

# Chapter 13

## Dealing with Risks and Uncertainties

*Our fundamental need is not the elucidation of the mysterious, but an appreciation of the significance of the obvious.*

John Droege, **Freight Terminals and Trains**, 1925

# Risks

- Risk is anything that can go wrong, possibly leading to failure of the project:
  - Construction risks – accidents, cost overruns or delays
  - Financial risks – inability to finance the project
  - International risks – political instability, unfavorable exchange rates, government interference
  - Infrastructure failure
  - Lack of demand
  - High operating costs

# Uncertainty

- Inability to predict what will happen:
  - Demand
  - Interest rates
  - Costs of materials
  - Time required for construction
  - Public reaction to project
  - Environmental impacts

# Methods for Dealing with Risks and Uncertainty

- Chapter 11
  - Sensitivity analysis
  - Scenarios
- Chapter 13
  - Simulation
  - Probabilistic risk assessment
  - Performance-based technology scanning

# Modeling Performance

- Questions to be addressed:
  - How will capabilities or performance change if the project is implemented?
  - If system capabilities or performance change, what will happen to demand?
  - How will uncertainties affect the success of the project?
- System models can be run repeatedly to address these and other questions related to uncertainty.

# Probabilistic Risk Assessment (PRA)

- A structured methodology for improving safety
- Risk reflects both the probability and the consequences of an accident or incident.
- Reducing either the frequency or severity of an accident will reduce risk.
- PRA provides a way of comparing the cost effectiveness of various options for reducing risk.

# Performance-Based Technology Scanning (PBTS)

- Technology scanning:
  - What technologies might be relevant to an infrastructure-based system?
- Performance-based analysis:
  - What aspects of performance might be affected by new technologies?
  - How will the market respond to changes in performance?
- PBTS provides a way of identifying the most promising technologies and research opportunities.

# Simulating Financial Results

- Basic equations for financial performance:

$$\text{Investment} = \text{Equity} + \text{Debt}$$

$$\text{Profit} = \text{Revenue} - \text{Cost} - (I\%)(\text{Debt})$$

$$\text{ROI} = \text{Profit}/\text{Equity}$$

- Given expectations for revenue, cost, interest rates, and total investment, will we be able to earn a sufficient ROI to satisfy our investors?



# Random Variables

- Values for a random variable may be generated from a distribution or from a set of possible values.
- Spreadsheets can be used to:
  - Generate values for variables that follow a normal distribution or certain other standard statistical distributions.
  - Generate random numbers that can be used to select a value from a finite set of possible values.
- Values for one random variable may depend upon or determine the values for others.

# Use of Random Numbers

- When a random number function is encountered, a spreadsheet will generate a random number RAND() between 0 and 1.
- To select X from a uniform distribution between A and B:

$$X = A + \text{RAND}() (B-A)$$

- To define a set of N values for x:

$$X = V_1 \text{ if } 0 \leq \text{RAND}() < R_1$$

$$X = V_2 \text{ if } R_1 \leq \text{RAND}() < R_2$$

...

$$X = V_N \text{ if } R_{N-1} \leq \text{RAND}() < 1$$

# Use of Random Numbers (Continued)

- It is possible to create new, possibly quite complex random variables:

$$R_3 = R_1 + R_2$$

$$R_4 = R_1 / R_2$$

$$R_5 = R_3 + R_4 = R_1 + R_2 + R_1 / R_2$$

- It is possible to have one column per time period, so that the spreadsheet calculates performance in time  $t+1$  as a function of performance in time  $t$ . Copying to additional columns extends the simulation through additional time periods.

# Example: Will ROI Be OK?

- Proposal:
  - Purchase toll road for \$100 million
  - Toll revenues: \$20 to \$25 million/year
  - Operating expenses: \$10 to \$15 million/year
  - Financing:
    - Bonds: \$80 million at 8%
    - Equity: \$20 million
    - MARR for equity investors: 10%
- Question: Will ROI be acceptable?

## Example: Will ROI Be OK?

- Equations:

$$\text{Profit} = \text{Toll Revenue} - \text{Op Expense} - \$6.4$$

$$\text{ROI} = \text{Profit}/\$20 \text{ million}$$

- Random variables: Toll revenue and operating expense are used to calculate profit and ROI

# Example: Will ROI Be OK?

				Investment	\$100	million	
				Debt	\$80	million	
				Interest	8%		
Year	Random Number 1	Random Number 2	Revenue	Cost	Interest	Profit	ROI
1	0.8877	0.1381	24.44	10.69	6.40	7.35	36.7%
2	0.9971	0.0775	24.99	10.39	6.40	8.20	41.0%
3	0.6517	0.1919	23.26	10.96	6.40	5.90	29.5%
...	...	...	...	...	...	...	....
19	0.9305	0.3955	24.65	11.98	6.40	6.27	31.4%
20	0.9416	0.4310	24.71	12.16	6.40	6.15	30.8%
Total			455.57	245.72	128.00	81.85	20.5%

# Probabilistic Risk Assessment (PRA)

- Risk can be defined as the product of two factors:
  - The probability of an accident or incident
  - The consequences of an accident or incident.
- Reducing either the frequency or severity of an accident will reduce risk.
- Cost-effectiveness: compare the reduction in risk resulting from an alternative to the cost of that alternative.

# Types of Consequences

- Many types of consequences:
  - Fatalities (operators, users, abutters)
  - Injuries
  - Property damage (system, users, abutters)
  - Delays
  - Disruption of service
- A weighting scheme is needed to reflect the relative importance of the consequences



# Weighting Consequences

- Many are readily quantifiable in monetary terms, based upon past experience and models of expected performance.
- Some consequences are harder to predict:
  - Significant disruptions may have long-term economic impacts on the region
  - Perceptions of risk may affect demand for the system
- Some consequences – notably fatalities and injuries – are very difficult to even discuss.

# **Considering Fatalities and Serious Injuries: *Who can put a value on a human life??***

- Legal cases:
  - What were the expected lifetime earnings of an individual killed in an accident?
  - What were the hospital, rehabilitation, and long-term care costs of someone severely injured?
  - What price can be put on loss of loved ones or loss of one's own capabilities?
- These questions all assume that a particular individual was injured or killed.

# Considering Fatalities and Serious Injuries: *Who can put a value on a human life??*

- Frequently heard after a fatal accident:
  - We should spend whatever is necessary to ensure that this never happens again!
  - If we save only one future life, it will all be worth it!
- But remember, “it ain’t necessarily so!” The same money could be used in many other ways to improve safety, to promote public health, to reduce exposure to risks and to many other ways to avoid future fatalities.

# Another Way to Consider Fatalities

- What would individuals pay to reduce their exposure to risk?
- How much should we – as a society – be willing to pay to take actions that are expected to reduce the risks of fatal accidents?

*These two questions are related, and surveys and studies can be designed to provide answers to them. The issue is not “the value of a human life” but “the value of reducing risks” – a benefit that is shared by all of the users of a system.*

# Values for Reducing Risks

- Surveys can examine what people would pay to reduce risk of fatalities by 1/1million in various activities.
- Studies can examine what do when offered a choice of reducing risks. What kinds of risks do we accept?
  - Not wearing seatbelts in automobiles or helmets when riding a bike?
  - Driving after drinking or when very tired?
  - Participating in risky sports?
- Public agencies can use such information to decide upon a value to use in regulating risks: this is sometimes called the value of a “statistical life”, and typical values are in the range \$1 to \$6 million.

# Risk – Something We All Accept



# Example: Auto Safety Options

## Base Case Assumptions

- Probability of fatal accident: 1/100 million miles
- Average miles per year: 10,000
- Risk of fatality per year: 1 in 10 thousand
- Value of “statistical fatality”: \$2.5 million
- Base risk/year: \$250

## Example: Auto Safety Options

<b>Option</b>	<b>Reduction in Probability of Fatality</b>	<b>Cost per Car</b>	<b>Risk</b>
Base	0	0	\$250/year
Seat Belts	50%	\$100	\$125/year
Airbag	80%		\$25/year
Collision Avoidance	10%	\$20,000	\$22.50/year



# Example: Auto Safety Options

<b>Option</b>	<b>Reduction in Risk/Year</b>	<b>Cost/year per Car</b>	<b>Cost Effectiveness</b>
Base	0	0	N.A.
Seat Belts	\$125	\$12	10.4
Airbag	\$100	\$60	1.7
Collision Avoidance	\$2.50	\$2,400	0.001

# Global Risks of an Infrastructure-Based System

- Identify all types of accidents
- Estimate probabilities as a function of time or usage
- Estimate the expected consequences
- Calculate risks for each type of accident
- Sum over all segments and all types of accident

# Global Risks of an Infrastructure-Based System

- Risks related to:
  - Construction
  - Normal operations
  - Maintenance and rehabilitation
  - Deteriorating infrastructure
  - Structural failure
  - Natural disasters (earthquakes, floods, etc.)
- Some risks relate to minor, common events, while others relate to rare, potentially catastrophic events.

# Risk Factors, Three Systems

	<b>Major Canal</b>	<b>Skyscraper</b>	<b>Urban highway</b>
Risk of fatality/ Construction Worker	0.05	0.001	0.001
Construction Workers	20,000	1,000	1,000
Risk of fatality per user, normal Operation	0.2 per million	0.02 per million	2 per million trips
Users per year	1 million	3 million	30 million
Daily usage	40 ships per day	3,000 occupants	100,000 vehicles/day

	<b>Major Canal</b>	<b>Skyscraper</b>	<b>Urban highway</b>
Potential fatalities from structural failure	10	2,000	100
Likelihood of failure in 100 years	0.01	0.01	0.01
Expected fatalities:			
Construction (total)	1,000	1	1
Operations (per year)	0.2/year or 20 in 100 years	0.06/year or 6 in 100 years	60/year or 6,000 in 100 years
Failure (life of project)	1 in 100 years	20 in 100 years	1 in 100 years

# Perceived Risks

- Perceptions are important
- Perceptions do not necessarily match the facts
- Public response to a project is based upon perceptions, not the facts
- Some kinds of accidents or incidents are feared much more than others

# Perceived Risks

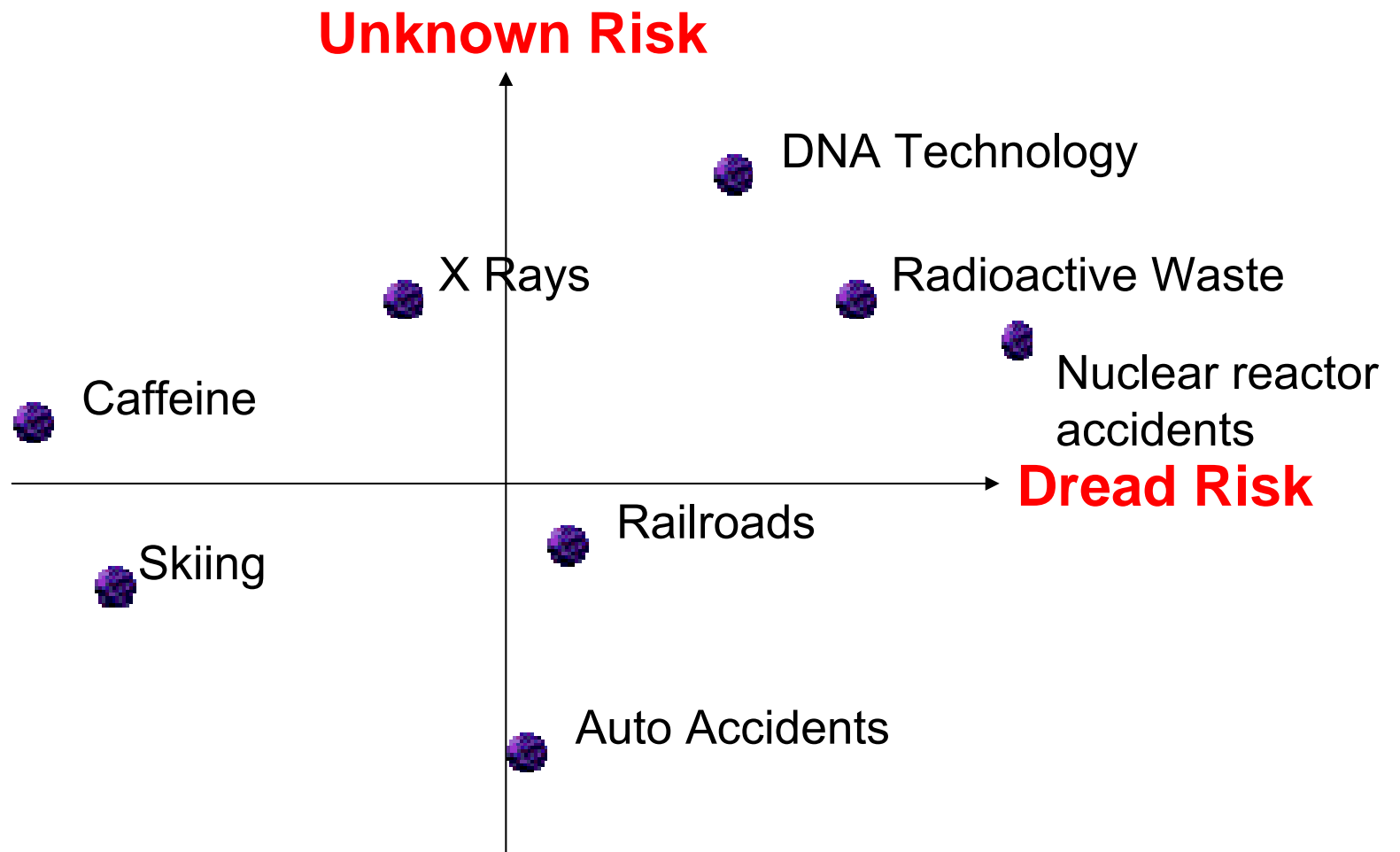
## UNKNOWN RISKS

- Not observable
- Unknown to those exposed
- Effect delayed
- New risk introduced by projects
- Risk unknown to science

## DREAD RISKS

- Dreadful feelings
- Catastrophic
- Fatal consequences
- Not equitable
- High risk to future generations
- Not easily reduced
- Involuntary

Source: Source : P. Slovic, B. Fischhoff, S. Lichtenstein, "Perilous Progress: Managing the Hazards of Technology", (Westview, Boulder, CO, 1985), p. 91-125.



Adapted from: P. Slovic, B. Fischhoff, S. Lichtenstein, in "Perilous Progress: Managing the Hazards of Technology", (Westview, Boulder, CO, 1985) p 91-125



# Weighting Risks for Catastrophic Events

- People do seem to fear catastrophic events much more than a large number of minor events, even if the expected number of casualties is the same.
- When evaluating global risks, the expected fatalities from rare, but catastrophic events can be weighted more heavily than those resulting from routine accidents.
- For example, a study for JR East Railway concluded that an appropriate weighting factor would be the number of expected fatalities raised to the power  $1/3$ .

# Indirect Consequences

- An incident, though not severe, could suggest risks are far greater than previously imagined:
  - Three-mile island
- Responses to incidents may be more emotional than rational:
  - Over-reaction
  - Irrelevant reaction
  - Ineffective or counter-productive reaction
- Advance planning, public awareness of risks, and effective response capabilities can limit irrational responses

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