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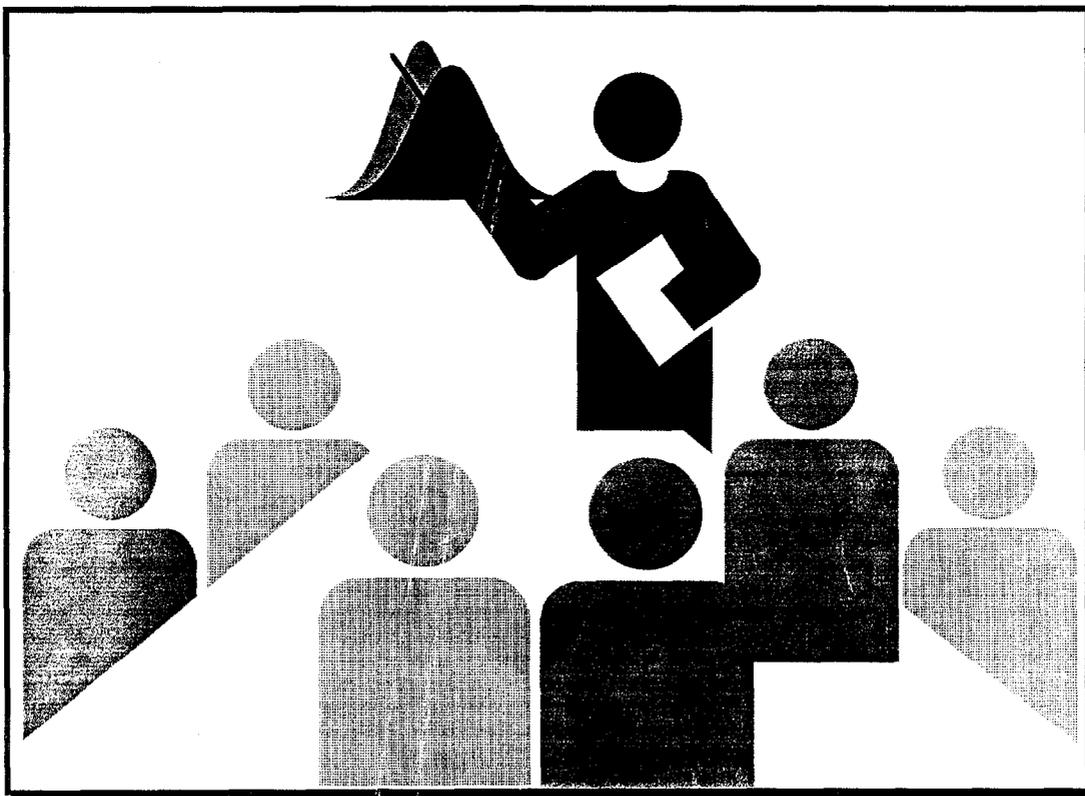


U.S. Department of Transportation
Federal Highway Administration



Life Cycle Cost Analysis in Pavement Design

Demonstration Project No.115



Participant's Manual



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

Life Cycle Cost Analysis in Pavement Design

- In Search of Better Investment Decisions -

Pavement Division
Office of Engineering
Federal Highway Administration

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PROJECT TASK TEAM



DP-115 Phases

- ❶ Traditional approach and probabilistic concepts
- ❷ SHA Case Studies
- ❸ Probabilistic LCCA

Phase I Objective

- Provide training and practice on application of traditional LCCA

- Introduce probabilistic concepts

Workshop Outline

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

Major Focus ...

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

End Session

LCCA Background

Life Cycle Cost Estimation What's changed is the emphasis

- ### Session Overview
- Definitions
 - Driving Forces
 - Implementing Guidance
 - National Pavement Design Review

Session Overview

- Definitions
 - Life Cycle Cost Analysis
 - Useable Project Segment
 - Deterministic Approach
 - Probabilistic Approach

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.”

Useable Project Segment

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

Deterministic Approach

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

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.

Session Overview

- Definitions
- Driving Forces
 - ISTEA (91)
 - AASHTO-FHWA Symposium (93)
 - Executive Order 12893 (94)
 - NHS Designation Act (95)
 - NQI Survey (95)

ISTEA (1991)

■ Sections: 1024 & 1025

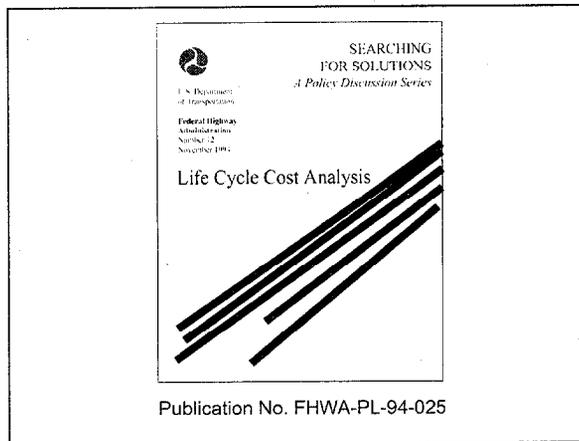
Factors to be *considered* ...
the use of life-cycle costs in the
design and engineering of bridges,
tunnels, or pavements.

LCCA Symposium (93)

■ AASHTO Survey

■ Issues ...

- Policy/Planning/Programming
- Bridge Analysis
- Pavement Analysis
- Technical Details



Executive Order 12893 (94)

“Principles for Federal Infrastructure Investments ”

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

NHS Designation Act (95)

Section 303, “Quality Improvement,”

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

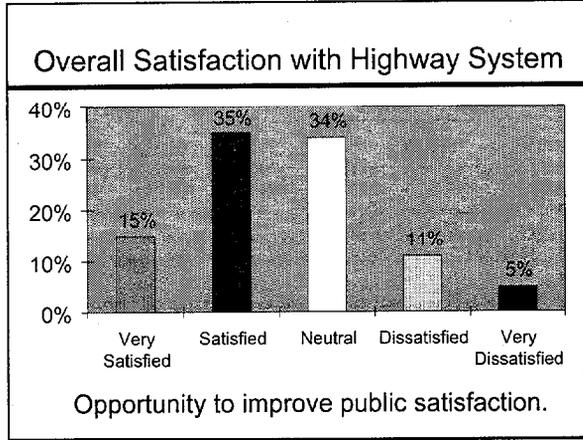
NQI

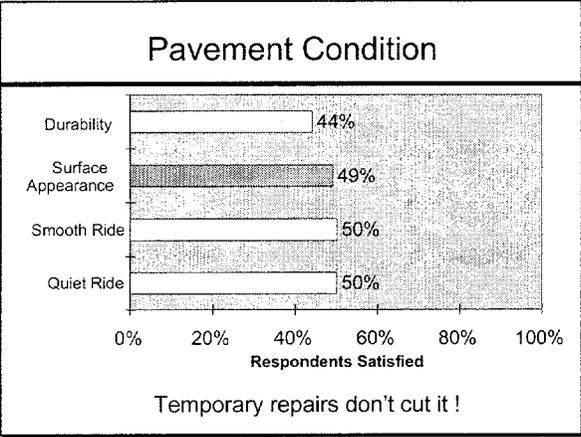


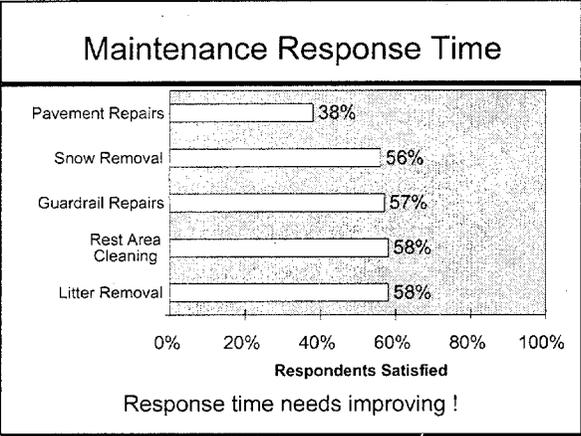
- National Policy on Quality of Highways (92)
- Survey conducted (11/95)

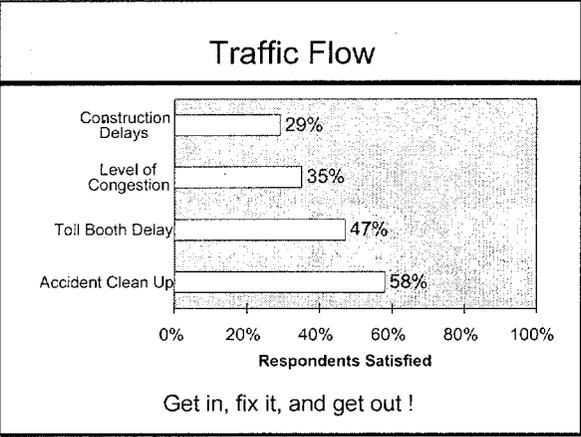
<p>National Highway User Survey</p> <p>National Quality Initiative</p>  <p>Steering Committee</p>	NQI SURVEY
	1 Introduction
	2 Background of Survey
	4 Survey Design and Methodology
	6 Profile of Respondents
	8 Major Findings
	17 Additional Findings
	20 Summary
	<small>Coopers & Lybrand L.L.P.</small>

- ### Survey Highlights
- Overall satisfaction
 - Pavement condition
 - Maintenance response time
 - Traffic flow









Priorities ...

- Pavement Condition
- Safety
- Traffic Flow

Session Overview

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

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

LCCA Policy Statement (9/96)

FHWA Philosophy - LCCA

- Is a decision support tool
- Results are not decisions
- Results often less important than logical evaluation process

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

Policy Statement Con't ...

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

Technical Bulletin

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

DP 115

- Workshop
- Case studies
- Future activities

Additional Resources

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

Session Overview

- Definitions
- Driving Forces
- Implementing Guidance
- National Pavement Design Review
 - Background
 - Purpose
 - General Findings (LCCA)

Background

- OIG/GAO reviews
- FHWA reviews 1995 - 1996
- 52 SHAs
- Areas addressed:
 - ✓ Design procedures
 - ✓ LCCA
 - ✓ Traffic

Purpose

Collect SHA pavement design information:

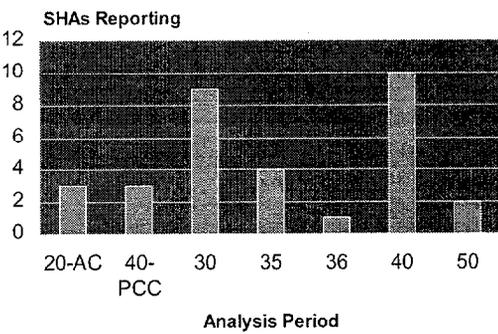
- Life-cycle cost analysis
- Design procedures
- Traffic data collection & projections

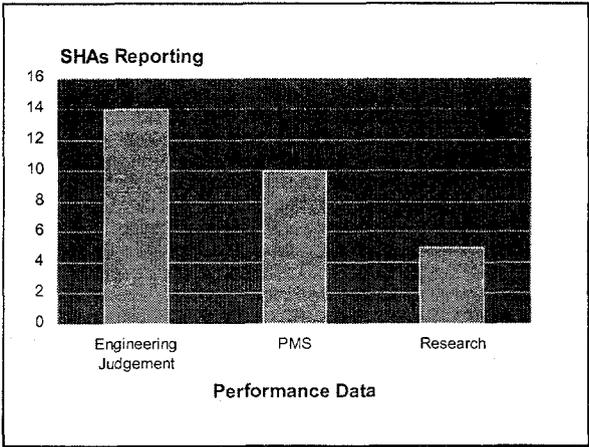
LCCA General Findings

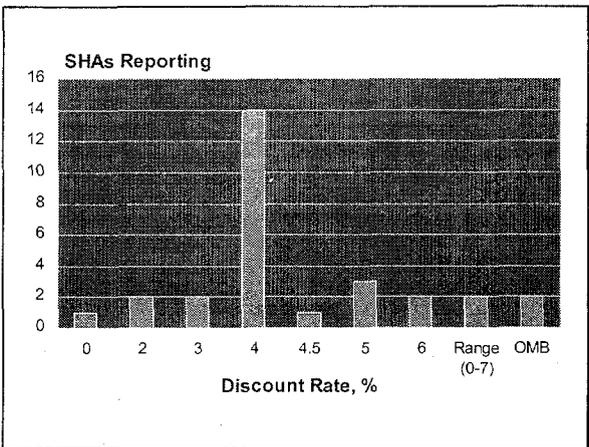
- Procedures
- Analysis Periods
- Performance Periods
- Discount Rates
- User Costs

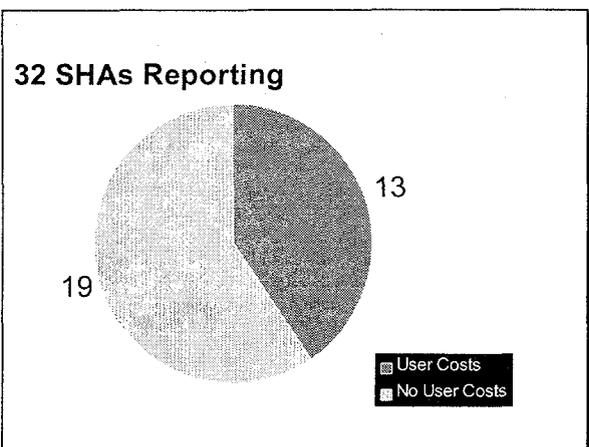
NPDR LCCA Procedures

- Number Reporting 50
- Documented Procedures 32
 - Advanced Procedures 11
- Not Documented 18
 - Informal Procedures 8
 - Not Documented or Informal 10









Session Summary

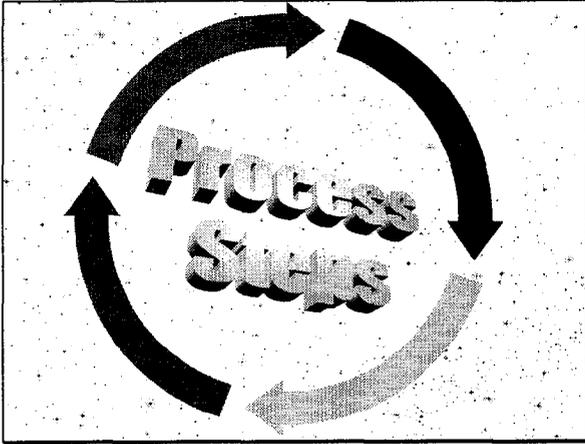
- Definitions
- Driving Forces
- Implementing Guidance
- National Pavement Design Review

End Session



Session Overview
<ul style="list-style-type: none">■ Levels of Application■ LCCA Process Steps

Levels of Application
<ul style="list-style-type: none">■ Funding levels■ Program allocation■ Project selection■ Design selection



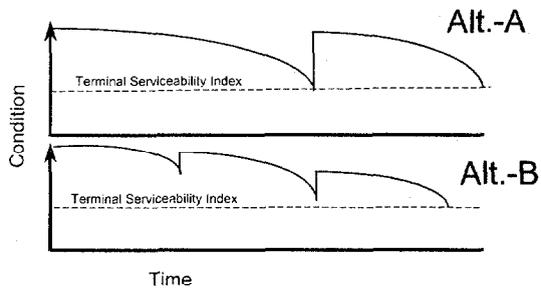
LCCA Process Steps
<ul style="list-style-type: none">❶ Establish strategies for analysis period.❷ Establish activity timing❸ Estimate agency costs❹ Estimate user costs❺ Develop expenditure streams❻ Compute NPV❼ Analyze results❽ Reevaluate strategies

1. Establish Strategies for Analysis Period
<ul style="list-style-type: none">■ Initial pavement designs■ Subsequent maintenance and rehabilitations

LCCA Process Steps

- ❶ Establish strategies for analysis period
- ❷ Establish activity timing

2. Establish Activity Timing



Example: PCC M&R Activities

Yr.	Activity
0	→ PCC New Construction
5	→ Clean & Seal Jnts, Seal coat shoulders
10	→ Same as 5
15	→ Same as 5
20	→ Same plus patch & slab stabilization
25	→ Same as 5
30	→ Overlay, saw and seal joints
35	→ Seal coat shoulders

LCCA Process Steps

- Establish strategies for analysis period
- Establish activity timing
- Estimate agency costs

3. Estimate Agency Cost

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

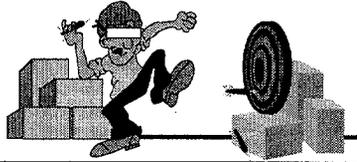
Sources ...

- SHA historical bid data

- Bid Analysis Management System (BAMS)

LCCA Process Steps

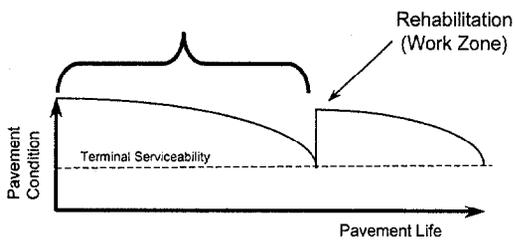
- ❶ Establish strategies for analysis period
- ❷ Establish activity timing
- ❸ Estimate agency costs
- ❹ Estimate user costs

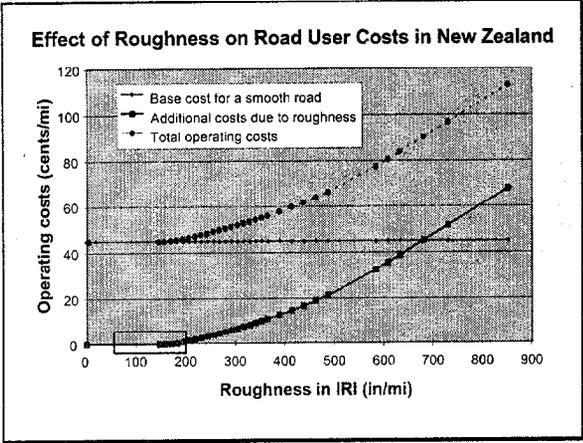


4. Estimate User Costs

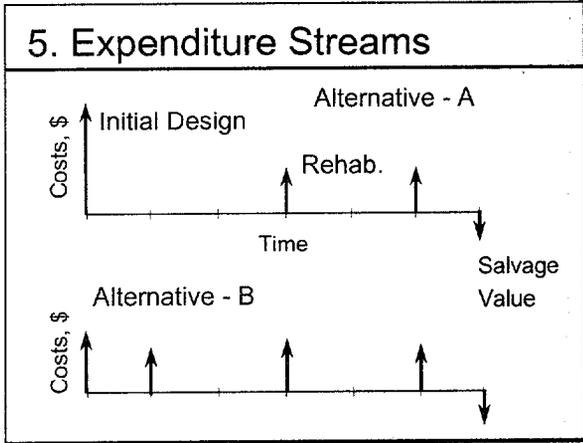
- Costs incurred by the user over the analysis period
 - Normal operations
 - Work zone conditions
- Includes:
 - Vehicle operating costs
 - User delay costs
 - Crash costs

Between Work Zone Costs





- ### LCCA Process Steps
- ❶ Establish strategies for analysis period
 - ❷ Establish activity timing
 - ❸ Estimate agency costs
 - ❹ Estimate user costs
 - ❺ Develop expenditure streams



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

Definition

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

6. NPV Equation

NPV = Initial Cost +

$$\sum_{i=1}^N \text{Future Cost}_i \times \left[\frac{1}{(1 + I)^{n_i}} \right]$$

I = discount rate
n = year of expenditure

Present Worth Factors

Year	Discount Rate (I)				
	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
•	•	•	•	•	•
•	•	•	•	•	•
•	•	•	•	•	•

$NPV = (\text{Future Cost}) \times (\text{Present Worth Factor})$

NPV Agency

NPV User

NPV Total

Since User Costs may Dominate
Separate Agency and User Costs

LCCA Process Steps

- ❶ Establish strategies for analysis period
- ❷ Establish activity timing
- ❸ Estimate agency costs
- ❹ Estimate user costs
- ❺ Develop expenditure streams
- ❻ Compute NPV
- ❼ Analyze results

7. Analyze Results



What if ...

Sensitivity Analysis

✓ Best Case

✓ Most Likely Case

✓ Worst Case



Example

Sensitivity Analysis

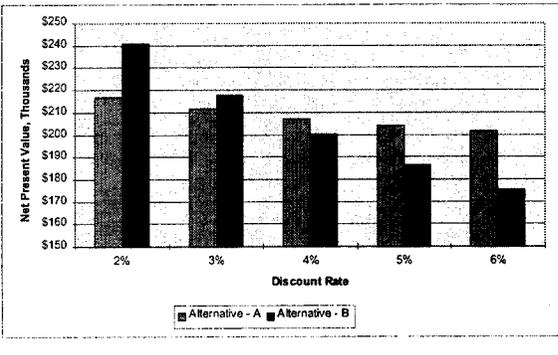
Alternative - A

Activity	Year	Cost	Discounted Cost				
			2%	3%	4%	5%	6%
Constr.	0	\$188.0	\$188.0	\$188.0	\$188.0	\$188.0	\$188.0
Rehab.	10	\$ 10.0	\$ 8.2	\$ 7.4	\$ 6.8	\$ 6.1	\$ 5.6
Rehab.	20	\$ 15.0	\$ 10.1	\$ 8.3	\$ 6.8	\$ 5.6	\$ 4.7
Rehab.	30	\$ 15.0	\$ 8.3	\$ 6.2	\$ 4.6	\$ 3.5	\$ 2.6
Salvage	35	\$ 4.5	\$ 2.2	\$ 1.6	\$ 1.1	\$ 0.8	\$ 0.6
NPV			\$216.8	\$211.5	\$207.4	\$204.1	\$201.5

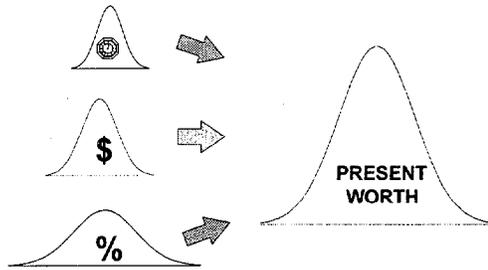
Alternative - B

Activity	Year	Cost	Discounted Cost				
			2%	3%	4%	5%	6%
Constr.	0	\$125.0	\$125.0	\$125.0	\$125.0	\$125.0	\$125.0
Rehab.	15	\$ 80.0	\$ 59.4	\$ 51.4	\$ 44.4	\$ 38.5	\$ 33.4
Rehab.	30	\$ 80.0	\$ 44.2	\$ 33.0	\$ 24.7	\$ 18.5	\$ 13.9
Salvage	35	\$ 24.0	\$ 12.0	\$ 8.5	\$ 6.1	\$ 4.4	\$ 3.1
NPV			\$240.6	\$217.8	\$200.2	\$186.3	\$175.4

Example: Sensitivity Analysis NPV vs. Discount Rate



Monte Carlo Simulation



7. Analyze Results Con't

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

Implications



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

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

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

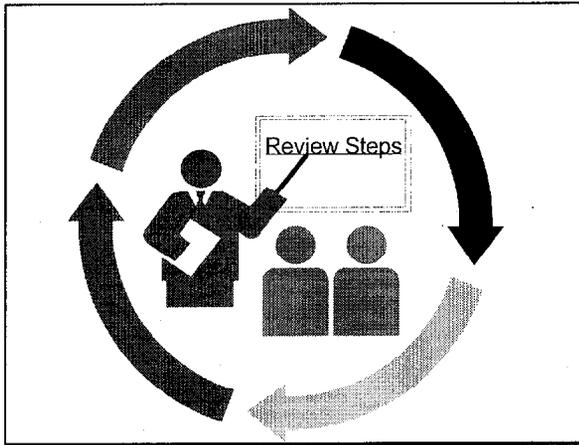
Additional considerations ...

- 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

General

LCCA:

- ✓ Decision support tool
- ✓ Results are not decisions
- ✓ Results often less important than the logical evaluation process

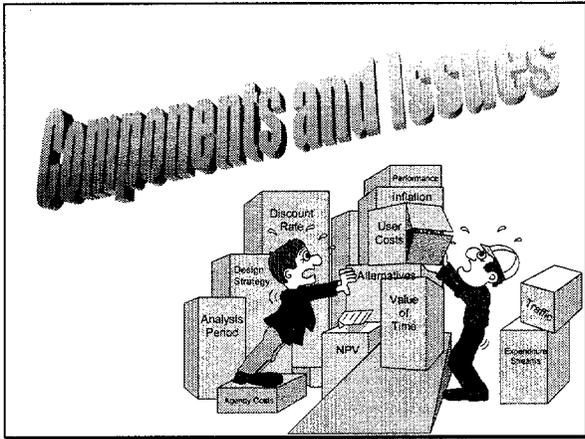


LCCA Process Steps

- 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

End Session

**Key Points to Address in
Future Sessions ?**

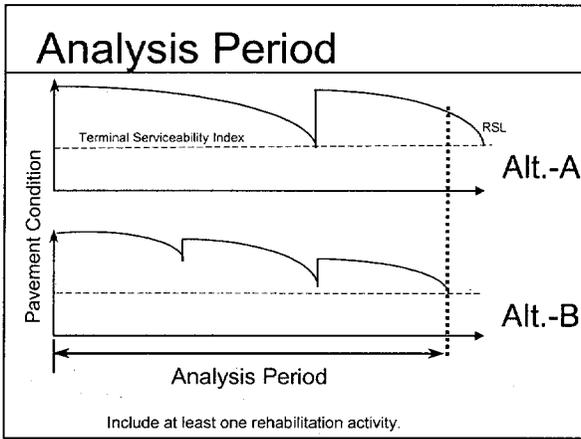


Session Overview

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

Session Overview Con't

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



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

- ### Traffic - Characteristics
- AADT
 - Traffic mix
 - Growth rates
 - Directional hourly distribution

Traffic - Projections

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

Traffic - Hourly Demand

Sources:

- Traffic data
- Typical default values
 - PennDOT
 - MicroBencost

Example

PennDOT AADT Distribution - Hourly Percentages

Hour	Traffic Pattern Group					
	Interstate		Prin. Arterial		Min. Arterial	
	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

Design Strategy

- Initial design
- Identify supporting rehabs
- Viable and competitive

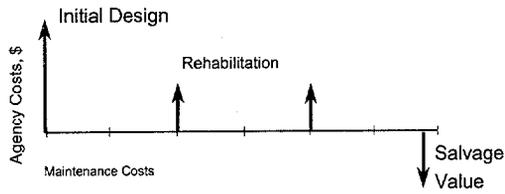
PCC Design Strategy

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

Performance Estimates

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

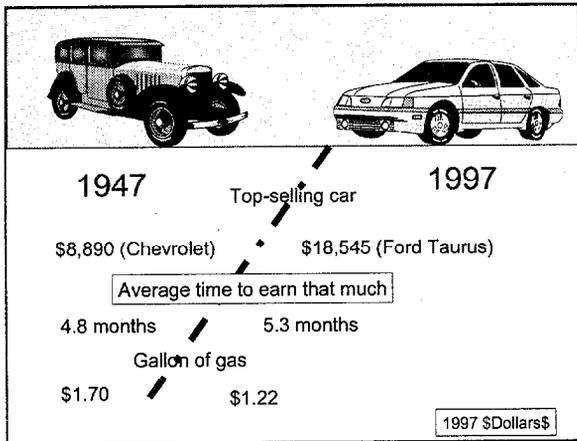
Expenditure Streams



Costing and Discounting

■ Costing - Type of Dollars

- Constant (real)
- Inflated (nominal)



Example: Deflation

Computer Cost:

- 1989 - \$2,500
- 1997 - \$2,000

Costing and Discounting

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

Discounting - Rate Factors

- 4.0% - Real
- 3.5% - Inflation
- 4.0% - Risk premium
-
- 11.5% - Nominal

Discounting - Matching Dollars & Rates

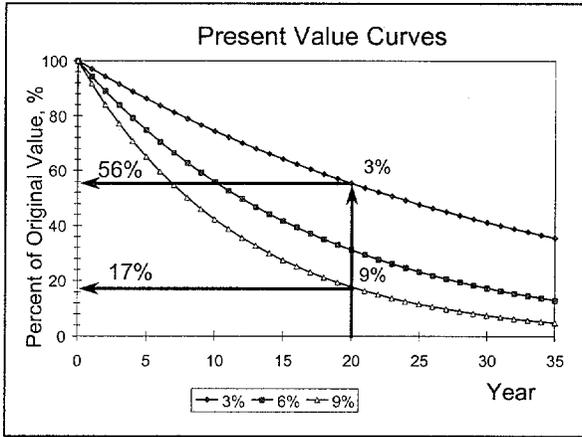
- Real dollars and rates
- Nominal dollars and rates
- Never mix nominal and real

Discounting "True-isms"

- Present costs valued higher
- Out year costs worth less

Discounting "True-isms"

- Low Rates -
Favor higher initial costs and lower future costs
- High Rates -
Favor lower initial costs and higher future costs



Discount Rate Selection

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

Opportunity Cost - Personal

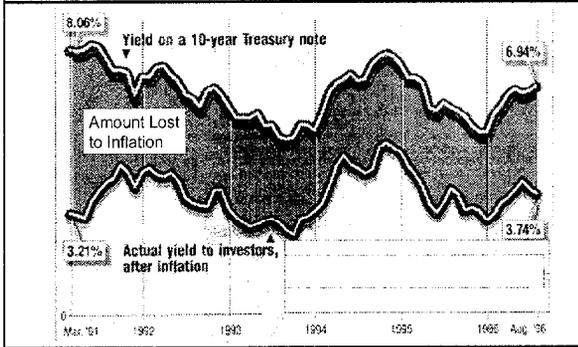
- 401K - IRA 28% - 35%+
- Credit Cards 15% - 22%
- Signature Loans 12% - 15%
- Car Loans 8% - 12%
- Home Equity 7% - 11%
- Mortgage 5% - 8%
- Savings/Checking 0% - 3%

Opportunity Cost - Gov't

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



Real Discount Rate



Real Discount Rates Source: OMB Circular A-94

YEAR	Investment Maturity				
	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
Avg	3.2	3.4	3.6	3.8	4.0
STD	0.5	0.6	0.6	0.7	0.7

(No Inflation Premium)

Circular A-94

Discount Rates Web Address:

[http://www.whitehouse.gov/
WH/EOP/OMB/html/circulars
/a094/a094.html#ap-a](http://www.whitehouse.gov/WH/EOP/OMB/html/circulars/a094/a094.html#ap-a)

Recommend

- ➔ 3 to 5 %
- ➔ Real rates with real dollars

Economic Indicators

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

Economic Indicator of Choice
<p style="text-align: center;"><u>Net</u> <u>Present</u> <u>Value</u></p>

Agency Costs
<ul style="list-style-type: none">■ Design and Engineering■ Initial Construction■ Maintenance of Traffic■ Maintenance■ Rehabilitation■ Operating Cost <p style="text-align: center;">Salvage Value Sunk Costs</p>

Salvage Value
<ul style="list-style-type: none">■ Remaining service life<ul style="list-style-type: none">● % of last rehab cost ■ Residual value<ul style="list-style-type: none">● Value of recycled material

Sunk Costs

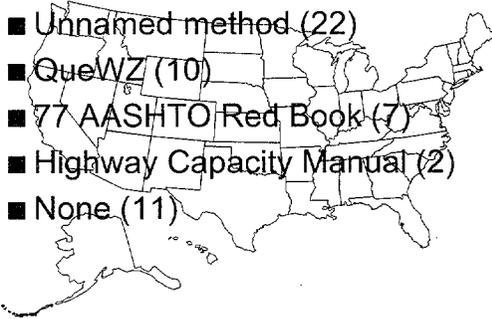
... costs that are not relevant to the decision at hand

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

AASHTO User Cost Survey

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



User Cost Components

- Vehicle Crash cost
- Vehicle operating cost
- User delay

User Cost Components

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

User Cost Components

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

Vehicle Operating Cost

- Normal operation
- Work zones

VOC Normal Operations

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

VOC in Work Zones

- Speed change cost
- Stopping cost
- Idling cost

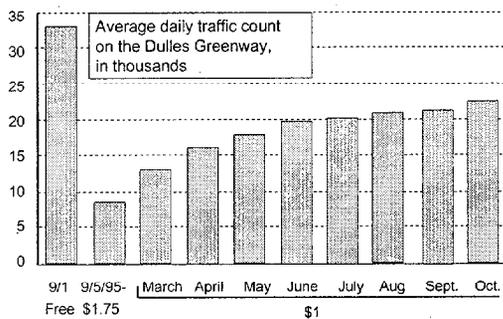
Value of Time: Sources

- A + B Bidding - Lane rentals
- Toll facilities
- Congestion pricing
- Lexus lanes (HOT)
- DOT OST - FHWA HERS
- Research studies

A + B Bidding

- Louisiana I-10
- Estimate \$44M Bid \$88M
- Eliminate A + B
- Estimate \$55M Bid \$69M

Toll Facilities



Congestion Pricing

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

Lexus Lanes

- San Diego I-15
 - \$10 Million experiment 12/96
 - Started at \$50/mo., now at \$70
 - 700 permits with 400 waiting
- Orange Co - Riverside Freeway
 - \$2.25 saves 20 minutes

Lexus Lanes Con't

- Houston Katy Freeway
 - 2 for 3 @ \$2.00

Value of Time (USDOT 1997)

Travel Category	\$ / Person Hour			
	Local		Inter City	
	Low	High	Low	High
Business	15.00	22.60	15.00	22.60
Personal	6.00	10.20	10.20	15.30
Mixed	6.40	10.70	10.40	15.70
Trucks	16.50	16.50	16.50	16.50

1995 Dollars

Value of Time (HERS 1997)

Source: Highways Economic Requirement System 9/97

Travel Category	\$ / Veh. Hour		
	Autos	Trucks	
		Single Unit	Combination
Business	28	26	31
Personal	13	NA	NA
% AADT Personal	90%	0%	0%
Wt. Avg.	14	26	31

1995 Dollars

Value of Time (Research Studies)

Our Recommendation ...

Vehicle Class	\$ / Vehicle Hour	
	Value	Range
Passenger Vehicles	11.58	10.00 - 13.00
Single Unit Trucks	18.54	17.00 - 19.00
Combination Trucks	22.31	21.00 - 24.00

1996 Dollars

Further Information ...

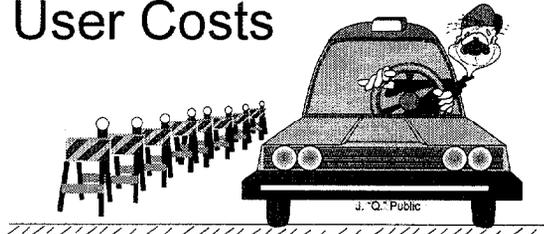
- LCCA Tech Bulletin
 - Fundamental principles
 - Accepted procedures
 - LCCA issues
 - Case studies
 - Uncertainty and variability
 - Computer software

Parting Caveat

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

End Session

Introduction to Project Level User Costs



Federally Funded Highway Programs to Increase User Efficiency

- Advanced Traffic Management System
- Advanced Traveler Information System
- Arizona Driver Advisory System (ADAS)
- Advanced Driver and Vehicle Advisory Navigation Concept (ADVANCE)
- Atlanta Bus Routing New Jersey Parkway
- Alabama Advanced Traffic Control System (ATCS)
- Advanced Rural Transportation Information and Coordination (ARTIC)
- Atlanta Kick
- Boston Advanced Traffic Management Systems (ATMS)
- Michigan Driver Information Radio Experimenting with Communication Technology (DIRECT)
- During Incidents Vehicles Exit to Reduce Travel Time (DIVERT)
- Michigan Faster and Safer Travel through Traffic Routing and Advanced Controls (FAST-TRAC)
- Minnesota Goldstar Project Genesis
- Integrated Corridor Traffic Management (ICTM)
- Integrated Freeway Ramp Meter / Aerial Adaptive Signal Control (IRMAASC)
- Intelligent Vehicle Highway System
- Intelligent Transportation Systems
- Evaluating Environmental Impacts of IVHS Using LIDAR Technology
- Mobile Video Surveillance Ramp Metering and Wireless Communications Systems
- North Seattle Advanced Traffic Management System
- Puget Sound "Help Me" Message System Field Test (PushMe)
- IVHS for Voluntary Emissions Reduction (Real-Time Emissions Detection)
- San Diego Smart Call Box
- San Jose Spectrum Radio Traffic Signal Interconnect
- Seattle Wide Area Information For Travelers (SWIFT)
- Travel Demand Management / Emissions Detection (TDM/ED)
- Transcal
- San Antonio Advanced Traffic Management System
- TRANSCOM's System for Managing Incidents and Traffic (TRANSMIT)
- Ray Area International Traveler Information System
- Travelink
- Advanced Traffic Information System Operational Test



Session Overview

- Definition
- Operating Conditions
- Components
- Work zone

User Costs Defined

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.

Operating Conditions

- Normal
- Work zone

Components

- Vehicle operating
- User delay
- Circuity
- Crash

Our Primary Focus ...

Vehicle Operating

User Delay



Work Zone

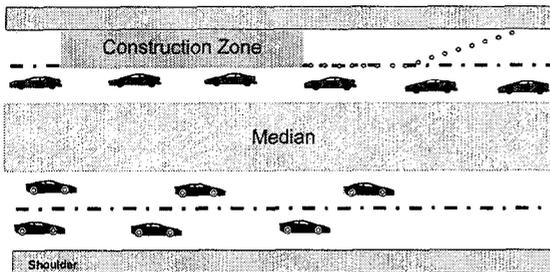
Crash
Costs

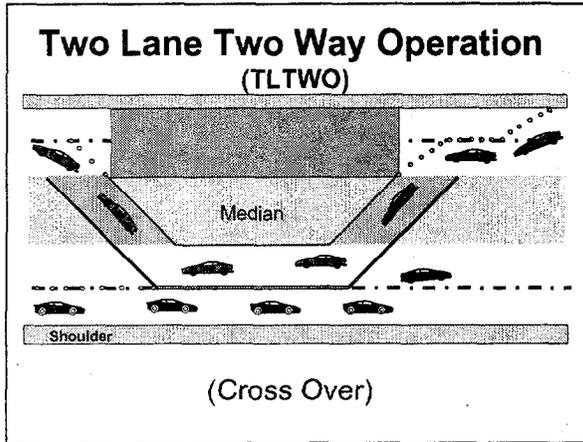


Work Zone Types

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

Single Lane Closure (SLC)





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

- WZ User Costs Function of ...**
- Type
 - Characteristics
 - Duration
 - Frequency
 - Timing
 - Traffic

Work Zone Duration

Includes:

- Hours per day
- Number of days

Work Zone Frequency

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

Work Zone Timing

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

Net Present Value (NPV)

NPV = Initial Cost +

$$\sum_{i=1}^N \text{Future Cost}_i \times \left[\frac{1}{(1 + I)^{n_i}} \right]$$

I = discount rate

n = year of expenditure

Work Zone Analysis

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

Work Zone Analysis Con't

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

McTrans Ph: 1-800-226-1013

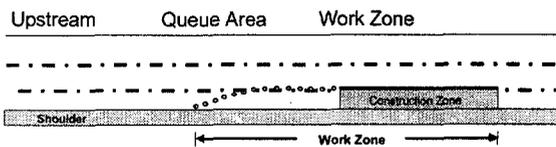
■ MicroBenCost: ~ \$110

■ QueWZ: ~ \$20

Includes: software, documentation,
and shipping

Work Zone Operations

Work Zone Operations



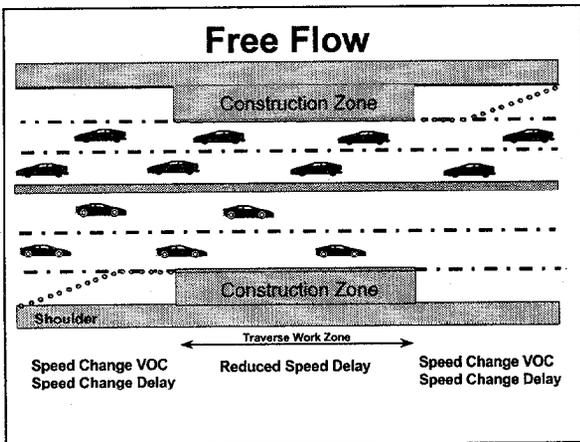
WZ Operations

- ① Free Flow (Base Case)
WZ Capacity Exceeds Demand
- ② Forced Flow (Congestion)
Demand Exceeds WZ Capacity

① Free Flow

Cost components ...

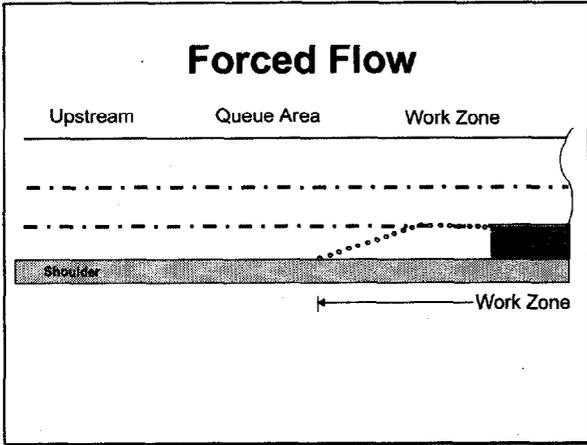
- Speed change costs
 - VOC
 - Delay
- Reduced speed costs
 - Delay

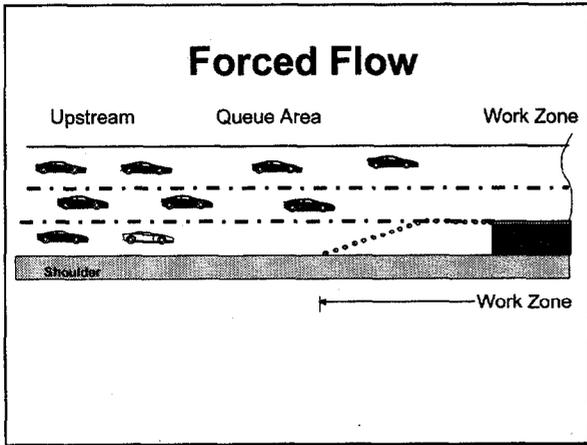


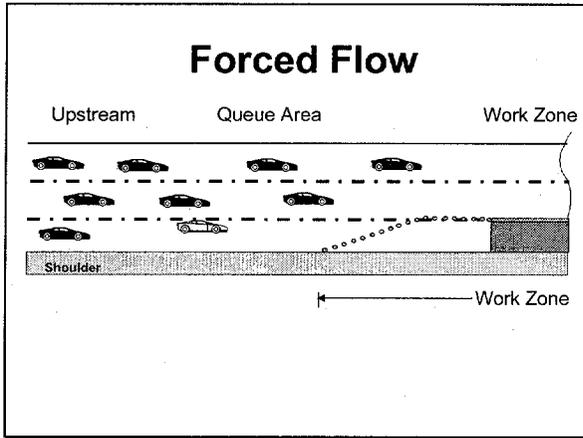
② Forced Flow

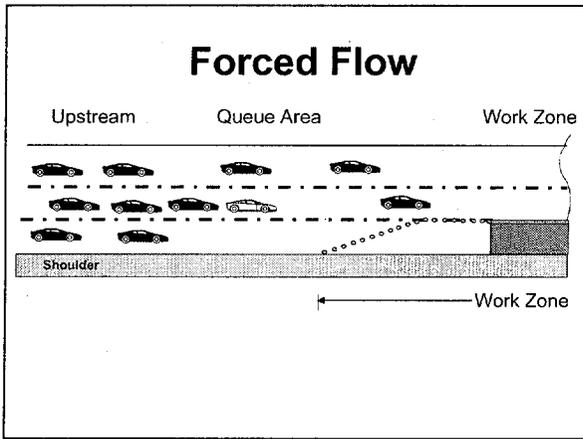
Cost components ...

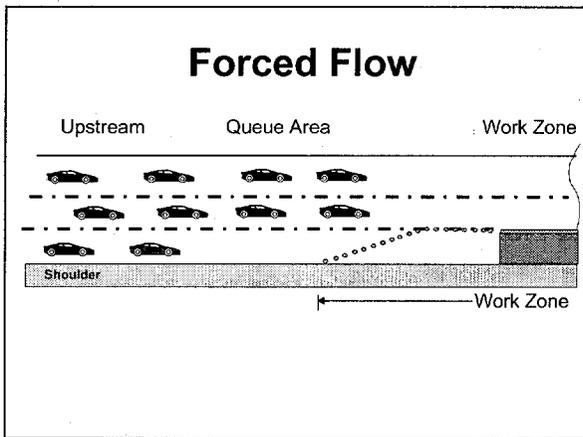
- Stopping cost
 - VOC
 - Delay
- Queuing costs
 - Idling
 - Delay

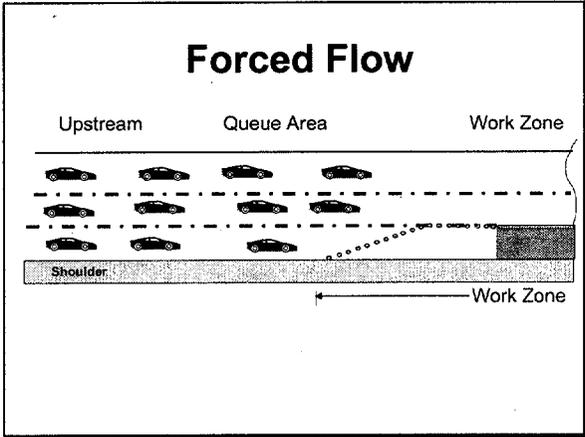


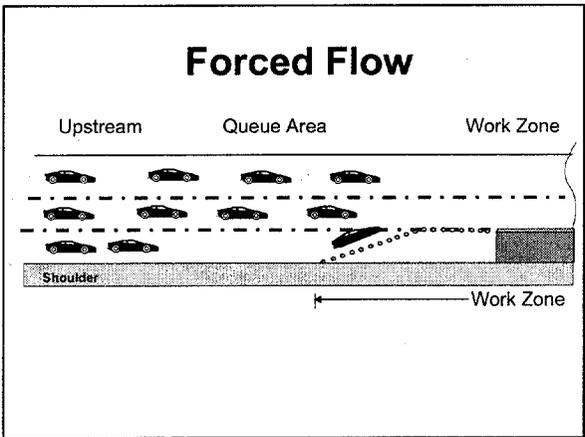


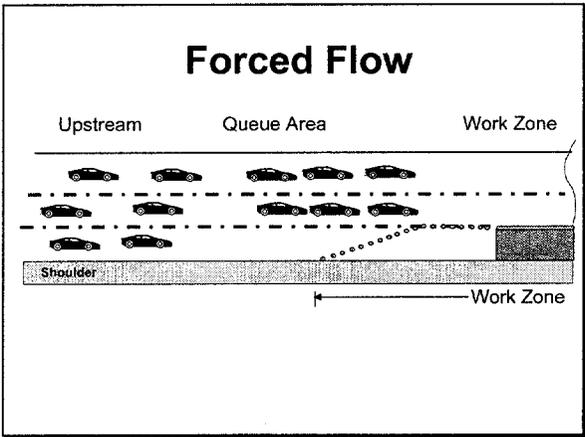


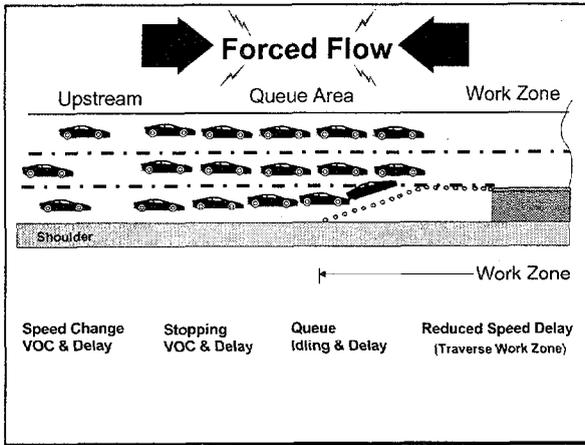






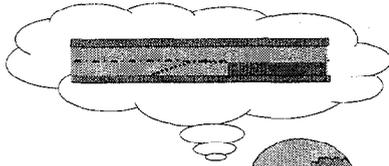






End Session

Work Zone User Costs



Calculation Steps



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)

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. Circuitry
11. Crash Costs
12. Sum Total User Costs

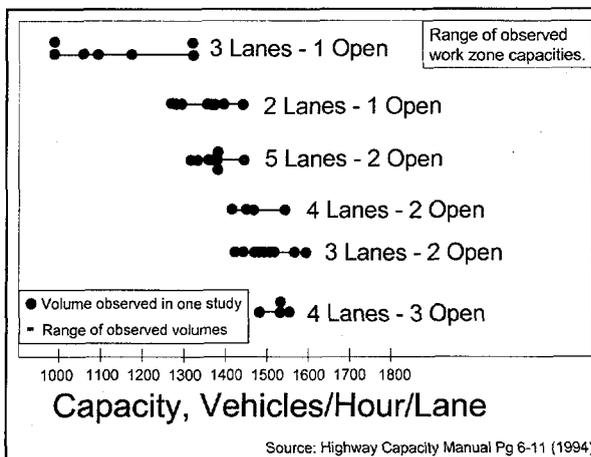
1. Determine Capacity

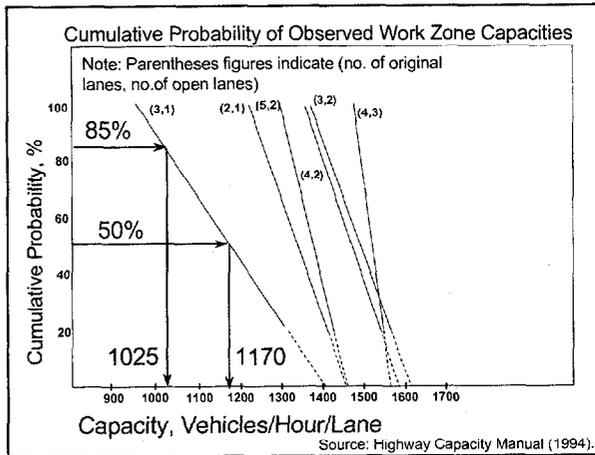
- With and without WZ
- Resources:
 - Research studies
 - Highway Capacity Manual

Work Zone Capacity

Directional Lanes		No Of Studies	Capacity	
Normal Operations	WorkZone Operations		(vph)	(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





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

- ### Queue Dissipation Cap.
- Ranges from 1500 to 2000 vphpl
 - See HCM Page 2-32.
 - Has significant impact on time to clear queue.

2. Calculate Directional Hrly Demand

Directional Hourly Demand =

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

Sources

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

Rural Default Hourly Distributions, MicroBenCost

Hour	Interstate		Principal Arterials			Minor Arterials			Major Collectors			
	ADT	% Direction	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									
⋮												

Rural Default Hourly Distributions Con't, MicroBenCost

Hour	Interstate		Principal Arterials			Minor Arterials			Major Collectors		
	ADT	Direction	ADT	Direction		ADT	Direction		ADT	Direction	
		In		Out	In		Out	In		Out	In
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								
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								

Same Same Same

Example

PennDOT AADT Distribution - Hourly Percentages

Hour	Traffic Pattern Group					
	Interstate		Prin. Arterial		Min. Arterial	
	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

Example

PennDOT AADT Distribution - Hourly Percentages

Hour	Traffic Pattern Group					
	Interstate		Prin. Arterial		Minor Arterial	
	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

3. Identify User Cost Components

➔ Free Flow

- Speed Change
- Reduced Speed



➔ Forced Flow

- Stopping
- Queuing



Free Flow Cost Components

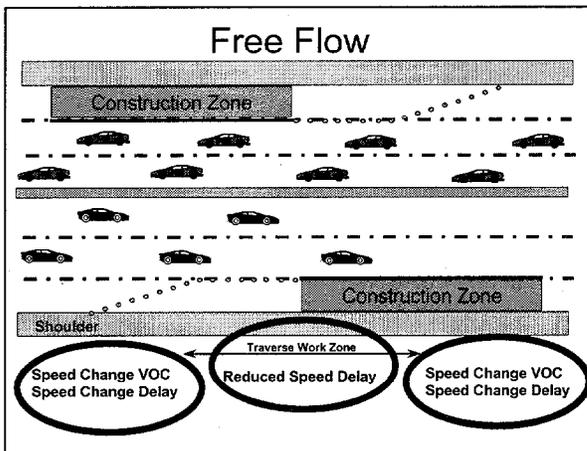
WZ capacity not exceeded ...

➔ Speed change costs

- VOC
- Delay

➔ Reduced speed costs

- Delay



Forced Flow Cost Components

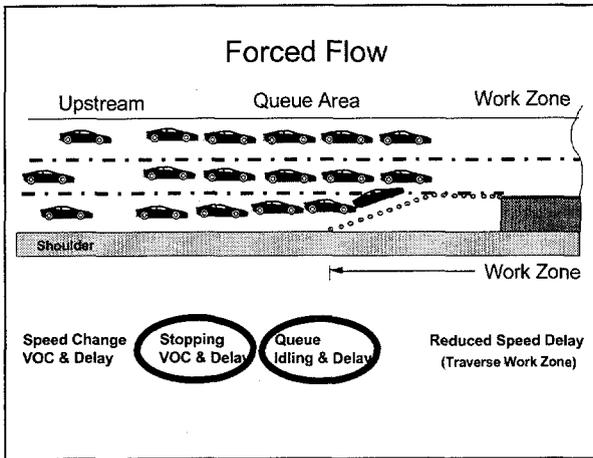
WZ capacity exceeded ...

➔ Stopping cost

- VOC
- Delay

➔ Queuing costs

- Idling
- Delay



4. Quantify Traffic Affected by Each Component

- Lane closure hours
- 24 Hours analysis period

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

Twenty Four Hour Analysis Period - SouthBound

Hour	Hourly Distr. (%)	Demand (vph)	Cap. (vph)	Queue Rate (vph)	Queued Veh.	Vehicles That Stop	WZ Vehicles
		(AADT)(b)		(c-d)	$(e_i + f_{i-1})$	If $f > 0, c, 0$	If $d = 3027, c, 0$
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
0 - 1	0.9	607	3,027	(2,420)	0	0	607
1 - 2	0.5	337	3,027	(2,690)	0	0	337
2 - 3	0.4	270			0	0	270
3 - 4	0.4	270			0	0	270
4 - 5	0.6	404	3,027	(2,622)	0	0	404
5 - 6	1.8	1,213	6,285	(5,072)	0	0	0
6 - 7	4.4	2,966	6,285	(3,319)	0	0	0
7 - 8	6.2	4,179	6,285	(2,106)	0	0	0
8 - 9	5.7	3,842	6,285	(2,443)	0	0	0
9 - 10	5.1	3,438	3,027	411	411	3,438	3,438
10 - 11	5.2	3,505	3,027	479	890	3,505	3,505
11 - 12	5.6	3,775	3,027	748	1,638	3,775	3,775
		0		0	0	0	0
		0		0	0	0	0
		0		0	0	0	0

All Lanes Open

Queue Developing

Free Flow

■ Speed Change

- Autos $32,625 (60)(.9) = 1,761,750$ veh.
- SU $32,625 (60)(.054) = 105,705$ veh.
- Combo $32,625 (60)(.046) = 90,045$ veh.

■ Reduced Speed

- Same as above

Forced Flow

■ Stopping

- Autos $42,644 (60) (.9) = 2,302,776$ veh.
- SU $42,644 (60) (.054) = 138,167$ veh.
- Combo $42,644 (60) (.046) = 117,697$ veh.

■ Queuing

- Same as above

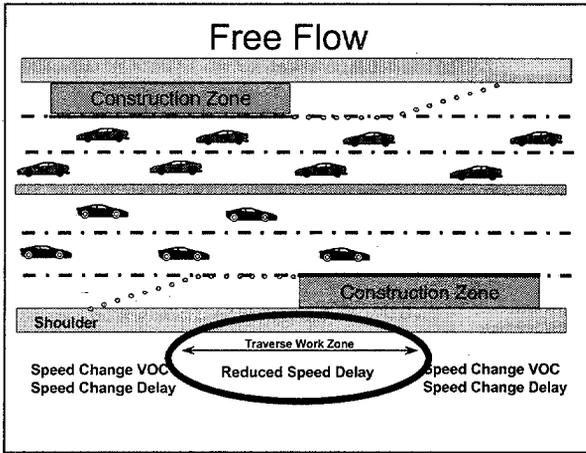
5. Compute Reduced Speed Delay

✓ Traverse Work Zone



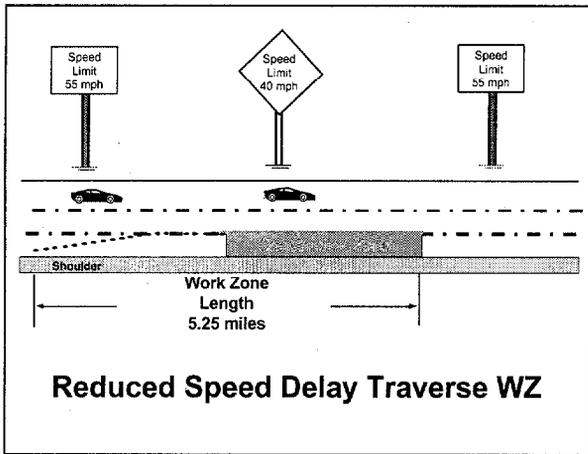
✓ Que





Reduced Speed Delay (Traverse WZ)

- Reduced speed delay is the increased travel time necessary to traverse the work zone at the posted speed compared to the up stream posted speed.



Reduced Speed Delay (WZ)

Reduced Speed Delay =

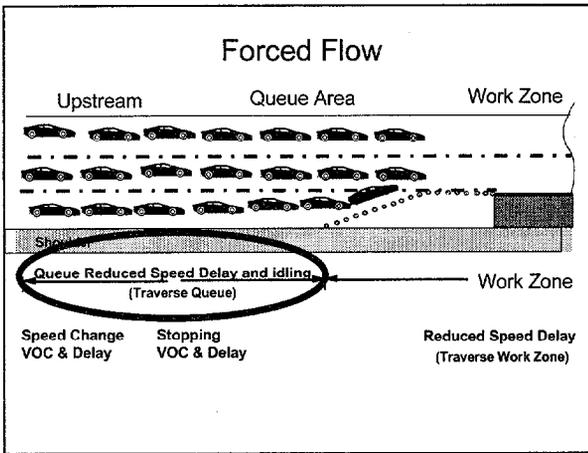
$$\frac{\text{WZ Length}}{\text{WZ Speed}} - \frac{\text{WZ Length}}{\text{Upstream Speed}}$$

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 = 0.3358 Hours



Reduced Speed Delay (Queue)

Reduced Speed Delay =

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

Reduced Speed Delay (Queue)

Reduced Speed Delay =

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

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

Reduced Speed Delay (Queue)

- Determine Queue Speed
- Determine average queue length

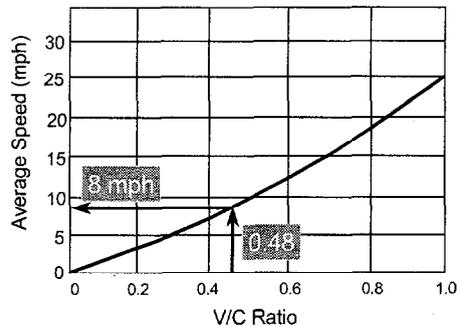
Reduced Speed Delay (Queue)

■ Determine Queue Speed

$$V/C = \text{Vol}_{\text{Que}} / \text{Capacity}_{\text{Free Flow}}$$

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

Average Speed vs. V/C Ratio for LOS - F



Source: NCHRP 133 (1972)

Reduced Speed Delay Queue

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

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

Reduced Speed Delay (Queue)

- ✓ Determine Queue Speed
- Determine average queue length

Reduced Speed Delay (Queue)

$$\text{Average Queue Length} = \frac{\text{Maximum Queue Length}}{2}$$

Reduced Speed Delay (Queue)

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

Traffic Density (veh./mi.)

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

Change in Traffic Density

=

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

Change in Traffic Density

=

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

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

Twenty Four Hour Analysis Period - SouthBound

Hour	Hourly Distr. (%)	Demand (vph)	Cap. (vph)	Queue Rate (vph)	Queued Veh.	Vehicles That Stop	WZ Vehicles
(a)	(b)	(AADT)(b)	(c)	(c-d)	(e+f ₁)	If f>0,c,0	If a=3027,c,0
(a)	(b)	(c)	(e)	(e)	(f)	(g)	(h)
0 - 1	0.9	607	3,027	(2,420)	0	0	607
1 - 2	0.5	337	3,027	(2,690)	0	0	337
2 - 3	0.4	270	3,027	(2,757)	0	0	270
3 - 4	0.4	270	3,027	(2,757)	0	0	270
4 - 5	0.6	404	3,027	(2,622)	0	0	404
5 - 6	1.8	1,213	6,285	(5,072)	0	0	0
6 - 7	4.4	2,966	6,285	(3,319)	0	0	0
7 - 8	6.2	4,179	6,285	(2,106)	0	0	0
8 - 9	5.7	3,842	6,285	(2,443)	0	0	0
9 - 10	5.1	3,438	3,027	411	411	3,438	3,438
10 - 11	5.2	3,505	3,027	479	890	3,505	3,505
11 - 12	5.6	3,775	3,027	748	1,638	3,775	3,775
.
.
.
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Table Continued

Hour	Hourly Distr. (%)	Demand (vph)	Cap. (vph)	Queue Rate (vph)	Queued Veh. (veh.)	Vehicles That Stop	WZ Vehicles
(a)	(b)	(AADT)(b)	(c)	(c-d)	(e+f ₁)	If f>0,c,0	If a=3027,c,0
(a)	(b)	(c)	(e)	(e)	(f)	(g)	(h)
12 - 13	6.0	4,044	3,027	1,018	2,656	4,044	4,044
13 - 14	5.9	3,977	3,027	950	3,606	3,977	3,977
14 - 15	6.4	4,314	3,027	1,287	4,893	4,314	4,314
15 - 16	7.4	4,988	5,454	(466)	4,427	4,988	0
16 - 17	7.8	5,258	5,454	(196)	4,231	5,258	0
17 - 18	7.5	5,055	5,454	(399)	3,832	5,055	0
18 - 19	5.9	3,977	5,454	(1,477)	2,355	3,977	0
19 - 20	4.9	3,303	5,454	(2,151)	204	313	0
20 - 21	4.0	2,696	3,027	(330)	0	0	2,696
21 - 22	3.3	2,224	3,027	(802)	0	0	2,224
22 - 23	2.4	1,618	3,027	(1,409)	0	0	1,618
23 - 24	1.7	1,146	3,027	(1,881)	0	0	1,146
Total						42,644	32,625

Change in Traffic Density

=

Queue Volume - Upstream Volume

Queue Speed Upstream Speed

(3027 vph)
(8 mph)

-

(4314 vph)
(55 mph)

Change in Traffic Density

=

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

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

$$= 300 \text{ veh./mi.}$$

Reduced Speed Delay (Queue)

Maximum Queue Length =

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

$$\frac{4,893 \text{ vehicles}}{300 \text{ vehicles/mile}} = 16.3 \text{ Miles}$$

Reduced Speed Delay (Queue)

Average Queue Length =

$$\text{Maximum Queue Length} / 2$$

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

Reduced Speed Delay (Queue)

Caution:

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

Reduced Speed Delay Queue

<u>Queue Length</u>	-	<u>Queue Length</u>
Queue Speed		Upstream Speed
<u>8.15 Miles</u>	-	<u>8.15 Miles</u>
8 Mph		55 mph

Reduced Speed Delay Queue

<u>Queue Length</u>	-	<u>Queue Length</u>
Queue Speed		Upstream Speed
<u>8.15 Miles</u>	-	<u>8.15 Miles</u>
8 Mph		55 mph
1.02 Hours	-	0.15 Hours
➔ Delay / Vehicle =		<u>0.87 Hours</u>

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

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

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)			Added Cost (\$/1000 Stops) (Excludes Idling Cost)		
	Pass Cars	Single Unit Trk	Comb. Truck	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

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

7. Assign Delay Cost Rates

Value of Time

Vehicle Class	\$ / Vehicle Hour	
	Value	Range
Passenger Vehicles	11.58	10.00 - 13.00
Single Unit Trucks	18.54	17.00 - 19.00
Combination Trucks	22.31	21.00 - 24.00

Aug. 1996 Dollars

8. Assign Traffic to Vehicle Classes

Vehicle classification:

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

	Cost Component	Vehicle Class	No. Vehicles
Free Flow	WZ Speed Change Delay	Pass	1,761,75
		SU	105,705
		Combo	90,045
	WZ Speed Change VOC	Pass	1,761,750
		SU	105,705
		Combo	90,045
	WZ Added Travel Time Delay	Pass	1,761,750
		SU	105,705
		Combo	90,045
Forced Flow	Queue Stopping Delay	Pass	2,302,776
		SU	138,167
		Combo	117,697
	Queue Stopping VOC	Pass	2,302,776
		SU	138,167
		Combo	117,697
	Queue Travel Delay	Pass	2,302,776
		SU	138,167
		Combo	117,697
Queue Idle VOC	Pass	2,302,776	
	SU	138,167	
	Combo	117,697	

9. Compute User Costs by Vehicle Class



Cost Component	Vehicle Class	No. Vehicles	Added Time (h/v)	Cost (\$/Hr.)	Cost (\$)	% of Total
WZ Speed Change Delay	Pass	1,761,750	0.00142	11.58	28,970	0.09
	SU	105,705	0.00220	18.54	4,311	0.01
	Combo	90,045	0.00963	22.31	19,346	0.06
WZ Speed Change VOC	Pass	1,761,750		0.03077	54,209	0.18
	SU	105,705		0.04692	4,960	0.02
	Combo	90,045		0.23956	21,571	0.07
WZ Added Travel Time Delay	Pass	1,761,750	0.0358	11.58	730,358	2.38
	SU	105,705	0.0358	18.54	70,160	0.23
	Combo	90,045	0.0358	22.31	71,919	0.23
Queue Stopping Delay	Pass	2,302,776	0.00442	11.58	117,864	0.38
	SU	138,167	0.00587	18.54	15,037	0.05
	Combo	117,697	0.01109	22.31	29,120	0.09
Queue Stopping VOC	Pass	2,302,776		0.05270	121,356	0.40
	SU	138,167		0.11397	15,747	0.05
	Combo	117,697		0.48221	56,755	0.19
Queue Added Travel Time Delay	Pass	2,302,776	0.87	11.58	23,199,546	75.64
	SU	138,167	0.87	18.54	2,228,606	7.27
	Combo	117,697	0.87	22.31	2,284,463	7.45
Queue Idle VOC	Pass	2,302,776	0.87	0.6927	1,387,766	4.52
	SU	138,167	0.87	0.7681	92,330	0.30
	Combo	117,697	0.87	0.8248	84,457	0.27
Total WZ User Cost = \$30,668,852						

Queue Added Travel Time Delay

Vehicle Class	No. Vehicles	Added Time (h/v)	Cost (\$/Hr.)	Cost	% of Total
Pass	2,302,776	0.87	11.58	23,199,546	75.64
SU	138,167	0.87	18.54	2,228,606	7.27
Combo	117,697	0.87	22.31	2,284,463	7.45

10. Circuitry

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

Driver Types

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

11. Crash Cost

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

Construction Costs and Safety Impacts of Work Zone Traffic Control Strategies
Volume II Informational Guide

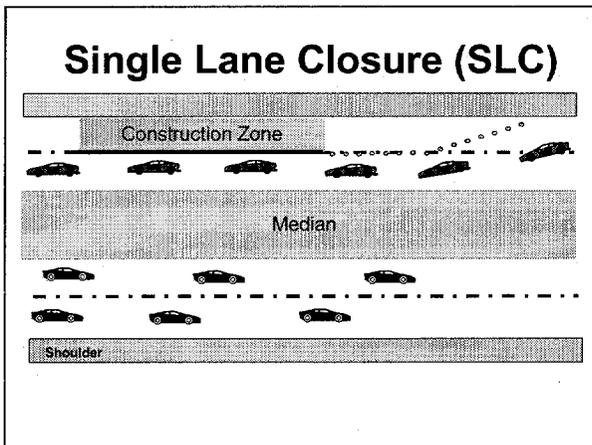
Publication No. FHWA-RD-89-210 (Dec. 1989) December 1989

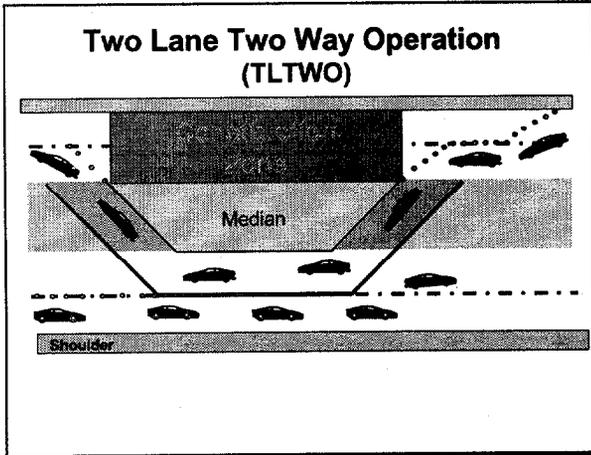
Publication No. FHWA-RD-89-210 (Dec. 1989)

“Construction Cost and Safety Impacts of Work Zone Traffic Control Strategies”

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Transportation Research Center
6300 Camp Road
McLean, Virginia 22102-2296



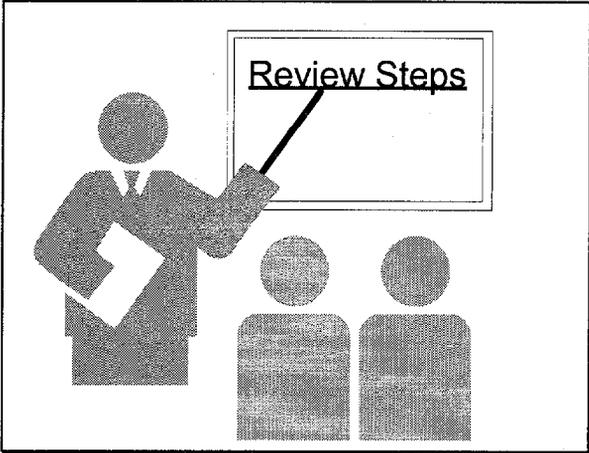


- Constraints of Study**
- Single lane closure (SLC) versus two-lane two-way operation (TLTWO) Rural, 4-lane divided highways
 - ADT: 10,000 to 30,000
 - 51 projects in 11 states
 - 3 had traffic delays

- 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

12. Sum Total User Costs

Delay & VOC
+ Circuity
+ Crash
Total User Costs



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

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. Circuitry
- 11. Crash Costs
- 12. Sum Total User Costs

End Session

Basic Statistics

Session Overview

- Probability Concepts
- Probability Distributions
- Measures of Central Tendency
- Measures of Variability
- Difference Between Means
- Interpreting Results

Probability Concepts

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

Two Same Birthdays

- Probability= $\frac{n!}{2!(n-2)!}$
- 20 people
 - $190/365=52\%$

Probability Development

- Theoretical
 - Math
- Empirical
 - Experience

Variables

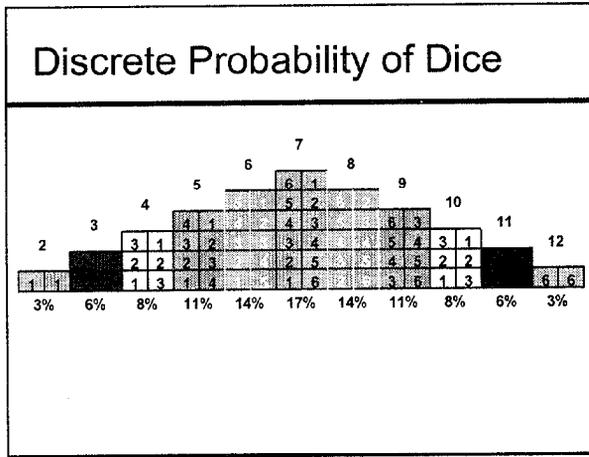
- Discrete
- Continuous

Discrete

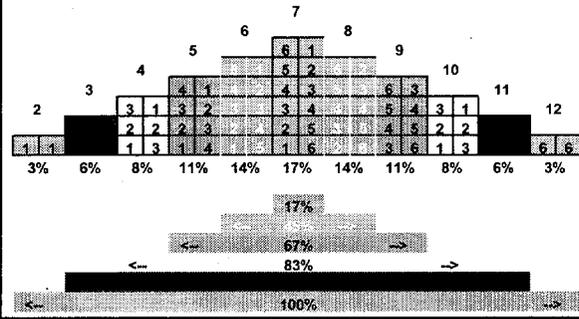
- Countable
- Examples - rolling dice
 - birthday
 - # of accidents

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

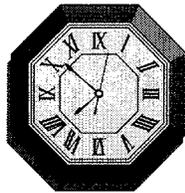


Discrete Probability of Dice



Continuous

■ Uncountable



Probability Distributions

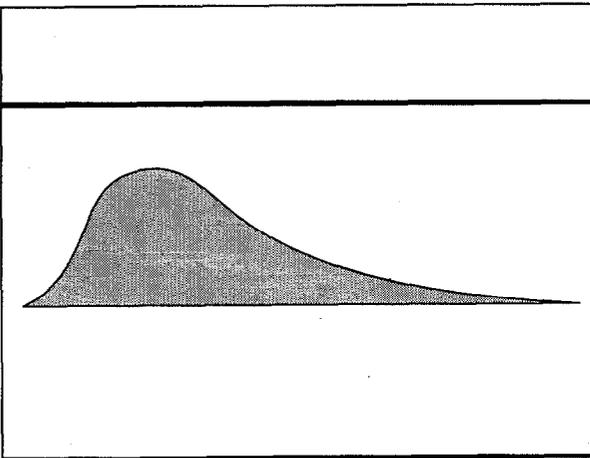
■ Common Varieties

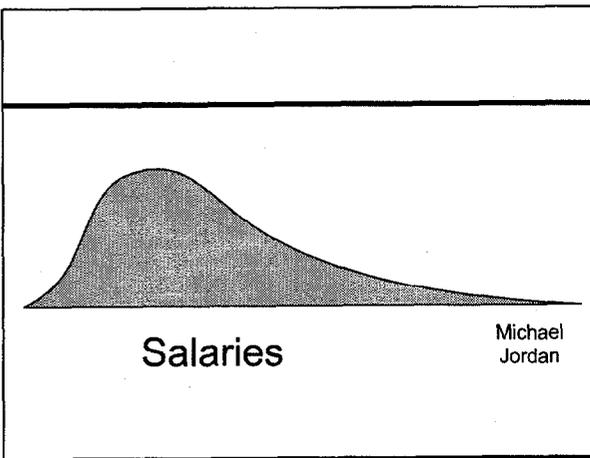
- Normal
- Uniform
- Triangular

Normal Distribution

- Bell shaped (mound) curve
 - Intelligence Tests
 - Defined by mean and std. dev.

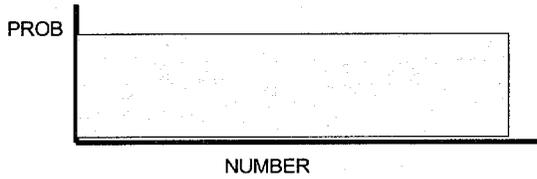






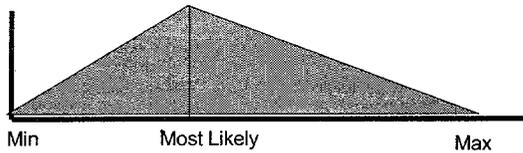
Uniform Distribution

- Equal Chance
- Lottery Numbers

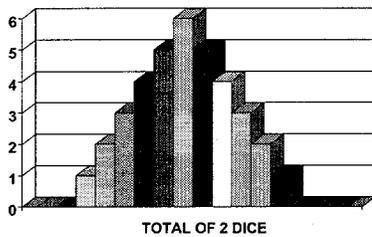


Triangular Distribution

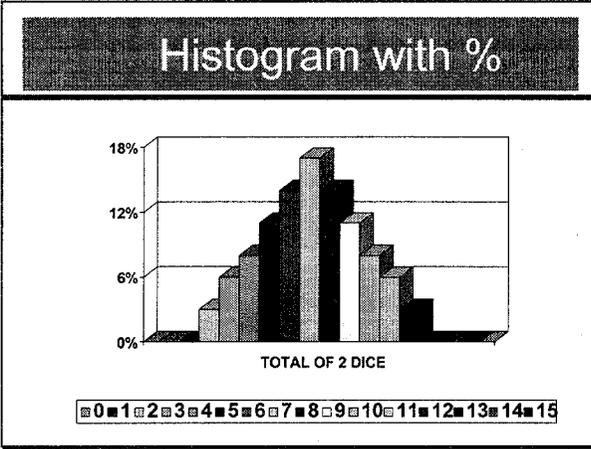
- Defined by:
 - Min - Most Likely - Max
- Handy for estimating

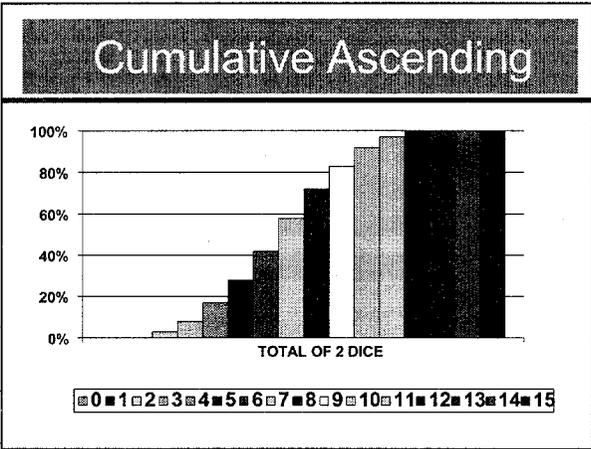


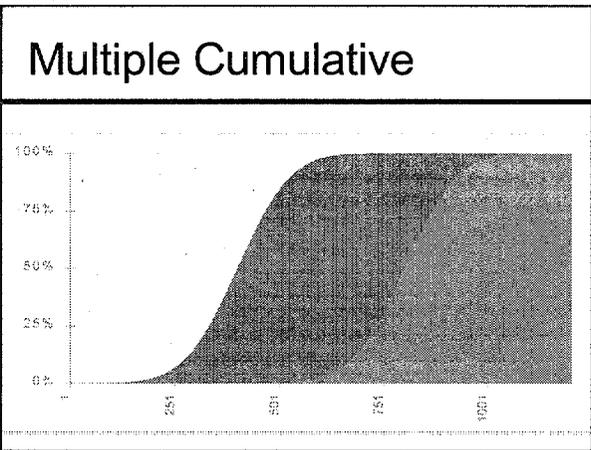
Histogram



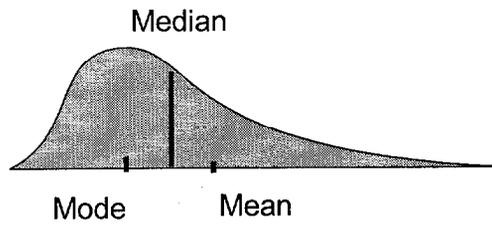
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15







Measures of Central Tendency



Mode

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

Median

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

Mean

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

Dice Example

- Mode
- Median
- Mean

Measures of Variability

- Range
- Standard Deviation
- Coefficient of Variation

Range

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

Standard Deviation

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

Formula

- Population

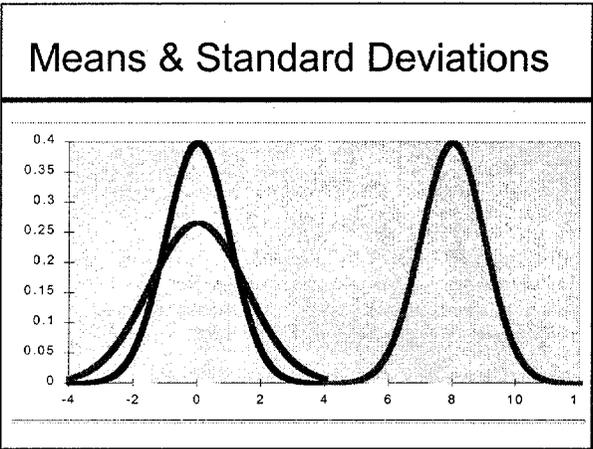
$$\sigma = \sqrt{\sum (x_i - \bar{x})^2 / n}$$

- Sample

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

Rule of Thumb

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



Applications

- 68% of data within 1σ
- 95% within 2σ
- 99.7% within 3σ

The diagram shows a normal distribution curve with shaded areas under the curve. The shaded areas represent the empirical rule: 68% of data within 1σ , 95% within 2σ , and 99.7% within 3σ .

Coefficient of Variation

■ COV = Std. Dev./ Mean

- Mean = 120
- Std. Dev. = 30
- COV = 25%

■ Use To Normalize Variation

Population - Set of all measurements of interest

Sample - Subset of measurements selected from the population

Random Sample

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

Statistical Inference

- Estimating population parameters from sample results
 - Average height of public employees based on attendees of this course

Precision of Inference Common Uses

- Standard Errors
- Confidence Intervals
- Are two samples from the same population?

Standard Error

- Effect of n on Standard Error
- Larger samples - Greater confidence

Confidence Intervals

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

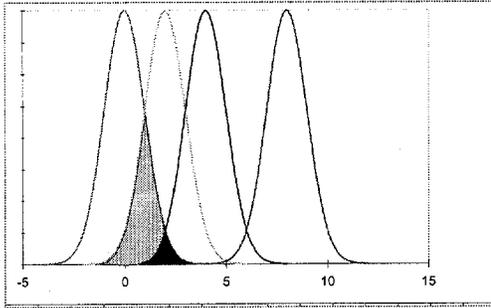
Difference Between Means

- Tests (Student - t)
- Significance levels
- Statistical versus practical significance

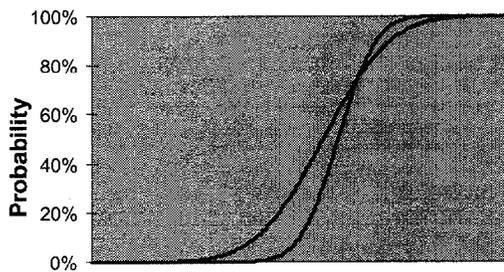
Interpreting Results

- Percentiles
- Distributions
 - Overlapping
 - Cumulative
 - Means (is this difference really significant?)

Overlapping Normals



Overlapping Cumulative



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

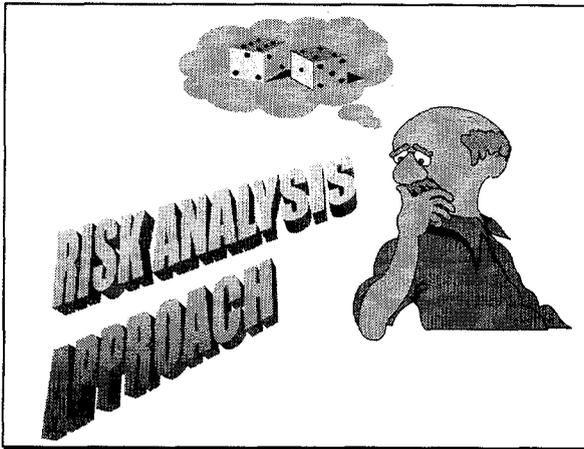
Interpreting R

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

Most Important Rule of Data

- 1 Point = Data
- 2 Points = Straight Line
- 3 Points = Scatter

End Session



Session Overview

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

Deterministic Approach

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

Deterministic Approach

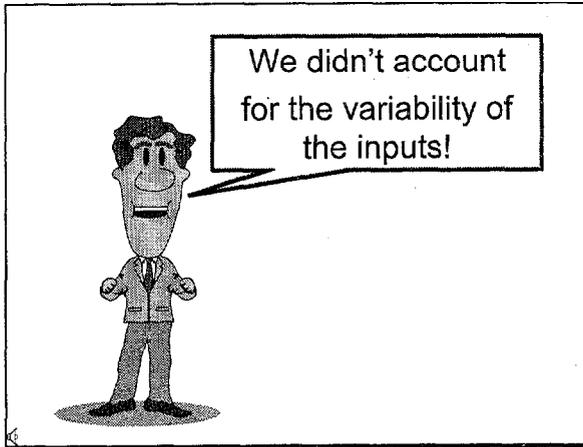
\$ 29.4 M \$ 26 M

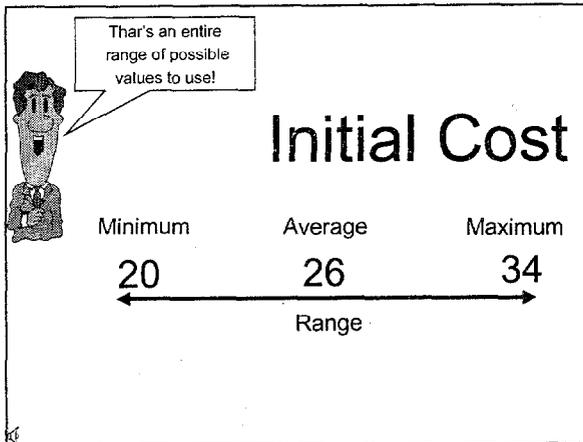
NPV = Initial Cost +

Future Cost x
\$ 9 M

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

5% 20 yrs





Variables to Include ...

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

Agency Costs

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

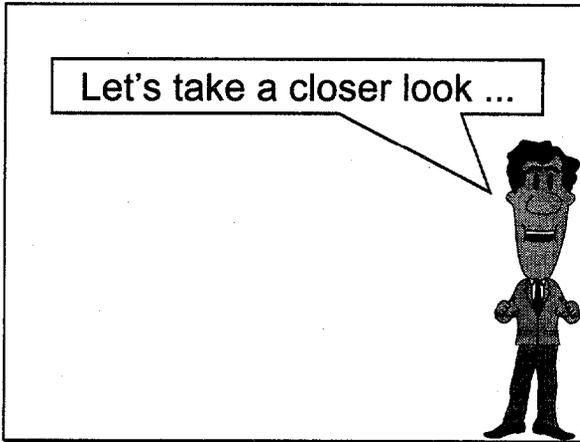
User Costs

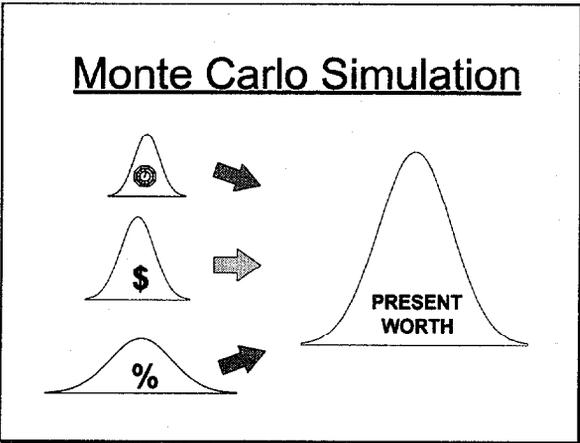
- Current traffic
- Future traffic
- Hourly demand
- Vehicle distributions
- Dollar value of delay time
- Work zone configuration
- Work zone hours of operation
- Work zone duration
- Work zone activity years
- Accident rates

Timing of Costs
<ul style="list-style-type: none">■ Pavement performance<ul style="list-style-type: none">● Pavement management systems● Research studies● Engineering judgement

Discount Rate
<ul style="list-style-type: none">■ Is your discount rate reasonable?<ul style="list-style-type: none">● Office of Management & Budget's Circular A-94● AASHTO survey● FHWA National Pavement Design Review

Describe Uncertainty
<ul style="list-style-type: none">■ Objective Method■ Subjective Method

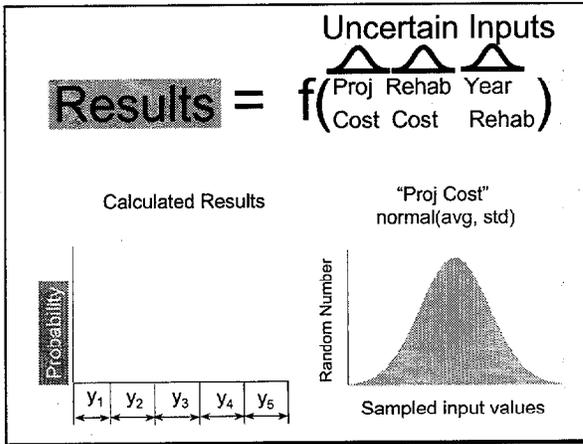


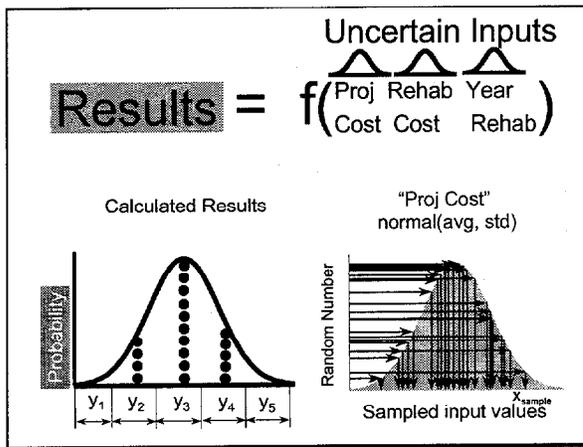


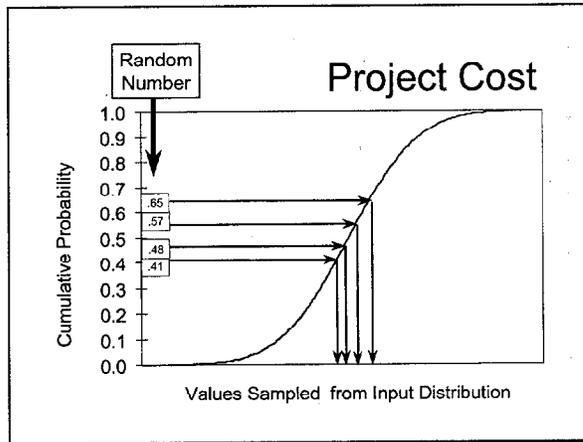
$$NPV = \text{Initial Cost} + \sum \text{Future Cost} \times \left[\frac{1}{(1+i)^n} \right]$$

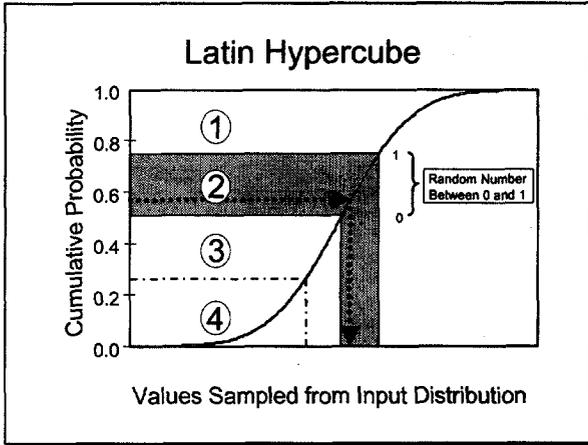
Uncertain Inputs
 (Proj Rehab Year)
 (Cost Cost Rehab)

Results = f





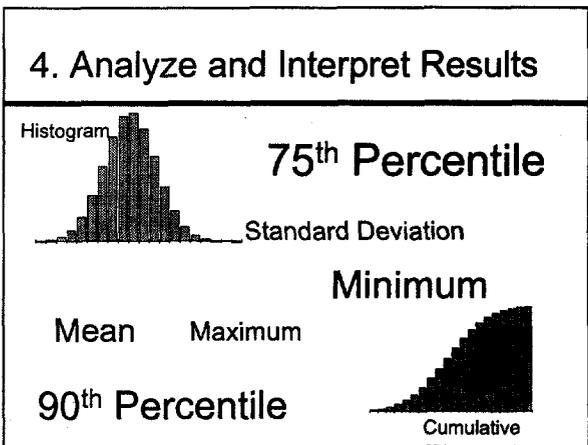




Combine Variability of Inputs to Generate Probability Distribution of Results

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

The equation is annotated with probability distribution curves. A bell curve is shown above 'Initial Cost'. A series of bell curves are shown above the summation term, with arrows indicating that the variability of each 'Future Cost' input contributes to the overall distribution of the NPV result.



How do I interpret these results?

Risk Analysis Results

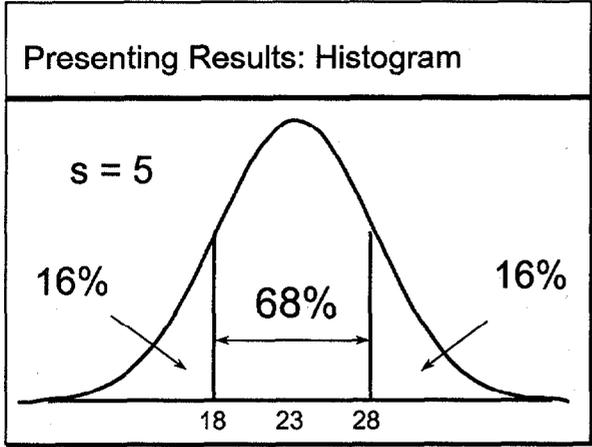
The image shows a man with a thoughtful expression, his hand on his chin, looking at a bar chart. The chart is labeled 'NPV' and consists of several vertical bars of varying heights, representing different risk scenarios. A speech bubble above the man contains the text 'How do I interpret these results?'.

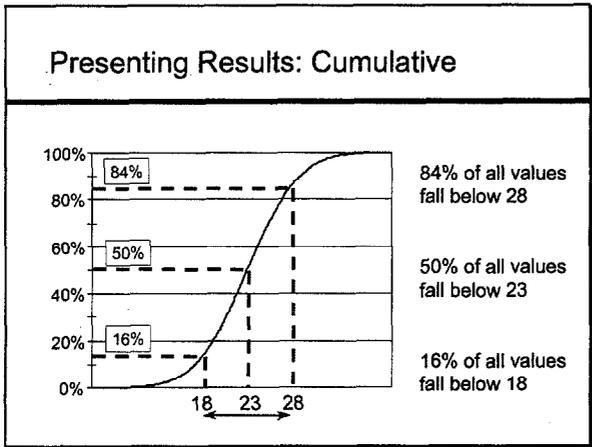
Probabilistic results provide ...

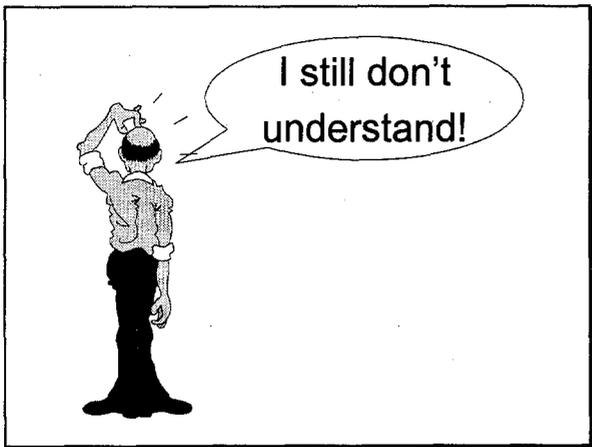
- ❶ Distribution of "complete" range of outcomes
- ❷ Probability of occurrence

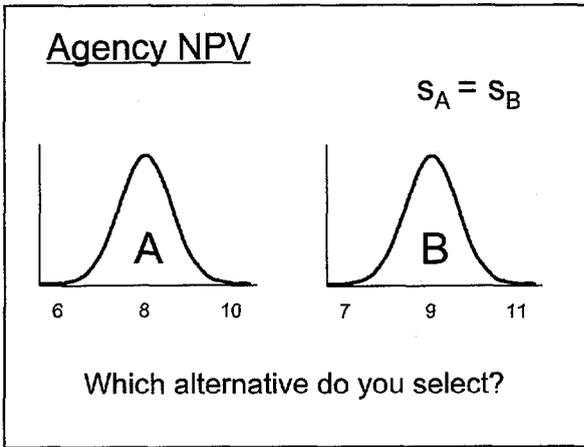
The diagram shows a bell-shaped normal distribution curve. The vertical axis is labeled 'Frequency' and the horizontal axis is labeled 'Range'. The peak of the curve is labeled 'Most Likely'. A box labeled 'Project Cost' is positioned at the center of the curve. The left tail of the curve is labeled 'Best Case' and the right tail is labeled 'Worst Case'. A double-headed arrow below the horizontal axis indicates the 'Range' of the distribution.

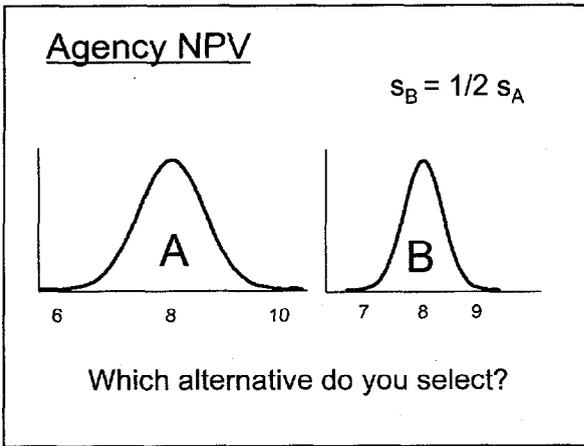
- ➔ Complete Range of Outcomes
- ➔ Likelihood of Occurrence

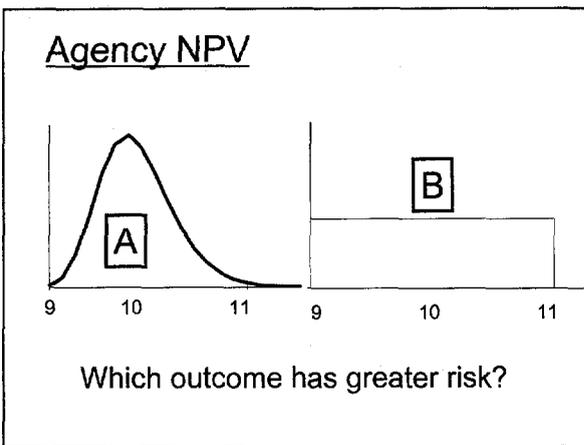


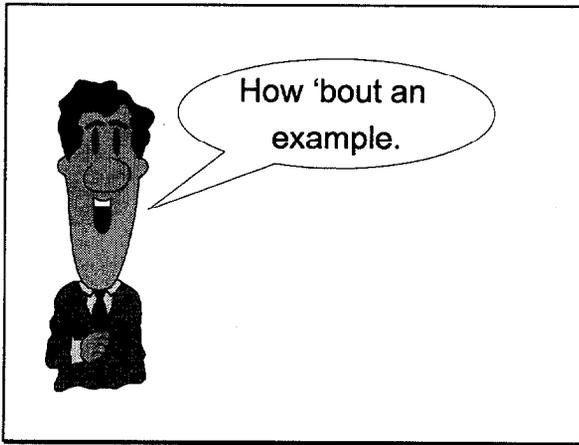


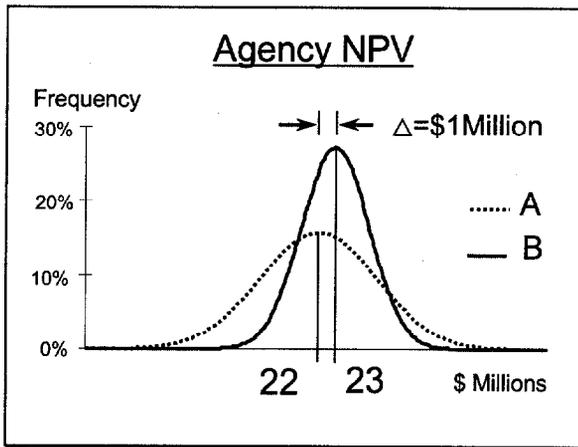


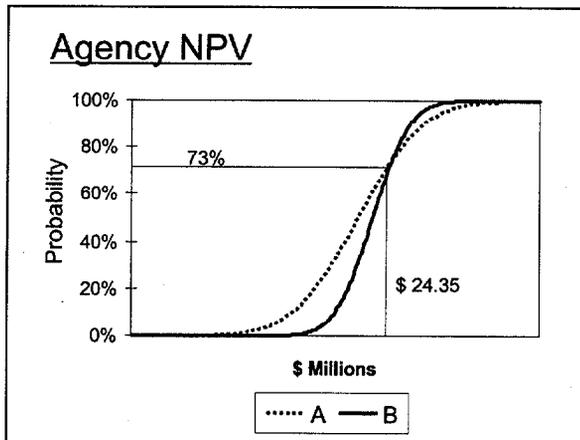


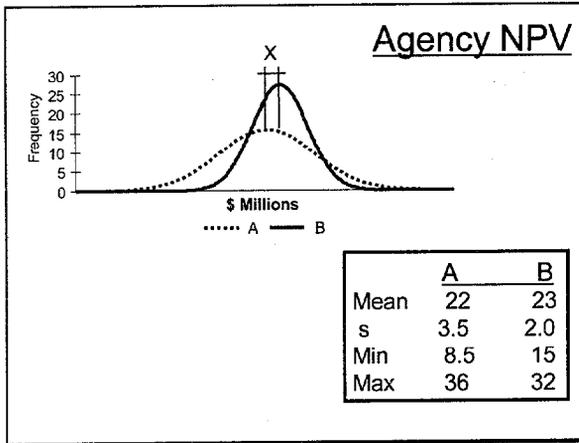












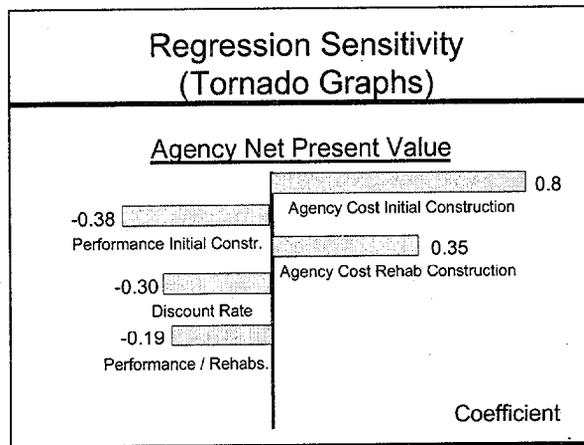
PERCENTILE	A	B	Δ
0	8.5	15	6.5
5	10.3	15.7	5.4
10	12.2	16.4	4.2
15	14.1	17.1	3.0
20	16.0	17.8	1.8
25	17.9	18.5	0.6
30	19.8	19.2	-0.4
35	20.7	19.9	-0.8
40	21.6	20.6	-1.0
45	22.5	21.3	-1.2
50	22.5	22.5	0.0
55	22.4	23.6	1.2
60	22.3	24.7	2.4
65	22.2	25.8	3.6
70	22.1	26.9	4.8
75	22.0	28.0	6.0
80	21.9	29.1	7.2
85	21.8	30.2	8.4
90	21.7	31.3	9.6
95	21.6	32.4	10.8
100	21.5	33.5	12.0

0 to 5 Δ \$ 3.2 million

→ Mean

→ Intersection

95 to 100 Δ \$ 2.8 million



Scenario Analysis

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

5. Make Consensus Decision

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



Risk Analysis Approach (Review)

- Identify structure and logic of problem
- Quantify assumptions w/ probabilistic descriptions of uncertain variables
- Simulate problem to obtain results
- Analyze and interpret results
- Make consensus decision

Applications



- Investment & new product analysis

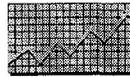


New Drug Research

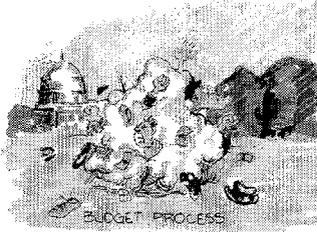


American Stock Exchange

Applications



- Investment & new product analysis
- Capital budgeting



Applications



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



WesTrack

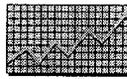
Applications



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



Applications



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



Applications



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

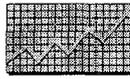


Example: Flexible Pavement Design

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

$$+ \frac{\log_{10} \frac{\Delta PSI}{4.2 - 1.5}}{1094}$$
$$+ 0.40 + \frac{1094}{(SN + 1)^{5.19}}$$
$$+ 2.32 \times \log_{10}(M_R) - 8.07$$

Disadvantages



Just Kidding

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



Advantages

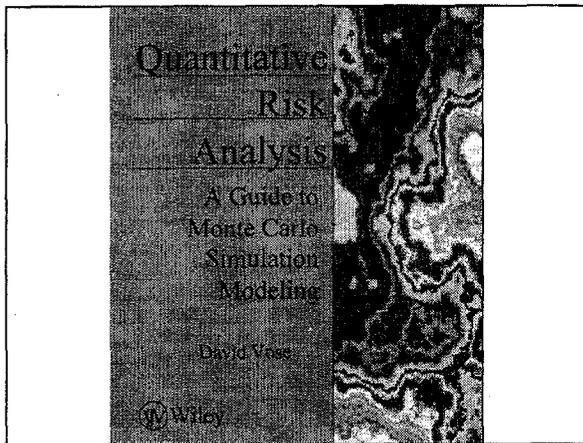


- Quantify risk
- Provide decisionmaker the opportunity to take mitigating action
- Justify budget requests, pavement structural designs, ...
- Scenario analysis to create better alternatives

Advantages Con't

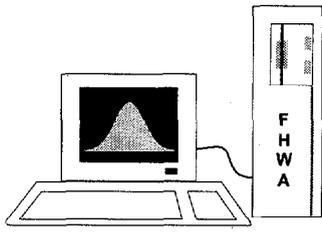


- Scenario analysis to create better alternatives
- Elevates the LCCA debate ...
 - From validity of results
 - To what is "our" best policy



End Session

@Risk Demonstration



Session Overview

Part 1

- Risk Refresher
- Adding Uncertainty to Models
- Running a Risk Analysis

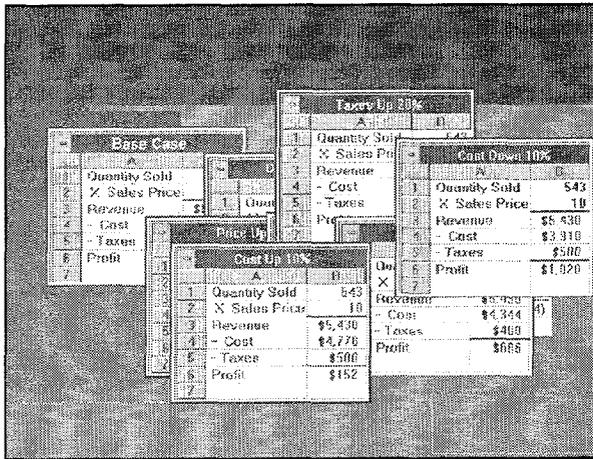
Part 2

- @Risk Results

What is Risk?

- Possibility of loss or gain
- Deviation from the expected
- Degree of probability of loss or gain
- Uncertainty
- Chance

	A	B	C	D
1	Quantity Sold	543		
2	X Sales Price	\$ 10		
3	Revenue	\$ 5,430		
4	- Cost	\$ 4,344		
5	- Taxes	\$ 500		
6	Profit	\$ 586		
7				
8				
9				
10				



Profit = \$152 Profit = \$895 Profit = \$453 Profit =
 = (\$123) Profit = \$324 Profit = \$1242 Profit =
 \$756 Profit = \$789 Profit = (\$123) Profit = \$987
 Profit = (\$456) Profit = \$786 Profit = \$698 Profit
 = \$834 Profit = \$932 Profit = \$734
 Profit = \$ Profit = \$145
 (\$345) Profit = \$14) Profit
 Profit = \$ Profit = \$648 Profit = (\$954) Profit =
 \$890 Profit = \$467 Profit = \$1000 Profit = \$432
 Profit = \$888 Profit = \$598 Profit = \$344 Profit
 = \$222 Profit = \$750 Profit = \$367 Profit = \$900

Help!

Modeling with @Risk

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

Microsoft Excel - Finance.xls

File Edit View Insert Format Tools Data Window Help

A1

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
FINANCE: The @RISK Demonstration Model - Product Launch Risk Analysis 1991-2000										
Price No Entry			\$69.25	\$87.25	\$117.72	\$111.48	\$98.33	\$93.48	\$90.71	\$89.33
Price With Entry			\$53.33	\$67.73	\$80.00	\$64.00	\$61.33	\$56.00	\$54.93	\$52.27
Volume No Entry			3500	4340	6580	5565	5180	5180	4970	4935
Volume With Entry			3300	4158	3564	3399	3300	3300	3432	3696
Competitor Entry:	0									
Design Costs	\$50,000.00									
Capital Investment		\$200,000.00								
Operating Expense Factor			0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Sales Price			\$69.25	\$87.25	\$117.72	\$111.48	\$98.33	\$93.48	\$90.71	\$89.33
Sales Volume			3500	4340	6580	5565	5180	5180	4970	4935
Sales Revenue			\$242,358	\$378,659	\$774,575	\$620,411	\$509,339	\$484,230	\$450,833	\$440,824
Unit Production Cost			\$23.33	\$24.27	\$25.24	\$26.25	\$27.30	\$28.39	\$29.52	\$30.71
Overhead			\$5,600	\$6,944	\$10,528	\$8,904	\$8,288	\$8,288	\$7,952	\$7,896
Cost of Goods Sold			\$87,267	\$112,261	\$176,590	\$154,968	\$149,685	\$155,341	\$154,687	\$159,426
Gross Margin			\$155,091	\$266,398	\$597,985	\$465,443	\$359,654	\$328,890	\$296,147	\$281,399
Operating Expense			\$12,799	\$16,465	\$25,900	\$22,729	\$21,954	\$22,784	\$22,688	\$23,383
Net Before Tax	(\$50,000)	\$0	\$142,292	\$249,933	\$572,085	\$442,715	\$337,700	\$306,106	\$273,459	\$258,016
Depreciation		\$40,000	\$40,000	\$40,000	\$40,000	\$40,000				
Tax	(\$23,000)	(\$18,400)	\$47,054	\$96,569	\$244,759	\$185,249	\$155,342	\$140,809	\$125,791	\$118,687
Taxes Owed	\$0	\$0	\$5,654	\$96,569	\$244,759	\$185,249	\$155,342	\$140,809	\$125,791	\$118,687
Net After Tax	(\$50,000)	\$0	\$136,637	\$153,364	\$327,326	\$257,466	\$182,358	\$165,297	\$147,668	\$139,329
Net Cash Flow	(\$50,000)	(\$200,000)	\$136,637	\$153,364	\$327,326	\$257,466	\$182,358	\$165,297	\$147,668	\$139,329
NPV 10%	\$632,273									

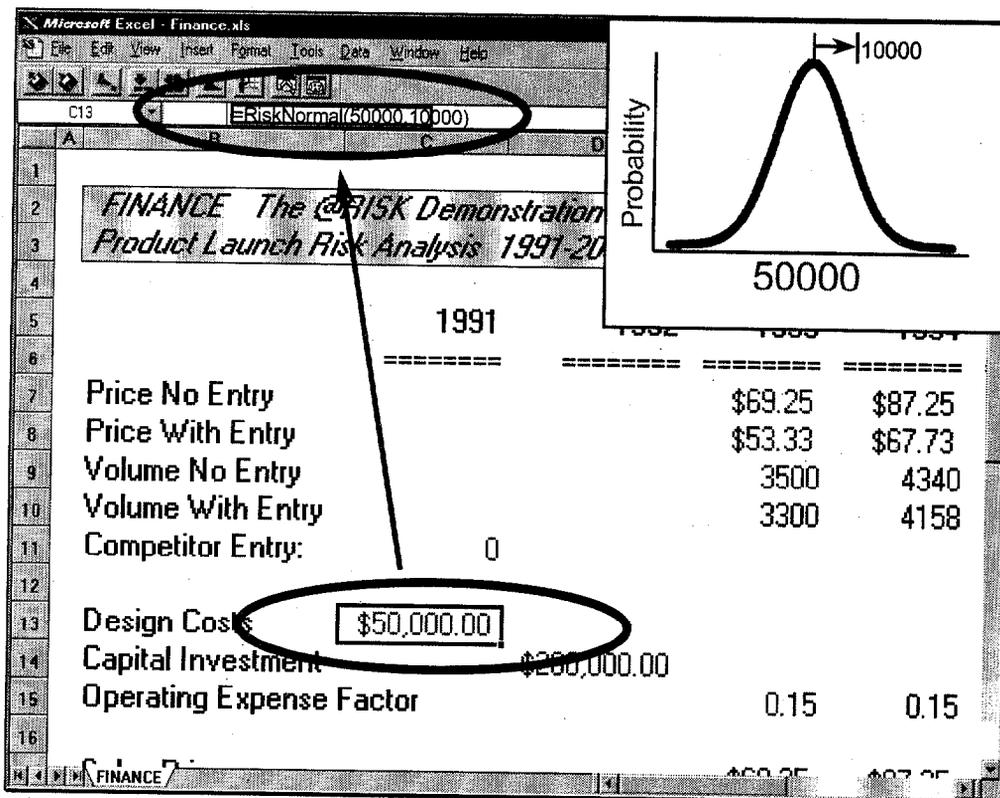
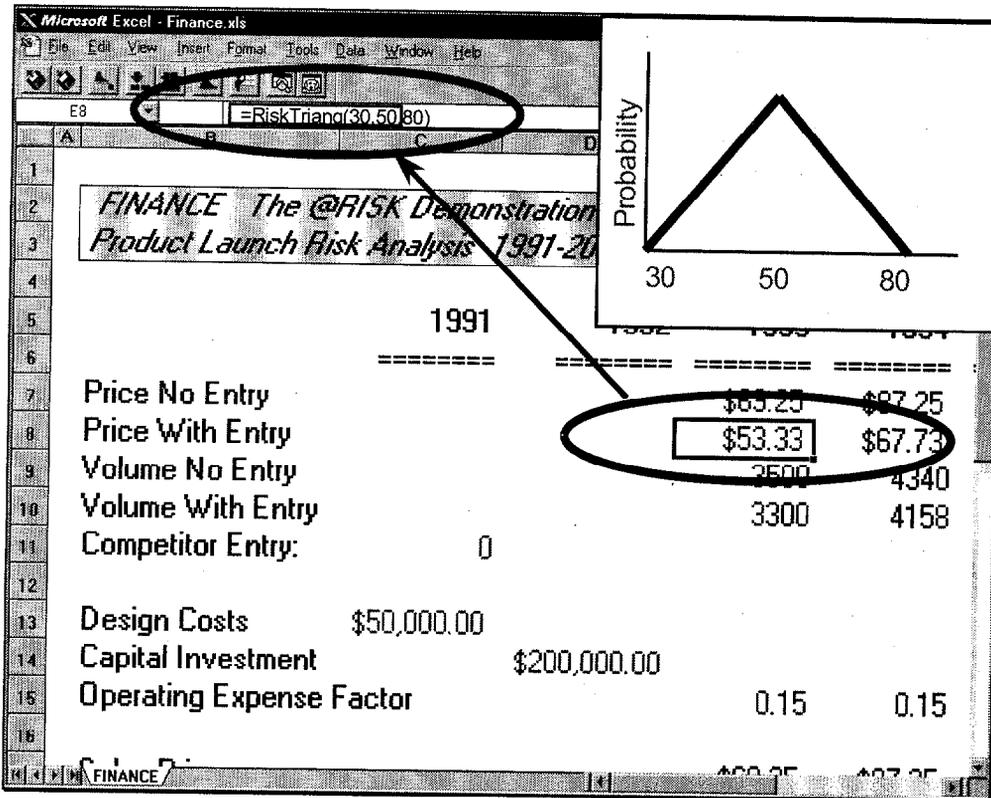
FINANCE

Adding Variability to Spreadsheet Models

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

@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



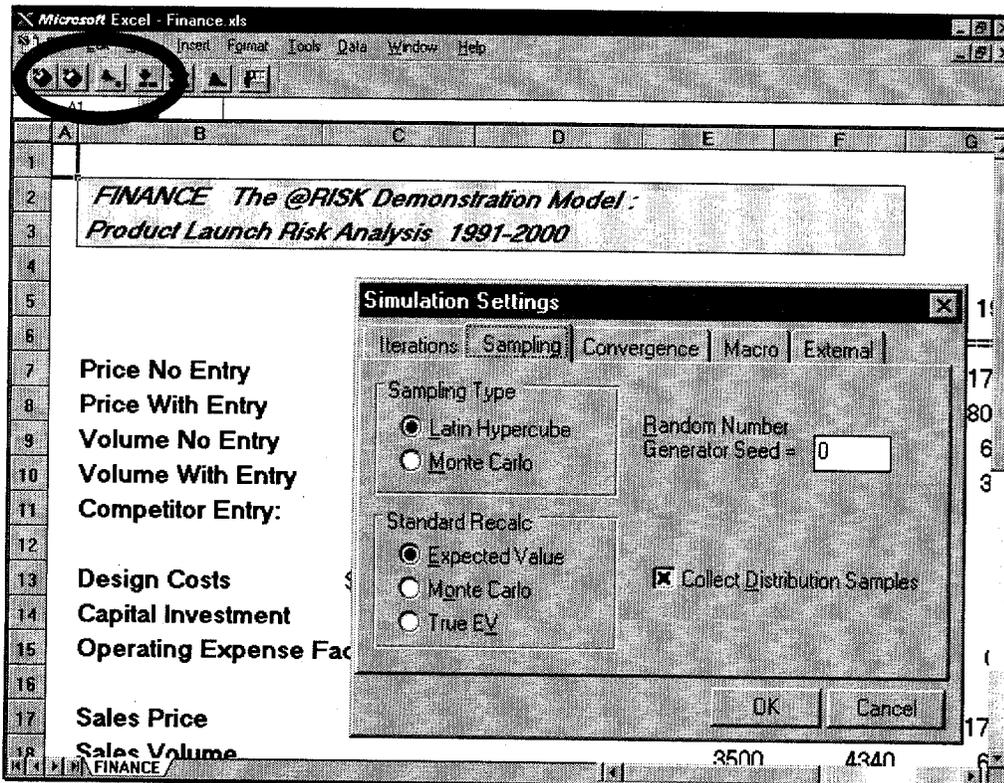
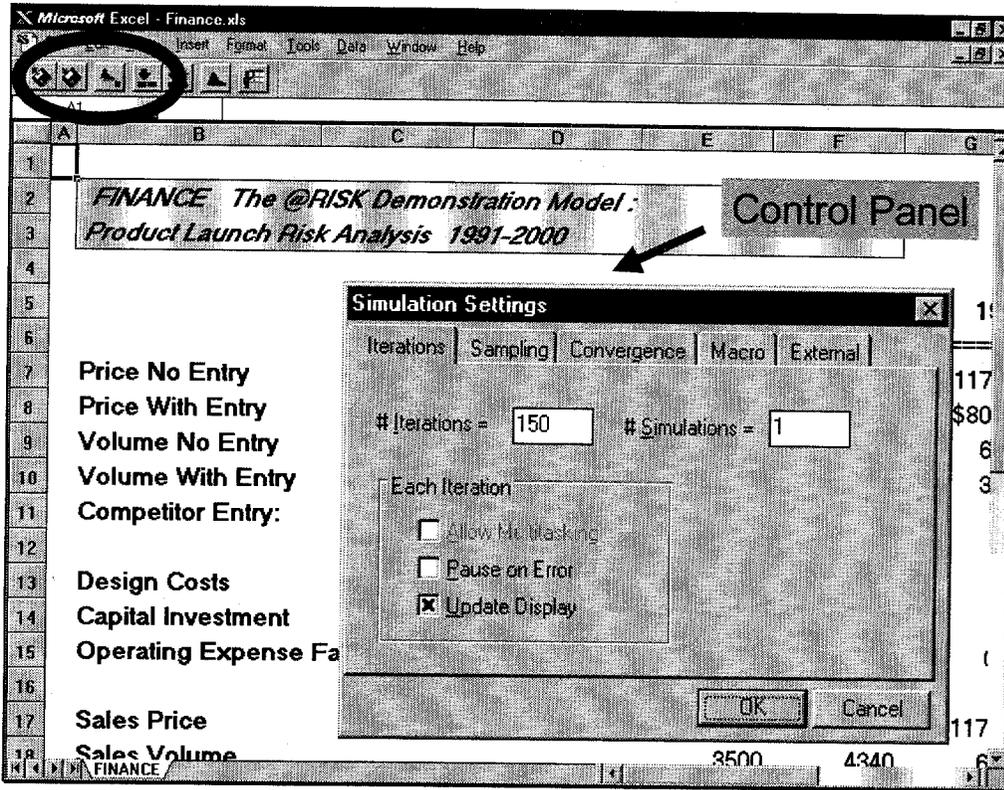
=RiskNormal(A1,A2)

=RiskNormal(3500*B7,C12/3000)

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

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

Running a Risk Analysis



Microsoft Excel - Finance.xls

File Edit View Insert Format Tools Data Window Help

FINANCE The @RISK Demonstration Model:
Product Launch Risk Analysis 1991-2000

Price No Entry
Price With Entry
Volume No Entry
Volume With Entry
Competitor Entry:

Design Costs
Capital Investment
Operating Expense F:

Sales Price
Sales Volume

3500 4340

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

Microsoft Excel - Finance.xls

File Edit View Insert Format Tools Data Window Help

FINANCE The @RISK Demonstration Model:
Product Launch Risk Analysis 1991-2000

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Price No Entry			\$69.25	\$87.25	\$117.72	\$111.48	\$98.33	\$93.48	\$90.71	\$89.33
Price With Entry			\$53.33	\$67.73	\$80.00	\$64.00	\$61.33	\$56.00	\$54.93	\$52.27
Volume No Entry			3500	4340	6580	5565	5180	5180	4970	4935
Volume With Entry			3300	4158	3564	3399	3300	3300	3432	3636
Competitor Entry:	0									
Design Costs	\$50,000.00									
Capital Investment		\$200,000.00								
Operating Expense Factor			0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Sales Price			\$69.25	\$87.25	\$117.72	\$111.48	\$98.33	\$93.48	\$90.71	\$89.33
Sales Volume			3500	4340	6580	5565	5180	5180	4970	4935
			\$242,358	\$378,659	\$774,575	\$620,411	\$509,339	\$484,230	\$450,833	\$440,824
			\$23.33	\$24.27	\$25.24	\$26.25	\$27.30	\$28.39	\$29.52	\$30.71
			\$5,600	\$6,944	\$10,528	\$8,904	\$8,288	\$8,288	\$7,952	\$7,896
			\$87,267	\$112,261	\$176,590	\$154,968	\$149,685	\$155,341	\$154,687	\$159,426
			\$155,091	\$266,398	\$597,985	\$465,443	\$359,654	\$328,890	\$296,147	\$281,399
			\$12,799	\$16,465	\$25,900	\$22,729	\$21,954	\$22,784	\$22,688	\$23,393
			\$0	\$142,292	\$249,933	\$572,085	\$442,715	\$337,700	\$306,106	\$273,459
			\$40,000	\$40,000	\$40,000	\$40,000	\$40,000			
			(\$18,400)	\$47,054	\$96,569	\$244,759	\$185,249	\$155,342	\$140,809	\$125,791
			\$0	\$5,654	\$96,569	\$244,759	\$185,249	\$155,342	\$140,809	\$125,791
			\$0	\$136,637	\$153,364	\$327,326	\$257,466	\$182,358	\$165,297	\$147,668
			(\$200,000)	\$136,637	\$153,364	\$327,326	\$257,466	\$182,358	\$165,297	\$147,668

GO!!!!

Simulating...

Sims: 1

Iters: 1000

Sim #: 1

Iter #: 750

76%

Cancel

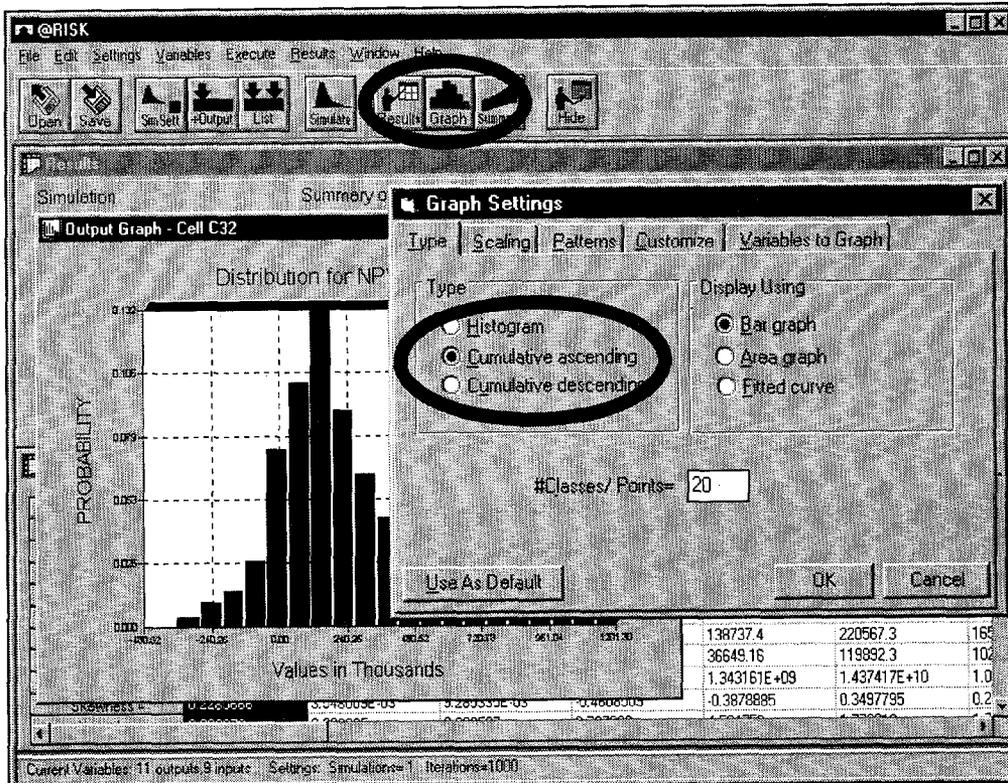
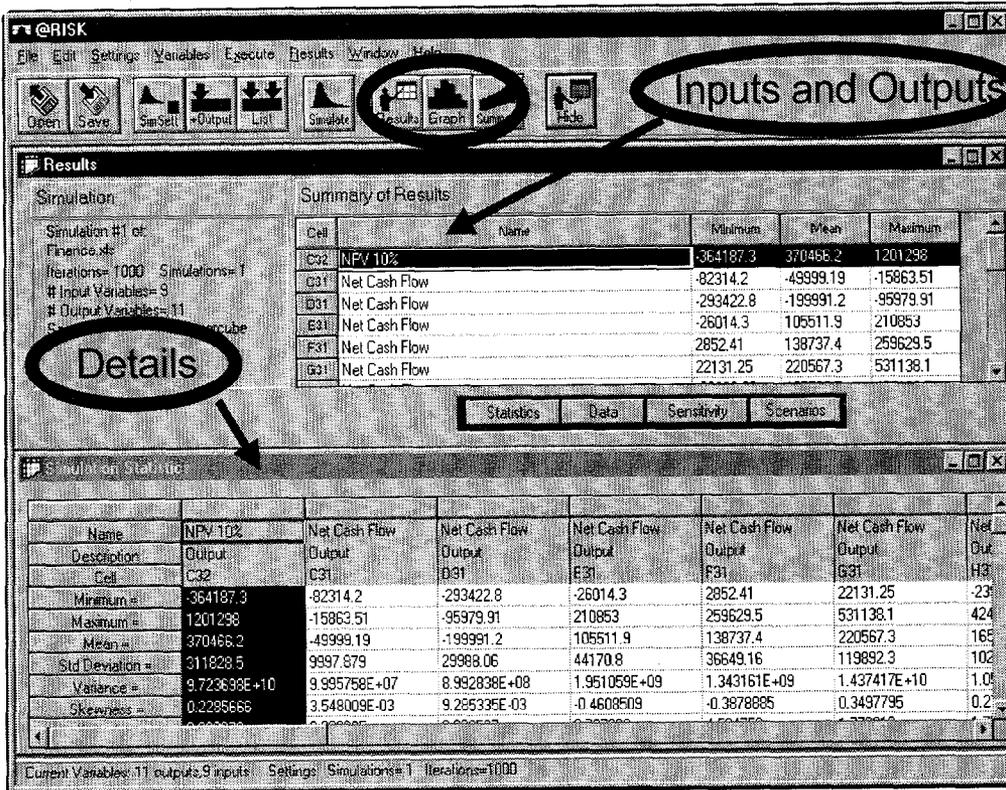
End Part 1

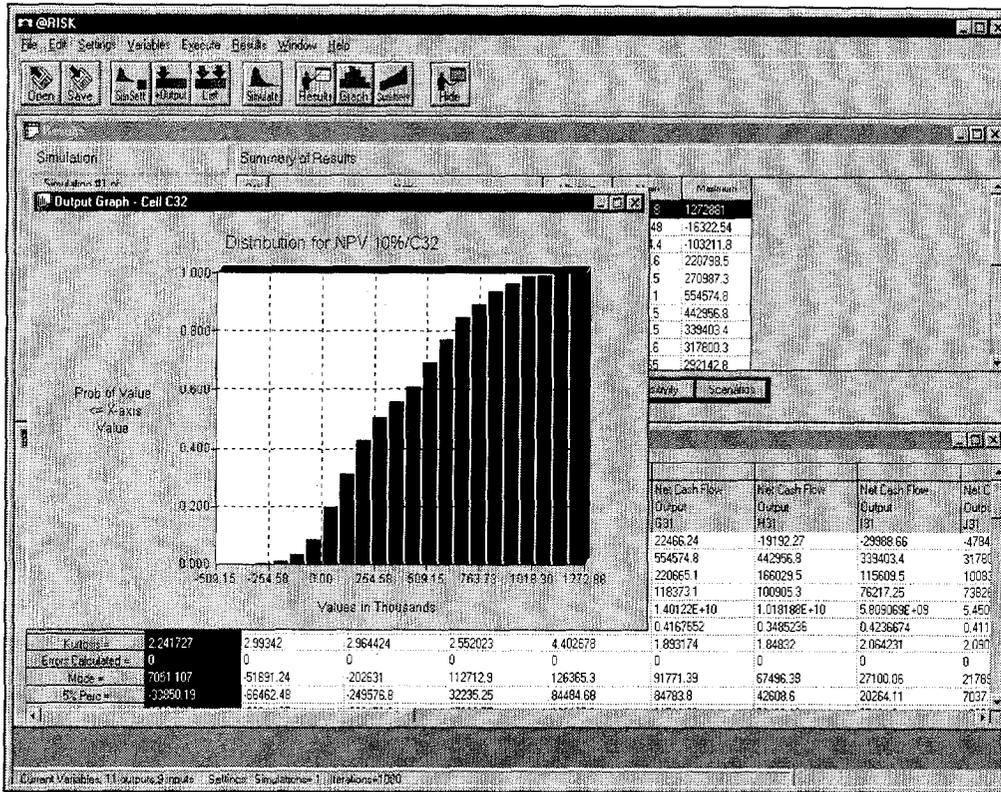
@Risk Demo (Part 2)

Simulation Results

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







@RISK

File Edit Settings Variables Execute Results Window Help

Open Save SimSet +Output List SimStats Results Graph Summary Help

Results Summary of Results

Simulation #1 of Finance.xls
Iterations=1000 Simulations=1
Input Variables=9
Output Variables=12
Sampling Type=Latin Hypercube
Runtime=00:00:32
Run on 5/15/97 at 10:21:16 AM

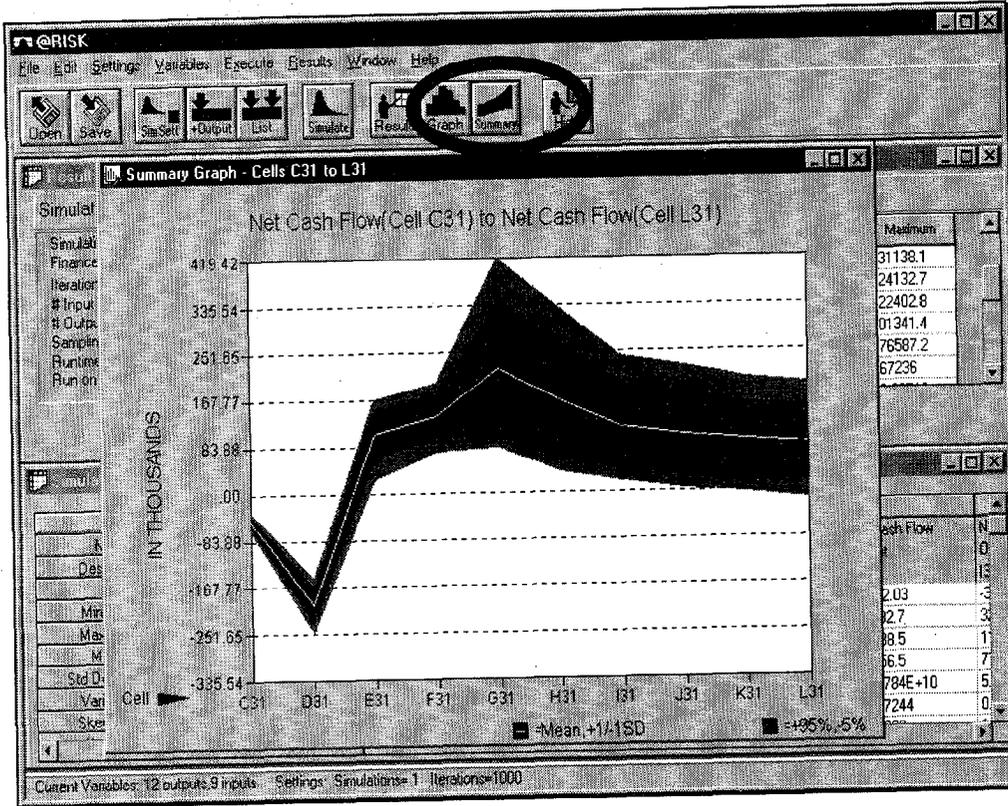
Cell	Name	Minimum	Mean	Maximum
G31	Net Cash Flow	22131.25	220567.3	531138.1
H31	Net Cash Flow	-23902.03	165738.5	424132.7
I31	Net Cash Flow	-35889.1	-115572.6	322402.8
J31	Net Cash Flow	-55715.83	100659.7	301341.4
K31	Net Cash Flow	-67320.55	90342.64	276597.2
L31	Net Cash Flow	-87309.37	83207.64	267236

Statistics Data Sensitivity Scenarios

Simulation #1 of Finance.xls

Name	Net Cash Flow	N					
Description	Output	Output	Output	Output	Output	Output	0
Cell	G31	H31	I31	J31	K31	L31	1
Minimum =	-82314.2	-293422.8	-26014.3	2852.41	22131.25	-23902.03	3
Maximum =	-15863.51	-95379.91	210853	259629.5	531138.1	424132.7	3
Mean =	-49999.19	-199991.2	105511.9	138737.4	220567.3	165738.5	1
Std Deviation =	9397.879	29968.06	44170.8	36649.16	119692.3	102556.5	7
Variance =	9.995758E+07	8.992838E+08	1.951059E+09	1.343161E+09	1.437417E+10	1.051784E+10	5
Skewness =	3.549009E-03	9.285335E-03	-0.4608509	-0.3878885	0.3497795	0.2727244	0

Current Variables: 12 outputs, 9 inputs Settings: Simulations=1 Iterations=1000



Results

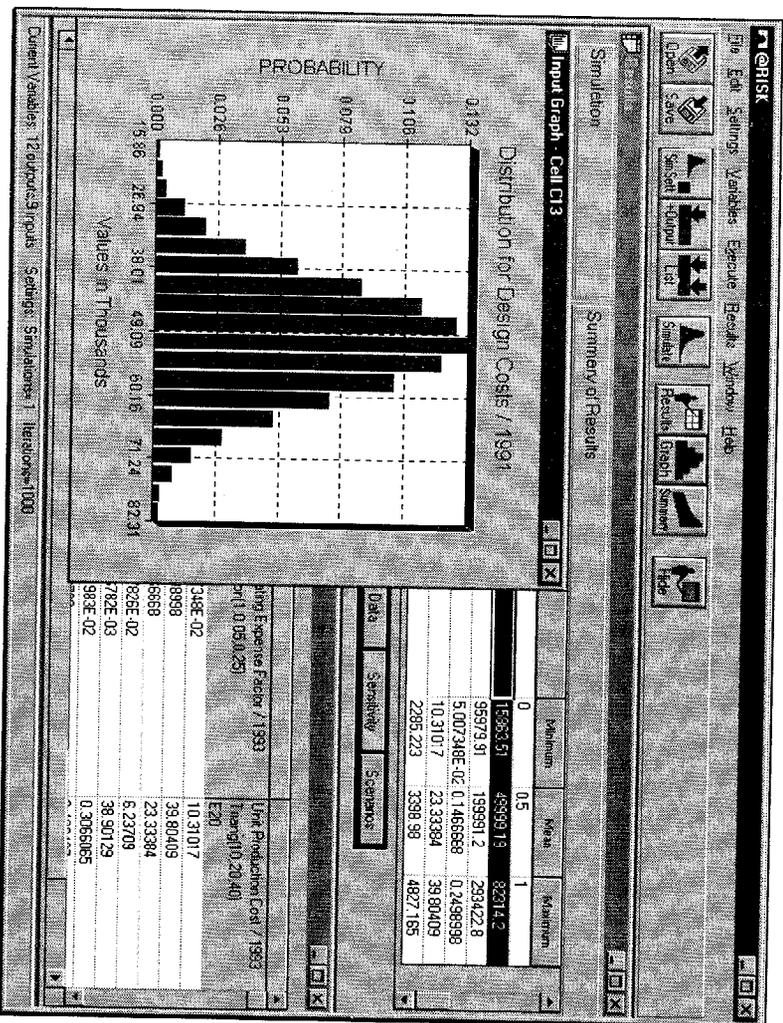
Simulation Summary of Results

Cell	Minimum	Mean	Maximum
C11 (Input) Competitor Entry / 1991	0	0.5	1
C13 (Input) Design Costs / 1991	15863.51	49393.19	82314.2
E14 (Input) Capital Investment / 1992	95979.91	199991.2	293422.8
E15 (Input) Operating Expense Factor / 1993	5.007348E-02	0.1466668	0.2498998
E20 (Input) Unit Production Cost / 1993	10.31017	23.33384	39.80409
E21 (Input) Overhead / 1993	2285.223	3398.98	4827.165

Statistics Data Sensitivity Scenarios

Name	Design Costs / 1991	Capital Investment / 1992	Operating Expense Factor / 1993	Unit Production Cost / 1993
Description	Normal(50000,10000)	Normal(200000,30000)	Tripon(1,0.05,0.25)	Triang(10,20,40)
Cell	C13	D14	E15	E20
Minimum =	15863.51	95979.91	5.007348E-02	10.31017
Maximum =	82314.2	293422.8	0.2498998	39.80409
Mean =	49393.19	199991.2	0.1466668	23.33384
Std Deviation =	9997.879	29988.06	5.767826E-02	6.23709
Variance =	9.995758E-07	8.992838E+08	3.326782E-03	38.90129
Skewness =	-3.549009E-03	-9.285335E-03	6.941983E-02	0.3068065

Current Variables: 12 outputs, 9 inputs Settings: Simulations=1 Iterations=1000



PT@RISK

File Edit Settings Variables Expense Events Window Help

Open Save Select Input List Simulate Results Graph Summary Help

Simulation

Simulation #1 of 1
Iterations= 1000 Simulations= 1
Input Variables= 9
Output Variables= 12
Sampling Type= Latin Hypercube
Run on= 5/15/97 at 10:21:16 AM

Summary of Results

Cell	Name	Minimum	Mean	Maximum
G32	Net Cash Flow Output	82314.2	48999.13	130123.8
D31	Net Cash Flow Output	-293422.8	-199991.2	-58979.91
E31	Net Cash Flow Output	28014.3	109511.9	210883
F31	Net Cash Flow Output	2882.41	289829.5	289829.5
G31	Net Cash Flow Output	22131.25	220867.3	331781.1

Statistics: D.G. Scenario: Scenarios

Name	Description	Dupl	Net Cash Flow Output	Min	Max			
Cell	Cell	Cell	Cell	Cell	Cell	Cell	Cell	Cell
Minimum =	82314.2	253422.8	-26014.3	2852.41	22131.25	143	42	23
Maximum =	-15863.51	-96979.91	210883	289829.5	531138.1	42	188	102
Mean =	48999.13	-199991.2	109511.9	198737.4	220867.3	188	102	102
Std Deviation =	3997.879	23988.06	44170.8	96649.16	119892.3	102	102	102
Variance =	3.997598E+07	8.982038E+08	1.951099E+09	1.343161E+10	1.437417E+10	1.0	1.0	1.0
St.devress =	0.2289566	9.285335E+03	0.4508609	-0.3878885	0.3497795	0.2	0.2	0.2

Current Variables: 12 outputs 9 inputs Settings: Simulations= 1 Iterations= 1000

@RISK - [Simulation Statistics]

File Edit Settings Variables Execute Results Window Help

Open Save Sim Sett +Output List Simulate Results Graph Summary Hide

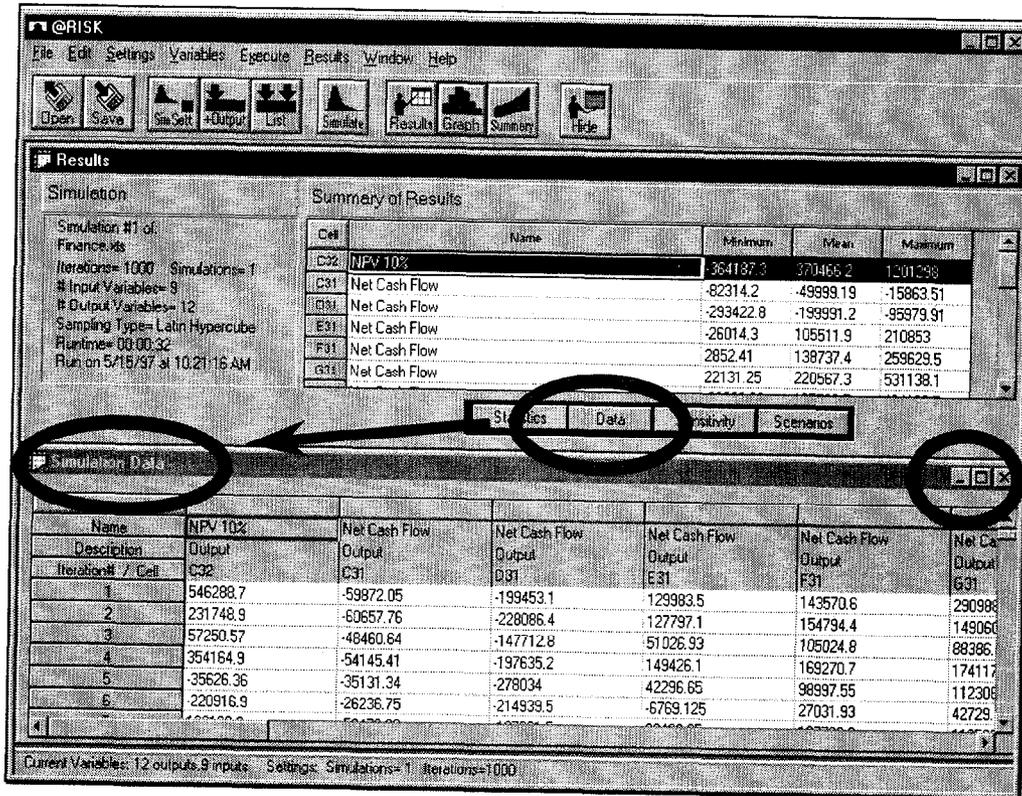
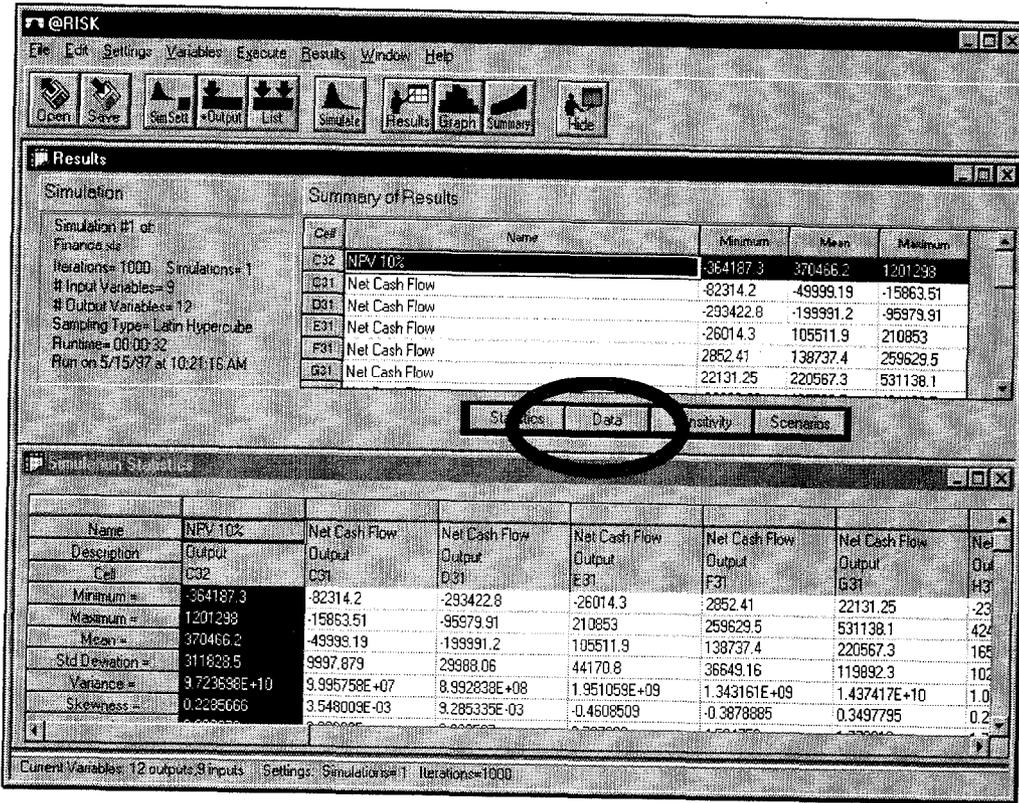
Name	NPV 10%	Net Cash Flow	Net				
Description	Output	Output	Output	Output	Output	Output	Outc
Cell	C32	C31	D31	E31	F31	G31	H31
Minimum =	-364187.3	-82314.2	-293422.8	-26014.3	2852.41	22131.25	-239
Maximum =	1201298	-15963.51	-95979.91	210853	253629.5	531138.1	424
Mean =	370466.2	-49999.19	-199991.2	105511.9	136737.4	220667.3	165
Std Deviation =	311826.5	9997.879	29988.06	44170.8	36649.16	119892.3	102
Variance =	9.723698E+10	9.995758E+07	8.992838E+08	1.951059E+09	1.343161E+09	1.437417E+10	1.05
Skewness =	0.2285666	3.548009E-03	9.285335E-03	-0.4608509	-0.3878886	0.3497795	0.27
Kurtosis =	2.096276	2.988835	2.980537	2.727398	4.504752	1.776613	1.75
Errors Calculated =	0	0	0	0	0	0	0
Mode =	131367.3	-50622.87	-198881.2	156413.1	125124.8	104710.7	834
5% Perc =	-62869.8	-66470.64	-249624.3	24622.41	73427.4	79979.41	353
10% Perc =	-8043682	-62861.92	-236526.8	44202.78	98061.47	89413.3	509
15% Perc =	43522.42	-60396.92	-231103	54275.04	108560.3	96870.57	588
20% Perc =	87754.37	-58432.11	-225293.4	67392.41	115729.6	103606.4	682
25% Perc =	115553.9	-56756.58	-220318.7	77596.76	121944.8	110637.7	749
30% Perc =	144639.6	-55263.07	-215762.2	83660.66	125272.9	118103.4	815
35% Perc =	172683.7	-53875.54	-211602.3	91524.57	128234.8	127056.6	885
40% Perc =	203966.6	-52553.61	-207604.9	96525.34	131320.8	137911.7	976
45% Perc =	260260.6	-51264.66	-203756	104982.3	135030.6	152041	109
50% Perc =	311393.5	-50001.37	-200024.7	112301.1	138662.9	181281.3	131
55% Perc =	400593.8	-48748.34	-196286.5	117274.1	141842.4	243536	188
60% Perc =	475171.3	-47485.98	-192403	122338.7	145474	269130	211
65% Perc =	535962.1	-46165.31	-188495.7	127756.5	148667.9	291199.1	228
70% Perc =	582293.3	-44763.53	-184333.3	133434.6	154122.8	311016.7	243

@RISK - [Simulation Statistics]

File Edit Settings Variables Execute Results Window Help

Open Save Sim Sett +Output List Simulate Results Graph Summary Hide

Name	NPV 10%	Net Cash Flow	Net				
Description	Output	Output	Output	Output	Output	Output	Outc
Cell	C32	C31	D31	E31	F31	G31	H31
50% Perc =	475171.3	-47485.98	-192403	122338.7	145474	269130	211
65% Perc =	535962.1	-46165.31	-188495.7	127756.5	148667.9	291199.1	228
70% Perc =	582293.3	-44763.53	-184333.3	133434.6	154122.8	311016.7	243
75% Perc =	633550.9	-43258.84	-179835.4	138446.8	158873.3	325890.5	256
80% Perc =	680906.1	-41587.64	-174758.5	144637.6	165345.1	343900.9	270
85% Perc =	728485.9	-39648.97	-169031.4	152156.6	173199.8	360023.6	284
90% Perc =	802413.2	-37229.05	-161563.4	158702.9	184612.4	384020	305
95% Perc =	877210.1	-33630.93	-150900.1	168645	198105.1	419420.3	331
Filter Minimum =							
Filter Maximum =							
Type 1 of 2 =							
# Values Filtered =	0	0	0	0	0	0	0
Scenario #1 =	>75%	>75%	>75%	>75%	>75%	>75%	>75%
Scenario #2 =	<25%	<25%	<25%	<25%	<25%	<25%	<25%
Scenario #3 =	>90%	>90%	>90%	>90%	>90%	>90%	>90%
Target #1 (Value) =							
Target #1 (Perc%) =							
Target #2 (Value) =							
Target #2 (Perc%) =							
Target #3 (Value) =							
Target #3 (Perc%) =							
Target #4 (Value) =							
Target #4 (Perc%) =							



@RISK - [Simulation Data]

File Edit Settings Variables Execute Results Window Help

Open Save Settings +Output List Simulate Results Graph Summary Hide

Name	NPV 10%	Net Cash Flow				
Description	Output	Output	Output	Output	Output	Output
Iteration# / Cell	C32	C31	D31	E31	F31	G31
1	546298.7	-59972.05	-199453.1	129983.5	143570.6	290986.
2	231748.9	60657.76	-228086.4	127797.1	154794.4	149050.
3	57250.57	-48460.64	-147712.8	51026.93	105024.8	89386.1
4	354164.9	-54145.41	-197635.2	149426.1	169270.7	174117.
5	-35626.36	-35131.34	-278034	42296.65	99997.55	112306.
6	-220916.9	-26236.75	-214939.5	-6769.125	27031.93	42729.6
7	120123.2	-59478.26	-187261.5	82422.85	127783.2	110596.
8	318168.7	-26694.64	-206440.6	75641.5	111794.9	208390.
9	473682.6	-47360.34	-155757.7	94627.51	123024	271930.
10	115131.2	-69968.17	-215954.8	88373.4	141362.6	115906.
11	207522	-61824.74	-190095.3	112473.6	143001.8	136888.
12	164339.2	-28820.9	-227482.6	96730.34	128819.9	124571.
13	612343.5	-49707.14	-211392.5	136621.7	151714.5	325890.
14	513978.3	-52454.02	-178818.6	113746.5	133345.6	280093.
15	60572.89	-60447.74	-204316.8	63357.05	125779.2	98053.8
16	90692.6	-49246.04	-215531.2	76354.25	124980.3	102552.
17	553709.4	-54638.98	-209473.3	136665.8	142723.1	288835.
18	504461.2	-65062.39	-235557.7	126339	164249.2	328399.
19	821769.4	-49796.59	-188973.3	151685.6	184862.2	403620.
20	27589.25	-65135.06	-188495.7	55203.85	105445.1	85793.3
21	935714.8	50814.16	-212908.4	175645.7	210225.9	438684.
22	233211	-65484.14	-199316.5	124707.7	148347.2	144821.
23	-65904.76	-48901.95	-246447.4	31492.57	75198.73	84906.5

@RISK

File Edit Settings Variables Execute Results Window Help

Open Save Settings +Output List Simulate Results Graph Summary Hide

Simulation Summary of Results

Simulation #1 of Finance.xls
 Iterations= 1000 Simulation= 1
 # Input Variables= 9
 # Output Variables= 12
 Sampling Type= Latin Hypercube
 Runtime= 00:00:32
 Run on 5/15/97 at 10:21:16 AM

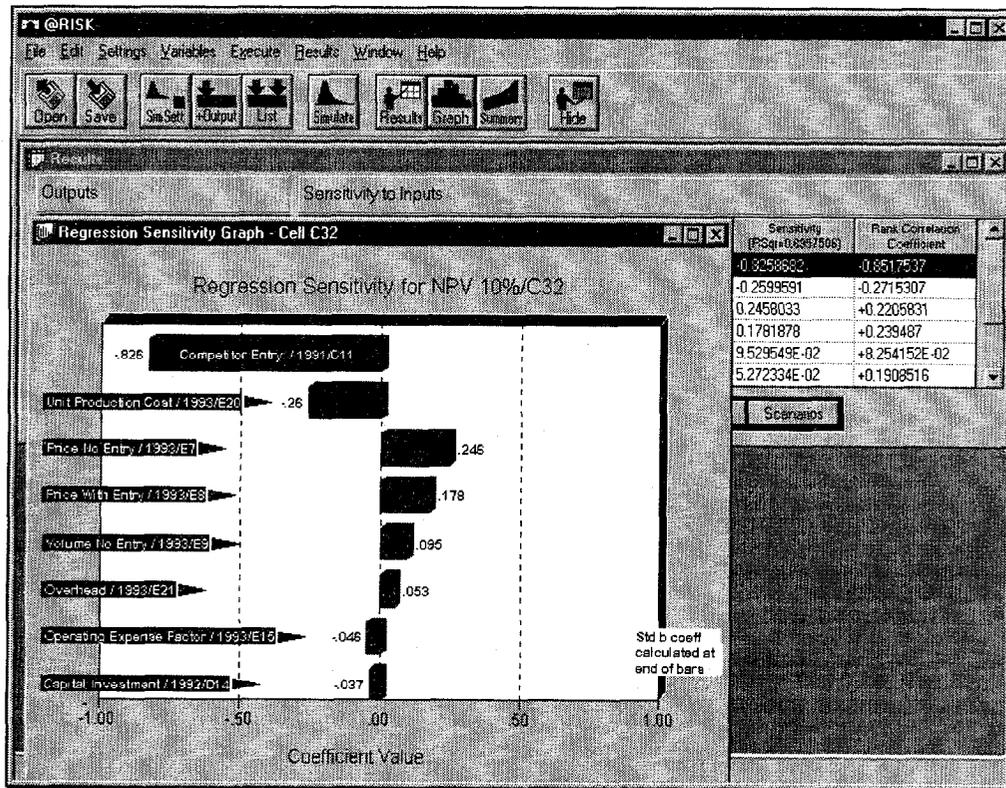
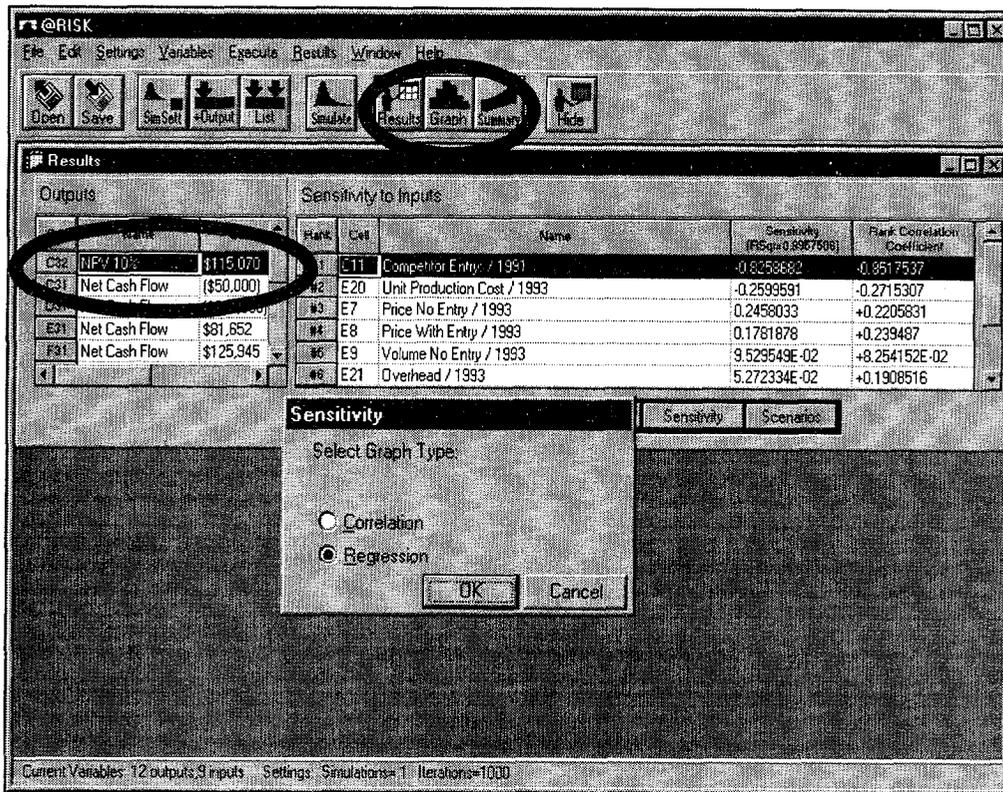
Cell	Name	Minimum	Mean	Maximum
C32	NPV 10%	364187.3	370466.2	1201238
D31	Net Cash Flow	-82314.2	-49999.19	-15863.51
E31	Net Cash Flow	-293422.8	-199991.2	-95979.91
F31	Net Cash Flow	-26014.3	105511.9	210853
G31	Net Cash Flow	2852.41	138737.4	259629.5
H31	Net Cash Flow	220567.3	531138.1	

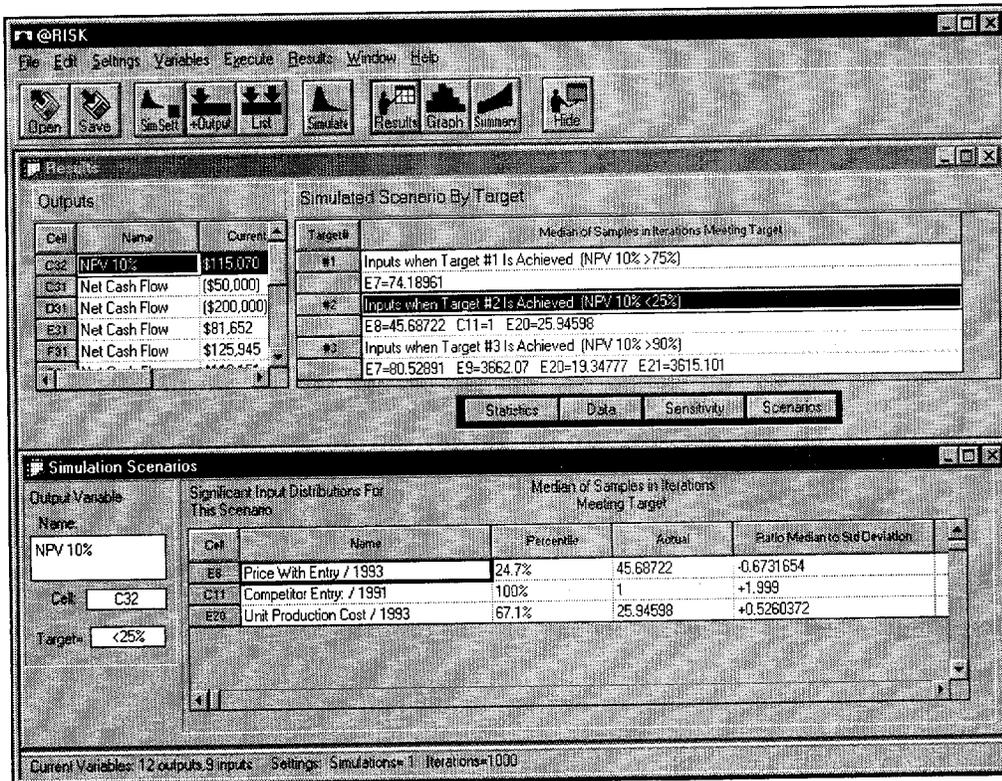
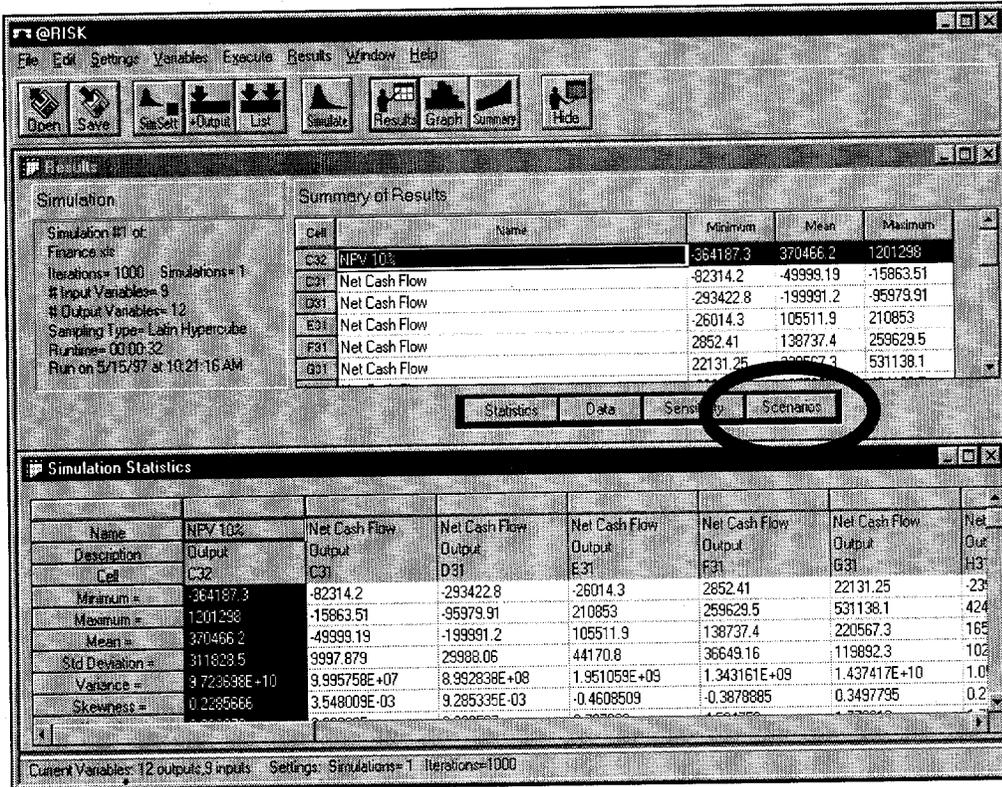
Statistics | **Sensitivity** | Scenarios

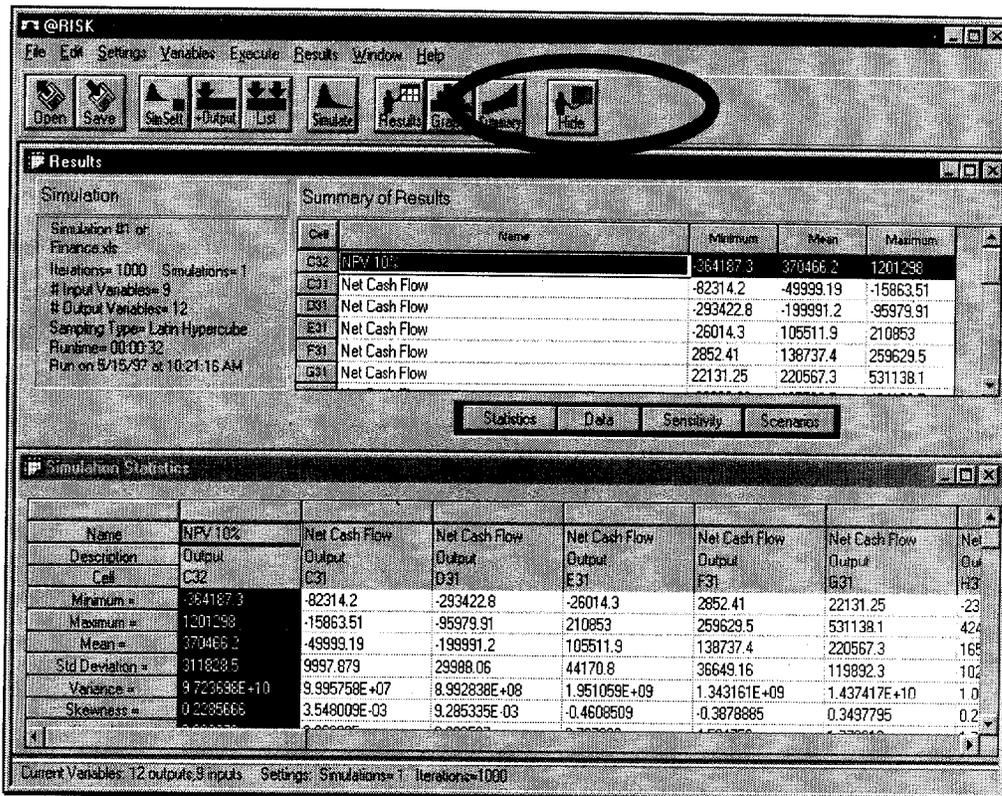
Simulation Statistics

Name	NPV 10%	Net Cash Flow	Net				
Description	Output	Output	Output	Output	Output	Output	Out
Cell	C32	E31	D31	E31	F31	G31	H31
Minimum =	364187.3	-82314.2	-293422.8	-26014.3	2852.41	22131.25	-23
Maximum =	1201238	-15863.51	-95979.91	210853	259629.5	531138.1	424
Mean =	370466.2	-49999.19	-199991.2	105511.9	138737.4	220567.3	168
Std Deviation =	311828.5	9997.879	29988.06	44170.8	36649.16	119892.3	102
Variance =	9.723698E+10	9.995759E+07	8.992838E+08	1.951059E+09	1.343161E+09	1.437417E+10	1.0
Skewness =	0.2285666	3.548009E-03	9.285335E-03	-0.4608509	-0.3878885	0.3497795	0.2

Current Variables: 12 outputs, 9 inputs Settings: Simulation=1 Iterations=1000







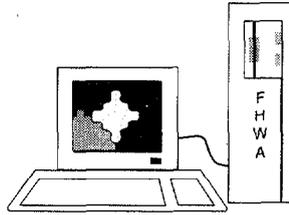
Microsoft Excel - Finance.xls
File Edit View Insert Format Tools Data Window Help

FINANCE The @RISK Demonstration Model:
Product Launch Risk Analysis 1991-2000

	1991	1992	1993	1994	1995
Price No Entry			\$69.25	\$87.25	\$117
Price With Entry			\$53.33	\$67.73	\$80
Volume No Entry			3500	4340	6
Volume With Entry			3300	4158	3
Competitor Entry:	0				
Design Costs	\$50,000.00				
Capital Investment		\$200,000.00			
Operating Expense Factor			0.15	0.15	
Sales Price			\$69.25	\$87.25	\$117
Sales Volume			3500	4340	6

End Session

BestFit Demonstration



Session Overview

- @Risk
- Adding Uncertainty to Models
- Introducing BestFit
- BestFitting a Probability Distribution

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A1

FINANCE The @RISK Demonstration Model
Product Launch Risk Analysis 1991-2000

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Price No Entry			\$69.25	\$87.25	\$117.72	\$111.48	\$98.33	\$93.48	\$90.71	\$89.33
Price With Entry			\$53.33	\$67.73	\$80.00	\$64.00	\$61.33	\$66.00	\$54.93	\$52.27
Volume No Entry			3500	4340	6580	5565	5180	5180	4970	4935
Volume With Entry			3300	4158	3564	3399	3300	3300	3432	3696
Competitor Entry:	0									
Design Costs	\$50,000.00									
Capital Investment		\$200,000.00								
Operating Expense Factor			0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Sales Price			\$69.25	\$87.25	\$117.72	\$111.48	\$98.33	\$93.48	\$90.71	\$89.33
Sales Volume			3500	4340	6580	5565	5180	5180	4970	4935
Sales Revenue			\$242,358	\$378,659	\$774,575	\$620,411	\$509,339	\$484,230	\$450,833	\$440,824
Unit Production Cost			\$23.33	\$24.27	\$25.24	\$26.25	\$27.30	\$28.39	\$29.52	\$30.71
Overhead			\$5,600	\$6,944	\$10,528	\$9,904	\$8,288	\$8,288	\$7,952	\$7,896
Cost of Goods Sold			\$87,257	\$112,261	\$176,590	\$154,968	\$149,685	\$155,341	\$154,687	\$159,426
Gross Margin			\$155,091	\$266,398	\$597,985	\$465,443	\$359,654	\$328,890	\$296,147	\$281,399
Operating Expense			\$12,799	\$16,465	\$25,900	\$22,729	\$21,954	\$22,784	\$22,688	\$23,383
Net Before Tax	(\$50,000)	\$0	\$142,292	\$249,933	\$572,085	\$442,715	\$337,700	\$306,106	\$273,459	\$258,016
Depreciation		\$40,000	\$40,000	\$40,000	\$40,000	\$40,000	\$40,000			
Tax	(\$23,000)	(\$18,400)	\$47,054	\$96,569	\$244,759	\$185,249	\$155,342	\$140,809	\$125,791	\$118,687
Taxes Owed	\$0	\$0	\$5,654	\$96,569	\$244,759	\$185,249	\$155,342	\$140,809	\$125,791	\$118,687
Net After Tax	(\$50,000)	\$0	\$136,637	\$153,364	\$327,326	\$257,466	\$182,358	\$165,297	\$147,668	\$139,329
Net Cash Flow	(\$50,000)	(\$200,000)	\$136,637	\$153,364	\$327,326	\$257,466	\$182,358	\$165,297	\$147,668	\$139,329
NPV 10%	\$632,273									

Modeling with @Risk

- Identify variables in your worksheet that are uncertain
- Over 30 built-in functions added to spreadsheet
- Describe uncertain variables as probability distributions

@Risk Probability Functions

Beta	Gamma	Normal
Binomial	Geometric	Pareto
Chi-Square		
Cumulative		Exponential
Dependent		Lognormal
Discrete		Normal
Discrete		
Error Function	Lognormal	Trigen
Erlang	Lognormal2	Uniform
Exponential	Negative Binomial	Weibull

Which One Should I Use?

The screenshot shows an Excel spreadsheet with the following elements:

- Formula Bar:** `=RiskNormal(50000,10000)` is entered in cell C13. The formula is circled in red.
- Graph:** A normal distribution curve is plotted. The x-axis is labeled with 50000 and 10000. The y-axis is labeled "Probability".
- Spreadsheet Content:**

<i>FINANCE The @RISK Demonstration Product Launch Risk Analysis 1991-20</i>		
Price		\$87.25
Price		\$67.73
Volum		4340
Volum		4158
Comp		
Desig		
Capital Investment	\$200,000.00	
Operating Expense Factor	0.15	0.15

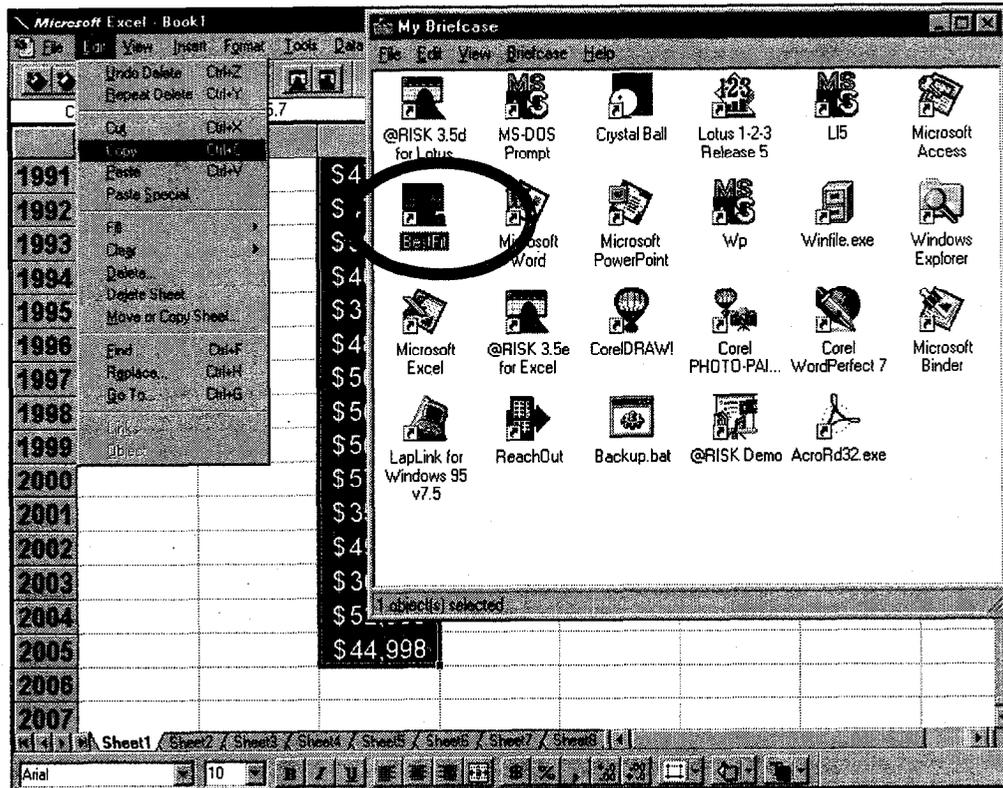
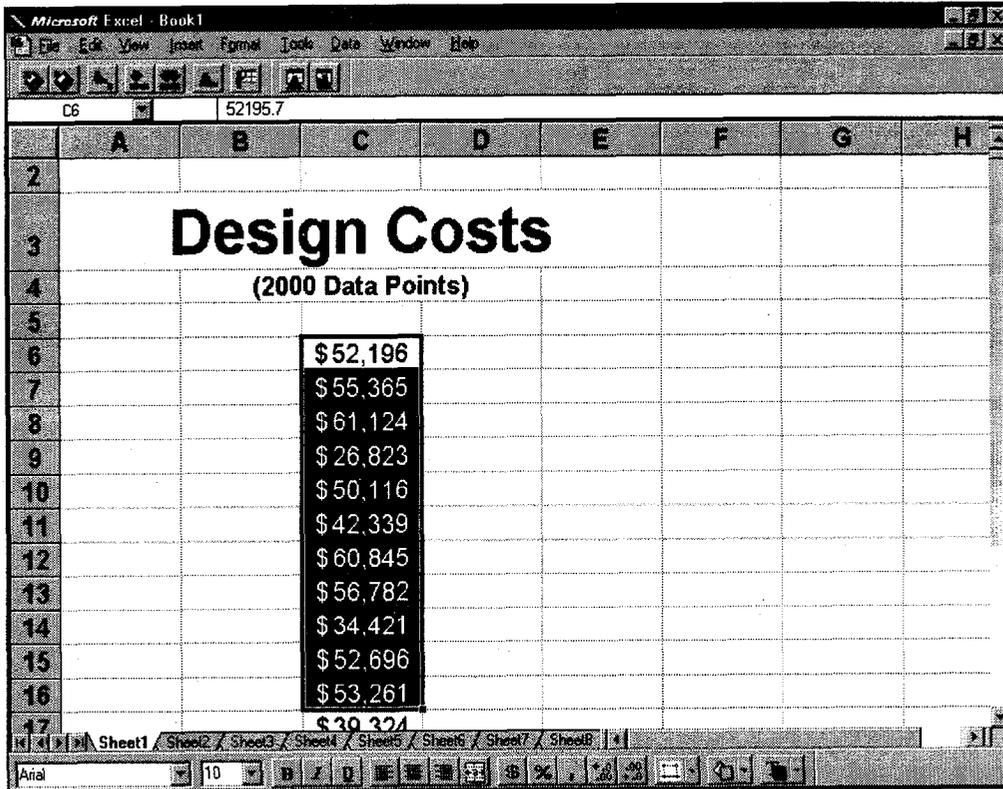
How Do I Know Its a Normal Distribution?

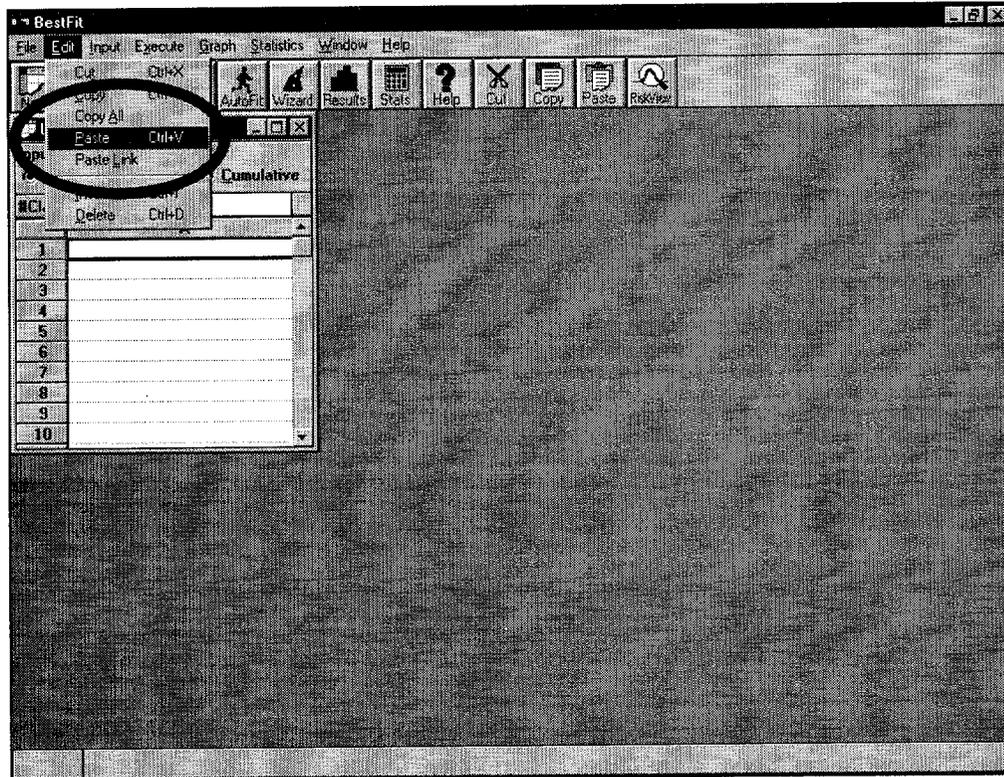
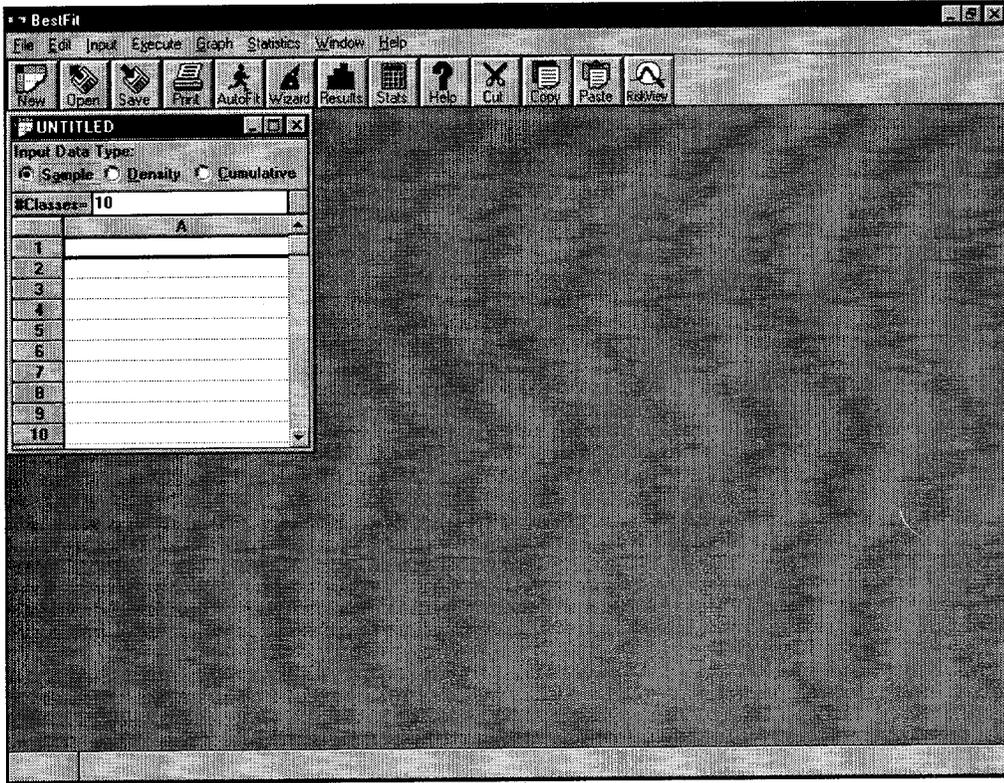
@Risk & BestFit

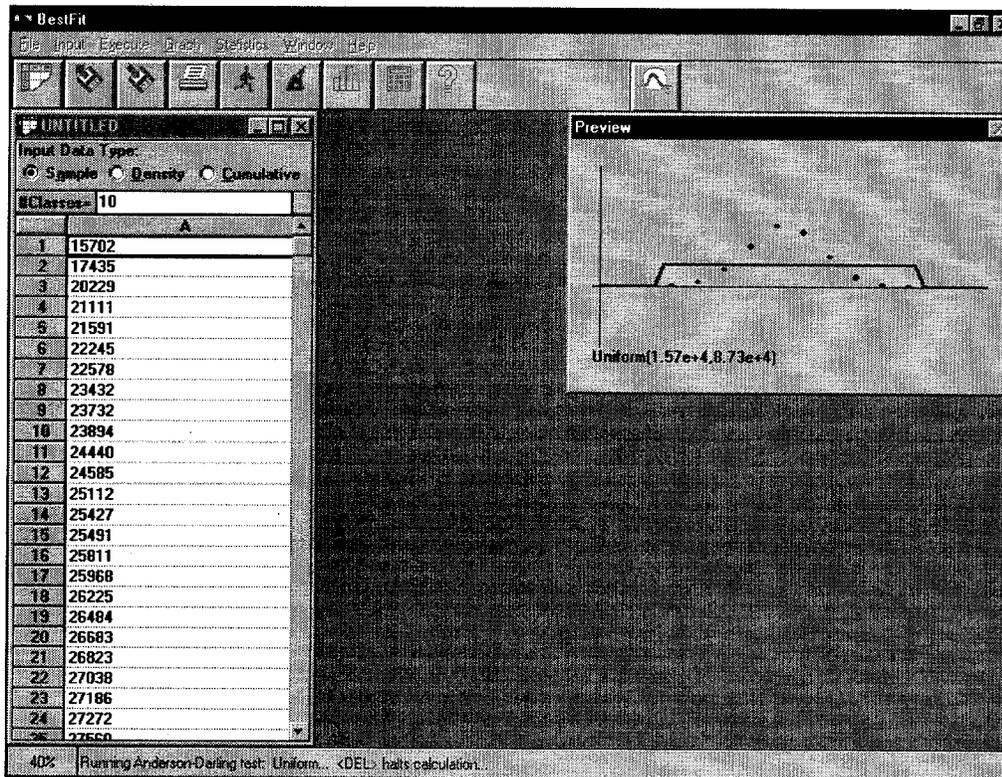
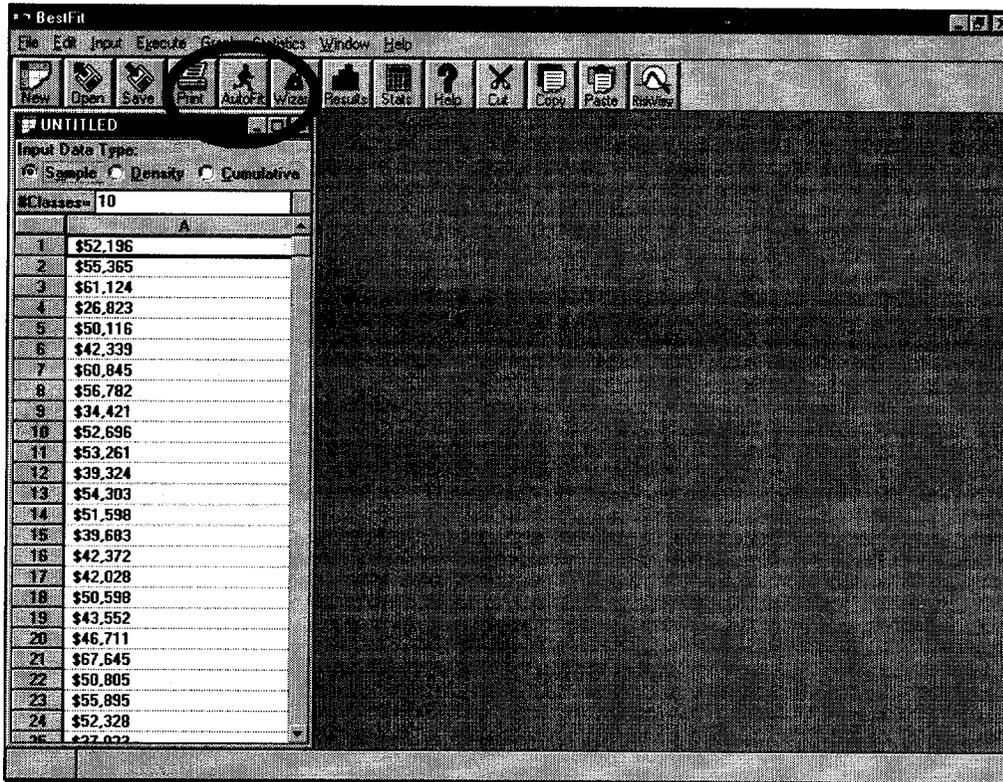


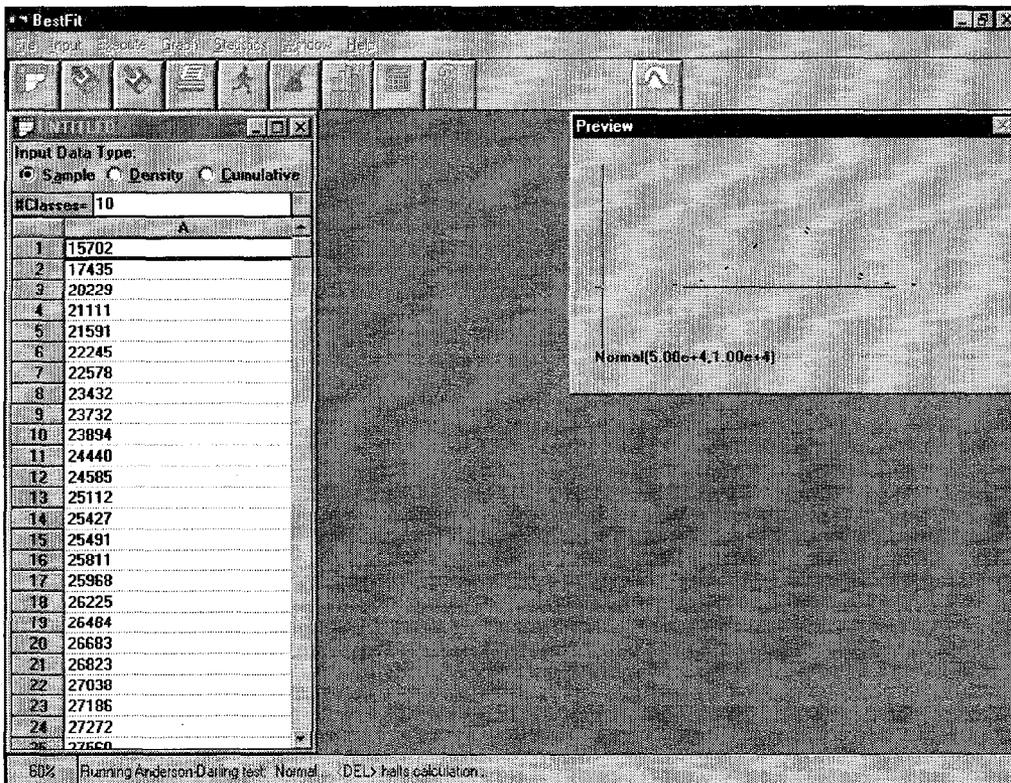
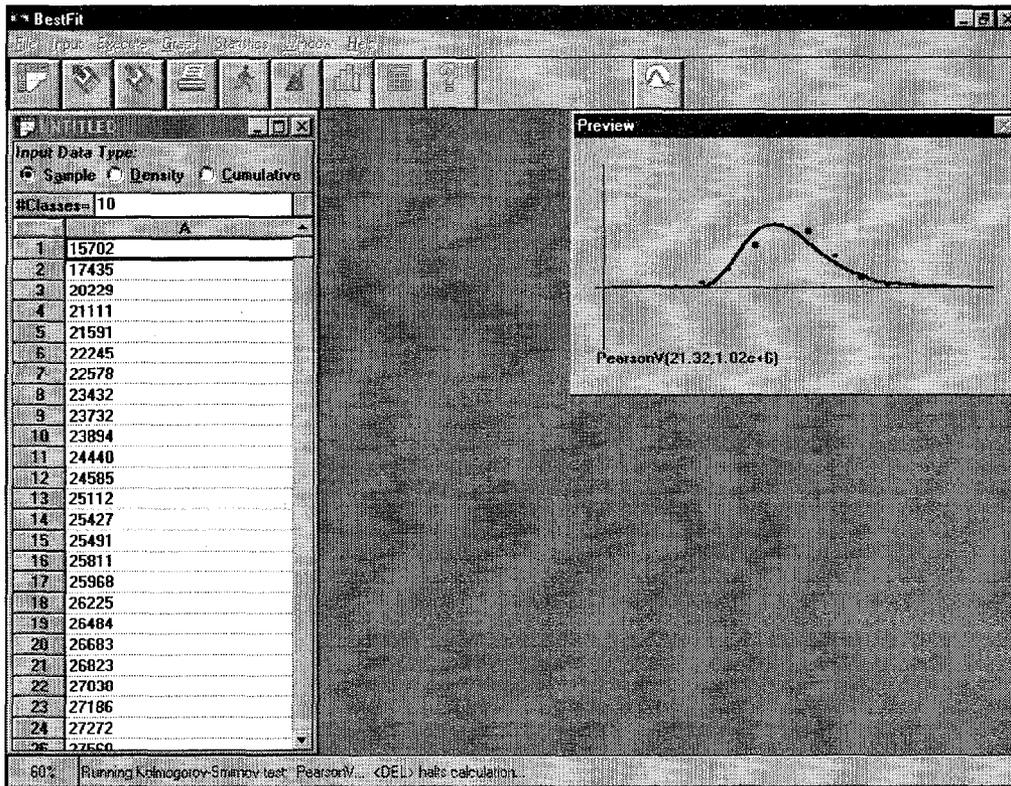
- Based on historical data input distribution models are developed using BestFit
- BestFit automatically determines the "bestfit" probability distribution
- Distribution model is "copied" directly into @Risk/Excel spreadsheet

	A	B	C	D	E	F	G	H
3								
4	Design Costs							
5	(2000 Data Points)							
6								
7			\$52,196					
8			\$55,365					
9			\$61,124					
10			\$26,823					
11			\$50,116					
12			\$42,339					
13			\$60,845					
14			\$56,782					
15			\$34,421					
16			\$52,696					
17			\$53,261					
18			\$39,324					









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

	A
1	15702
2	17435
3	20229
4	21111
5	21591
6	22245
7	22578
8	23432
9	23732
10	23894
11	24440
12	24585
13	25112
14	25427
15	25491
16	25811
17	25968
18	26225
19	26484
20	26683
21	26823
22	27038
23	27186
24	27272
25	27550

Results

Rank/Distribution:

- Normal
- Logistic
- Weibull
- Gamma
- Erlang
- Beta
- Triang
- Log-Logistic
- Lognorm
- Lognorm2

Display:

- Comparison
- Difference
- P-P
- Q-Q
- Triang
- K-S Test
- B-D Test

Rank By:

- Chi-Square
- K-S Test
- B-D Test

Select All

Graph Cancel

BestFit - [Statistics UNTITLED]

File Edit Input Execute Graph Statistics Window Help

New Open Save Print AutoFit Wizard Results Stats Help Copy RiskView

Rank/Distribution

Rank/Distribution	Chi-Square
1. Normal	2.433513
2. Logistic	42.9419
3. Beta	247.151773
4. Erlang	141.912053

Normal(5.00e+4, 1.00e+4)

	Input Distribution	Normal	Logistic	Beta	Erlang	Gamma
Parameter 1		5.000134e+4	5.000134e+4	5.653933	24.0	23.56
Parameter 2		1.000326e+4	5479.009511	6.134043	2083.389313	2123
Parameter 3						
Formula		Normal(5.00e+4, 1.00e+4)	Logistic(5.00e+4, 5.48e+3)	Beta(5.65, 6.13) * 7.16e+3	Erlang(24.00, 2.09e+3)	Gamma
Minimum	1.5702e+4			1.565787e+4		
Maximum	8.7217e+4			8.726113e+4		
Mean	5.000134e+4	5.000134e+4	5.000134e+4		5.000134e+4	5.000
Mode	4.789375e+4	5.000134e+4	5.000134e+4			4.787
Median	4.9994e+4	5.000134e+4	5.000134e+4			4.929
Standard Deviation	1.000326e+4	1.000326e+4	99.000000			1.030
Variance	1.000652e+8	1.000652e+8	99.000000			1.061
Skewness	6.818959e-3	0.0	0.0			0.412
Kurtosis	2.99614	3.0	4.2			3.254
Histogram	Histogram(1.5702e+4, 8.7217e+4)					
Minimum	1.5702e+4	1.5702e+4	1.5702e+4	1.5702e+4	1.5702e+4	1.570
Maximum	8.7217e+4	8.7217e+4	8.7217e+4	8.7217e+4	8.7217e+4	8.721
P1	7.0	5.10261	9.511148	0.333061	0.426757	0.492
P2	38.0	35.515393	34.403261	30.10865	19.546298	20.86
P3	154.0	148.275738	118.254638	169.428516	155.74744	159.1
P4	370.0	371.323827	342.894639	388.012848	426.730644	426.4
P5	547.0	557.782386	628.849528	529.557008	569.019143	563.8
P6	495.0	502.580954	532.192156	480.975544	451.616422	448.2
P7	274.0	271.629235	229.9489	288.363507	242.274392	242.7
P8	93.0	88.059507	72.256388	100.059541	95.588906	97.35

Cut and Paste the "Best" Result

Microsoft Excel - Finance.xls

File Edit View Insert Format Tools Data Window Help

C13

FINANCE The @RISK Demonstration Model
Product Launch Risk Analysis 1991-2000

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Price No Entry			\$69.25					\$8.48	\$90.71	\$89.33
Price With Entry			\$53.33					\$56.00	\$54.93	\$52.27
Volume No Entry			3500	4340				5180	4970	4935
Volume With Entry			3300	4158	3564	3399	3300	3300	3432	3696
Competitor Entry:	0									
Design Costs										
Capital Investment		\$200,000.00								
Operating Expense Factor			0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Sales Price			\$69.25	\$87.25	\$117.72	\$111.48	\$98.33	\$93.48	\$90.71	\$89.33
Sales Volume			3500	4340	6580	5565	5180	5180	4970	4935
Sales Revenue			\$242,358	\$378,659	\$774,575	\$620,411	\$509,339	\$484,230	\$450,833	\$440,824
Unit Production Cost			\$23.33	\$24.27	\$25.24	\$26.25	\$27.30	\$28.39	\$29.52	\$30.71
Overhead			\$5,600	\$6,944	\$10,528	\$8,904	\$8,288	\$8,288	\$7,952	\$7,896
Cost of Goods Sold			\$87,267	\$112,261	\$176,590	\$154,968	\$149,685	\$155,341	\$154,687	\$159,426
Gross Margin			\$155,091	\$266,398	\$597,985	\$465,443	\$359,654	\$328,890	\$296,147	\$281,399
Operating Expense			\$12,799	\$16,465	\$25,900	\$22,729	\$21,954	\$22,784	\$22,688	\$23,383
Net Before Tax	\$0	\$0	\$142,292	\$249,933	\$572,085	\$442,715	\$337,700	\$306,106	\$273,459	\$258,016
Depreciation		\$40,000	\$40,000	\$40,000	\$40,000	\$40,000				
Tax	\$0	(\$18,400)	\$47,054	\$96,569	\$244,759	\$185,249	\$155,342	\$140,809	\$125,791	\$118,687
Taxes Owed	\$0	\$0	\$28,654	\$96,569	\$244,759	\$185,249	\$155,342	\$140,809	\$125,791	\$118,687
Net After Tax	\$0	\$0	\$113,637	\$153,364	\$327,326	\$257,466	\$182,358	\$165,297	\$147,668	\$139,329

Paste Results Here.

Microsoft Excel - Finance.xls

File Edit View Insert Format Tools Data Window Help

A1 =RiskNormal(5.00e+4,1.00e+4)

FINANCE The @RISK Demonstration Model
Product Launch Risk Analysis 1991-2000

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Price No Entry			\$59.25	\$87.25	\$117.72	\$111.48	\$98.33	\$93.48	\$90.71	\$89.33
Price With Entry			\$53.33	\$67.73	\$80.00	\$64.00	\$61.33	\$56.00	\$54.93	\$52.27
Volume No Entry			3500	4340	6580	5565	5180	5180	4970	4935
Volume With Entry			3300	4158	3564	3399	3300	3300	3432	3696
Competitor Entry:	0									
Design Costs		\$50,000.00								
Capital Investment		\$200,000.00								
Operating Expense Factor			0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Sales Price			\$69.25	\$87.25	\$117.72	\$111.48	\$98.33	\$93.48	\$90.71	\$89.33
Sales Volume			3500	4340	6580	5565	5180	5180	4970	4935
Sales Revenue			\$242,358	\$378,659	\$774,575	\$620,411	\$509,339	\$484,230	\$450,833	\$440,824
Unit Production Cost			\$23.33	\$24.27	\$25.24	\$26.25	\$27.30	\$28.39	\$29.52	\$30.71
Overhead			\$5,600	\$6,944	\$10,528	\$8,904	\$8,288	\$8,288	\$7,952	\$7,896
Cost of Goods Sold			\$87,267	\$112,261	\$176,590	\$154,968	\$149,685	\$155,341	\$154,687	\$159,426
Gross Margin			\$155,091	\$266,398	\$597,985	\$465,443	\$359,654	\$328,890	\$296,147	\$281,399
Operating Expense			\$12,799	\$16,465	\$25,900	\$22,729	\$21,954	\$22,784	\$22,688	\$23,383
Net Before Tax	(\$50,000)	\$0	\$142,292	\$249,933	\$572,085	\$442,715	\$337,700	\$306,106	\$273,459	\$258,016
Depreciation		\$40,000	\$40,000	\$40,000	\$40,000	\$40,000				
Tax	(\$23,000)	(\$18,400)	\$47,054	\$96,569	\$244,759	\$185,249	\$155,342	\$140,809	\$125,791	\$118,687
Taxes Owed	\$0	\$0	\$28,654	\$96,569	\$244,759	\$185,249	\$155,342	\$140,809	\$125,791	\$118,687
Net After Tax	(\$50,000)	\$0	\$136,637	\$153,364	\$327,326	\$257,466	\$182,358	\$165,297	\$147,668	\$139,329
Net Cash Flow	(\$50,000)	(\$200,000)	\$136,637	\$153,364	\$327,326	\$257,466	\$182,358	\$165,297	\$147,668	\$139,329
NPV 10%			\$632,273							

\$50,000

Note ...

@Risk and BestFit have been used for illustration purposes. There are other software packages available to do risk analysis.

For More Information:

■ @Risk and BestFit

- Palisade Corporation
 - <http://www.palisade.com>
 - Phone: 800-432-7475

■ Crystal Ball

- Decisioneering
 - <http://www.decisioneering.com>
 - 800-289-2550

End Session



LCCA

Probabilistic Example

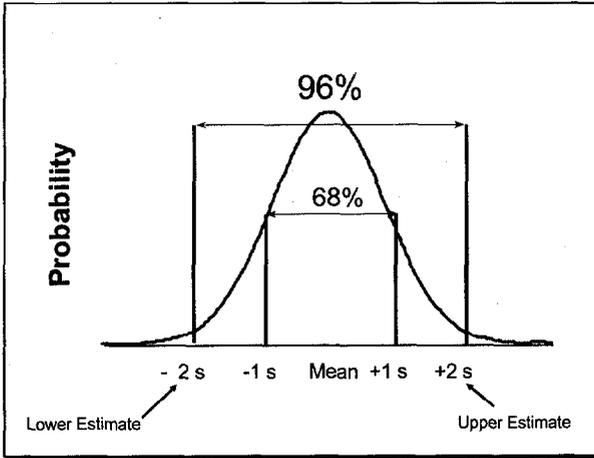
Given:

	Alternative A& B
Analysis Period	35 years
Daily Delay (Hours)	3000 hours
Routine Maintenance	Insignificant
Discount Rate	4% to 6%
Value of Time (\$ / hr)	\$8.00 to 12.00

Estimates:

	Avg	Std
Discount Rate	5%	0.5%
Value of Time (\$ / hr)	\$ 10.00	\$ 1.00

Given a range of values
how can I determine a
Standard Deviation?



Estimating a Standard Deviation

Upper Estimate Lower Estimate

96% Data ~ $\frac{UE_{96} - LE_{96}}{4} = s$

Given:

	Alternative - A			
	Initial		Rehabs.	
	Low	High	Low	High
Design Period / Life (years)	18	22	8	12
Agency Cost (\$ Millions)	25	27	8	10
Construction Period (days)	200	220	100	110

Estimates:

	Alternative - A			
	Initial		Rehabs.	
	Avg	Std	Avg	Std
Design Period / Life (years)	20	1.0	10	1.0
Agency Cost (\$ Millions)	26	0.5	9	0.5
Construction Period (days)	210	5.0	105	2.5

Given:

	Alternative - B			
	Initial		Rehabs.	
	Low	High	Low	High
Design Period / Life (years)	10	16	6	8
Agency Cost (\$ Millions)	18	24	4	6
Construction Period (days)	150	180	70	100

Estimates:

	Alternative - B			
	Initial		Rehabs.	
	Avg	Std	Avg	Std
Design Period / Life (years)	13	1.5	7	0.5
Agency Cost (\$ Millions)	21	1.5	5	0.5
Construction Period (days)	165	7.5	85	7.5

@Risk Functions

=RiskNormal(Average, Std)

	Alternative A		Alternative B	
	Initial	Rehabs	Initial	Rehabs
Discount Rate		5%		5%
SHA Value of Time	\$ 10.00	\$ 10.00	\$ 10.00	\$ 10.00
Design Period / Life (years)	20.0	10.0	13.0	7.0
Agency Cost (\$ Millions)	26.00	9.00	21.00	5.00
Construction Period (days)	210	105	165	85

Worksheet

Alternative A	Year			
	Initial	Rehab	Rehab	Salvage
	0.0	20.0	30.0	35.0
Agency Costs (Constant \$)	26.00	9.00	9.00	-4.50
Present Worth Factor		0.3769	0.2314	0.1813
Agency Cost (Present Worth)	26.00	3.39	2.08	-0.82
Total NPV (Agency Cost)	30.66			
User Costs (Constant \$)	6.30	3.15	3.15	0.00
Present Worth Factor		0.3769	0.2314	0.1813
User Cost (Present Worth)	6.30	1.19	0.73	0.00
Total NPV (User Cost)	8.22			
Grand Total NPV (all Costs)	38.87			

Worksheet

Alternative B	Year					
	Initial	Rehab	Rehab	Rehab	Rehab	Salvage
	0.0	13.0	20.0	27.0	34.0	35.0
Agency Costs (Constant \$)	21.00	5.00	5.00	5.00	5.00	-4.29
Present Worth Factor		0.5303	0.3769	0.2678	0.1904	0.1813
Agency Cost (Present Worth)	21.00	2.65	1.88	1.34	0.95	-0.78
Total NPV (Agency Cost)	27.05					
User Costs (Constant \$)	4.95	2.55	2.55	2.55	2.55	0.00
Present Worth Factor		0.5303	0.3769	0.2678	0.1904	0.1813
User Cost (Present Worth)	4.95	1.35	0.96	0.68	0.49	0.00
Total NPV (User Cost)	8.43					
Grand Total NPV (all Costs)	35.48					

Deterministic Results

Output	\$ Millions
A NPV Agency	30.66
A NPV User	8.22
A NPV Total	38.87
B NPV Agency	27.05
B NPV User	8.43
B NPV Total	35.48

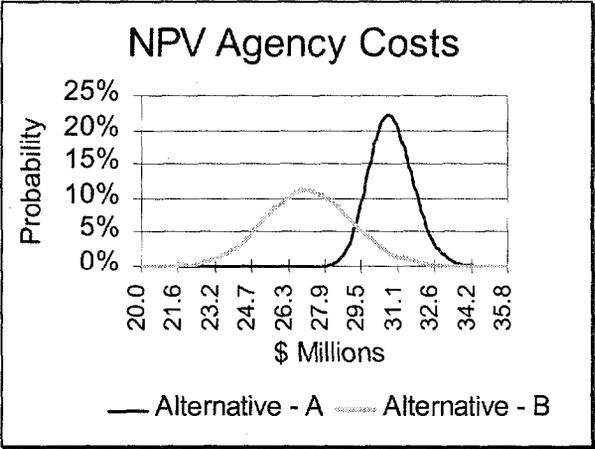
Simulation Processing

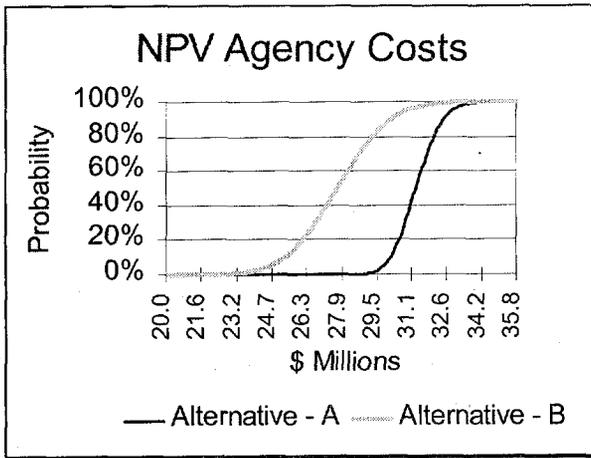
- Monte Carlo Sampling
- 18 Input Variables
- 6 Output Variables
- 20,000 iterations
- Run Time = 4 minutes 30 sec.

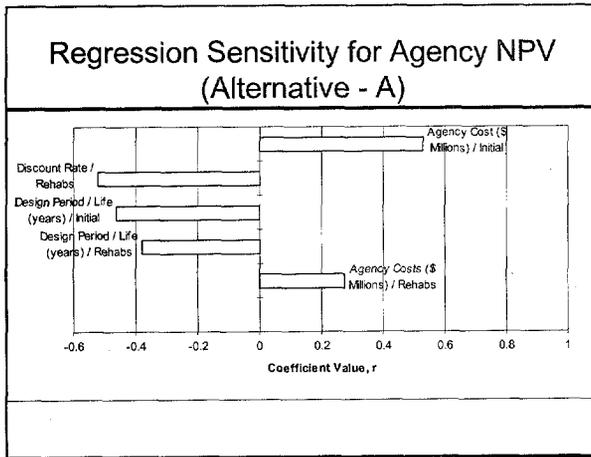
Simulation Results

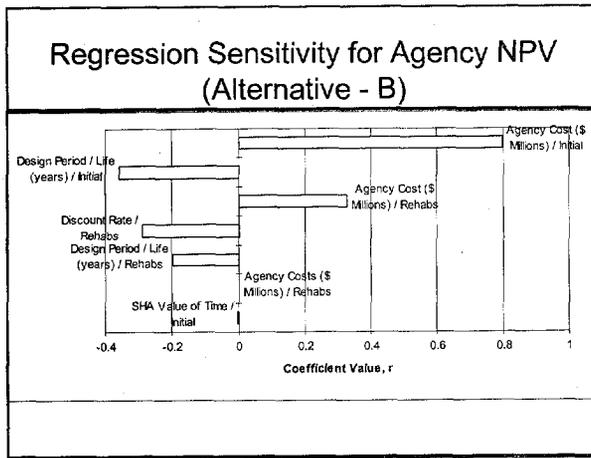
Summary Statistics

	Net Present Value					
	Agency Costs		User Costs		Total Costs	
	A	B	A	B	A	B
Mean	30.72	27.16	8.24	8.33	38.96	35.50
SD	0.95	1.88	0.72	0.89	1.34	2.31
Min	27.59	20.52	5.30	4.96	34.44	27.76
Max	36.17	37.06	11.01	12.82	47.18	47.93
5% Perc	29.25	24.09	7.07	6.93	36.89	31.74
25% Perc	30.07	25.89	7.75	7.71	38.05	33.92
50% Perc	30.67	27.12	8.24	8.30	38.92	35.42
75% Perc	31.32	28.41	8.72	8.92	39.83	37.00
95% Perc	32.36	30.27	9.46	9.85	41.27	39.38









Significant Input Variables Agency Costs (Alternative - A)

Value	Significant Input Variables for	Target= <25%
5.32%	Discount Rate / Rehabs	
20.62	Design Period / Life (years) / Initial	
25.64	Agency Cost (\$ Millions) / Initial	
Value	Significant Input Variables for	Target= >90%
4.51%	Discount Rate / Rehabs	
19.19	Design Period / Life (years) / Initial	
9.24	Design Period / Life (years) / Rehabs	
26.39	Agency Cost (\$ Millions) / Initial	

Significant Input Variables Agency Costs (Alternative - B)

Value	Significant Input Variables for	Target= <25%
19.54	Agency Cost (\$ Millions) / Initial	
Value	Significant Input Variables for	Target= >90%
4.72%	Discount Rate / Rehabs	
12.03	Design Period / Life (years) / Initial	
23.03	Agency Cost (\$ Millions) / Initial	
5.32	Agency Cost (\$ Millions) / Rehabs	

Statistics - (NPV \$ Millions)

	Net Present Value			
	Agency Costs			
	A	B	A-B	%Incr.
Mean	30.72	27.16	3.56	11.6%
SD	0.95	1.88	-0.93	-97.5%
Min	27.59	20.52	7.08	25.6%
Max	36.17	37.06	-0.89	-2.5%
5% Perc	29.25	24.09	5.16	17.6%
25% Perc	30.07	25.89	4.19	13.9%
50% Perc	30.67	27.12	3.55	11.6%
75% Perc	31.32	28.41	2.91	9.3%
95% Perc	32.36	30.27	2.08	6.4%

Agency Costs - Observations

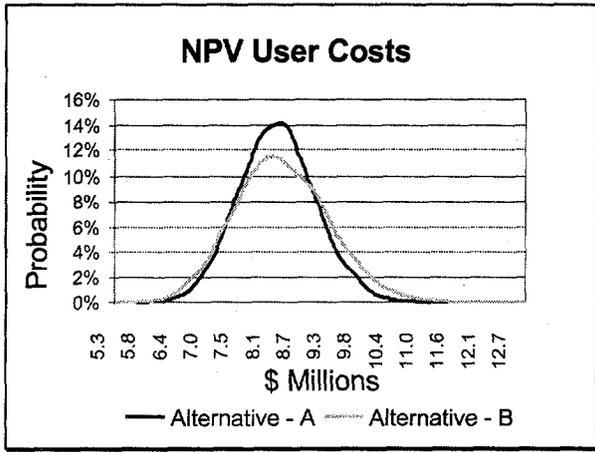
- Alternative A is less variable than Alternative B

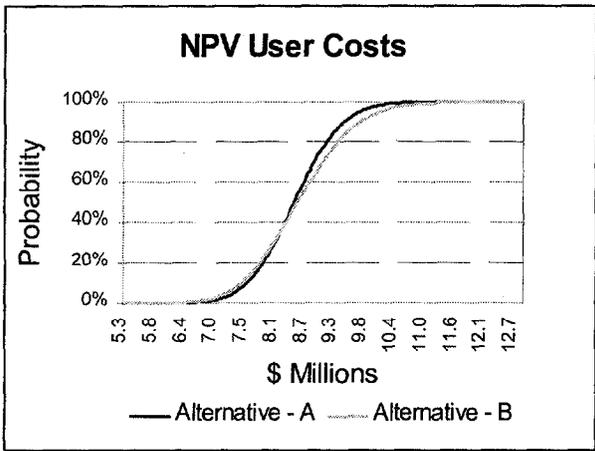
Agency Costs - Observations

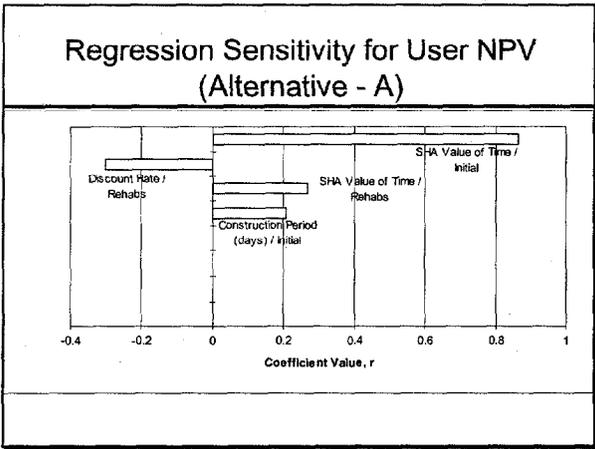
- Alternative A is less variable than Alternative B
- Maximum cost of Alternative A is less than Alternative B

Agency Costs - Observations

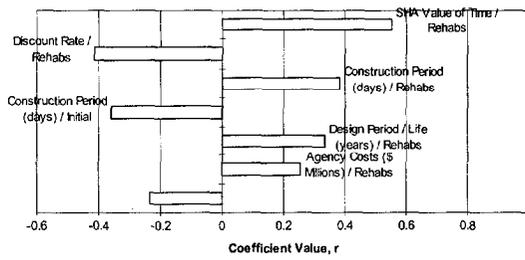
- Alternative A is less variable than Alternative B
- Maximum cost of Alternative A is less than Alternative B
- At the 95 th Percentile Alternative A will exceed cost Alternative B by 6.4 %.







Regression Sensitivity for User NPV (Alternative - B)



Significant Input Variables User Costs (Alternative - A)

Value	Significant Input Variables for	Target= <25%
8.93	SHA Value of Time / Initial	
	Value Significant Input Variables for	Target= >90%
4.72%	Discount Rate / Rehabs	
11.47	SHA Value of Time / Initial	
10.55	SHA Value of Time / Rehabs	

Significant Input Variables User Costs (Alternative - B)

Value	Significant Input Variables for	Target= <25%
9.31	SHA Value of Time / Initial	
13.77	Design Period / Life (years) / Initial	
	Value Significant Input Variables for	Target= >90%
4.66%	Discount Rate / Rehabs	
10.89	SHA Value of Time / Initial	
10.67	SHA Value of Time / Rehabs	
11.99	Design Period / Life (years) / Initial	
89.8	Construction Period (days) / Rehabs	

Statistics - (NPV \$ Millions)

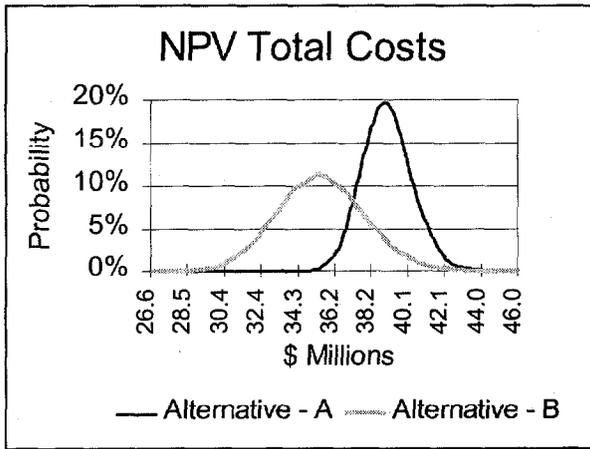
	Net Present Value			
	User Costs			
	A	B	A-B	%Incr.
Mean	8.24	8.33	-0.09	-1.1%
SD	0.72	0.89	-0.17	-23.2%
Min	5.30	4.96	0.34	6.5%
Max	11.01	12.82	-1.81	-16.4%
5% Perc	7.07	6.93	0.14	2.0%
25% Perc	7.75	7.71	0.05	0.6%
50% Perc	8.24	8.30	-0.06	-0.7%
75% Perc	8.72	8.92	-0.19	-2.2%
95% Perc	9.46	9.85	-0.39	-4.1%

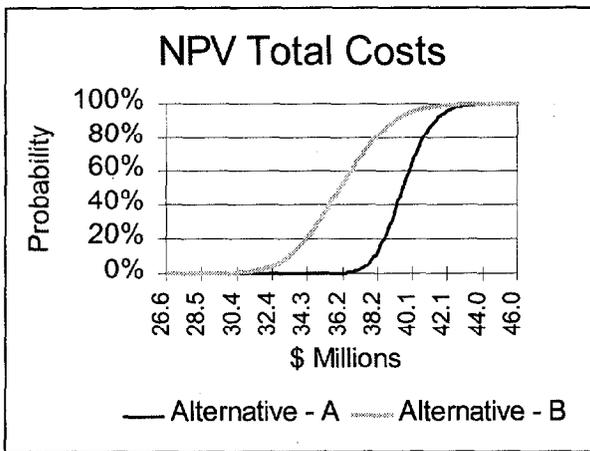
User Costs Observations

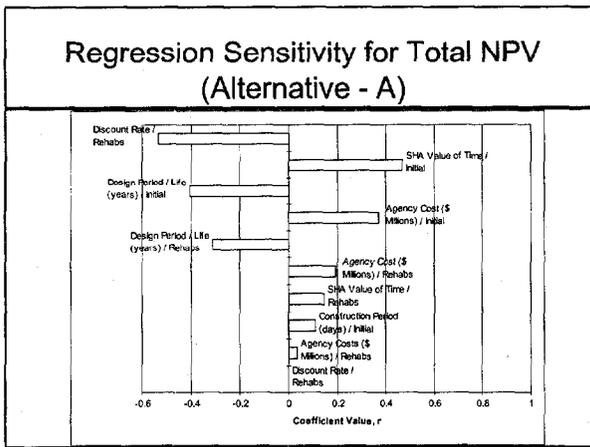
- User costs are approx. 20% of total NPV for both A & B

User Costs Observations

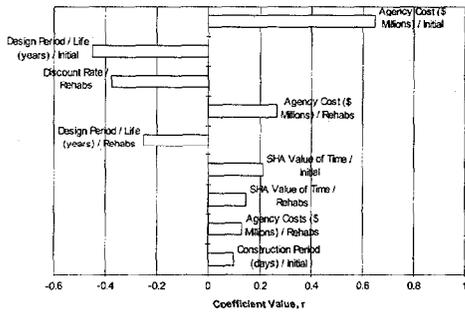
- User costs are approx. 20% of total NPV for both A & B
- When user costs dominate reevaluate rehabilitation strategy







Regression Sensitivity for Total NPV (Alternative - B)



Significant Input Variables Total Costs (Alternative - A)

Value	Significant Input Variables for	Target= <25%
5.33%	Discount Rate / Rehabs	
9.38	SHA Value of Time / Initial	
20.54	Design Period / Life (years) / Initial	
25.74	Agency Cost (\$ Millions) / Initial	
Value	Significant Input Variables for	Target= >90%
4.50%	Discount Rate / Rehabs	
10.79	SHA Value of Time / Initial	
19.27	Design Period / Life (years) / Initial	
9.38	Design Period / Life (years) / Rehabs	
26.28	Agency Cost (\$ Millions) / Initial	

Significant Input Variables Total Costs (Alternative - B)

Value	Significant Input Variables for	Target= <25%
13.83	Design Period / Life (years) / Initial	
19.78	Agency Cost (\$ Millions) / Initial	
Value	Significant Input Variables for	Target= >90%
4.64%	Discount Rate / Rehabs	
11.81	Design Period / Life (years) / Initial	
22.58	Agency Cost (\$ Millions) / Initial	
5.26	Agency Cost (\$ Millions) / Rehabs	

Statistics - (NPV \$ Millions)

	Net Present Value			
	Total Costs			
	A	B	A-B	%Incr.
Mean	38.96	35.50	3.47	8.9%
SD	1.34	2.31	-0.97	-72.2%
Min	34.44	27.76	6.68	19.4%
Max	47.18	47.93	-0.74	-1.6%
5% Perc	36.89	31.74	5.14	13.9%
25% Perc	38.05	33.92	4.13	10.8%
50% Perc	38.92	35.42	3.49	9.0%
75% Perc	39.83	37.00	2.83	7.1%
95% Perc	41.27	39.38	1.90	4.6%

Total Costs - Observations

- Alternative A is less variable than Alternative B

Total Costs - Observations

- Alternative A is less variable than Alternative B
- Maximum cost of Alternative A is less than Alternative B

Total Costs - Observations

- Alternative A is less variable than Alternative B
- Maximum cost of Alternative A is less than Alternative B
- At the 95th Percentile Alternative A will exceed cost Alternative B by 4.6%.

Conclusions

- Alternative B is more variable than Alternative A

Conclusions

- Alternative B is more variable than Alternative A
- More certain of higher costs associated with Alternative A than Alternative B

Which Alternative would you select?

Must define Agency's tolerance for risk.

**If User Costs Dominate ...
Reevaluate Alternatives**

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

End Session

Presentation Techniques



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

Know Your Audience

- Does your audience understand ...
 - LCCA?
 - Discounting?
 - User costs?
 - Value of time?
 - Risk Analysis/Probability?

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

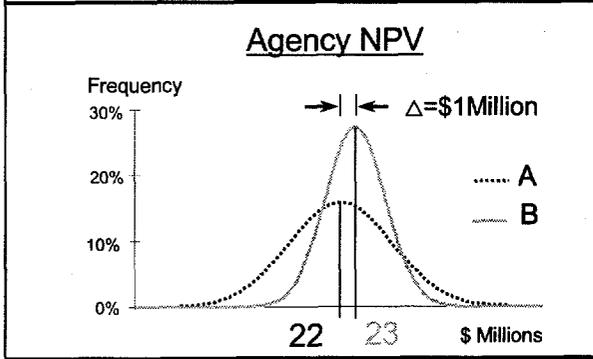
Report

- One Page Summary
- Supporting Documentation

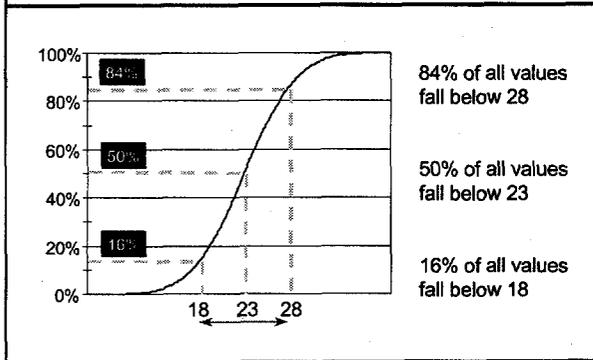
One Page Summary

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

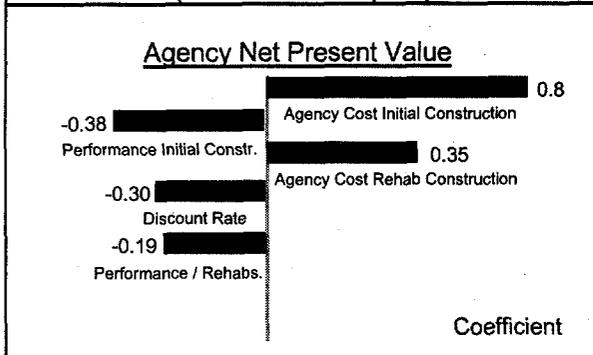
Histogram -



Cumulative -



Regression Sensitivity (Tornado Graphs)



Supporting Documentation

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

End Session

Benefits and Implementation



Benefits of LCCA

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

Benefits of LCCA Con't

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

Benefits of Risk Analysis

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

Benefits of Risk Analysis

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

Benefits of RA Con't

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

Caveats

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



Implementation

Probabilistic Approach

Obstacles

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

Implementation Steps

- Awareness
- Change
- Communication
- Resources



Plant the Seed

Four Stages of Learning

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

Implementation Steps
<ul style="list-style-type: none">■ Identify a champion■ Understand classical LCCA■ Assess current procedures■ Determine data availability■ Tap expert opinion

Probabilistic Champion
<ul style="list-style-type: none">■ Believer■ Well founded in LCCA■ Spread sheet literate■ Time available

Resources
<ul style="list-style-type: none">■ Equipment■ Software■ Personnel■ Training■ User groups

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>
 - pwd: risk

Top Management Support

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



Steering Committee

- LCCA procedure
- Probabilistic approach

Documentation

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

End Session

Workshop Summary

Key Areas Covered

- Traditional LCCA
- User Cost
- Risk Analysis Approach



Things to Remember

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

Recommendations

LCCA ...

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



Recommendations

Agency Costs ...

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



Recommendations

User Costs ...

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



Recommendations

■ Discount Rate

- 3% - 5% Real

■ Value of time

- Passenger \$10 - \$13
- Single Unit Trk \$17 - \$19
- Combo Trk \$21 - \$24

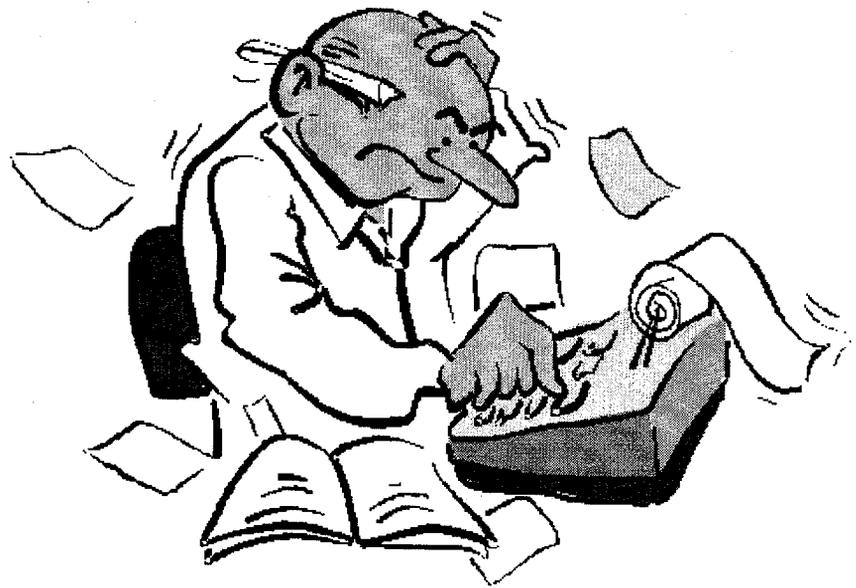
Recommend a risk analysis approach in the treatment of uncertainty.

Thank y'all for having us ...



The End

CLASS EXERCISES



**LIFE CYCLE COST ANALYSIS
IN PAVEMENT DESIGN
DP-115**

Example Problem

Net Present Value

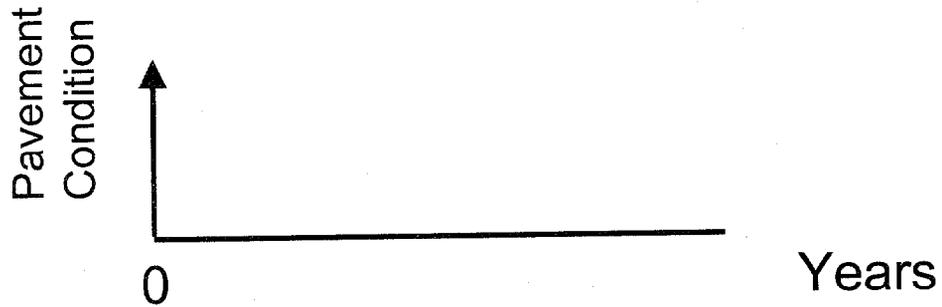
Compute the total Net Present Value (NPV) for the following Alternative.

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

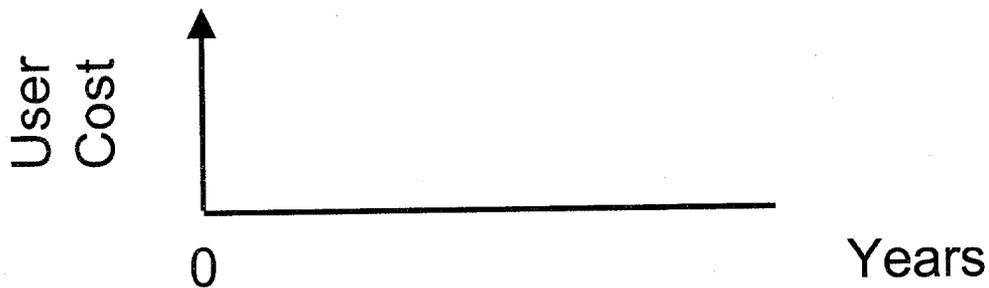
Assume the following:

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

Performance Curves



Expenditure Streams



Discount Rate Factors

n	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

$$NPV = InitialCost + \sum FutureCost \left[\frac{1}{(1+i)^n} \right]$$

NPV Agency

NPV =

NPV User

NPV =

Total NPV

Total NPV = NPV Agency + NPV User

=

+

=

Work Zone User Cost Class Exercise

The eastbound lane of a six lane facility is undergoing rehabilitation. Figures 1 and 2 provide a layout of the work zone and the associated cost components. The six lane 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 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 is posted at 35 mph. The free flow capacity of the roadway is estimated at 2100 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. The first problem is to identify and calculate the quantity of traffic associated with each work zone user cost component. Provide your answers in the tables that are provided. The second problem is to determine the reduced speed delay to traverse the queue and work zone. The third problem is to calculate the user costs associated with the queue. If time permits, calculate the total user costs associated with the work zone.

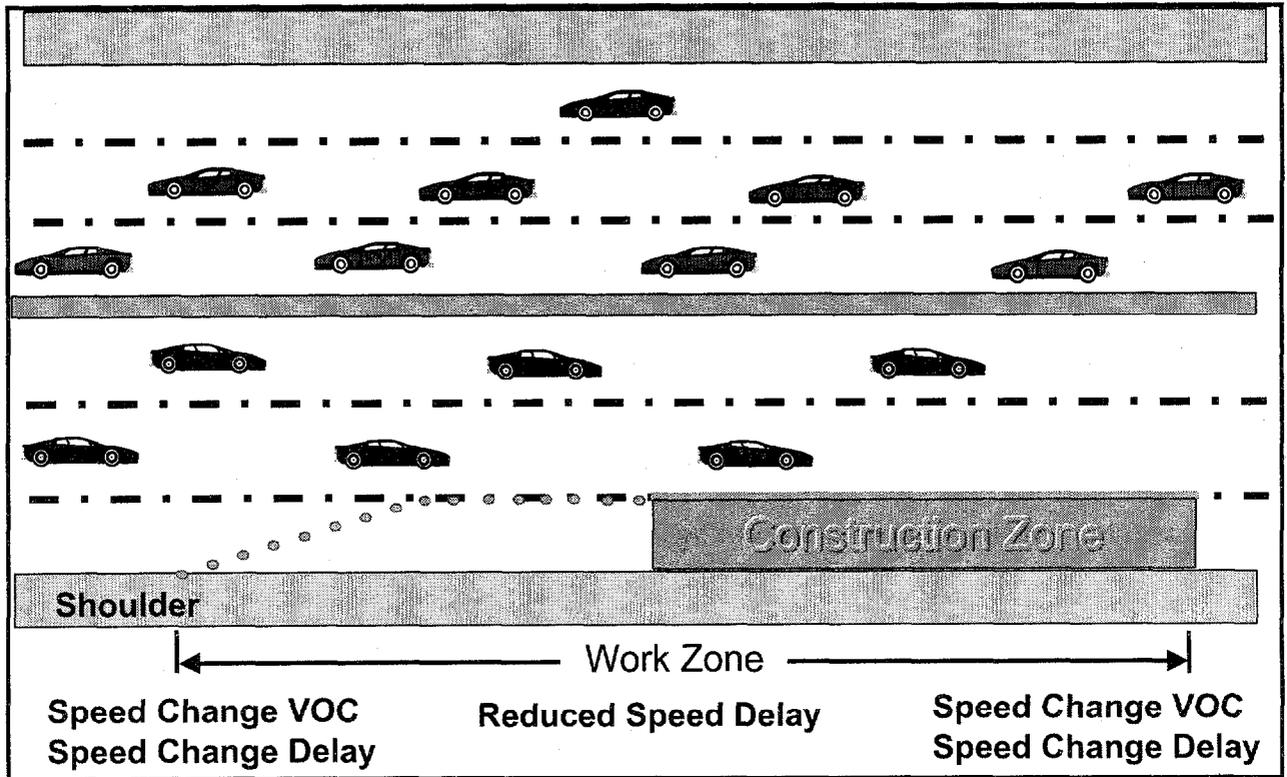


Figure 1. Work Zone User Cost Components at Free Flow Conditions.

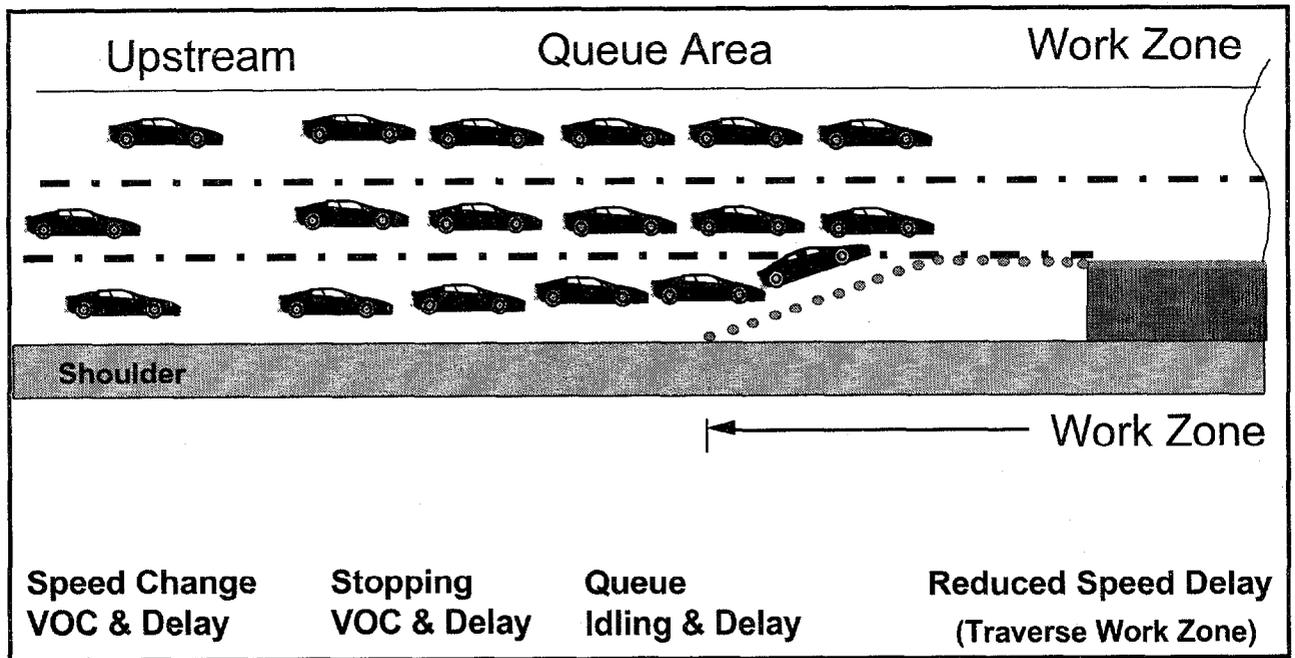


Figure 2. Work Zone User Cost Components at Forced Flow Conditions.

Table 1. Capacity Analysis of Work Zone Operation.

Eastbound		95,000 AADT					
Directional Factor		54.0%	51,300		Directional AADT		
Hour	% Hrly Distri.	Vehicle Demand	Capacity	Queuing Rate	Culm. Que Veh.	Vehicles that Stop	WZ Vehicles
		vph	vph	vph			
0 - 1	0.9	462	2,800	(2,338)	0	0	462
1 - 2	0.5	257	2,800	(2,544)	0	0	257
2 - 3	0.4	205	2,800	(2,595)	0	0	205
3 - 4	0.4	205	2,800	(2,595)	0	0	205
4 - 5	0.6	308	2,800	(2,492)	0	0	308
5 - 6	1.8	923	2,800	(1,877)	0	0	923
6 - 7	4.4	2,257	2,800	(543)	0	0	2,257
7 - 8	6.2	3,181	2,800	381	381	3,181	3,181
8 - 9	5.7	2,924	2,800	124	505	2,924	2,924
9 - 10	5.1	2,616	2,800	(184)	321	2,616	2,616
10 - 11	5.2	2,668	2,800	(132)	189	2,668	2,668
11 - 12	5.6	2,873	2,800	73	261	2,873	2,873
12 - 1	6.0	3,078	2,800	278	539	3,078	3,078
1 - 2	5.9	3,027	2,800	227	766	3,027	3,027
2 - 3	6.4	3,283	2,800	483	1,249	3,283	3,283
3 - 4	7.4	3,796	2,800	996	2,246	3,796	3,796
4 - 5	7.8	4,001	2,800	1,201	3,447	4,001	4,001
5 - 6	7.5	3,848	2,800	1,048	4,494	3,848	3,848
6 - 7	5.9	3,027	2,800	227	4,721	3,027	3,027
7 - 8	4.9	2,514	2,800	(286)	4,435	2,514	2,514
8 - 9	4.0	2,052	2,800	(748)	3,687	2,052	2,052
9 - 10	3.3	1,693	2,800	(1,107)	2,580	1,693	1,693
10 - 11	2.4	1,231	2,800	(1,569)	1,011	1,231	1,231
11 - 12	1.7	872	2,800	(1,928)	0	0	872
Total	100	51,300				45,811	51,300

Problem No. 1

Using the data from the 24 hour capacity analysis shown in Table 1 quantify the traffic affected in each of the following cost components for the duration of the project.

Base Case (Free Flow) Speed Change Delay

Vehicle Class	Eastbound Direction
90% Auto	
6% Single Unit	
4% Combination	
Total	

Base Case (Free Flow) Speed Change VOC

Vehicle Class	Eastbound Direction
90% Auto	
6% Single Unit	
4% Combination	
Total	

Base Case (Free Flow) Reduced Speed Delay

Vehicle Class	Eastbound Direction
90% Auto	
6% Single Unit	
4% Combination	
Total	

Forced Flow Stopping Delay

Vehicle Class	Eastbound
90% Auto	
6% Single Unit	
4% Combination	
Total	

Forced Flow Stopping VOC

Vehicle Class	Eastbound Direction
90% Auto	
6% Single Unit	
4% Combination	
Total	

Forced Flow Que Delay

Vehicle Class	Eastbound Direction
90% Auto	
6% Single Unit	
4% Combination	
Total	

Forced Flow Idling VOC

Vehicle Class	Eastbound Direction
90% Auto	
6% Single Unit	
4% Combination	
Total	

Problem No. 2

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

Average queue length calculations:

Direction	Max. No. Qued Veh.	Queue Vol./ Queue Speed	Upstream Vol./ Upstream Speed	Change Veh. Den.	Max. Queue Length (mi.)	Average Queue Length (mi.)
Eastbound						

Average queue delay per vehicle:

Direction	Time (Hours)		
	@ Upstream Speed	@Queue Speed	Difference
Eastbound			

Compute the reduced speed delay to traverse the work zone.

	Upstream Speed	Work Zone Length (miles)	Time (Hours)
	_____ mph	_____ mi.	_____ hrs.
	_____ mph	_____ mi.	_____ hrs.
Increased Time to Traverse the Work Zone:			_____ hrs.

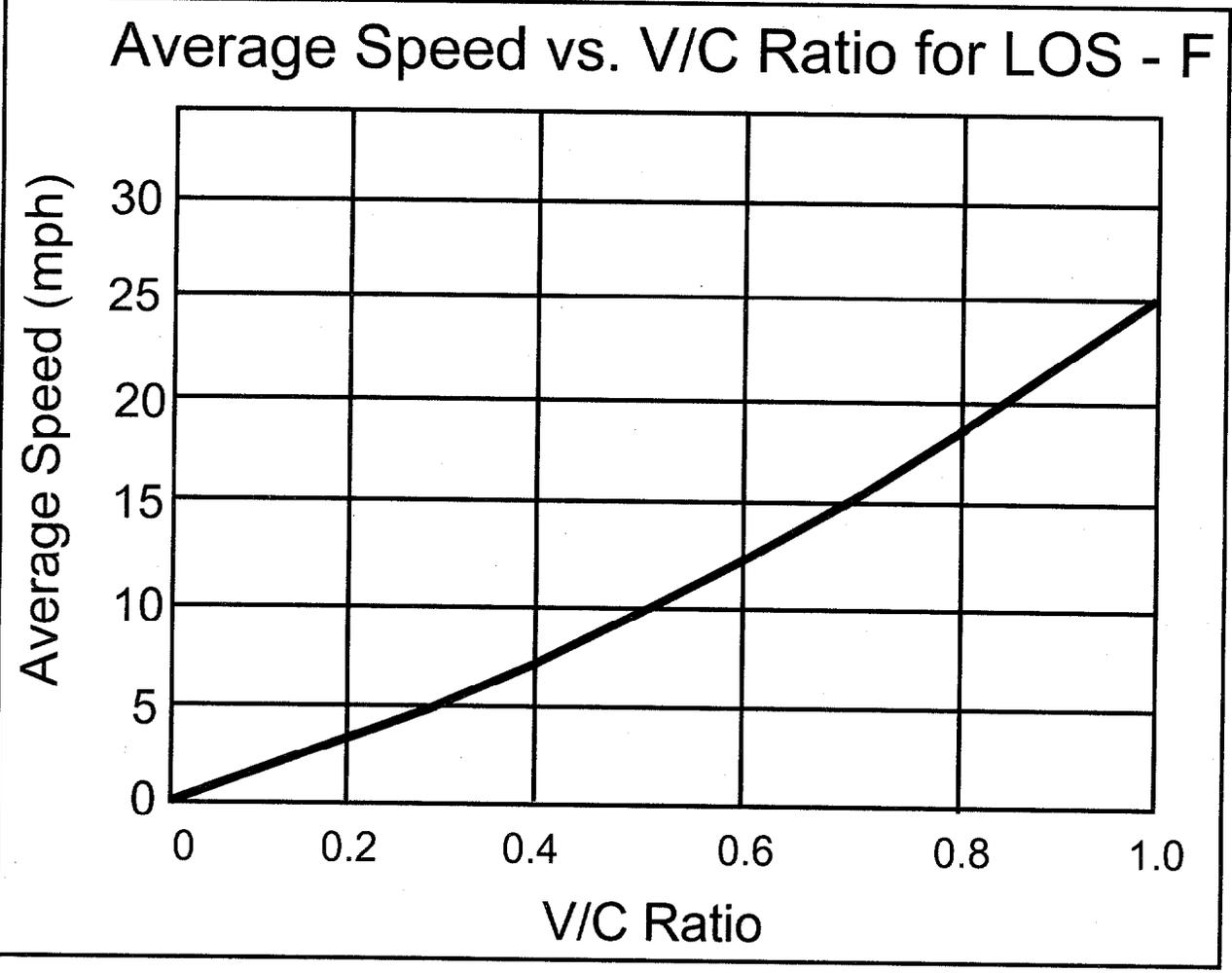


Figure 3. V/C Ratio versus Average Queue Speed (Source: NCHRP 133).

Table 2. 1 Added Time and Vehicle Running Cost / 1000 Stops and Idling Costs (Aug 96).

Initial Speed (mph)	Added Time (Hr / 1000 Stops) (Excludes Idling Time)			Added Cost (\$/1000 Stops) (Excludes Idling Time)		
	Pass Cars	Single Unit Truck	Combination Truck	Pass Cars	Single Unit Truck	Combination 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 (\$ / vehicle-hr)				0.6927	0.7681	0.8248

*Original data did not provide values for trucks at higher speed. Analysts will need to extrapolate these values when truck calculations are needed at these higher speeds.

Class Exercise

User Cost and NPV

Problem Statement:

A State highway agency is conducting a Life Cycle Cost Analysis of a proposed 6 lane facility (3 lanes per direction). The current AADT is 40000 vehicles per day per direction. The State is considering two proposed 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 per direction. Performance lives for two alternative design and rehabilitation strategies are shown in Table 1. *Compute the total Net Present Value (NPV) for each alternative A and B.* Assume a 35 year analysis period. Include in your analysis the effect of salvage value if applicable. Construction cost and days for initial construction and rehabilitation activities can be found in Figures 1 - 4. Real opportunity cost of money to the State highway agency is 4%. The SHA estimates the value of time to be \$10. Routine reactive maintenance cost differences between alternatives are insignificant. Use the formula provided to calculate net present value. Use Table 2 to summarize your selected input values. If needed use Table 3 for the appropriate discount factor. The cost of daily delay is shown in Table 4. Use Tables 5 and 6 as worksheets.

Table 1. Input variable ranges for Alternatives A & B.

	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 for Alternatives A & B.

	Alternative - A			Alternative - B				
	Initial	Rehabs.		Initial	Rehabs			
		1	2		1	2	3	4
Performance (years)								
Construction Cost \$								
Construction Days								
Daily Delay Cost \$								
User Cost \$								

NPV = Initial Cost +

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

Where:

NPV = Net Present Value

i = discount rate

n = years discounted

Table 3. Discount Factors.

Year n	Discount Rate				
	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 Construction - Alternative A

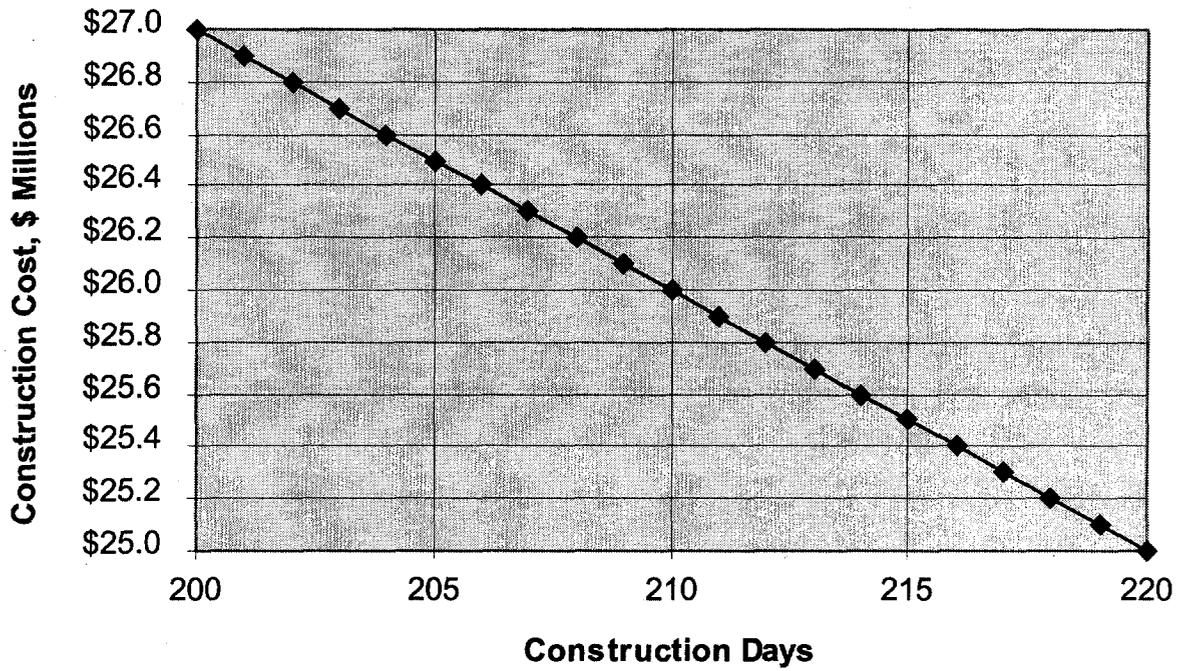


Figure 2. Rehabilitation Costs - Alternative A

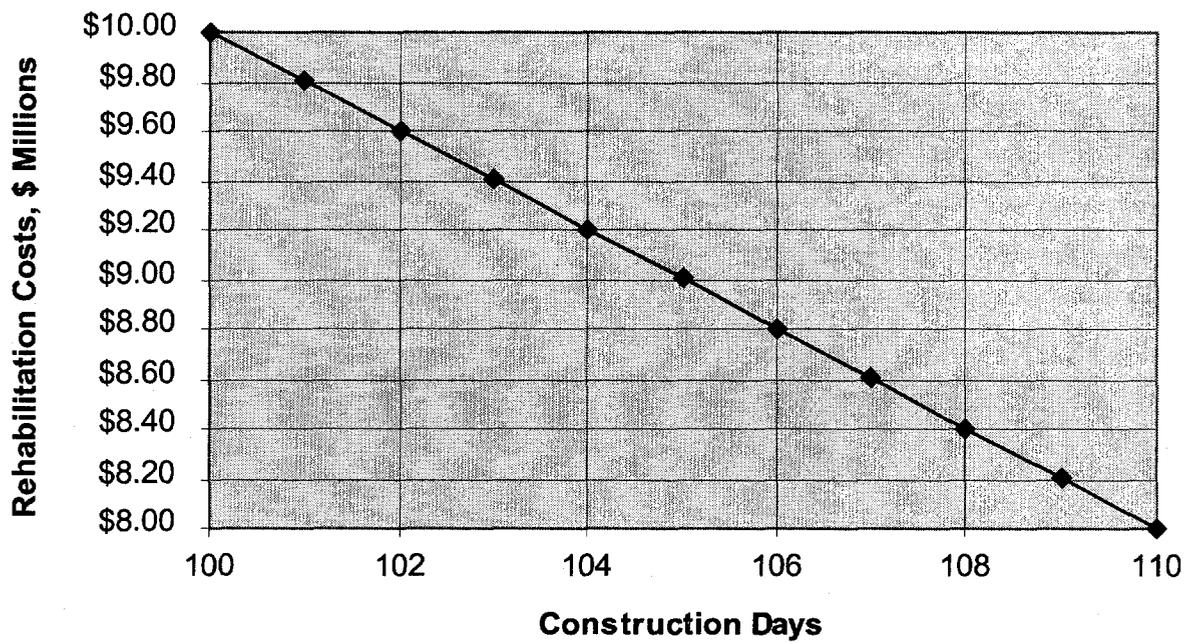


Figure 3. Initial Construction Costs - Alternative B

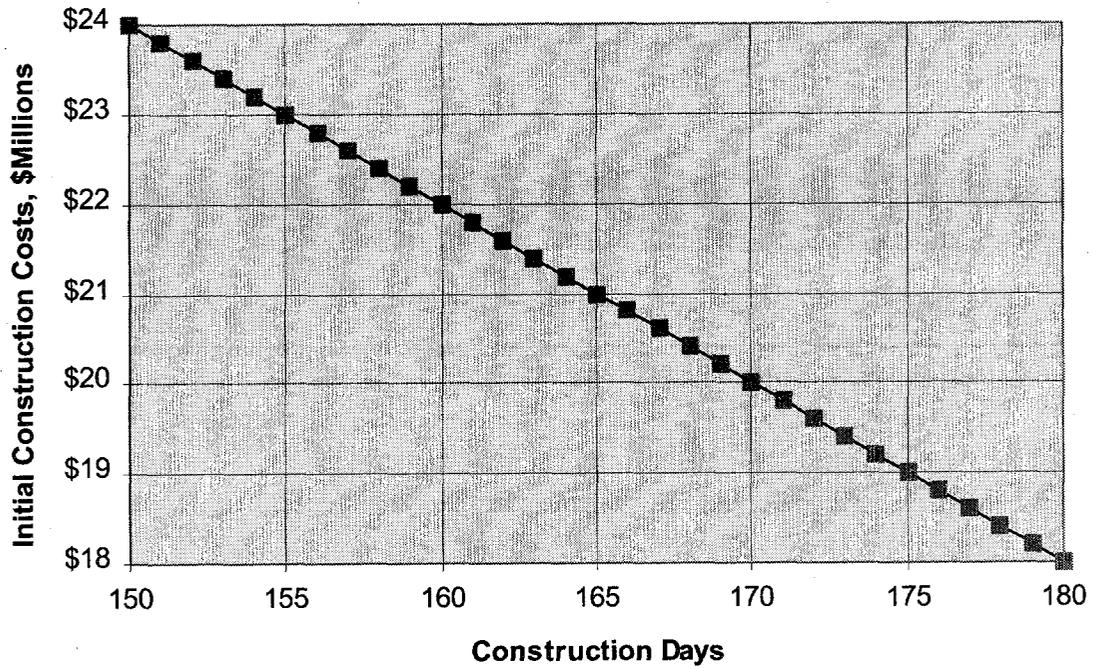


Figure 4. Rehabilitation Costs Alternative - B

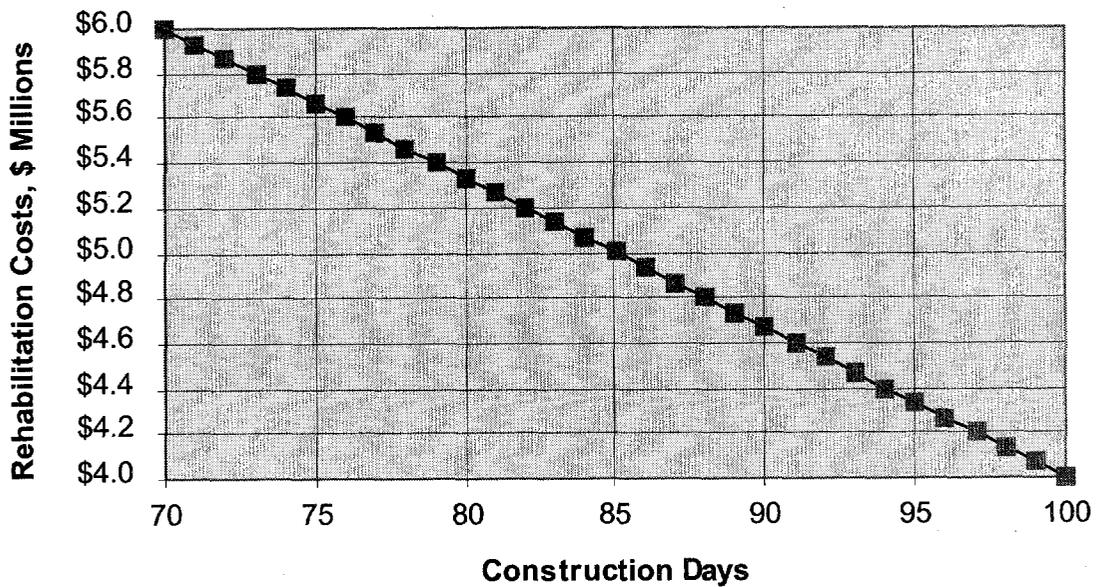


Table 4. Daily cost of delay.

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

Table 5. NPV Worksheet.

	Year					
Alternative - A						
Agency Cost (Constant \$)						
Present Worth Factor						
Agency Cost (Present Worth)						
Total NPV (Agency Cost)						
Construction Days						
Daily Delay (Constant \$)						
User Cost (Constant \$)						
Present Worth Factor						
User Cost (Present Worth)						
Total NPV (User Cost)						
Grand Total NPV (all costs)						

	Year					
Alternative - B						
Agency Cost (Constant \$)						
Present Worth Factor						
Agency Cost (Present Worth)						
Total NPV (Agency Cost)						
Construction Days						
Daily Delay (Constant \$)						
User Cost (Constant \$)						
Present Worth Factor						
User Cost (Present Worth)						
Total NPV (User Cost)						
Grand Total NPV (all costs)						

