, %
0.120
0.096
0.072
0.048
0.024
0.000
51.48
64.32
77.16
89.99
102.8
115.7
128.5
NPV ($ Millions)

59

Scenario Analysis Observations

User Costs Alternative A

- "Low" Initial Pavement Life produces Low User NPV
- The Combination of *"Low"* Initial Pvt. Life and *"High"* 1st Rehab. Life Produce Low User NPV

60

Scenario Analysis Observations

User Costs Alternative B

- "High" Initial Pavement Life produces Low User NPV
- "High" Constr. Days in the 4th Rehab produce "High" User Costs.

61

Which Alternative would you select?

Must define Agency's tolerance for risk.

62

If User Costs Dominate ... Reevaluate Alternatives

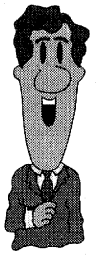
- Decrease construction time (accelerate contractor production)
- Lane Rental (A+B Bidding)
- Temporary bypass
- Increase shoulder strength
- Other?

63

End Session

1

Presentation Techniques



2

Know Your Audience

- Does your audience understand ...
  - LCCA?
  - Discounting?
  - User costs?
  - Value of time?

3

You need to know ...

- Do they need a Risk Primer?
- Do they buy into the risk analysis approach?
- Do they buy-in to your analysis

4

Here's Some Advice ...

- Don't bury them in statistics
- List significant inputs
  - Identify what's driving the tails of the distribution ...
  - Can you control it?
- Show results graphically

5

Report

- One page summary (???)
- Supporting documentation

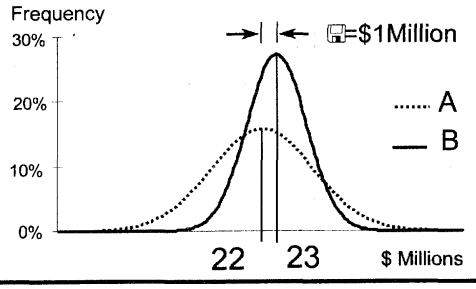
6

One Page Summary

- Inputs: List uncertain variables
- Outputs:
  - Histogram & Cumulative
  - Mean, Std. Dev., Percentiles
- Analysis of results
  - Tornado graphs, Scenario analysis
- Recommendations
  - Include level of risk

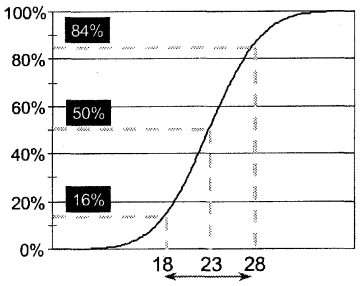
7

Histogram -



8

Cumulative -



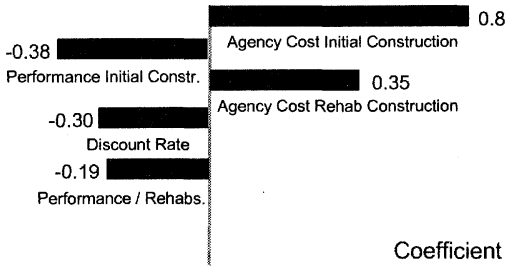
84% of all values fall below 28

50% of all values fall below 23

16% of all values fall below 18

9

Regression Sensitivity (Tornado Graphs)



10

Supporting Documentation

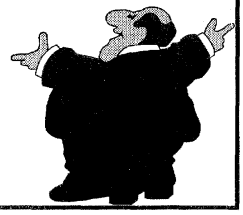
- Distributions with supporting justifications
- Structure and layout of model
- Sensitivity analysis of proposed distributions
- Analysis of uncertain events

11

End Session

1

Benefits and Implementation



2

Benefits of LCCA

- Informed decisions
- Sensitivity to user costs
- More effective use of resources
- Support funding requests

3

Benefits of LCCA Con't

- Objective basis for resource allocation
  - Network, project, & design
- Assess funding consequences

4

Benefits of Risk Analysis

- Better design strategies
- Improved design procedures
- Effective engineering input to policy decisions

5

Benefits of RA Cont'd

- Expose areas of uncertainty
- Quantify risk
- Opportunity for mitigating action
- Improved credibility
- Assess impact of risk on investment decisions
- Avoid disasters

6

Benefits of RA Cont'd

- Determine significance of difference between alternatives
- Examine influence of underlying variables on final results
- Evaluate all possible outcomes

7

Caveats

- New concept
- Requires statistical background
- Computer intensive
  - Proprietary software
  - Complex models
- Requires risk management "buy in" by senior executives

8

Implementation

9

Obstacles

- Lack of awareness
- Resistance to change
- Time pressures
- Lack of communication
- Unavailability of resources

10

Implementation Steps

- Awareness
- Change
- Communication
- Resources

11

Plant the Seed

12

Four Stages of Learning

1. Unconscious Incompetence
2. Conscious Incompetence
3. Conscious Competence
4. Unconscious Competence

13

Implementation Steps

- Identify a champion
- Understand classical LCCA
- Assess current procedures
- Determine data availability
- Tap expert opinion

14

Probabilistic Champion

- Believer
- Well founded in LCCA
- Spreadsheet literate
- Time available

15

Resources

- Equipment
- Software
- Personnel
- Training
- User groups

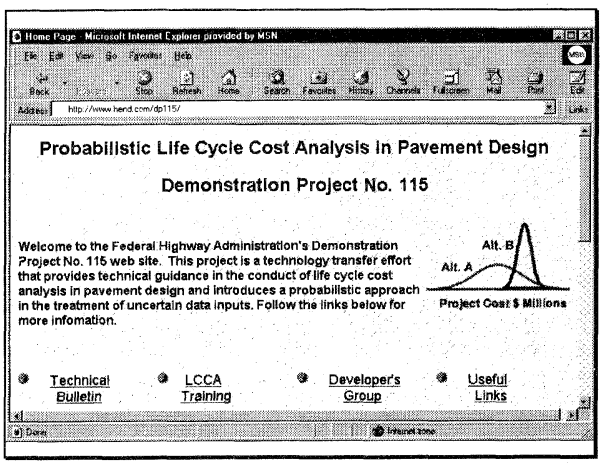
16

Resources Con't

- DP 115 Case Study States
  - Two contacts per state
  - List of names & address available upon request
- DP 115 Web Site

  http://www.hend.com/dp115

17



18

Top Management Support

- Establish objectives
- Provide policy input
- Provide resources
- Provide "Bureaucratic Clout"

19

Steering Committee

- LCCA procedure
- Probabilistic approach

20

Documentation

- Standardize SHA's approach to LCCA
- Document SHA LCCA procedures
- Apply consistently

21

End Session

1

Workshop Summary

2

Key Areas Covered

- Traditional LCCA
- User Cost
- Risk Analysis Approach

3

Things to Remember

- LCCA decision support tool
- NHS LCCA requirements
- Document procedures
- Document inputs
- Dispose of all issues

4

Recommendations

LCCA ...

- Long analysis periods
- Constant dollars
- Real discount rates (3-5%)
- NPV

5

Recommendations

- Value of time
  - Passenger $10 - $13
  - Single Unit Trk $17 - $20
  - Combo Trk $21 - $24

6

Recommendations

Agency Costs ...

- Include agency overhead
- Ignore sunk cost
- Don't sweat reactive maintenance and salvage value

7

Recommendations

User Costs ...

- Traffic grows
- Queuing cost dominate
- Hourly distributions key
- $ Value of time major influence
- Circuity can be major

8

Recommend a risk analysis approach in the treatment of uncertainty.

9

The End

Class Exercise No. 1
Net Present Value

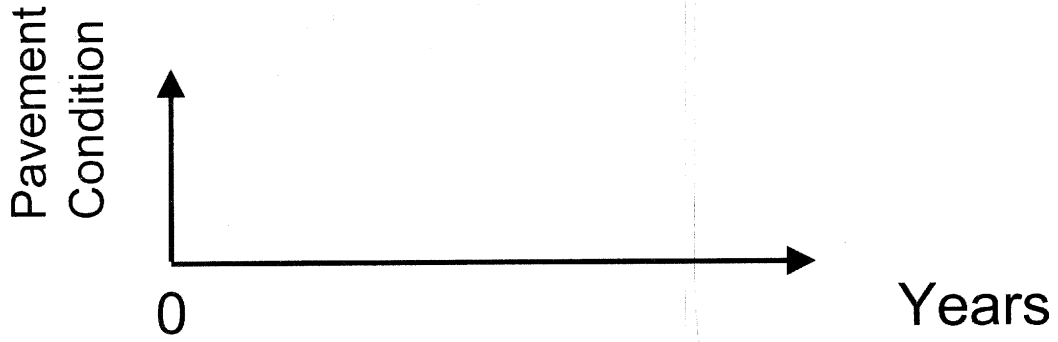
Compute the Net Present Value (NPV) for the following Alternative.

	Initial Constr.	Rehab.
Design Period, (yrs)	20	10
Agency Cost ($ Millions)	26	9
Construction Period (days)	210	105

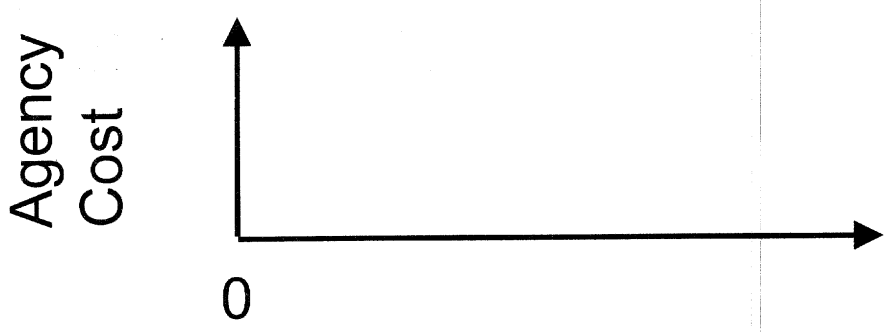
Assume the following:

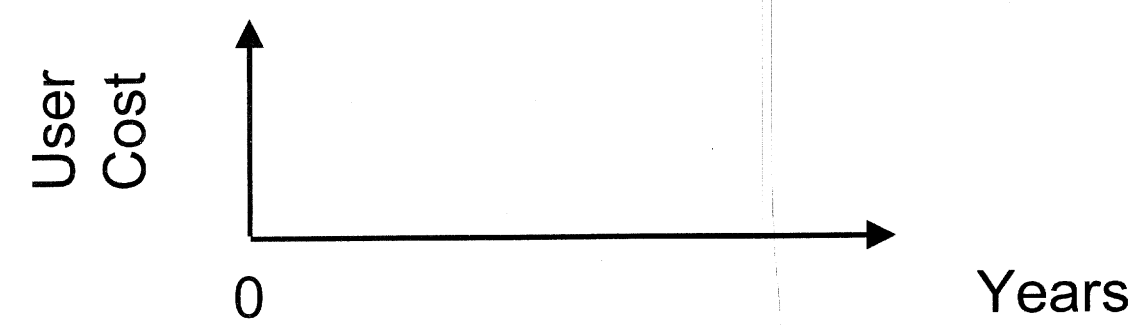
Analysis Period (yrs)	30
Daily Delay (Hours)	3000
Routine Maintenance	Insignificant
Discount Rate, %	4
Value of Time ($/hr)	10

Performance Curve



Expenditure Streams





User Cost Calculations

User Cost = Construction Days x Daily Delay x Value of Time

Initial Construction

User Cost = _____ days x _____ hrs/day x _____$/ hr.

= $_____

Rehabilitation

User Cost = _____ days x _____ hrs/day x _____$/ hr.

= $_____

$$NPV = InitialCost + \sum_{k=1}^{N} FutureCost\left[\frac{1}{(1+i)^{n_k}}\right]$$

Note: Quantity in brackets is present value factor from page 1.5.

Agency Cost

NPV =

User Cost

NPV =

Present Value Factors

Year n	Discount Rate, (i)				
	4.0%	4.5%	5.0%	5.5%	6.0%
1	0.9615	0.9569	0.9524	0.9479	0.9434
2	0.9246	0.9157	0.9070	0.8985	0.8900
3	0.8890	0.8763	0.8638	0.8516	0.8396
4	0.8548	0.8386	0.8227	0.8072	0.7921
5	0.8219	0.8025	0.7835	0.7651	0.7473
6	0.7903	0.7679	0.7462	0.7252	0.7050
7	0.7599	0.7348	0.7107	0.6874	0.6651
8	0.7307	0.7032	0.6768	0.6516	0.6274
9	0.7026	0.6729	0.6446	0.6176	0.5919
10	0.6756	0.6439	0.6139	0.5854	0.5584
11	0.6496	0.6162	0.5847	0.5549	0.5268
12	0.6246	0.5897	0.5568	0.5260	0.4970
13	0.6006	0.5643	0.5303	0.4986	0.4688
14	0.5775	0.5400	0.5051	0.4726	0.4423
15	0.5553	0.5167	0.4810	0.4479	0.4173
16	0.5339	0.4945	0.4581	0.4246	0.3936
17	0.5134	0.4732	0.4363	0.4024	0.3714
18	0.4936	0.4528	0.4155	0.3815	0.3503
19	0.4746	0.4333	0.3957	0.3616	0.3305
20	0.4564	0.4146	0.3769	0.3427	0.3118
21	0.4388	0.3968	0.3589	0.3249	0.2942
22	0.4220	0.3797	0.3418	0.3079	0.2775
23	0.4057	0.3634	0.3256	0.2919	0.2618
24	0.3901	0.3477	0.3101	0.2767	0.2470
25	0.3751	0.3327	0.2953	0.2622	0.2330
26	0.3607	0.3184	0.2812	0.2486	0.2198
27	0.3468	0.3047	0.2678	0.2356	0.2074
28	0.3335	0.2916	0.2551	0.2233	0.1956
29	0.3207	0.2790	0.2429	0.2117	0.1846
30	0.3083	0.2670	0.2314	0.2006	0.1741
31	0.2965	0.2555	0.2204	0.1902	0.1643
32	0.2851	0.2445	0.2099	0.1803	0.1550
33	0.2741	0.2340	0.1999	0.1709	0.1462
34	0.2636	0.2239	0.1904	0.1620	0.1379
35	0.2534	0.2143	0.1813	0.1535	0.1301

Class Exercise No. 2
Net Present Value

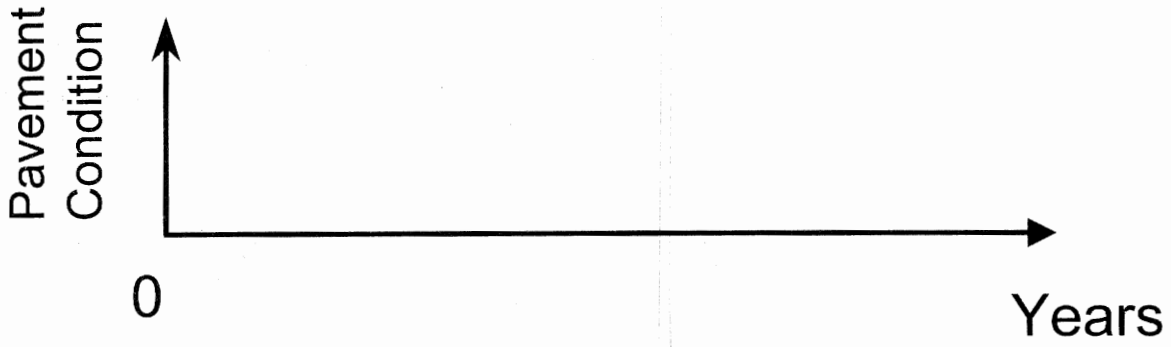
Compute the Net Present Value (NPV) for the following Alternative.

	Initial Constr.	Rehab.
Design Period, (yrs)	20	8
Agency Cost ($ Millions)	30	9
Construction Period (days)	200	80

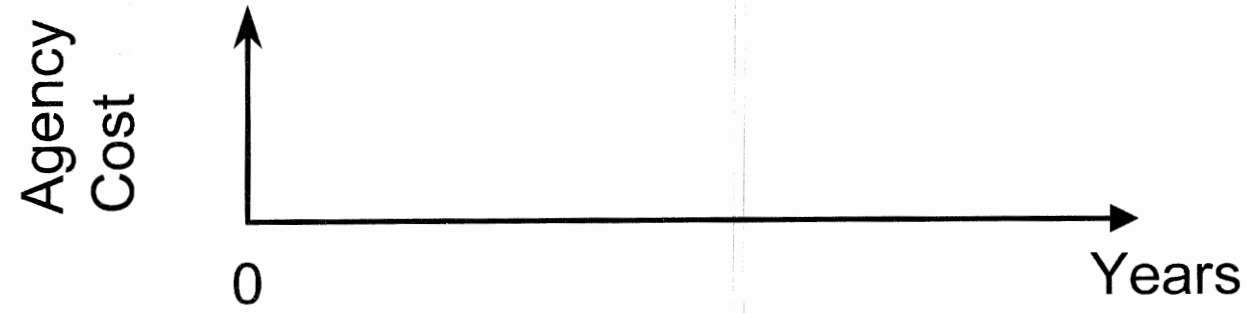
Assume the following:

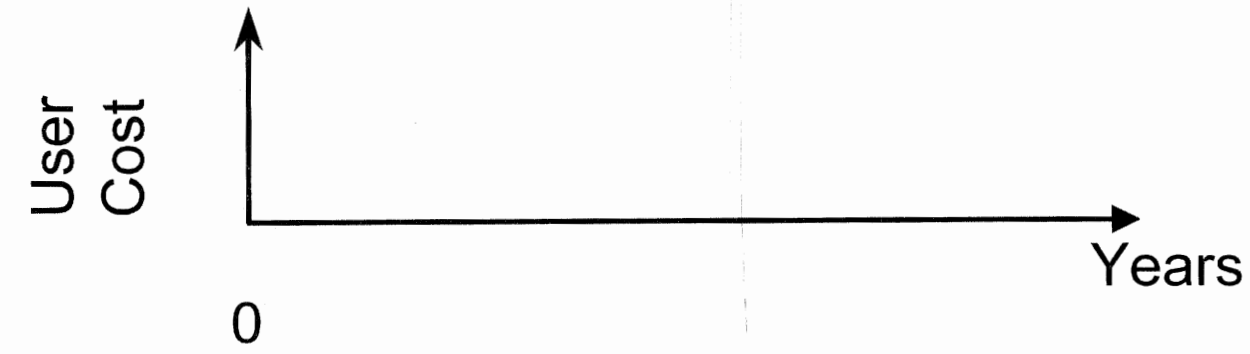
Analysis Period (yrs)	30
Daily Delay (Hours)	4000
Routine Maintenance	Insignificant
Discount Rate, %	4
Value of Time ($/hr)	15

Performance Curve



Expenditure Streams





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Initial Construction

User Cost = _____ days x _____ hrs/day x _____$/ hr.

= $_____

Rehabilitation

User Cost = _____ days x _____ hrs/day x _____$/ hr.

= $_____

$$NPV = InitialCost + \sum_{k=1}^{N} FutureCost\left[\frac{1}{(1+i)^{n_k}}\right]$$

Note: Quantity in brackets is present value factor from page 2.5.

Agency Cost

NPV =

User Cost

NPV =

Present Value Factors

Year n	Discount Rate, (i)				
	4.0%	4.5%	5.0%	5.5%	6.0%
1	0.9615	0.9569	0.9524	0.9479	0.9434
2	0.9246	0.9157	0.9070	0.8985	0.8900
3	0.8890	0.8763	0.8638	0.8516	0.8396
4	0.8548	0.8386	0.8227	0.8072	0.7921
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6	0.7903	0.7679	0.7462	0.7252	0.7050
7	0.7599	0.7348	0.7107	0.6874	0.6651
8	0.7307	0.7032	0.6768	0.6516	0.6274
9	0.7026	0.6729	0.6446	0.6176	0.5919
10	0.6756	0.6439	0.6139	0.5854	0.5584
11	0.6496	0.6162	0.5847	0.5549	0.5268
12	0.6246	0.5897	0.5568	0.5260	0.4970
13	0.6006	0.5643	0.5303	0.4986	0.4688
14	0.5775	0.5400	0.5051	0.4726	0.4423
15	0.5553	0.5167	0.4810	0.4479	0.4173
16	0.5339	0.4945	0.4581	0.4246	0.3936
17	0.5134	0.4732	0.4363	0.4024	0.3714
18	0.4936	0.4528	0.4155	0.3815	0.3503
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22	0.4220	0.3797	0.3418	0.3079	0.2775
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29	0.3207	0.2790	0.2429	0.2117	0.1846
30	0.3083	0.2670	0.2314	0.2006	0.1741
31	0.2965	0.2555	0.2204	0.1902	0.1643
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33	0.2741	0.2340	0.1999	0.1709	0.1462
34	0.2636	0.2239	0.1904	0.1620	0.1379
35	0.2534	0.2143	0.1813	0.1535	0.1301

Class Exercise No. 3
Work Zone User Cost

The eastbound lanes of a six-lane facility are undergoing rehabilitation. Figures 1 and 2 provide a layout of the work zone and the associated user cost components. The facility carries 95,000 vehicles per day of which 90% are passenger cars, 6% single unit trucks, and 4% combination unit trucks. The directional factor is 54% for the eastbound direction. A 7 mile work zone closing one lane will be in place 24 hours each day until construction is complete. It is estimated to take 75 days to complete construction. The upstream approach speed is posted at 55 mph and the speed through the work zone will be posted at 35 mph. The free flow capacity of the roadway is estimated at 2100 vehicles per hour per lane (vphpl) while the work zone capacity is estimated at 1400 vphpl. A capacity analysis of the work zone is shown in Table 1. This class exercise includes three separate problems identified below.

Problem ❶

Determine the quantity of traffic associated with each work zone user cost component.

Problem ❷

Determine the reduced speed delay to traverse the work zone and queue.

Problem ❸

Calculate the user costs associated with the work zone.

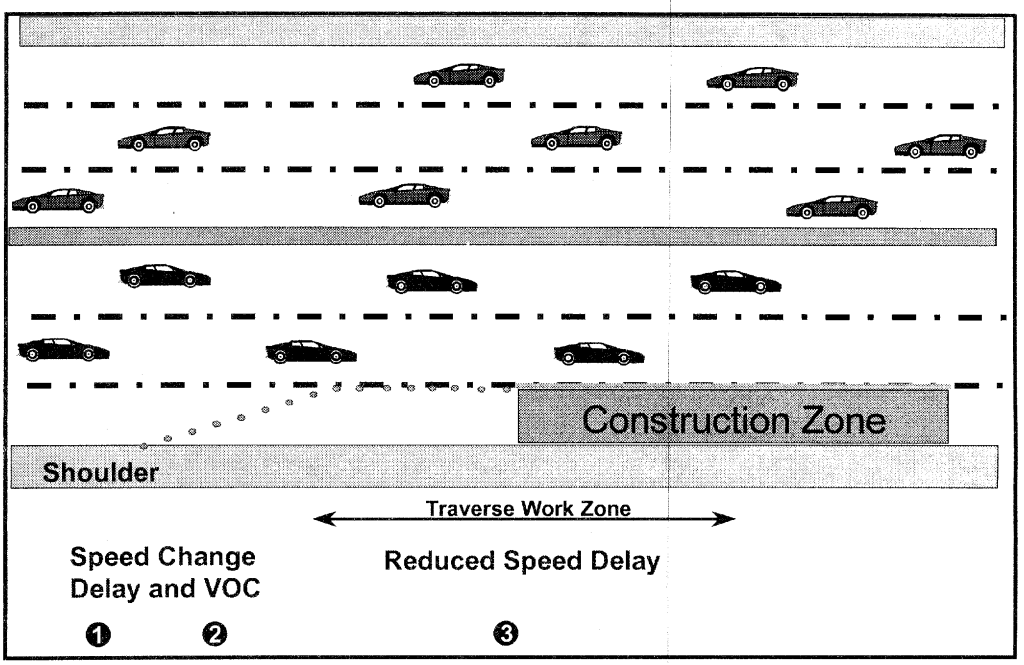


Figure 1. Eastbound Work Zone User Cost Components at Free Flow Conditions.

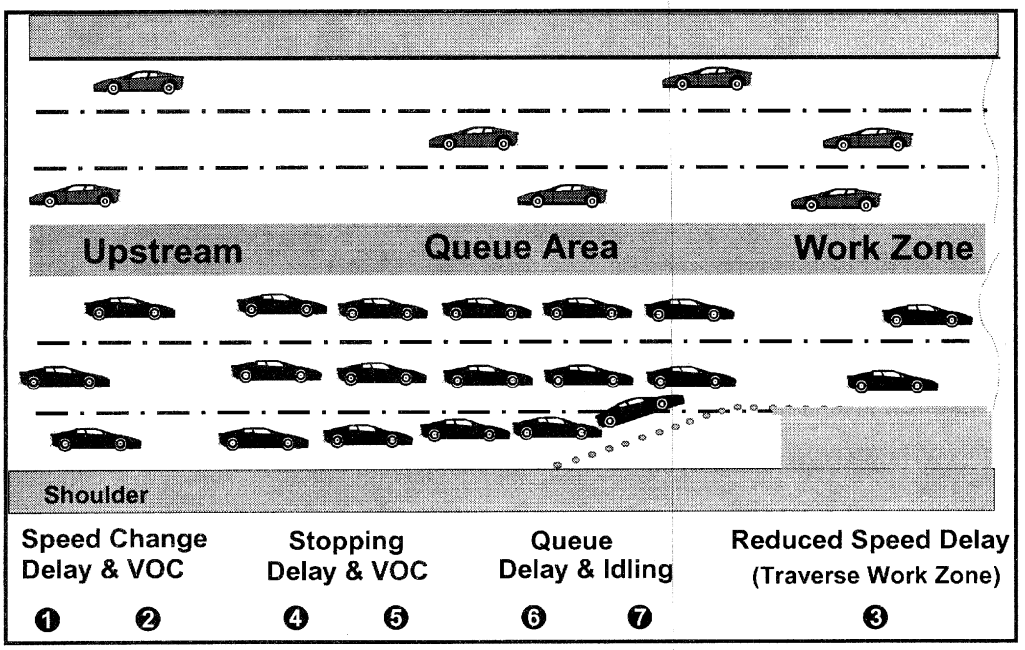


Figure 2. Eastbound Work Zone User Cost Components at Forced Flow Conditions.

Table 1. Capacity Analysis of Work Zone Operation.

		Eastbound					AADT	95,000		
Directional Factor			54.0%			Directional AADT		51,300		
			Hrly	Vehicle		Queuing	Culm.	Vehicles that ...		
			Distri.	Demand	Capacity	Rate	Que Veh.	Stop	Traverse WZ	SlowDown
Hour			%	vph	vph	vph		55-0-55	at 35 mph	55-35-55
0	-	1	0.9	462	2,800	(2,338)	0	0	462	462
1	-	2	0.5	257	2,800	(2,544)	0	0	257	257
2	-	3	0.4	205	2,800	(2,595)	0	0	205	205
3	-	4	0.4	205	2,800	(2,595)	0	0	205	205
4	-	5	0.6	308	2,800	(2,492)	0	0	308	308
5	-	6	1.8	923	2,800	(1,877)	0	0	923	923
6	-	7	4.4	2,257	2,800	(543)	0	0	2,257	2257
7	-	8	6.2	3,181	2,800	381	381	3,181	3,181	0
8	-	9	5.7	2,924	2,800	124	505	2,924	2,924	0
9	-	10	5.1	2,616	2,800	(184)	321	2,616	2,616	0
10	-	11	5.2	2,668	2,800	(132)	189	2,668	2,668	0
11	-	12	5.6	2,873	2,800	73	261	2,873	2,873	0
12	-	13	6.0	3,078	2,800	278	539	3,078	3,078	0
13	-	14	5.9	3,027	2,800	227	766	3,027	3,027	0
14	-	15	6.4	3,283	2,800	483	1,249	3,283	3,283	0
15	-	16	7.4	3,796	2,800	996	2,246	3,796	3,796	0
16	-	17	7.8	4,001	2,800	1,201	3,447	4,001	4,001	0
17	-	18	7.5	3,848	2,800	1,048	4,494	3,848	3,848	0
18	-	19	5.9	3,027	2,800	227	4,721	3,027	3,027	0
19	-	20	4.9	2,514	2,800	(286)	4,435	2,514	2,514	0
20	-	21	4.0	2,052	2,800	(748)	3,687	2,052	2,052	0
21	-	22	3.3	1,693	2,800	(1,107)	2,580	1,693	1,693	0
22	-	23	2.4	1,231	2,800	(1,569)	1,011	1,231	1,231	0
23	-	24	1.7	872	2,800	(1,928)	0	457	872	415
		Total	100	51,300				46,268	51,300	5,032

Note: The number of vehicles required to stop (55-0-55 mph) during the last hour (23-24) is prorated based on the amount of time required to clear the queue remaining in the previous hour.

Problem No. 2

Compute the reduced speed delay to traverse the work zone.

		Work Zone Length	Time
Work Zone Speed	_____ mph	_____ mi.	_____ hrs.
Upstream Speed	_____ mph	_____ mi.	_____ hrs.
	Ⓐ Increased Time to Traverse the Work Zone:		_____ hrs.

Compute the reduced speed delay to traverse the queue.

Computation Step		Value
❶ Maximum number of queued vehicles		
Queue Volume (V_Q) "Capacity of Work Zone"		
Queue Capacity (C_Q) "Upstream Capacity"		
V_Q/C_Q		
Queue Speed (S_Q) *(See Figure 3 Page 3.7)*		
❷ Work Zone Density (V_Q/S_Q)		
Upstream Volume (V_U) "Demand at Max. No. Queued Vehicles"		
Upstream Speed (S_U)		
❸ Upstream Density (V_U/S_U)		
△ Density (❷ - ❸)		
❹ Maximum Queue Length (❶ / △ Density)		
❺ Average Queue Length (❹ / 2)		
Queue Travel Time	❻ ❺ /Queue Speed (S_Q) (hrs)	
	❼ ❺ /Upstream Speed (S_U) (hrs)	
Ⓑ Queue Delay (hrs) (❻ - ❼)		

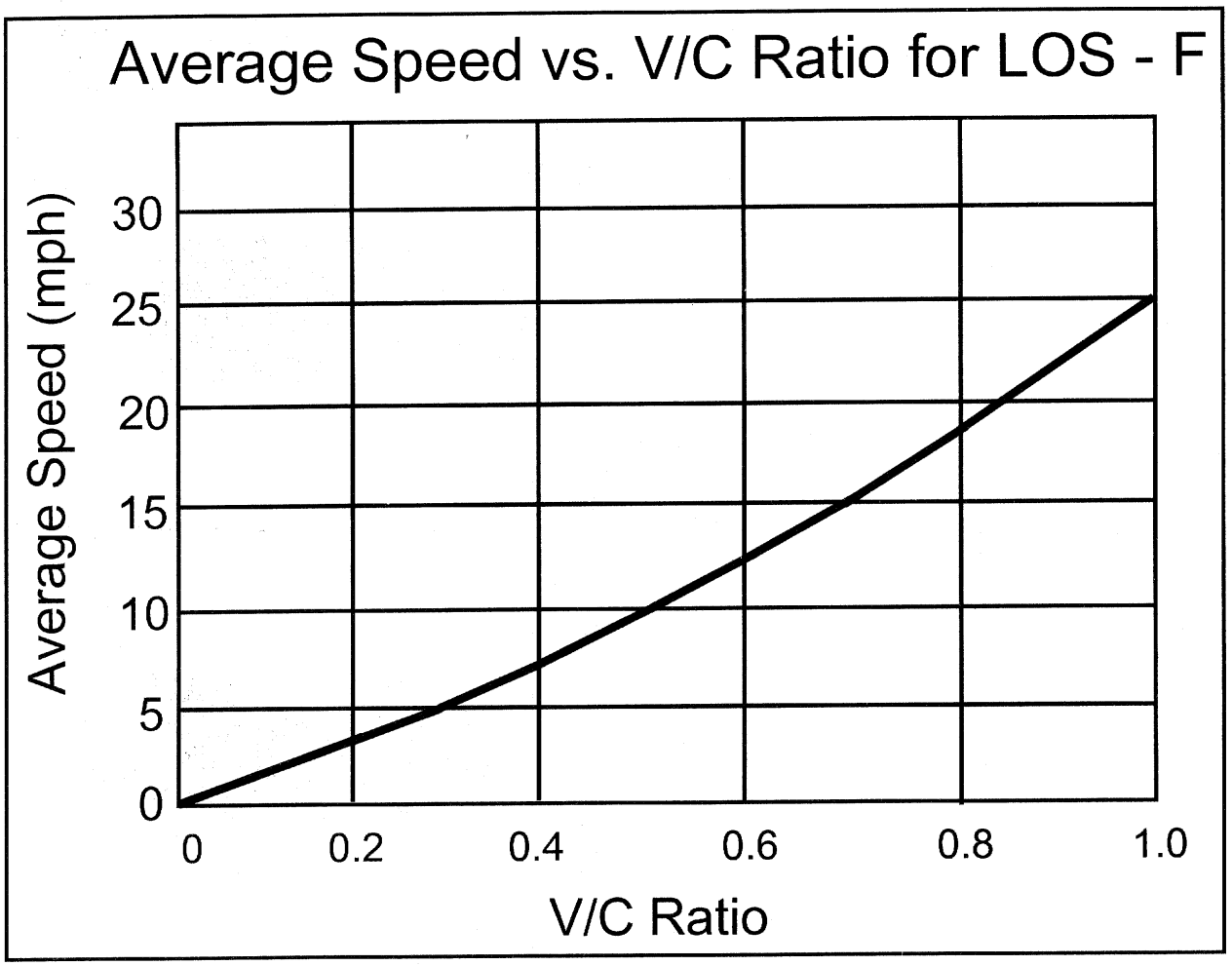


Figure 3. V/C Ratio versus Average Queue Speed (Source: NCHRP 133).

$V = V_Q$ = Capacity in Work Zone

$C = C_Q$ = Upstream Capacity

Problem No. 3

Compute the following user costs associated with the work zone.

Cost Component	Veh. Class	Number Vehicles	Added VOC	Added Time (Hrs/Veh.)	Value of Time[4] ($/Veh. Hr)	Cost ($)	%
❶WZ Speed Change Delay (55-35-55)	Auto			_____/1000 [1,3]			
	SU			_____/1000 [1,3]			
	Combo			_____/1000 [1,3]			
❷WZ Speed Change VOC (55-35-55)	Auto		_____/1000 [1,2]				
	SU		_____/1000 [1,2]				
	Combo		_____/1000 [1,2]				
❸WZ Reduced Speed Delay (35 vs. 55)	Auto			_____[5]			
	SU			_____[5]			
	Combo			_____[5]			
❹Queue Stopping Delay (55-0-55)	Auto			_____/1000 [1,3]			
	SU			_____/1000 [1,3]			
	Combo			_____/1000 [1,3]			
❺Queue Stopping VOC (55-0-55)	Auto		_____/1000 [1,2]				
	SU		_____/1000 [1,2]				
	Combo		_____/1000 [1,2]				
❻Queue Added Travel Time Delay (Queue Speed vs 55)	Auto			_____[6]			
	SU			_____[6]			
	Combo			_____[6]			
❼Queue Idle VOC	Auto		_____[7]	_____[6]			
	SU		_____[7]	_____[6]			
	Combo		_____[7]	_____[6]			
Total Work Zone User Cost >>>>>							

Notes:

1. See Table 2 Page 3.9 for added time and vehicle running cost.
2. Speed change VOC typically given as $/1000 Veh.
3. Speed change delay typically given as Hr/1000 Veh.
4. See Table 3 Page 3.9 for recommended values of time.
5. See Problem No.2 Page 3.6 Answer Ⓐ
6. See Problem No. 2. Page 3.6 Answer Ⓑ
7. See bottom of Table 2 on Page 3.9 for Idle cost rates. Note Idling cost units $/Veh.-Hr.

Table 2. Added Time and Vehicle Running Cost / 1000 Stops and Idling Costs (August 1996).

Initial Speed (mph)	Added Time (Hr / 1000 Stops) (Excludes Idling Time)			Added Cost ($/1000 Stops) (Excludes Idling Time)		
	Pass. Cars	Trucks		Pass. Car	Trucks	
		Single	Combination		Single	Combination
5	1.02	0.73	1.10	2.70	9.25	33.62
10	1.51	1.47	2.27	8.83	20.72	77.49
15	2.00	2.20	3.48	15.16	33.89	129.97
20	2.49	2.93	4.76	21.74	48.40	190.06
25	2.98	3.67	6.10	28.67	63.97	256.54
30	3.46	4.40	7.56	36.10	80.23	328.21
35	3.94	5.13	9.19	44.06	96.88	403.84
40	4.42	5.87	11.09	52.70	113.97	482.21
45	4.90	6.60	13.39	62.07	130.08	562.14
50	5.37	7.33	16.37	72.31	145.96	642.41
55	5.84	8.07	20.72	83.47	160.89	721.77
60	6.31	8.80	27.94	95.70	178.98	798.99
65	6.78	9.53	NA	109.02	195.84	NA
70	7.25	NA	NA	123.61	NA	NA
75	7.71	NA	NA	139.53	NA	NA
80	8.17	NA	NA	156.85	NA	NA
Idling Cost ($ / vehicle-hour)				0.6927	0.7681	0.8248

Table 3. Recommended Value of Time (August 1996).

Vehicles Class	$ / Vehicle hour	
	Value	Range
Passenger	11.58	10 – 13
Single Unit	18.54	17 – 19
Combination	22.31	21 – 24

Class Exercise No. 4
Life Cycle Cost Analysis

A State highway agency is conducting a Life Cycle Cost Analysis of a 6-lane facility (3 lanes per direction). The current directional AADT is 40,000 vehicles per day. The State is considering two alternatives for the initial construction and rehabilitation strategy for one direction. Planned work zones will be in place 24 hours per day during which time the facility is reduced to 2 lanes of operation. Performance life ranges for the two alternative strategies are shown in Table 1.

Compute the total Net Present Value (NPV) for each alternative. Use a 35 year analysis period. Include in your analysis the effect of salvage value, if applicable. Construction costs are directly related to the number of days allowed for initial construction and rehabilitation activities as shown in Figures 1 - 4. Use Table 2 to summarize your selected input values. Real opportunity cost of money to the State highway agency is 4%. The SHA estimates the value of time to be $10 per hour. Routine reactive maintenance cost differences between alternatives are insignificant. Use the formula provided to calculate net present value. If needed use Table 3 for the appropriate discount factor. Use Table 4 to determine the daily cost of delay. Use Table 5 as a worksheet.

Table 1. Performance life ranges.

	Alternative – A				Alternative – B			
	Initial		Rehabs.		Initial		Rehabs.	
	Low	High	Low	High	Low	High	Low	High
Performance (years)	16	24	8	12	10	16	6	8

Table 2. Selected input values.

	Alternative – A			Alternative – B				
		Rehabs.			Rehabs			
	Initial	1	2	Initial	1	2	3	4
Performance (years)								
❶Construction Days[1]								
❷Agency Cost[2] ($)								
❸Daily Delay Cost[3] ($)								
❹User Cost $ (❶ x ❸)								

Notes: [1,2] See Figures 1.4
[3] See Table 4 Page 4.5

Table 3. Discount factors.

Year	Discount Rate				
n	4.0%	4.5%	5.0%	5.5%	6.0%
0	1.0000	1.0000	1.0000	1.0000	1.0000
1	0.9615	0.9569	0.9524	0.9479	0.9434
2	0.9246	0.9157	0.9070	0.8985	0.8900
3	0.8890	0.8763	0.8638	0.8516	0.8396
4	0.8548	0.8386	0.8227	0.8072	0.7921
5	0.8219	0.8025	0.7835	0.7651	0.7473
6	0.7903	0.7679	0.7462	0.7252	0.7050
7	0.7599	0.7348	0.7107	0.6874	0.6651
8	0.7307	0.7032	0.6768	0.6516	0.6274
9	0.7026	0.6729	0.6446	0.6176	0.5919
10	0.6756	0.6439	0.6139	0.5854	0.5584
11	0.6496	0.6162	0.5847	0.5549	0.5268
12	0.6246	0.5897	0.5568	0.5260	0.4970
13	0.6006	0.5643	0.5303	0.4986	0.4688
14	0.5775	0.5400	0.5051	0.4726	0.4423
15	0.5553	0.5167	0.4810	0.4479	0.4173
16	0.5339	0.4945	0.4581	0.4246	0.3936
17	0.5134	0.4732	0.4363	0.4024	0.3714
18	0.4936	0.4528	0.4155	0.3815	0.3503
19	0.4746	0.4333	0.3957	0.3616	0.3305
20	0.4564	0.4146	0.3769	0.3427	0.3118
21	0.4388	0.3968	0.3589	0.3249	0.2942
22	0.4220	0.3797	0.3418	0.3079	0.2775
23	0.4057	0.3634	0.3256	0.2919	0.2618
24	0.3901	0.3477	0.3101	0.2767	0.2470
25	0.3751	0.3327	0.2953	0.2622	0.2330
26	0.3607	0.3184	0.2812	0.2486	0.2198
27	0.3468	0.3047	0.2678	0.2356	0.2074
28	0.3335	0.2916	0.2551	0.2233	0.1956
29	0.3207	0.2790	0.2429	0.2117	0.1846
30	0.3083	0.2670	0.2314	0.2006	0.1741
31	0.2965	0.2555	0.2204	0.1902	0.1643
32	0.2851	0.2445	0.2099	0.1803	0.1550
33	0.2741	0.2340	0.1999	0.1709	0.1462
34	0.2636	0.2239	0.1904	0.1620	0.1379
35	0.2534	0.2143	0.1813	0.1535	0.1301

Figure 1. Initial Agency Construction Costs
Alternative A

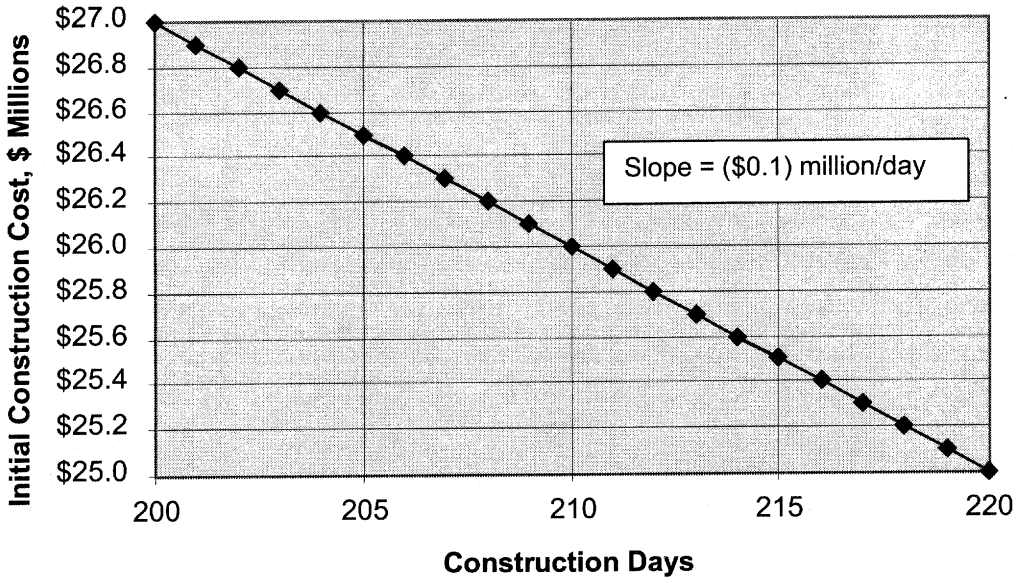


Figure 2. Agency Rehabilitation Costs
Alternative A

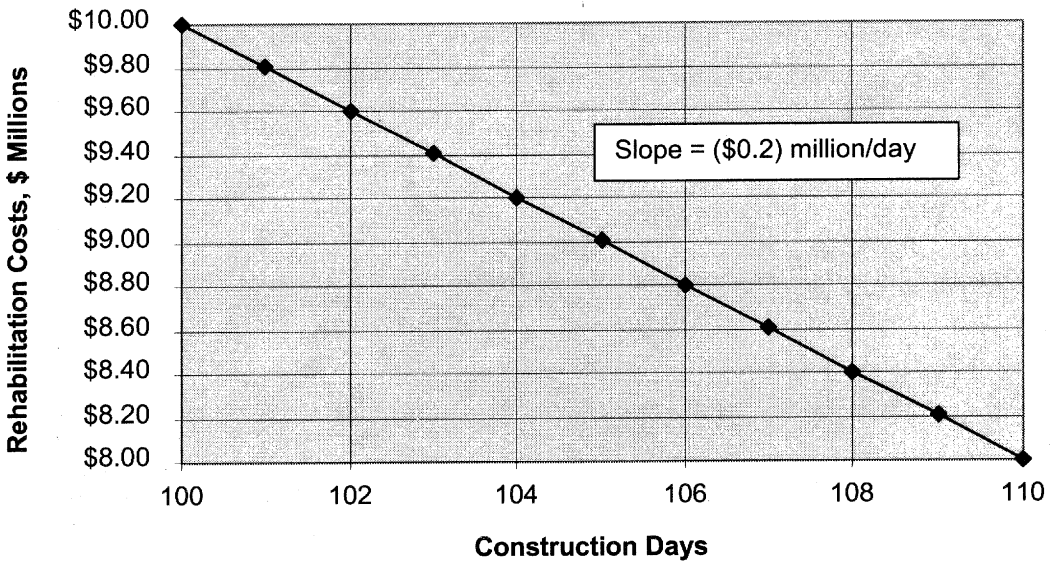


Figure 3. Initial Agency Construction Costs - Alternative B

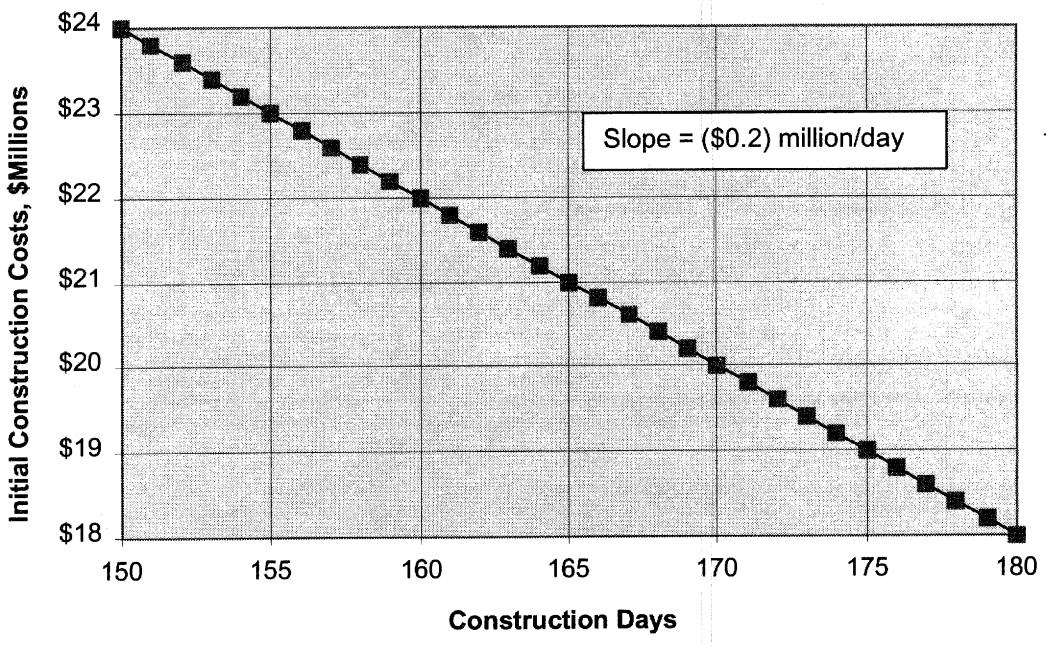


Figure 4. Agency Rehabilitation Costs Alternative - B

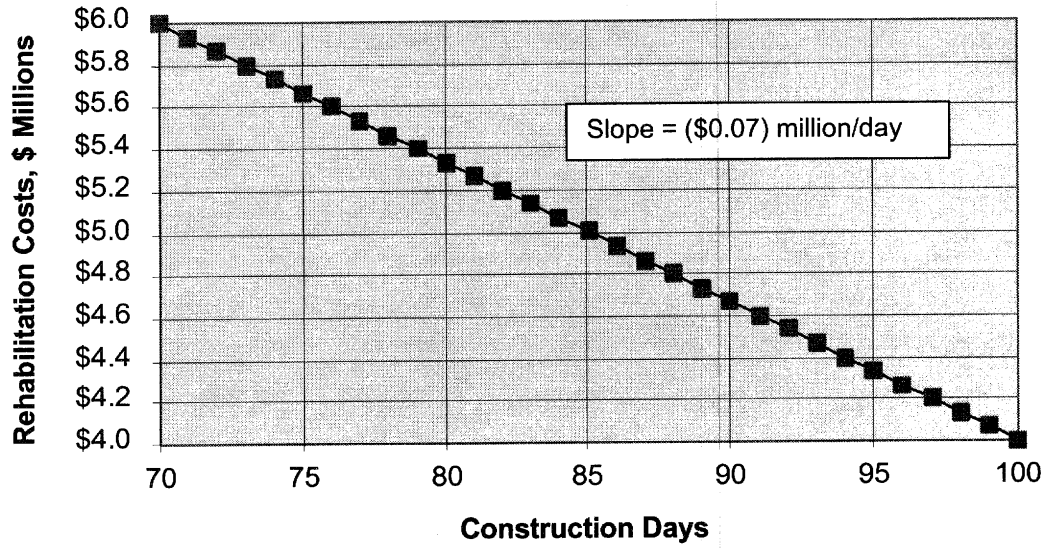


Table 4. Daily cost of delay.

	Value Time	$ 10.00	**per hour**	
	Directional AADT(initial)	40000	**vpd**	
	Traffic Growth Rate	3	**percent**	
	Delay Per Veh. Growth Rate	10	**percent**	
Year	**AADT**	**Delay/Veh. min**	**Daily Delay hours**	**Daily Cost**
0	40000	5.0	3333	$ 33,333
1	41200	5.5	3777	$ 37,767
2	42436	6.1	4279	$ 42,790
3	43709	6.7	4848	$ 48,481
4	45020	7.3	5493	$ 54,929
5	46371	8.1	6223	$ 62,234
6	47762	8.9	7051	$ 70,511
7	49195	9.7	7989	$ 79,889
8	50671	10.7	9051	$ 90,514
9	52191	11.8	10255	$ 102,553
10	53757	13.0	11619	$ 116,192
11	55369	14.3	13165	$ 131,646
12	57030	15.7	14915	$ 149,155
13	58741	17.3	16899	$ 168,993
14	60504	19.0	19147	$ 191,469
15	62319	20.9	21693	$ 216,934
16	64188	23.0	24579	$ 245,786
17	66114	25.3	27848	$ 278,476
18	68097	27.8	31551	$ 315,513
19	70140	30.6	35748	$ 357,476
20	72244	33.6	40502	$ 405,020
21	74412	37.0	45889	$ 458,888
22	76644	40.7	51992	$ 519,920
23	78943	44.8	58907	$ 589,070
24	81312	49.2	66742	$ 667,416
25	83751	54.2	75618	$ 756,182
26	86264	59.6	85675	$ 856,755
27	88852	65.5	97070	$ 970,703
28	91517	72.1	109981	$ 1,099,806
29	94263	79.3	124608	$ 1,246,081
30	97090	87.2	141181	$ 1,411,809
31	100003	96.0	159958	$ 1,599,580
32	103003	105.6	181232	$ 1,812,324
33	106093	116.1	205336	$ 2,053,363
34	109276	127.7	232646	$ 2,326,460
35	112554	140.5	263588	$ 2,635,880
36	115931	154.6	298645	$ 2,986,452
37	119409	170.0	338365	$ 3,383,650
38	122991	187.0	383368	$ 3,833,675
39	126681	205.7	434355	$ 4,343,554
40	130482	226.3	492125	$ 4,921,247

Note:
Values shown are for illustrative purposes only.

Table 5. NPV Worksheet.

	Year					
Alternative - A	0					
Agency Cost (Constant $)						
Present Worth Factor						
Agency Cost (Present Worth)						
Total NPV (Agency Cost)						
User Cost (Constant $)						
Present Worth Factor						
User Cost (Present Worth)						
Total NPV (User Cost)						
Grand Total NPV (all costs)						

	Year					
Alternative - B	0					
Agency Cost (Constant $)						
Present Worth Factor						
Agency Cost (Present Worth)						
Total NPV (Agency Cost)						
User Cost (Constant $)						
Present Worth Factor						
User Cost (Present Worth)						
Total NPV (User Cost)						
Grand Total NPV (all costs)						

Class Exercise No. 1
Net Present Value (Solution)

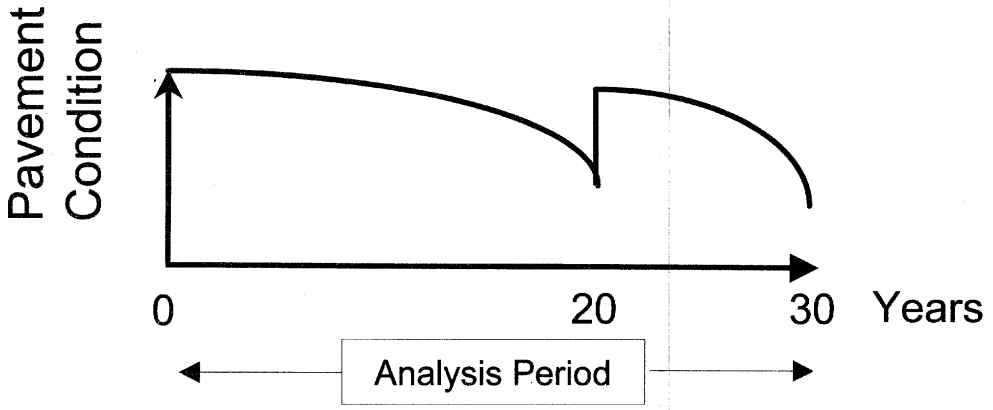
Compute the total Net Present Value (NPV) for the following Alternative.

	Initial Constr.	Rehab.
Design Period, (yrs)	20	10
Agency Cost ($ Millions)	26	9
Construction Period (days)	210	105

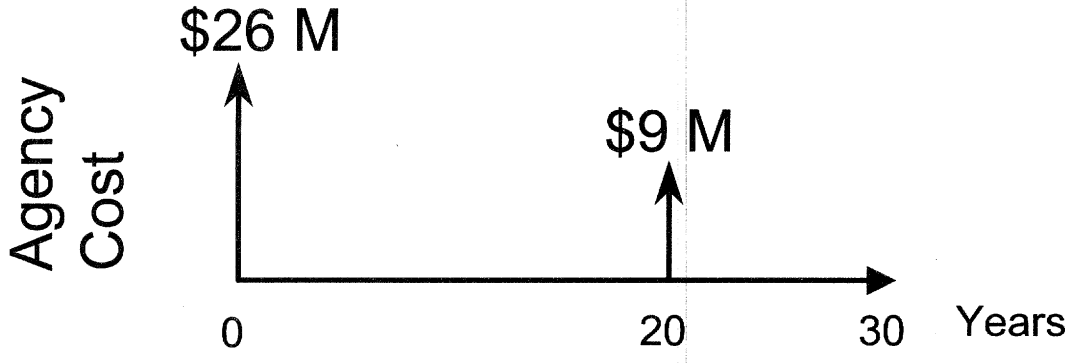
Assume the following:

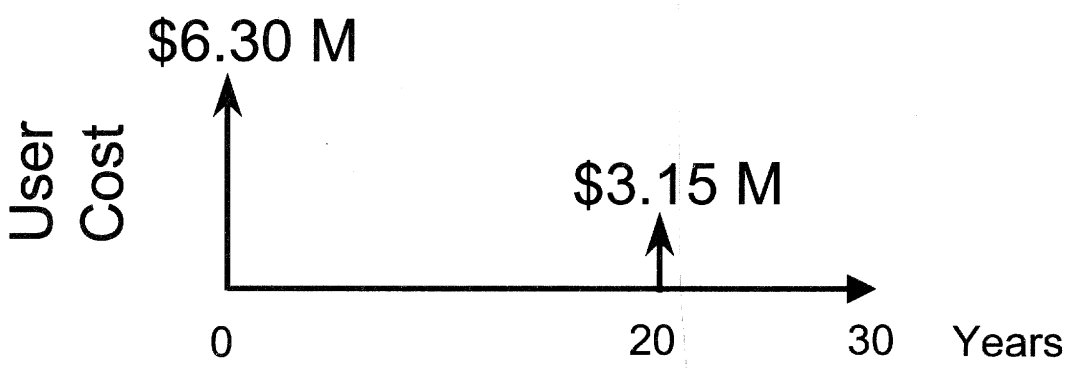
Analysis Period (yrs)	30
Daily Delay (Hours)	3000
Routine Maintenance	Insignificant
Discount Rate, %	4
Value of Time ($/hr)	10

Performance Curve



Expenditure Streams





User Cost Calculations

User Cost = Construction Days x Daily Delay x Value of Time

Initial Construction

User Cost = 210 days x 3000 hrs/day x $10 / hr.

= $6.30 Million

Rehabilitation

User Cost = 105 days x 3000 hrs/day x $10 / hr.

= $3.15 Million

$$NPV = InitialCost + \sum_{k=1}^{N} FutureCost\left[\frac{1}{(1+i)^{n_k}}\right]$$

Note: Quantity in brackets is present value factor from page 1.5.

Agency Cost

NPV = $26 + $9 (0.4564) = $30.12 M

User Cost

NPV = $6.3 + $3.15 (0.4564) = $7.74 M

Present Value Factors

Year n	Discount Rate, (i)				
	4.0%	4.5%	5.0%	5.5%	6.0%
1	0.9615	0.9569	0.9524	0.9479	0.9434
2	0.9246	0.9157	0.9070	0.8985	0.8900
3	0.8890	0.8763	0.8638	0.8516	0.8396
4	0.8548	0.8386	0.8227	0.8072	0.7921
5	0.8219	0.8025	0.7835	0.7651	0.7473
6	0.7903	0.7679	0.7462	0.7252	0.7050
7	0.7599	0.7348	0.7107	0.6874	0.6651
8	0.7307	0.7032	0.6768	0.6516	0.6274
9	0.7026	0.6729	0.6446	0.6176	0.5919
10	0.6756	0.6439	0.6139	0.5854	0.5584
11	0.6496	0.6162	0.5847	0.5549	0.5268
12	0.6246	0.5897	0.5568	0.5260	0.4970
13	0.6006	0.5643	0.5303	0.4986	0.4688
14	0.5775	0.5400	0.5051	0.4726	0.4423
15	0.5553	0.5167	0.4810	0.4479	0.4173
16	0.5339	0.4945	0.4581	0.4246	0.3936
17	0.5134	0.4732	0.4363	0.4024	0.3714
18	0.4936	0.4528	0.4155	0.3815	0.3503
19	0.4746	0.4333	0.3957	0.3616	0.3305
20	0.4564	0.4146	0.3769	0.3427	0.3118
21	0.4388	0.3968	0.3589	0.3249	0.2942
22	0.4220	0.3797	0.3418	0.3079	0.2775
23	0.4057	0.3634	0.3256	0.2919	0.2618
24	0.3901	0.3477	0.3101	0.2767	0.2470
25	0.3751	0.3327	0.2953	0.2622	0.2330
26	0.3607	0.3184	0.2812	0.2486	0.2198
27	0.3468	0.3047	0.2678	0.2356	0.2074
28	0.3335	0.2916	0.2551	0.2233	0.1956
29	0.3207	0.2790	0.2429	0.2117	0.1846
30	0.3083	0.2670	0.2314	0.2006	0.1741
31	0.2965	0.2555	0.2204	0.1902	0.1643
32	0.2851	0.2445	0.2099	0.1803	0.1550
33	0.2741	0.2340	0.1999	0.1709	0.1462
34	0.2636	0.2239	0.1904	0.1620	0.1379
35	0.2534	0.2143	0.1813	0.1535	0.1301

Class Exercise No. 2
Net Present Value (Solution)

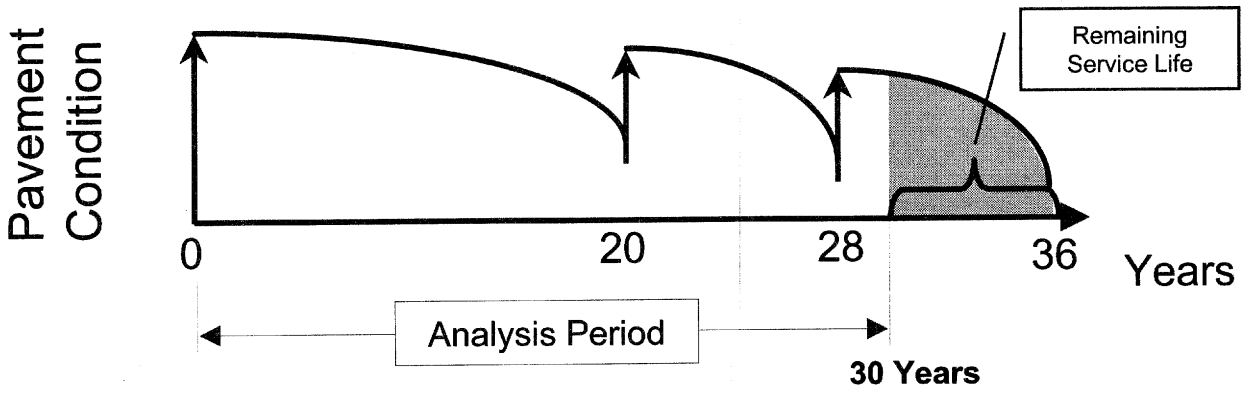
Compute the total Net Present Value (NPV) for the following Alternative.

	Initial Constr.	Rehab.
Design Period, (yrs)	20	8
Agency Cost ($ Millions)	30	9
Construction Period (days)	200	80

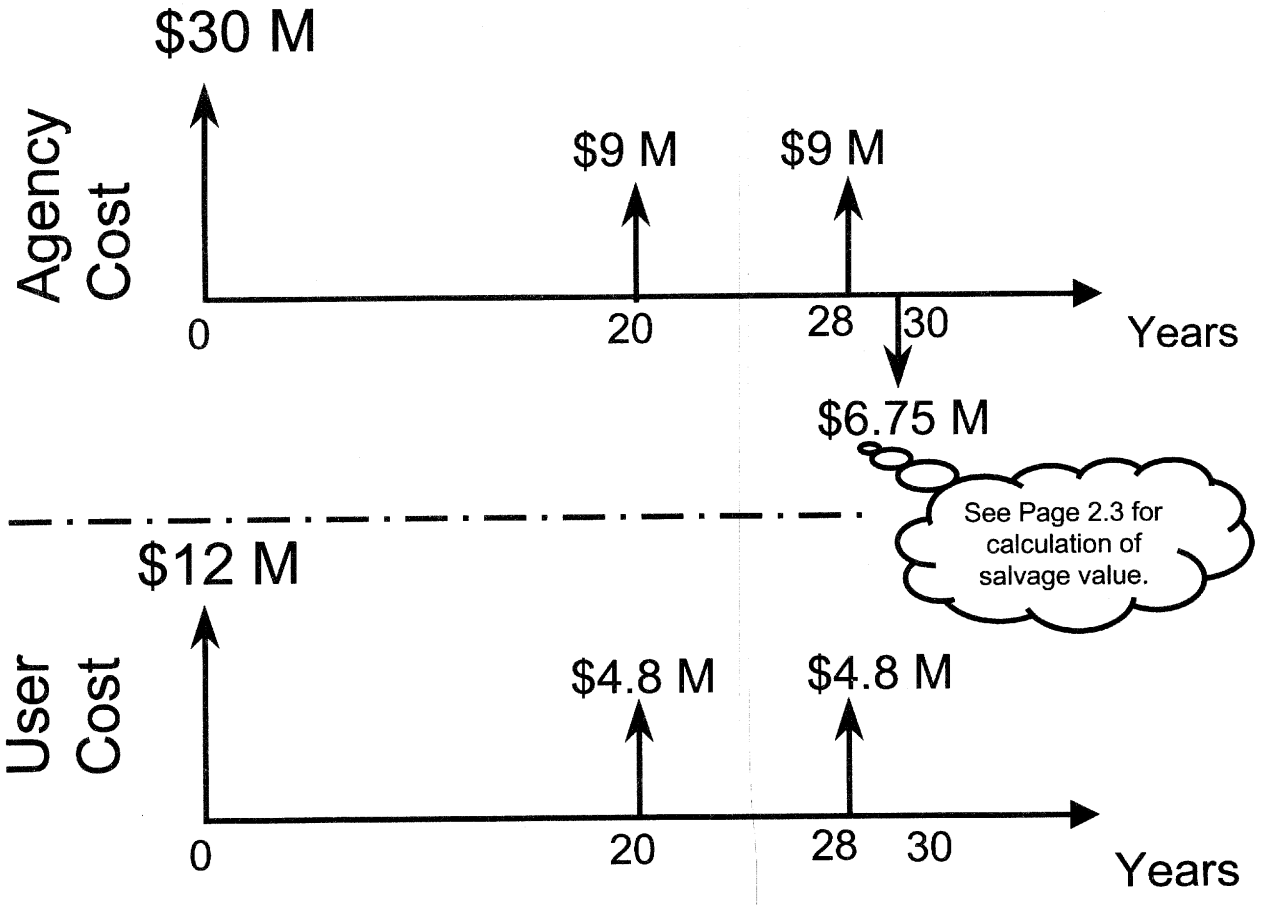
Assume the following:

Analysis Period (yrs)	30
Daily Delay (Hours)	4000
Routine Maintenance	Insignificant
Discount Rate, %	4
Value of Time ($/hr)	15

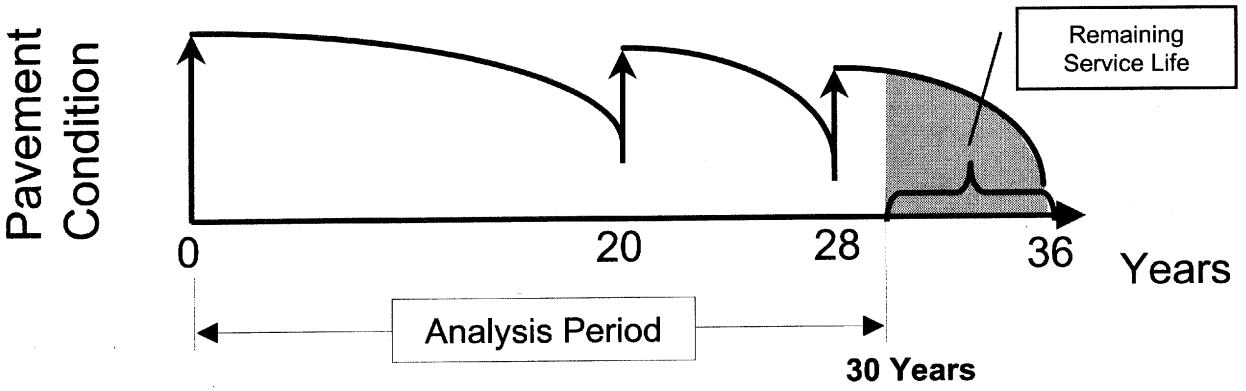
Performance Curve

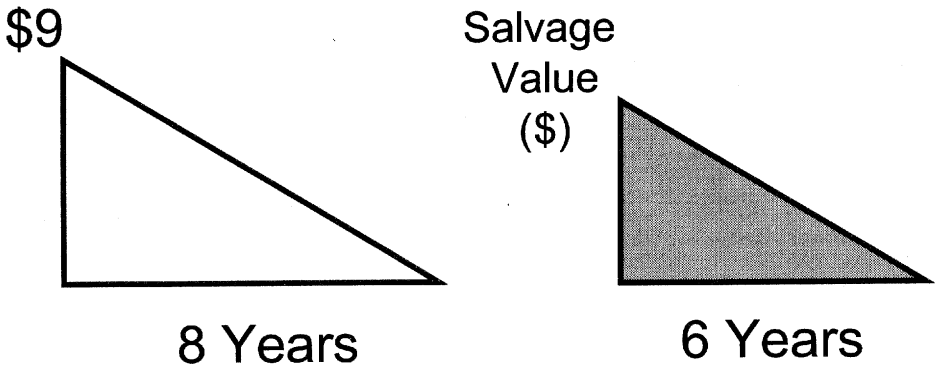


Expenditure Streams



Salvage Value Calculation





Salvage Value = (9 / 8) * 6 = $ 6.75

User Cost Calculations

User Cost = Construction Days x Daily Delay x Value of Time

Initial Construction

User Cost = 200 days x 4000 hrs/day x $15 / hr.

= $12 Million

Rehabilitation

User Cost = 80 days x 4000 hrs/day x $15 / hr.

= $4.8 Million

$$NPV = InitialCost + \sum_{k=1}^{N} FutureCost\left[\frac{1}{(1+i)^{n_k}}\right]$$

Note: Quantity in brackets is present value factor from page 2.6.

Agency Cost

NPV = \$30 + \$9(0.4564) + \$9 (0.3335) - \$6.75 (0.3083)
= \$35.03 M

User Cost

NPV = \$12 + \$4.8(0.4564) + \$4.8 (0.3335)
= \$15.79 M

Table 3. Discount Factors.

Year	Discount Rate				
n	4.0%	4.5%	5.0%	5.5%	6.0%
0	1.0000	1.0000	1.0000	1.0000	1.0000
1	0.9615	0.9569	0.9524	0.9479	0.9434
2	0.9246	0.9157	0.9070	0.8985	0.8900
3	0.8890	0.8763	0.8638	0.8516	0.8396
4	0.8548	0.8386	0.8227	0.8072	0.7921
5	0.8219	0.8025	0.7835	0.7651	0.7473
6	0.7903	0.7679	0.7462	0.7252	0.7050
7	0.7599	0.7348	0.7107	0.6874	0.6651
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9	0.7026	0.6729	0.6446	0.6176	0.5919
10	0.6756	0.6439	0.6139	0.5854	0.5584
11	0.6496	0.6162	0.5847	0.5549	0.5268
12	0.6246	0.5897	0.5568	0.5260	0.4970
13	0.6006	0.5643	0.5303	0.4986	0.4688
14	0.5775	0.5400	0.5051	0.4726	0.4423
15	0.5553	0.5167	0.4810	0.4479	0.4173
16	0.5339	0.4945	0.4581	0.4246	0.3936
17	0.5134	0.4732	0.4363	0.4024	0.3714
18	0.4936	0.4528	0.4155	0.3815	0.3503
19	0.4746	0.4333	0.3957	0.3616	0.3305
20	0.4564	0.4146	0.3769	0.3427	0.3118
21	0.4388	0.3968	0.3589	0.3249	0.2942
22	0.4220	0.3797	0.3418	0.3079	0.2775
23	0.4057	0.3634	0.3256	0.2919	0.2618
24	0.3901	0.3477	0.3101	0.2767	0.2470
25	0.3751	0.3327	0.2953	0.2622	0.2330
26	0.3607	0.3184	0.2812	0.2486	0.2198
27	0.3468	0.3047	0.2678	0.2356	0.2074
28	0.3335	0.2916	0.2551	0.2233	0.1956
29	0.3207	0.2790	0.2429	0.2117	0.1846
30	0.3083	0.2670	0.2314	0.2006	0.1741
31	0.2965	0.2555	0.2204	0.1902	0.1643
32	0.2851	0.2445	0.2099	0.1803	0.1550
33	0.2741	0.2340	0.1999	0.1709	0.1462
34	0.2636	0.2239	0.1904	0.1620	0.1379
35	0.2534	0.2143	0.1813	0.1535	0.1301

Figure 1. Initial Agency Construction Costs
Alternative A

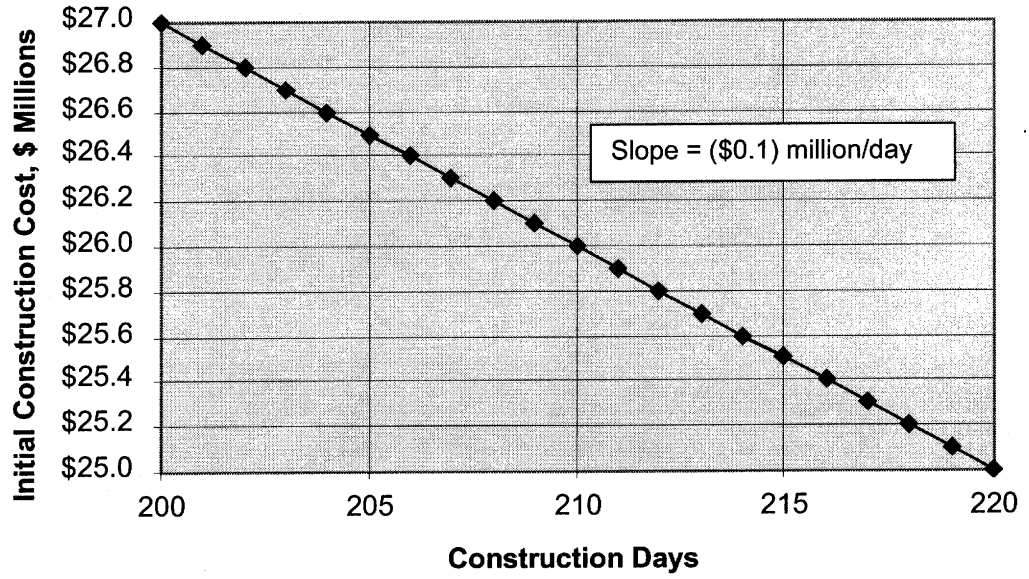


Figure 2. Agency Rehabilitation Costs
Alternative A

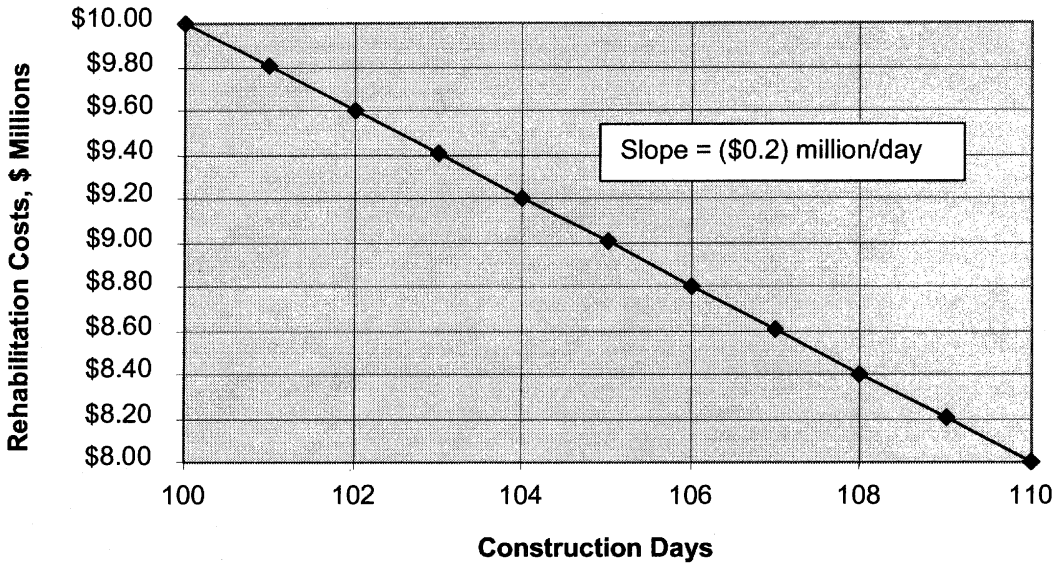


Figure 3. Initial Agency Construction Costs - Alternative B

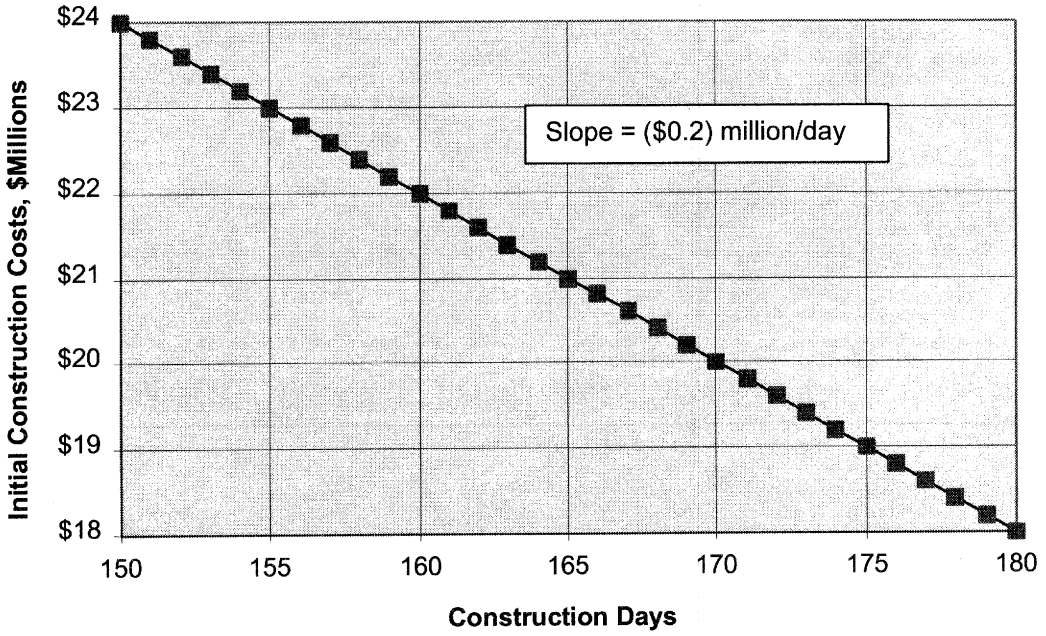


Figure 4. Agency Rehabilitation Costs Alternative - B

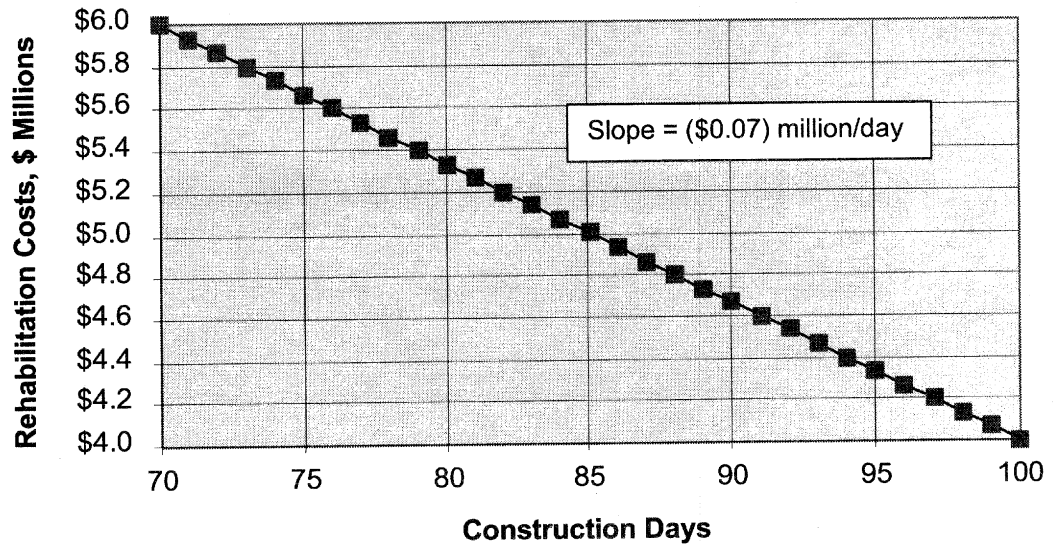


Table 4. Daily cost of delay.

Value Time	$ 10.00	**per hour**		
Directional AADT(initial)	40000	**vpd**		
Traffic Growth Rate	3	**percent**		
Delay Per Veh. Growth Rate	10	**percent**		

Year	AADT	Delay/Veh. min	Daily Delay hours	Daily Cost
0	40000	5.0	3333	$ 33,333
1	41200	5.5	3777	$ 37,767
2	42436	6.1	4279	$ 42,790
3	43709	6.7	4848	$ 48,481
4	45020	7.3	5493	$ 54,929
5	46371	8.1	6223	$ 62,234
6	47762	8.9	7051	$ 70,511
7	49195	9.7	7989	$ 79,889
8	50671	10.7	9051	$ 90,514
9	52191	11.8	10255	$ 102,553
10	53757	13.0	11619	$ 116,192
11	55369	14.3	13165	$ 131,646
12	57030	15.7	14915	$ 149,155
13	58741	17.3	16899	$ 168,993
14	60504	19.0	19147	$ 191,469
15	62319	20.9	21693	$ 216,934
16	64188	23.0	24579	$ 245,786
17	66114	25.3	27848	$ 278,476
18	68097	27.8	31551	$ 315,513
19	70140	30.6	35748	$ 357,476
20	72244	33.6	40502	$ 405,020
21	74412	37.0	45889	$ 458,888
22	76644	40.7	51992	$ 519,920
23	78943	44.8	58907	$ 589,070
24	81312	49.2	66742	$ 667,416
25	83751	54.2	75618	$ 756,182
26	86264	59.6	85675	$ 856,755
27	88852	65.5	97070	$ 970,703
28	91517	72.1	109981	$ 1,099,806
29	94263	79.3	124608	$ 1,246,081
30	97090	87.2	141181	$ 1,411,809
31	100003	96.0	159958	$ 1,599,580
32	103003	105.6	181232	$ 1,812,324
33	106093	116.1	205336	$ 2,053,363
34	109276	127.7	232646	$ 2,326,460
35	112554	140.5	263588	$ 2,635,880
36	115931	154.6	298645	$ 2,986,452
37	119409	170.0	338365	$ 3,383,650
38	122991	187.0	383368	$ 3,833,675
39	126681	205.7	434355	$ 4,343,554
40	130482	226.3	492125	$ 4,921,247

Note:
Values shown are for illustrative purposes only.

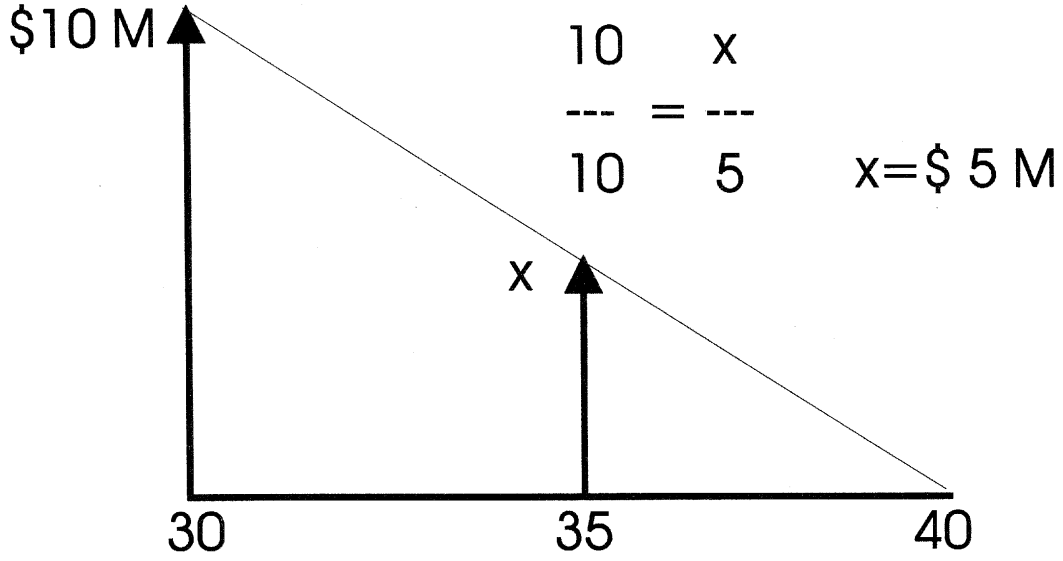
Table 5. Solution

	Year					
Alternative - A	**0**	**20**	**30**	**35**		
Agency Cost (Constant $)	25.00 M	10.00 M	10.00 M	-5.00 M		
Present Worth Factor	1.000	0.4564	0.3083	0.2534		
Agency Cost (Present Worth)	25.00 M	4.564 M	3.083 M	-1.267 M		
Total NPV (Agency Cost)	31.38					
User Cost (Constant $)	7.333 M	40.50 M	141.2 M			
Present Worth Factor	1.000	0.4564	0.3083			
User Cost (Present Worth)	7.333 M	18.48 M	43.53 M			
Total NPV (User Cost)	69.34 M					
Grand Total NPV (all costs)	100.7 M					

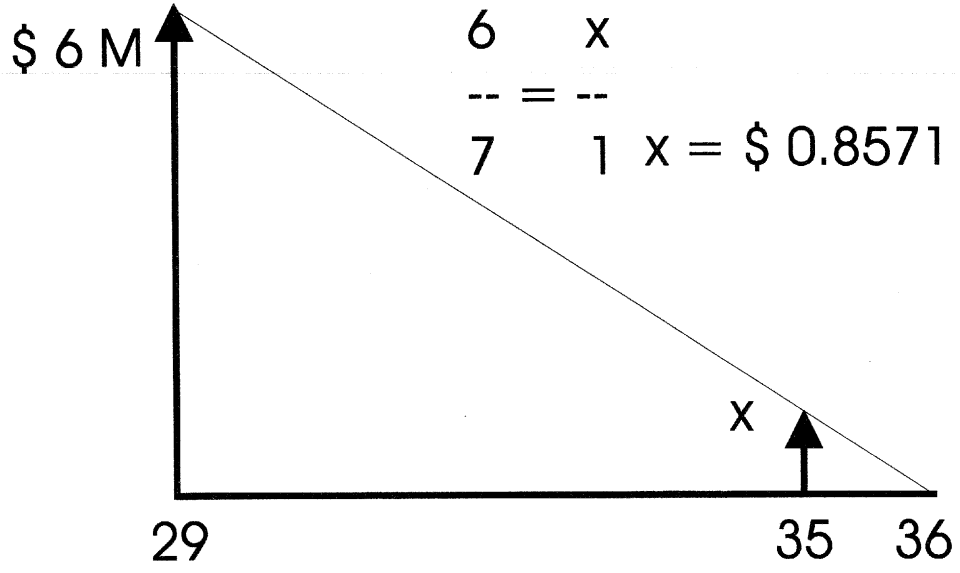
	Year					
Alternative - B	**0**	**15**	**22**	**29**	**35**	
Agency Cost (Constant $)	18.00 M	6.000 M	6.000 M	6.000 M	-0.8571 M	
Present Worth Factor	1.000	0.5553	0.4220	0.3207	0.2534	
Agency Cost (Present Worth)	18.00 M	3.332 M	2.532 M	1.924 M	-0.2172 M	
Total NPV (Agency Cost)	25.57 M					
User Cost (Constant $)	6.000 M	15.18 M	36.39 M	87.22 M		
Present Worth Factor	1.000	0.5553	0.4220	0.3207		
User Cost (Present Worth)	6.000 M	8.429 M	15.54 M	27.97 M		
Total NPV (User Cost)	57.94 M					
Grand Total NPV (all costs)	83.51 M					

Selection of Construction Days.

Alternative	Agency Cost	User Cost	Construction Days (Range)	Construction Days (Selection)
Alt - A Initial	100,000 / day	**33,333 / day**	200 to 220	220
Alt - A Rehab Year 20	**200,000 / day**	405,020 / day	100 to 110	100
Alt - B Initial	200,000 / day	**33,333 / day**	150 to 180	180
Alt - B Rehab Year 15	**70,000 / day**	216,934 / day	70 to 100	70



$$\frac{10}{10} = \frac{x}{5} \qquad x = \$\ 5\ M$$



$$\frac{6}{7} = \frac{x}{1} \qquad x = \$\ 0.8571\ M$$

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