ESD.36 System Project Management

Project Risk Management

Instructor(s)

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Lecture 11

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Massachusetts Institute of Technology

Outline

- Layers of Risk and Classical Risk Management
- Review: Project NPV, Value at Risk (VAR) Concept
- Example: Garage Case

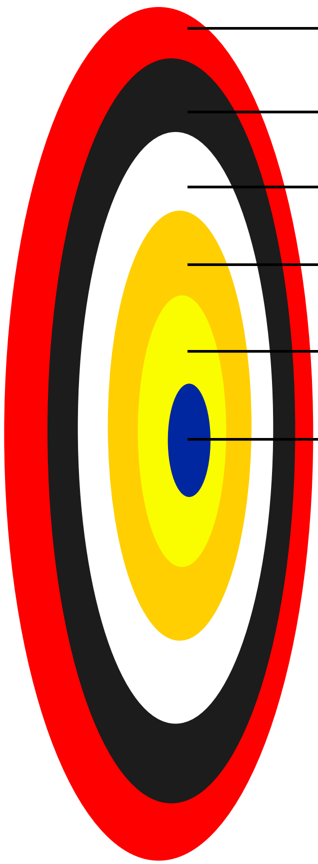
Layers of Risk
Classical Risk Management

Projects entail many types of risks

- Projects bring together many risks
- In energy (petroleum) field …..
    - Subsurface (e.g. Macondo well)
    - Fiscal
    - Market
    - Technology
    - Partner, contractor
    - Project execution
    - Operability

- Project Manager authority and influence limited relative to set of risks that matter
- Nature, degree of manageability and, therefore, desired mental model , differs by risk type, nature of outcome

Layers of Risk



Natural Risks
- Geology
- Weather

Market Risks
- Commodity Prices
- Exchange rates
- Interest rates
- Risk premium

Country/Fiscal
- Political stability
- Terrorism
- Financial, economic stability, inflation
- Regulatory stability or intervention
- Contract enforcement
- Legal stability

Industry/Competitive
- Industry evolution
- Demand, growth rates
- Supply conditions
- Competition
- Infrastructure

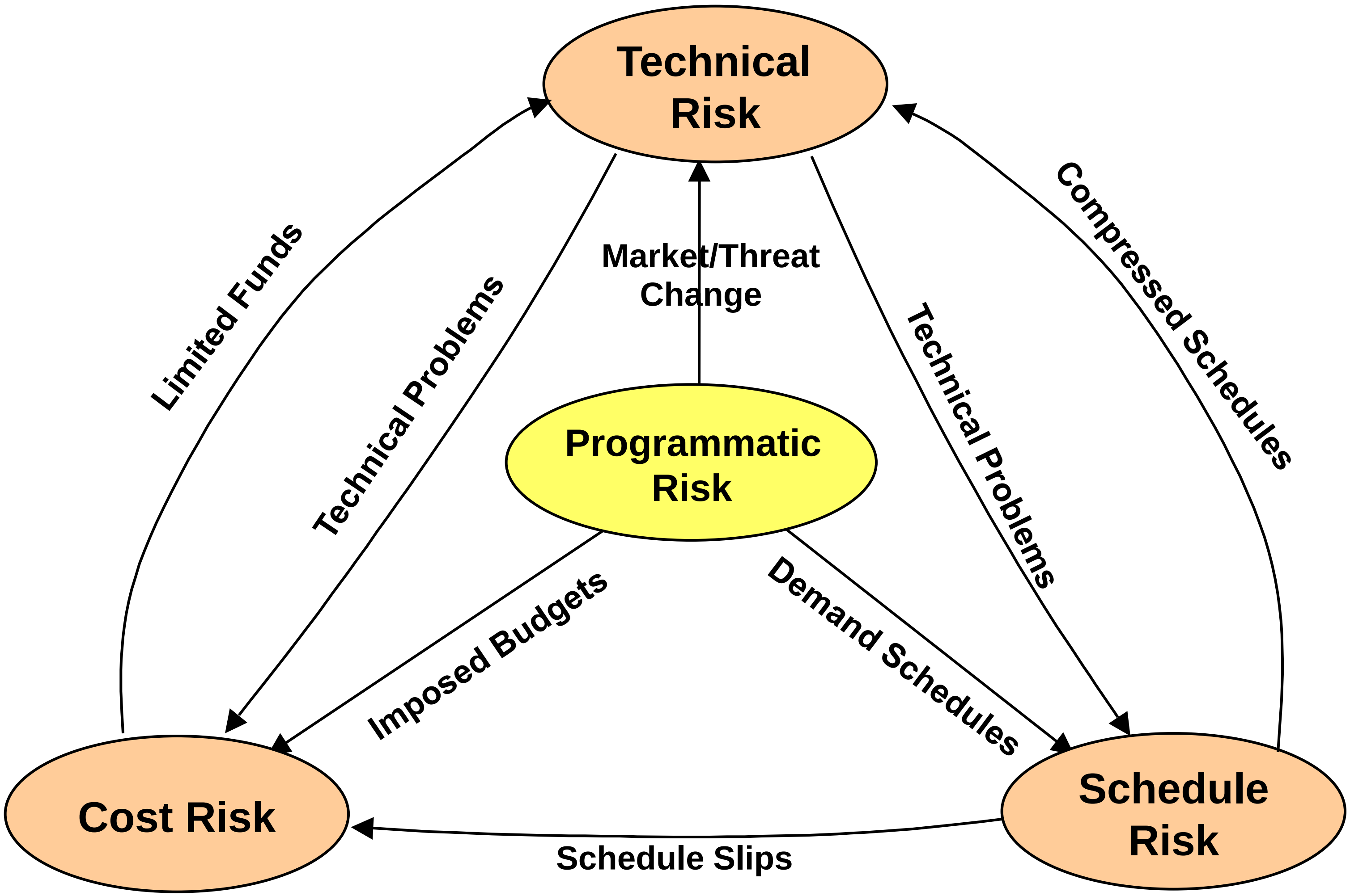
Technical/ Project Risks
- Construction
- Operations
- Partner/ally
- Technical
- Project management

High Influence ⟷ Low Influence

Context: Energy Industry

Source: D. Lessard

Risk Categories

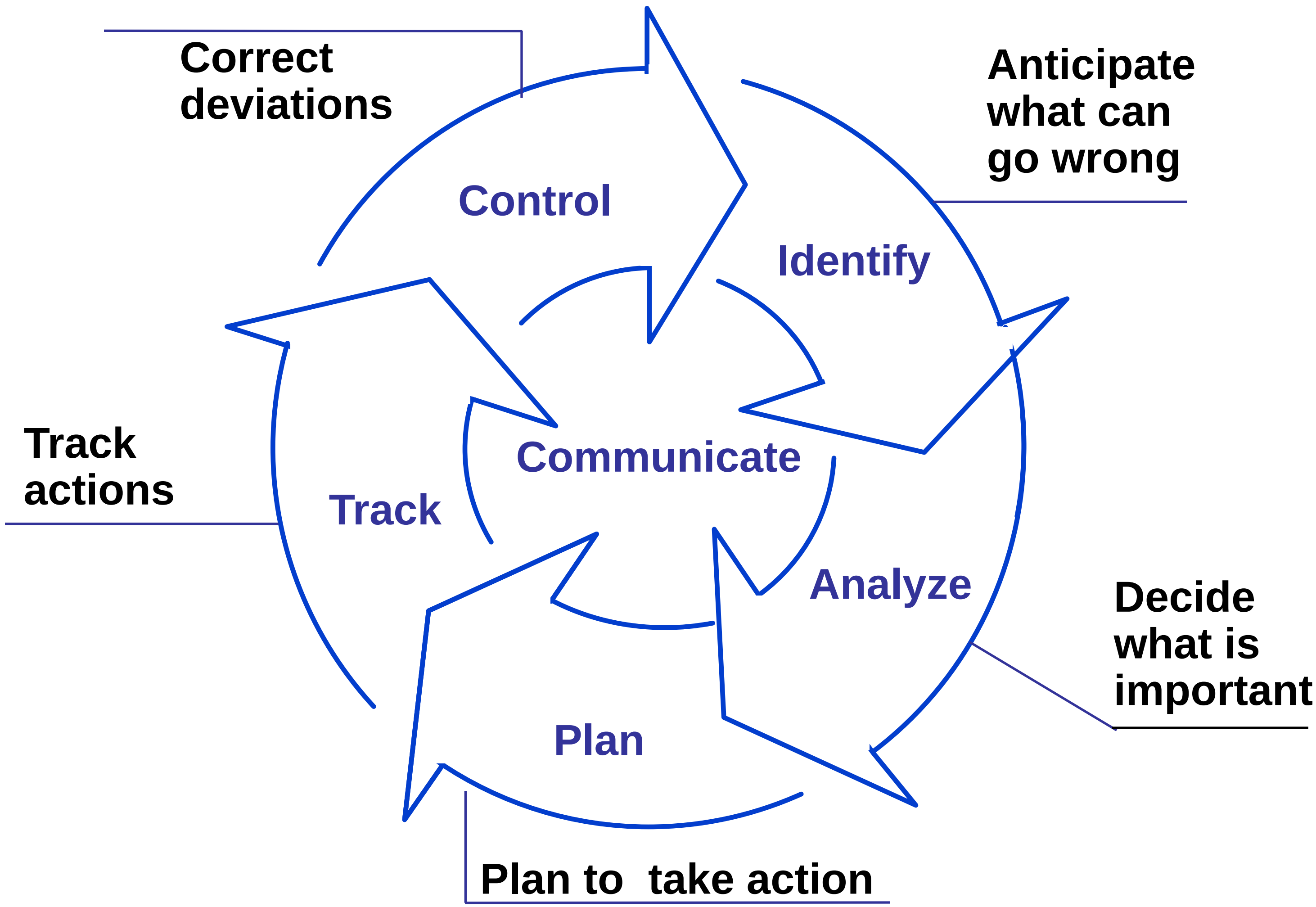


Mission Success and Failure

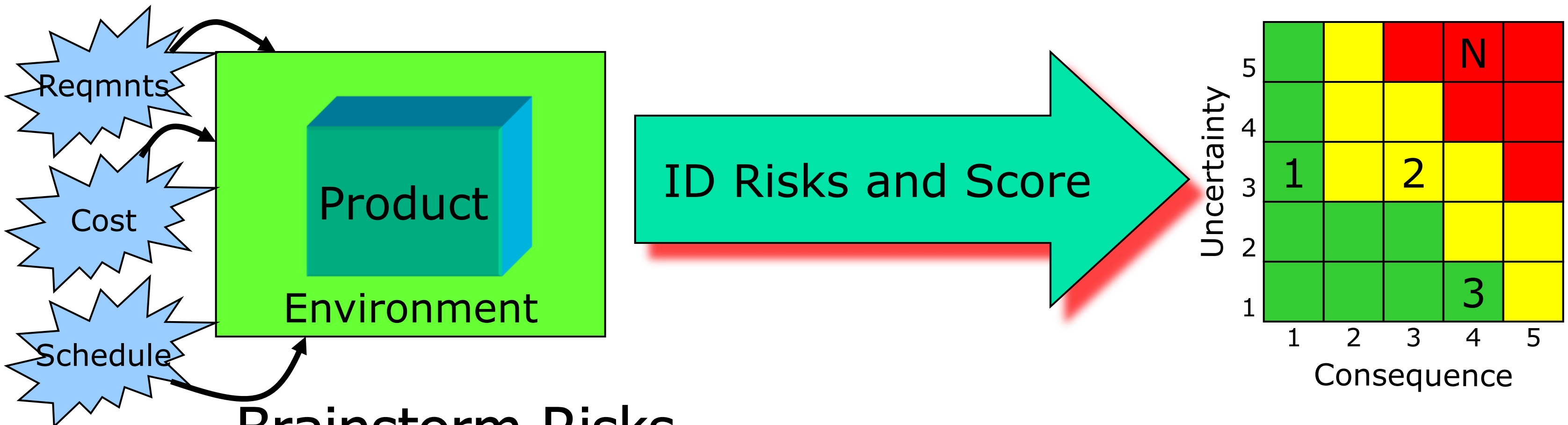
1992	**Mars Observer**	**US**	**Failure**	**Lost prior to Mars arrival**
1996	Mars Global Surveyor	US	Success	More images than all Mars Missions prior
1996	Mars 96	USSR	Failure	Launch vehicle failure
1996	**Mars Pathfinder**	**US**	**Success**	**Technology experiment lasting 5 times plan**
1998	Nozomi	Japan	Failure	No orbit insertion; fuel problems
1998	**Mars Climate Orbiter**	**US**	**Failure**	**Lost on arrival**
1999	**Mars Polar Lander**	**US**	**Failure**	**Lost on arrival**
1999	Deep Space 2 Probes	US	Failure	Lost on arrival (carried on Mars Polar Lander)
2001	**Mars Odyssey**	**US**	**Success**	**High resolution images of Mars**
2003	**Mars Express Orbiter/**	**ESA**	**Success/Failure**	**Orbiter imaging Mars and lander lost**
2003	**MER Spirit**	**US**	**Success**	**Operating lifetime of more than 15 times**
2003	**MER- Opportunity**	**US**	**Success**	**Operating lifetime of more than**
2005	**MRO**	**US**	**Success**	**Returned more than 26 terabits of**
2007	**Phoenix Mars Lander**	**US**	**Sucesss**	**Landed in North Polar Regions**
2012	**Mars MSL Curiosity**	**US**	**Success**	**Landed large RTG powered rover at Gale Crater**

Despite recent string of successes less than 50% of pre-2001 missions successful

A Risk Management Framework



Risk ID/Assessment



- Brainstorm Risks
  - Probability that a particular event will occur
  - Impact or Consequence if the event does indeed occur
- Aggregate Into Categories
  - Rule of Thumb Limit @ N≈20
- Score (Based on Opinion & Data)
- Involve <u>All</u> Stakeholders

Quantitative Assessment

Risk = Probability * Consequence

PROBABILITY → / CONSEQUENCES ↓	FREQUENT (HIGH)* 0.7<P<1.0	PROBABLE (MEDIUM)* 0.4<P<0.7	IMPROBABLE (LOW)* 0<P<0.4	IMPOSSIBLE P = 0
CATASTROPHIC 1.0 - 0.9	0.9 HIGH	0.7	0.4	0.0
CRITICAL 0.8 - 0.7	0.8	0.6 MEDIUM	0.3	0.0 NONE
MARGINAL 0.6 - 0.4	0.6	0.4	0.2 LOW	0.0
NEGLIGABLE 0.3 - 0.0	0.3	0.2	0.1	0.0

* Additional terminology, not in US Air Force Guide on Software Risk Abatement
Note: Risk rating is consistent with R = P*C

Often used to track risk history over project

Concept Question 1

- Which of the following risks are most challenging to deal with?
  - Low Probability – Low Impact
  - Low Probability – High Impact
  - High Probability – Low Impact
  - High Probability – High Impact
  - Medium Probability – Medium Impact
  - They are all difficult

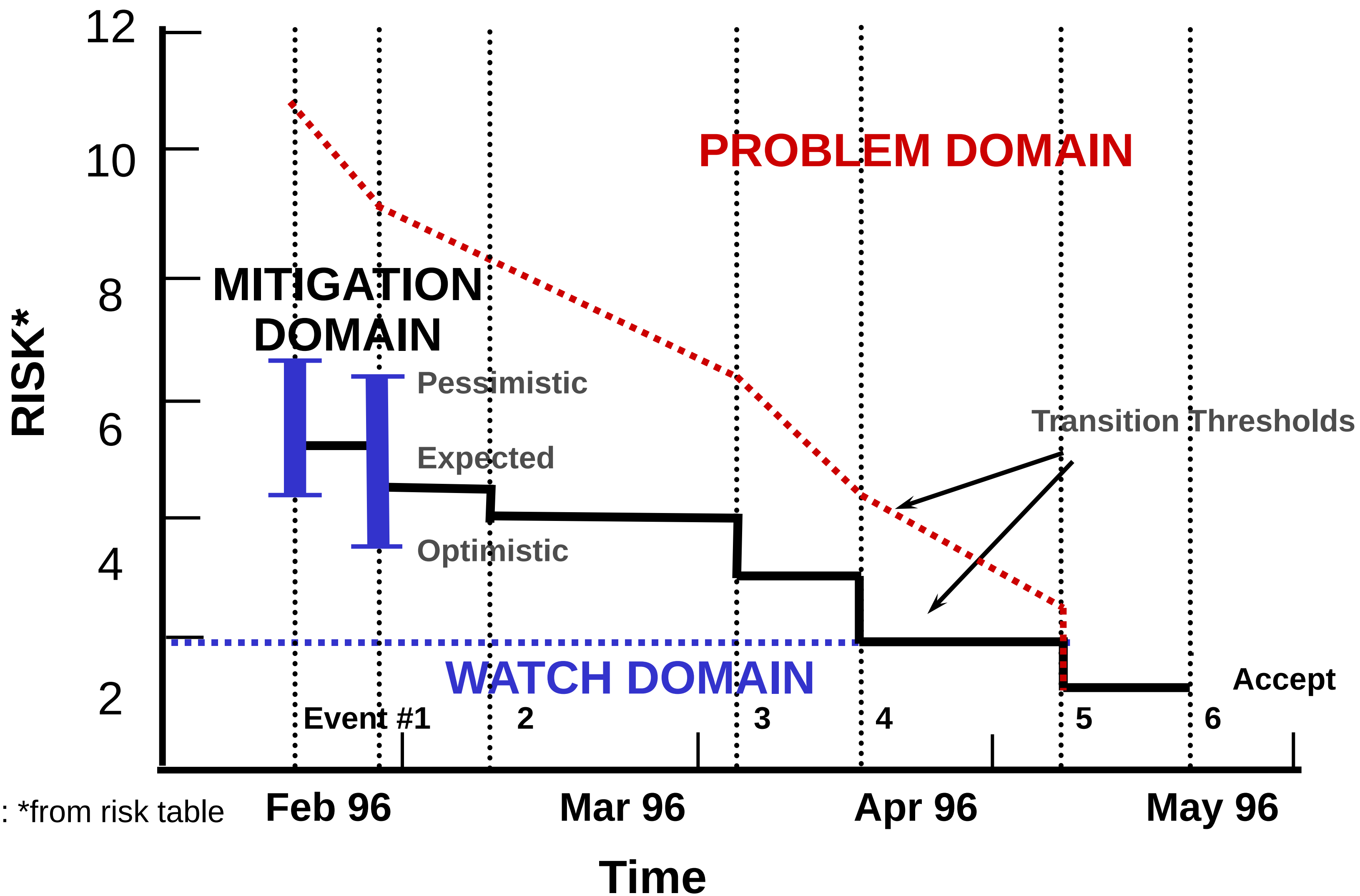
Risk Sector Plot (NASA)

Attribute: Probability		
Level	Value	Criteria
5	Near certainty	Everything points to this becoming a problem, always has
4	Very likely	High chance of this becoming a problem
3	Likely (50/50)	There is an even chance this may turn into a problem
2	Unlikely	Risk like this may turn into a problem once in awhile
1	Improbable	Not much chance this will become problem

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

Attribute: Impact				
Level	Value	Technical Criteria	Cost Criteria	Schedule Criteria
5	Catastrophic	Can't control the vehicle OR Can't perform the mission	> $10 Million	Slip to level I milestones
4	Critical	Loss of mission, but asset recoverable in time	$ 10 M ≤ X < $ 5 Million	Slip to level II milestones
3	Moderate	Mission degraded below nominal specified	$ 5 M ≤ X < $ 1 Million	Slip to level III milestones
2	Marginal	Mission performance margins reduced	$ 1 M ≤ X < $ 100 K	Loss of more than one month schedule margin
1	Negligible	Minimum to no impact	Minimum to no impact	Minimum to no impact

Threshold Risk Metric (NASA)

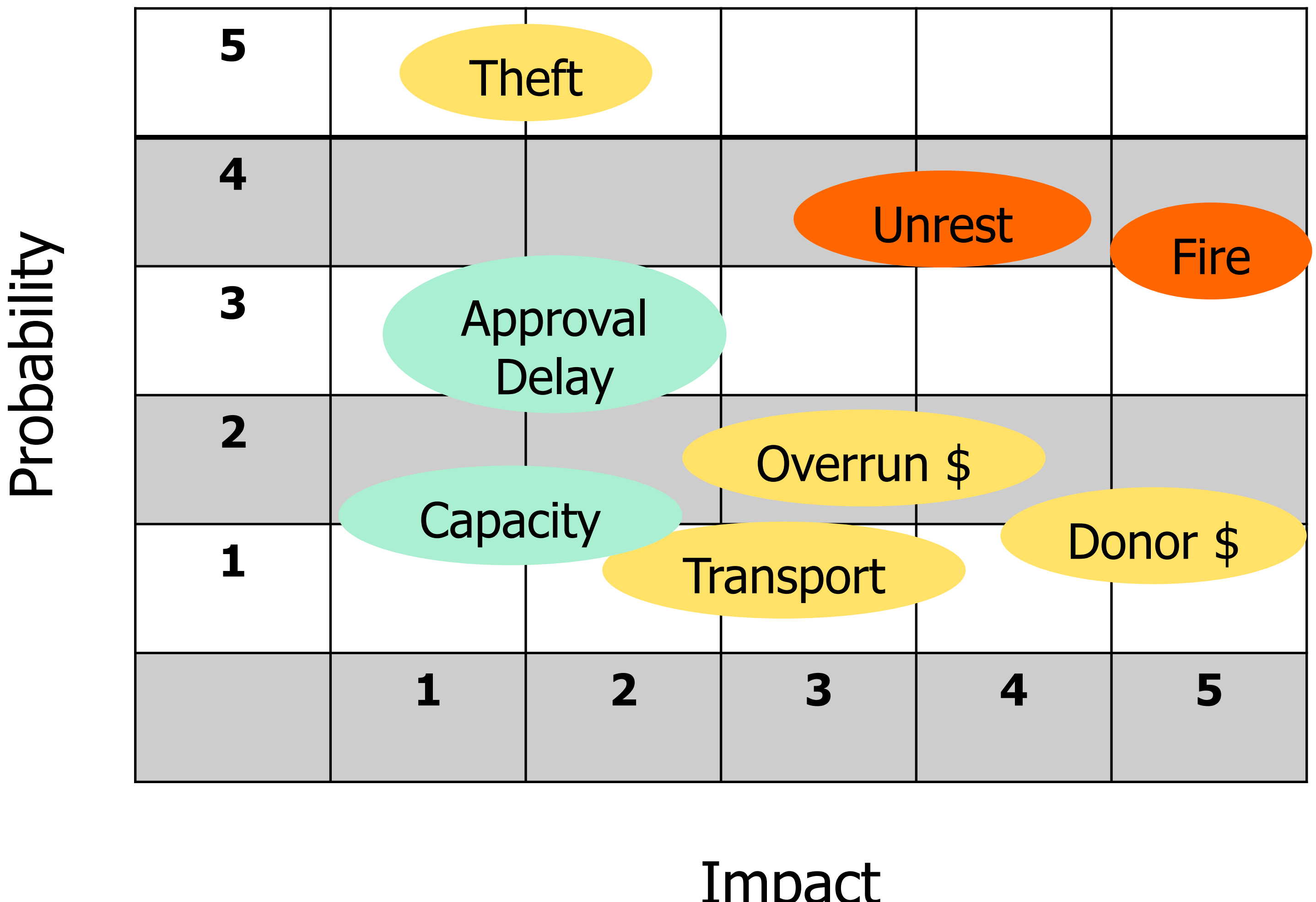


Note: *from risk table

Application to Hum Log DC

- Risks in HumLog Distribution Center Project
  - Technical
    - Fire
    - Blocked Transportation
    - Over or under Capacity
  - Cost
    - Cost overrun by Contractor
    - Donor do not fulfill $ commitments
  - Schedule
    - Delay in Host Government Approval
  - Programmatic
    - Contractor Non-Performance
    - Political Unrest, Looting, Theft

Risk Matrix for HumLog DC Project



Risk Mitigation Plan

Risk	Risk Score	Mitigation
Fire	20	Sprinkler System, Hydrant …
Political Unrest	16	Fence, Evacuation Plan
Donor $ Withdrawal	10	Weekly Project Updates, $ Risk Pool
Theft	8	Security System, Inventory Tracking
Approval Delay	6	Government Liaison Officer
Cost Overrun	6	EVM, Firm Fixed Price Contract
Transport Blocking	3	Alternate Transport Path (Sea)
Under-Capacity	1	Lease extra capacity locally

Review of Project NPV, VAR

NPV as the main criterion

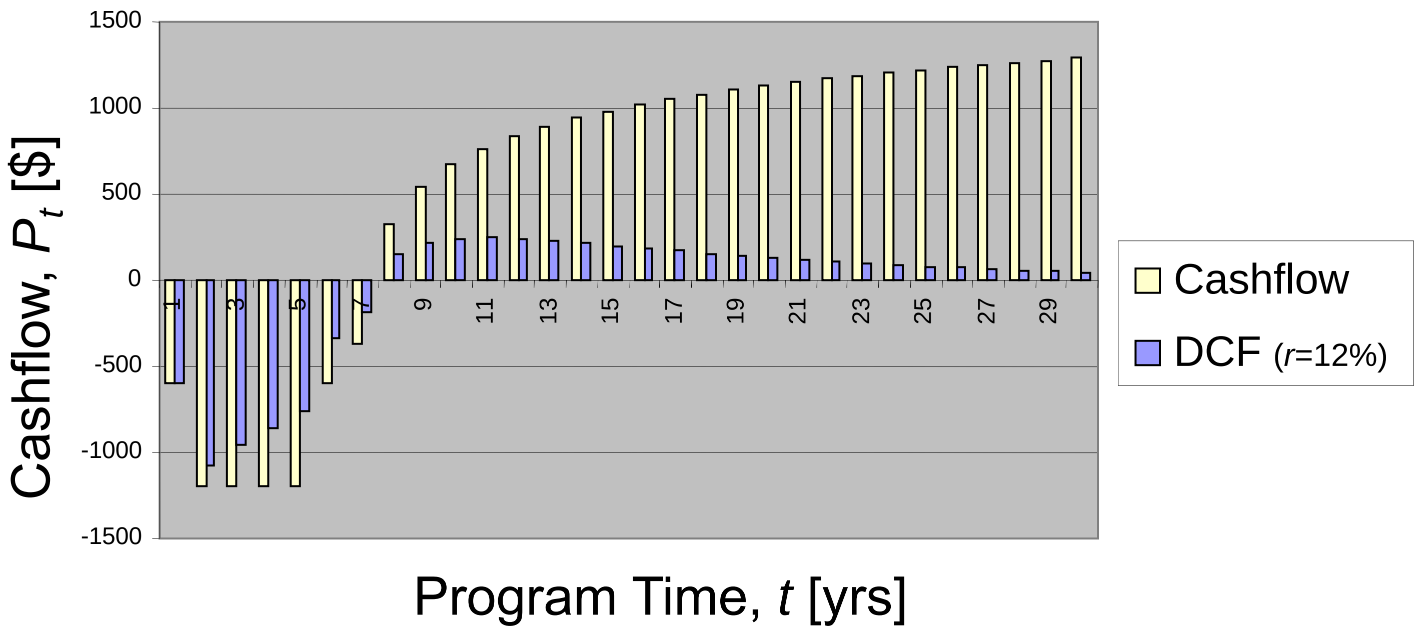
- Net Present Value (NPV)
  - Is typically the <u>key</u> criterion for deciding go/no-go on projects
  - Treats undertaking as an <u>investment project</u>
  - Often used to <u>select</u> among alternative (competing) projects
  - The project will cause <u>expenditures</u>: conceptual design, detailed design, manufacturing, implementation, operations
  - The project will yield <u>revenues</u>: sales from products and services
  - Both expenditures and revenues occur <u>over time</u> and must be discounted.
- Other Financial Metrics
  - Payback period
  - Internal Rate of Return (IRR)
  - Return on Investment (ROI)

Net Present Value (NPV)

- Measure of present value of various cash flows in different periods in the future
- Cash flow in any given period discounted by the value of a dollar today at that point in the future
  - "Time is money"
  - A dollar tomorrow is worth less today since if properly invested, a dollar today would be worth more tomorrow
- Rate at which future cash flows are discounted is determined by the "discount rate" or "hurdle rate"
  - Discount rate is equal to the amount of interest the investor could earn in a single time period (usually a year) if s/he were to invest in an *equally risky* investment

Net Present Value (NPV)

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t}$$



Discounted Cash Flow (DCF)

- Forecast the cash flows, C_0, C_1, ..., C_T of the project over its economic life
  - Treat investments as negative cash flow
- Determine the appropriate opportunity cost of capital (i.e. determine the discount rate r)
- Use opportunity cost of capital to discount the future cash flow of the project
- Sum the discounted cash flows to get the net present value (NPV)

$$NPV = C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \ldots + \frac{C_T}{(1+r)^T}$$

DCF example

Period	Discount Factor	Cash Flow	Present Value
0	1	-150,000	-150,000
1	0.935	-100,000	-93,500
2	0.873	+300000	+261,000

Discount rate = 7%

NPV = $18,400

Concept Question 2

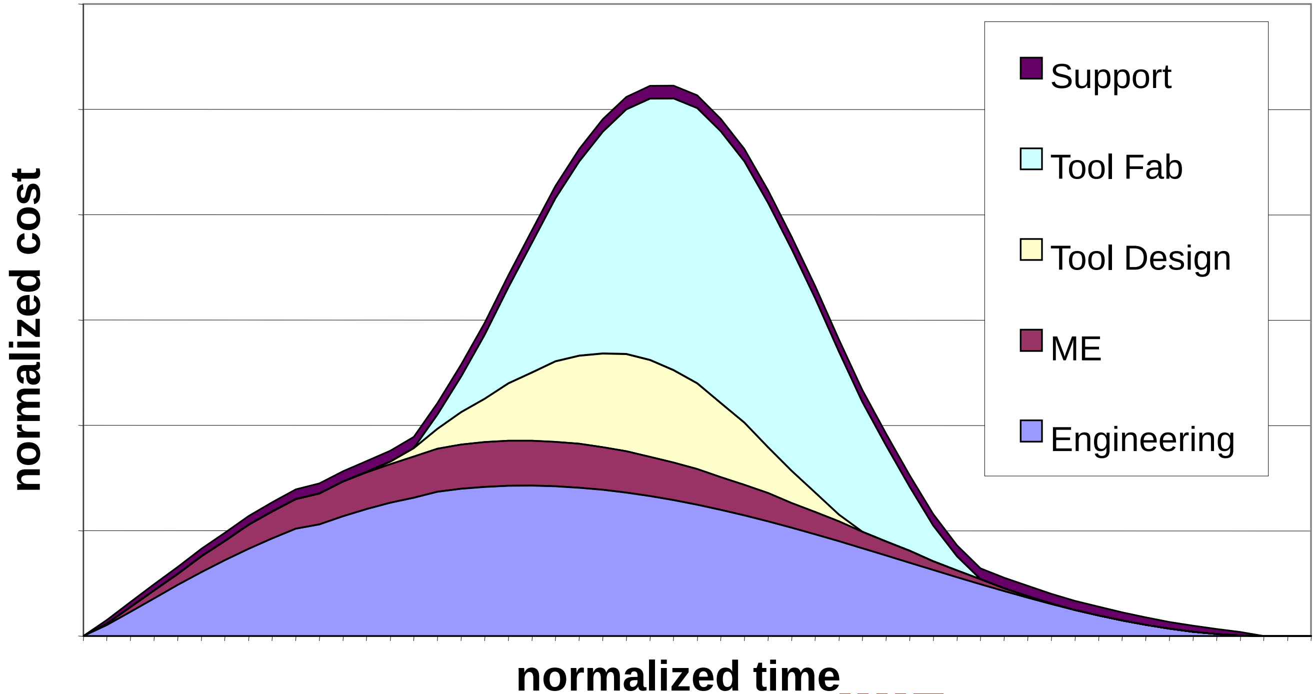
- The cash flows on a project are expected to be -$10M (year 0), $5M (year 1), $5M (year 2) and $5M (year 3). What is the NPV with a discount rate of r=10%?
  - +$5M
  - -$4.5M
  - +$2.2M
  - -$1.2M
  - $0M
  - Please … no more concept questions ;{

Development Cost Model

- Cashflow profiles based on beta curve:

$$c(t) = Kt^{\alpha-1}(1-t)^{\beta-1}$$

- Typical development time ~1-6 years
- Learning effects captured – span, cost



Risk-Adjusted Discount Rate

- DCF analysis assumes a fixed schedule of cash flows
- What about uncertainty?
- Common approach: use a risk-adjusted discount rate
- The discount rate is often used to reflect the risk associated with a project: the riskier the project, use a higher discount rate
- Typical discount rates for technology programs: 12-20%
- Issues with this approach?

Value at Risk Concept

- Value at Risk (VAR) recognizes fundamental reality: actual value of any design or project can only be known probabilistically

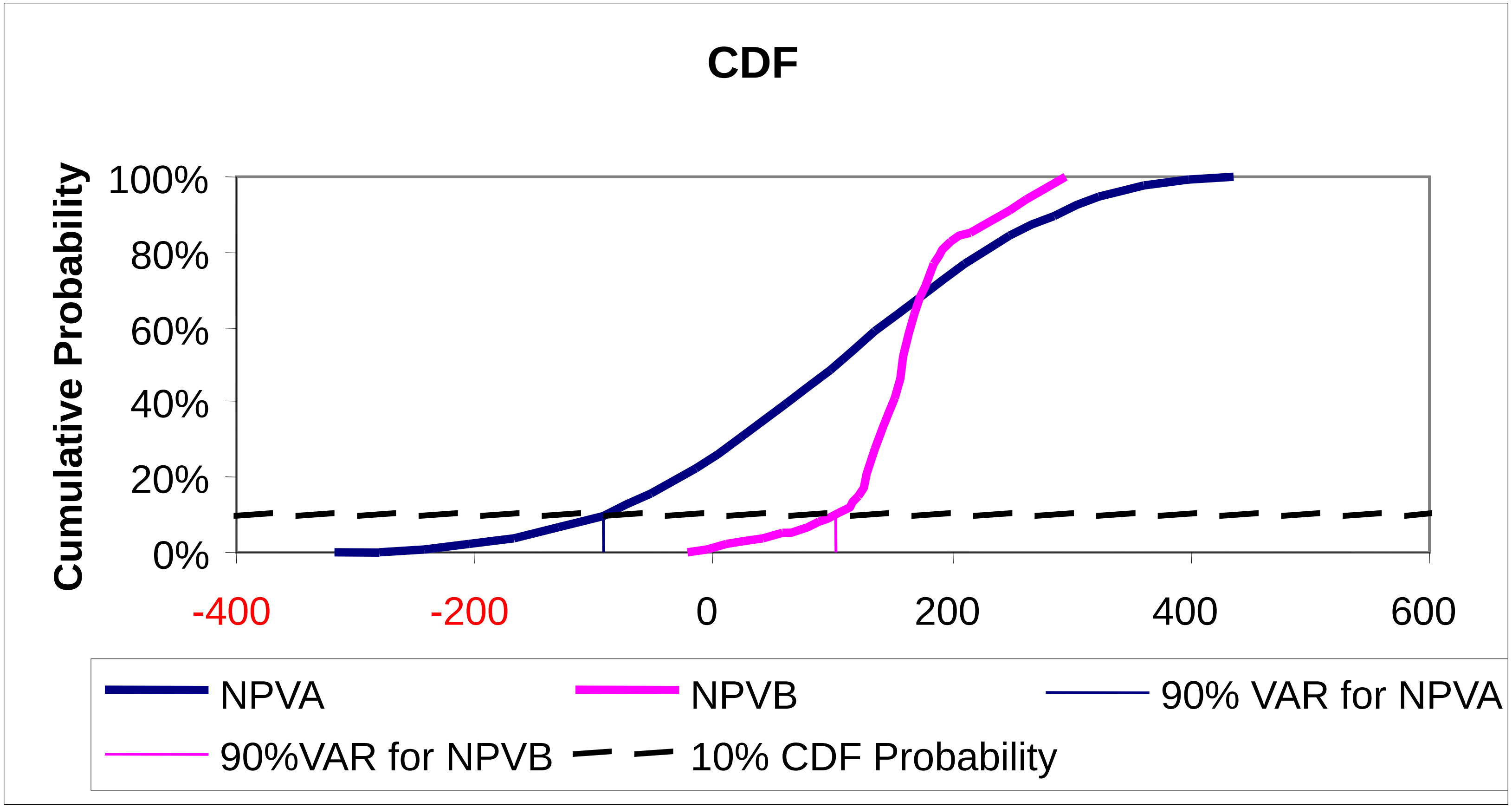
- Because of inevitable uncertainty in
  - Future demands on system
  - Future performance of technology
  - Many other market, political factors

Value at Risk Definition

- Value at Risk (VAR) definition:
  - A loss that will not be exceeded at some specified confidence level
  - "We are *p* percent certain that we will not loose more than *V* dollars for this project."
- VAR easy to see on cumulative probability distribution (see next figure)

VAR Cumulative Distribution Function

- Look at distribution of NPV of designs A, B:
  - 90% VAR for NPVA is -$91
  - 90% VAR for NPVB is $102

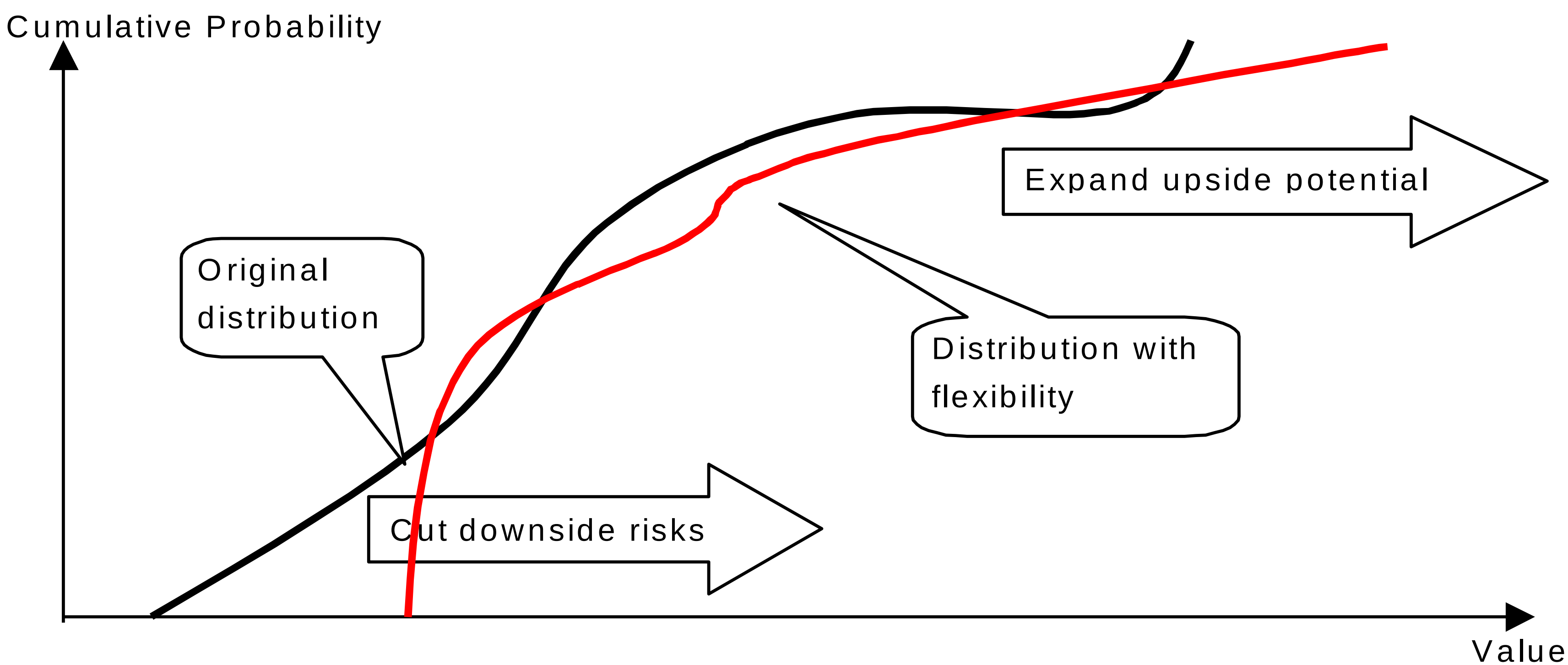


VAR and Flexibility

- VAR is a common financial concept
- It stresses downside losses, risks
- However, designers also need to look at upside potential: "Value of Gain"
- Flexible design provides value by both:
  - Decreasing downside risk
  - Increasing upside potential
  - See next figure

Sources of value for flexibility

Cut downside ; Expand Upside



Value-at-Risk-and-Gain (VARG)

Parking Garage Project Example

Valuing Options by Spreadsheet: Parking Garage Case Example
Richard de Neufville, Stefan Scholtes and Tao Wang -- ASCE Journal of Infrastructure Systems, Vol.12, No.2. pp. 107-111, 2006

Intended "Take-Aways"

- Design project for fixed objective (mission or specifications) is engineering base case
- Recognizing variability => different design (because of system non-linearities)
- Recognizing flexibility => even better design (it avoids costs, expands only as needed)

Inspiration - Comments

- This is a simplified educational case
- But similar real world situations exist
- Applicable to general technical projects

Bluewater development in England (http://www.bluewater.co.uk/)

Image by John Winfield http://bit.ly/16Eala4> on Wikimedia Commons. License: CC-BY-SA

Parking Garage Case

- Garage in area where population expands
  - New commercial/retail opportunities
- Actual demand is necessarily uncertain
  - Demand drives capacity for # of parking spots
- Design Opportunity: Strengthened structure
  - enables future addition of floor(s) (flexibility)
  - costs more initially (flexibility costs)
- Design issue: is extra cost worthwhile?

Parking Garage Case details

- Demand
  - At start is for 750 spaces
  - Over next 10 years is expected to rise (exponentially) by another 750 spaces
  - After year 10 maybe 250 more spaces
  - could be 50% off the projections, either way;
  - Annual volatility for growth is 10%
  - Consider 20 years
- Average annual revenue/space used = $10,000
- The discount rate is taken to be 12%

Parking Garage details (Cont)

- Costs
  - annual operating costs (staff, cleaning, etc.) = \$2,000 /year/space available

    (note: spaces used is often < spaces available)
  - Annual lease of the land = \$3.6 Million
  - construction cost = \$16,000/space + 10% for each level above the first level
- Site can accommodate 200 cars per level

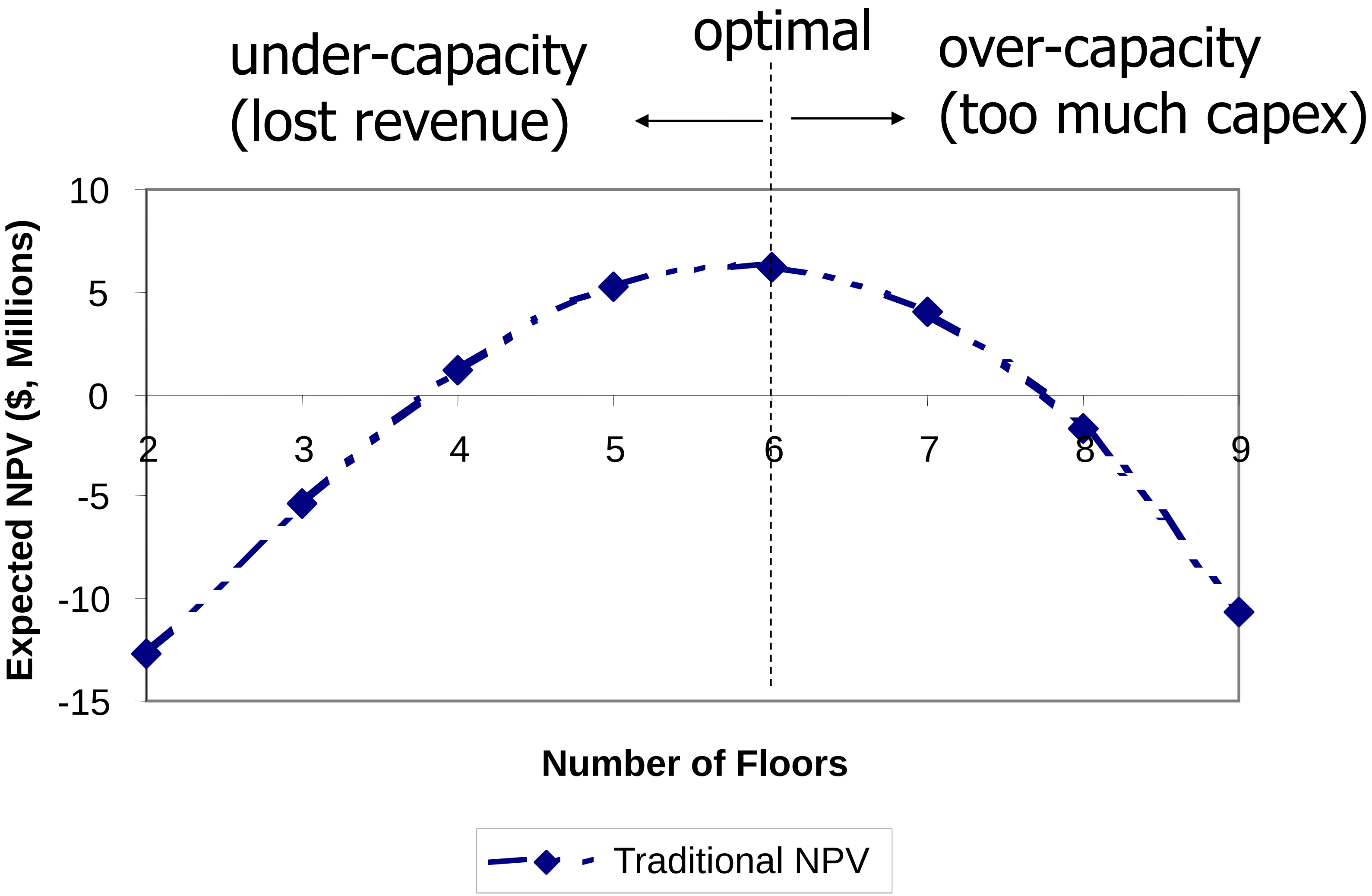
Step 1: Set up base case

Demand growth as predicted, no variability

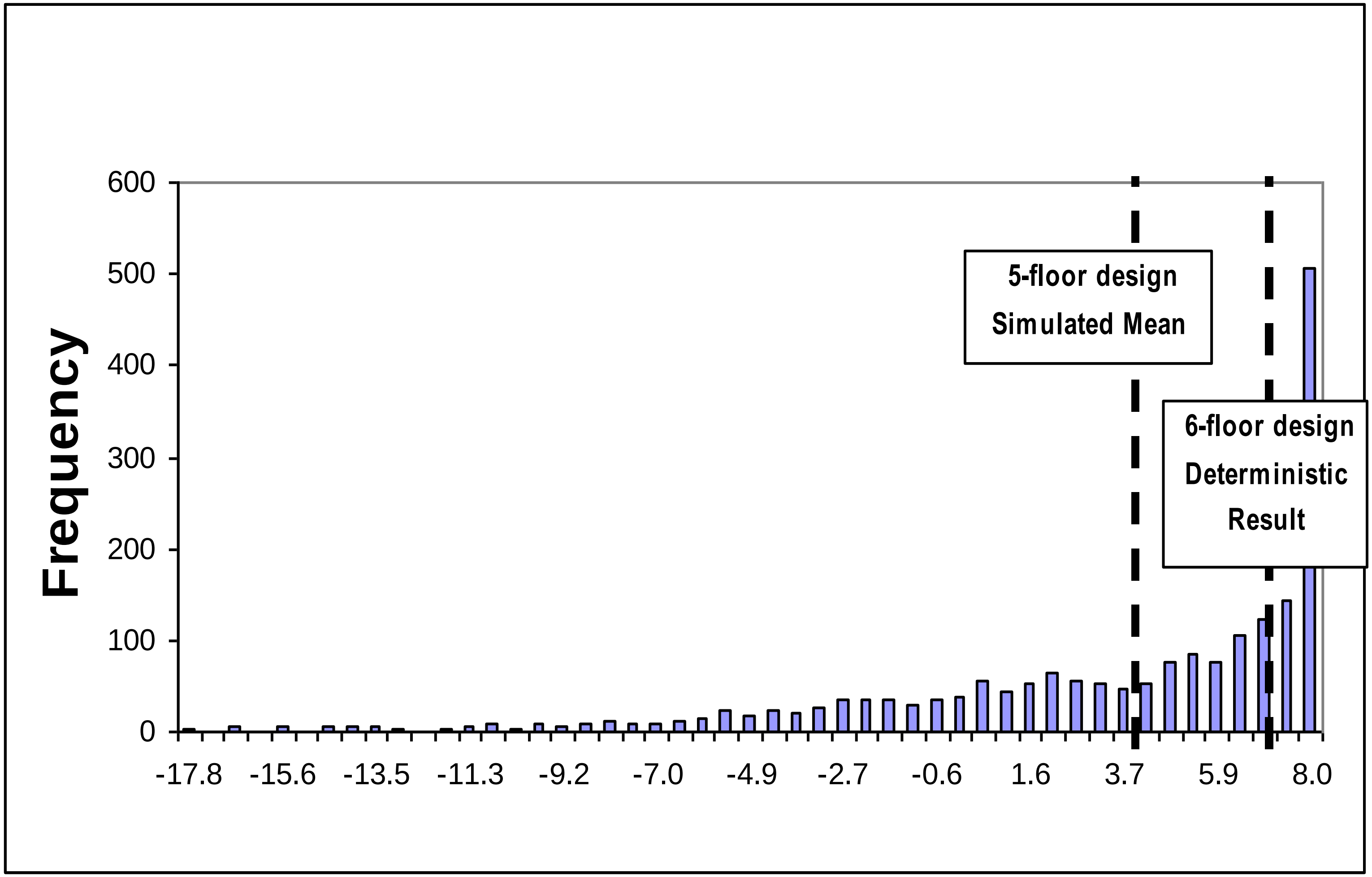
Year	0	1	2	3	19	20
Demand		750	893	1,015	1,688	1,696
Capacity		1,200	1,200	1,200	1,200	1,200
Revenue		$7,500,000	$8,930,000	$10,150,000	$12,000,000	$12,000,000
Recurring Costs						
Operating cost		$2,400,000	$2,400,000	$2,400,000	$2,400,000	$2,400,000
Land leasing cost	$3,600,000	$3,600,000	$3,600,000	$3,600,000	$3,600,000	$3,600,000
Cash flow		$1,500,000	$2,930,000	$4,150,000	$6,000,000	$6,000,000
Discounted Cash Flow		$1,339,286	$2,335,778	$2,953,888	$696,641	$622,001
Present value of cash flow	$32,574,736					
Capacity costs for up to two levels	$6,400,000					
Capacity costs for levels above 2	$16,336,320					
Net present value	**$6,238,416**					

capex= capital expenditures=initial investment

Optimal design for base case (no uncertainty) is 6 floors

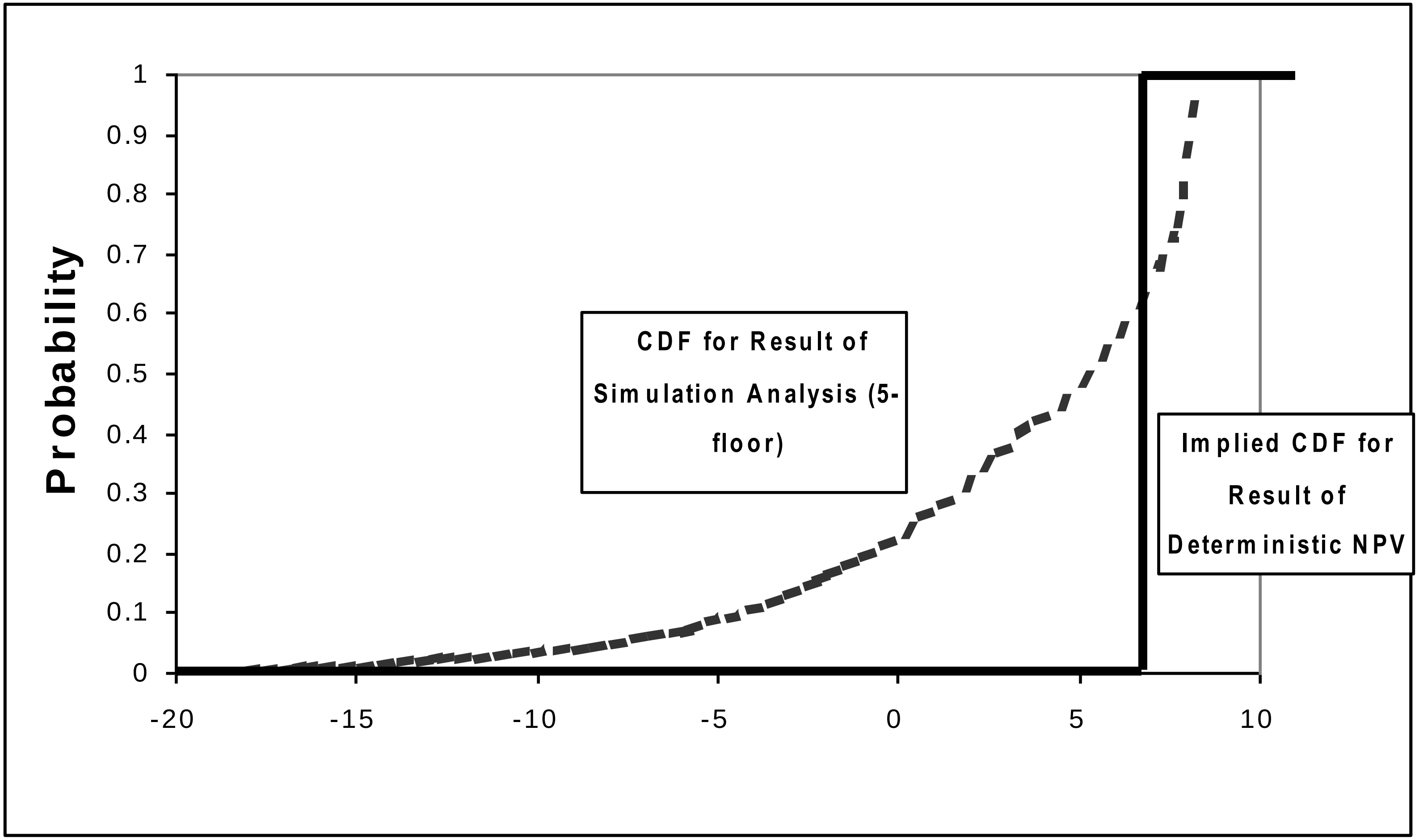


Step 2: Simulate uncertainty

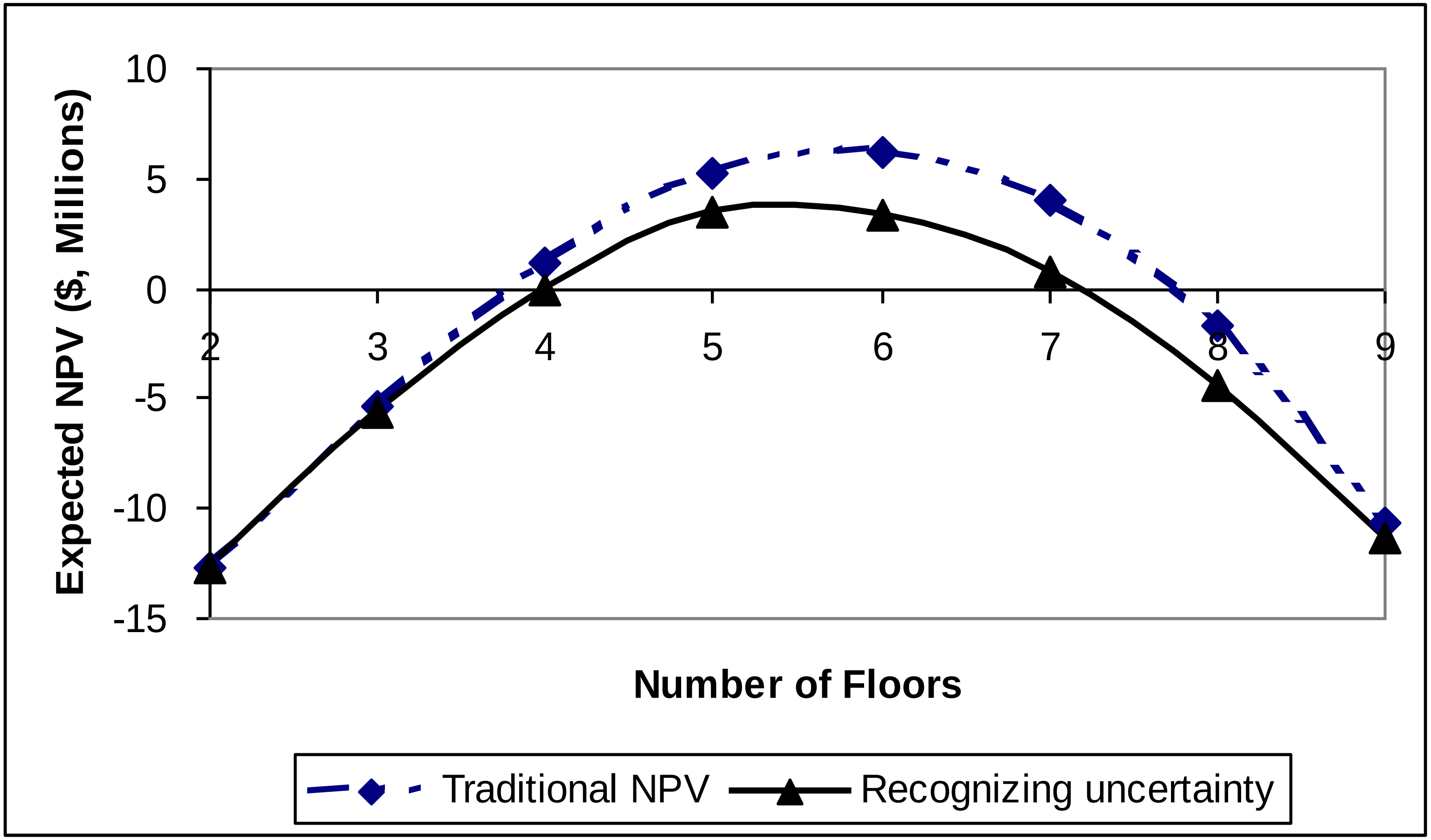


NPV Cumulative Distributions

Compare Actual (5 Fl) with (unrealistic) fixed 6 Fl design



Recognizing uncertainty => different design (5 floors)



Step 3: Introduce flexibility into design (expand when needed)

Year	0	1	2	3	19	20
Demand		820	924	1,044	1,519	1,647
Capacity		800	800	1,200	1,600	1,600
Decision on expansion			expand			
Extra capacity			400			
Revenue		$8,000,000	$8,000,000	$10,440,000	$15,190,000	$16,000,000
Recurring Costs						
Operating cost		$1,600,000	$1,600,000	$2,400,000	$3,200,000	$3,200,000
Land leasing cost	$3,600,000	$3,600,000	$3,600,000	$3,600,000	$3,600,000	$3,600,000
Expansion cost			$8,944,320			
Cash flow		$2,800,000	-$6,144,320	$4,440,000	$8,390,000	$9,200,000
Discounted Cash Flow		$2,500,000	-$4,898,214	$3,160,304	$974,136	$953,734
Present value of cash flow	$30,270,287					
Capacity cost for up to two levels	$6,400,000					
Capacity costs for levels above 2	$7,392,000					
Price for the option	$689,600					
Net present value	**$12,878,287**					

Including Flexibility => Another, better design:

4 Floors with strengthened structure enabling expansion

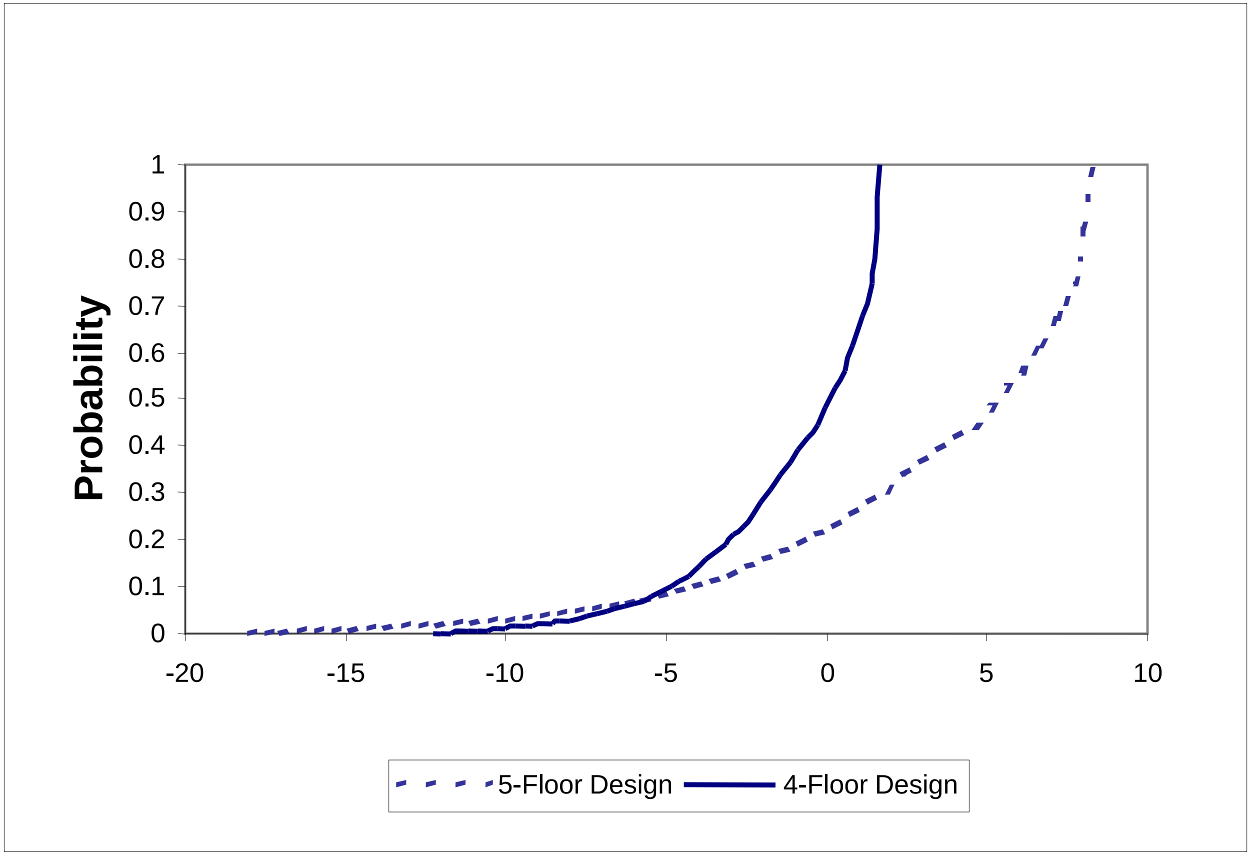
Summary of design results from different perspectives

Perspective	Simulation	Option Embedded	Design	Estimated Expected NPV
Deterministic	No	No	6 levels	$6,238,416
Recognizing Uncertainty	Yes	No	5 levels	$3,536,474
Incorporating Flexibilty	Yes	Yes	4 levels with strengthened structure	$10,517,140

Why is the optimal design much better when we design with flexibility?

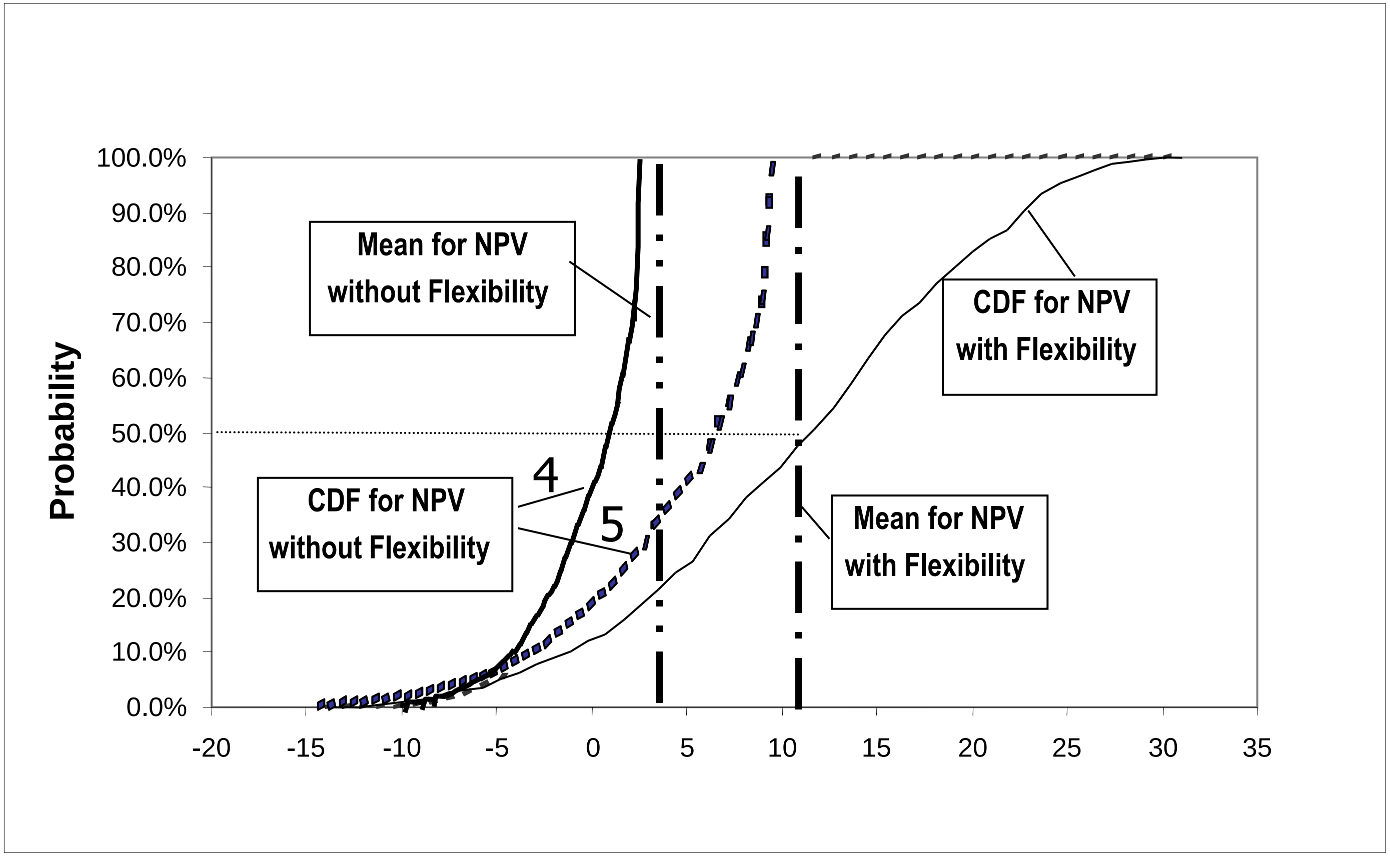
Sources of value for flexibility:

1) Minimize exposure to downside risk



Sources of value for flexibility:

2) Maximize potential for upside gain



Comparison of designs with and without flexibility

Design	Design with Flexibility Thinking (4 levels, strengthened structure)	Design without Flexibility thinking (5 levels)	Comparison
Initial Investment	$18,081,600	$21,651,200	Better with options
Expected NPV	$10,517,140	$3,536,474	Better with options
Minimum Value	-$13,138,168	-$18,024,062	Better with options
Maximum Value	$29,790,838	$8,316,602	Better with options

Wow! Everything is better! How did it happen?

Root cause: change the framing of the problem

- **recognize uncertainty**
- **add in flexibility thinking**

Summary from Garage Case

- Sources of value for flexibility
  - Cut downside risk
  - Expand upside potential
- VAR chart is a neat way to represent the sources of value for project flexibility
- Spreadsheet with simulation is a powerful tool for estimating value of flexibility

Real World meets Academia

Screenshot of the news article, "Logan Parking Squeeze Could Reach Crisis Level," from Boston Business Journal removed due to copyright restrictions. Please see http://www.bizjournals.com/boston/stories/2001/11/05/story3.html for further reference.

Summary

- Layers of Risk
- Classical Risk Management
  - Risk = Probability of Event X Impact of Event
  - Risk Management Cycle (identify, Analyze, Plan, Track, Control)
  - Risk Identification is not enough, must do something
- One way to aggregate risks is NPV
  - Some issues such as system safety need to be tracked in addition to NPV
- NPV is uncertain
  - Compute Value-at-Risk (VAR) curves
  - Shape VAR curves by embedding flexibility
- Real Options embody formal concept of flexibility

Acknowledgements

- Prof. Don Lessard
  - Concept of the Layers of Risk
- Prof. Richard de Neufville
  - Garage Case Study
  - Tao Wang, ESD PhD
    Real Options "in" Projects and Systems Design -- Identification of Options and Solutions for Path Dependency, Doctoral Dissertation, MIT, May, 2005

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