Value of Flexibility

Dr. Richard de Neufville

Professor of Engineering Systems and

Civil and Environmental Engineering

Massachusetts Institute of Technology

Value of Flexibility

an introduction
using a spreadsheet analysis
of a multi-story parking garage

Developed from

“Valuing Options by Spreadsheet: Parking Garage Case Example,”

ASCE J. of Infrastructure Systems, 2006

R. de Neufville, S. Scholtes, and T. Wang

Intended "Take-Aways"

- **Design 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)**

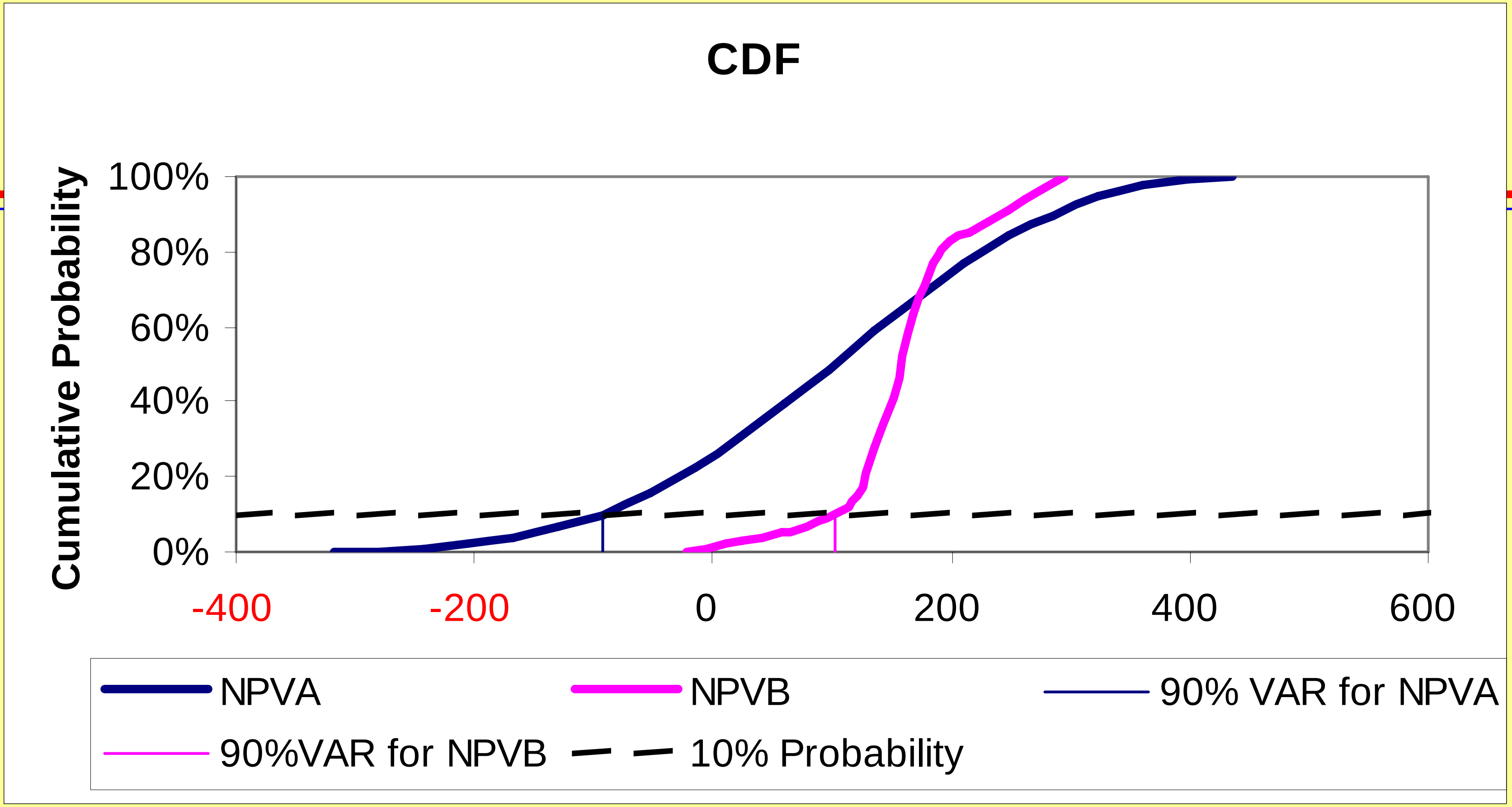
Value at Risk and Gain

- **Value at Risk and Gain (VARG) recognizes fundamental reality: value of any design 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 and Gain Definition

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



- **Look at distribution of NPV of designs A, B:**
  - **90% VARisk for NPVA,B are -$91, $102**
  - **20% VAGain for NPVA is around $210**

Notes

- **Cumulative distribution function (CDF) shows the probability that the value of a variable is < or = to quantity on x axis**

- **VARG can be found on the CDF curve:**
  - **90% VARisk => 10% probability the value is less or equal**
  - **NPV corresponding to the 10% CDF is 90% VARisk**
  - **NPV for 90% CDF is 10% Value at Gain**

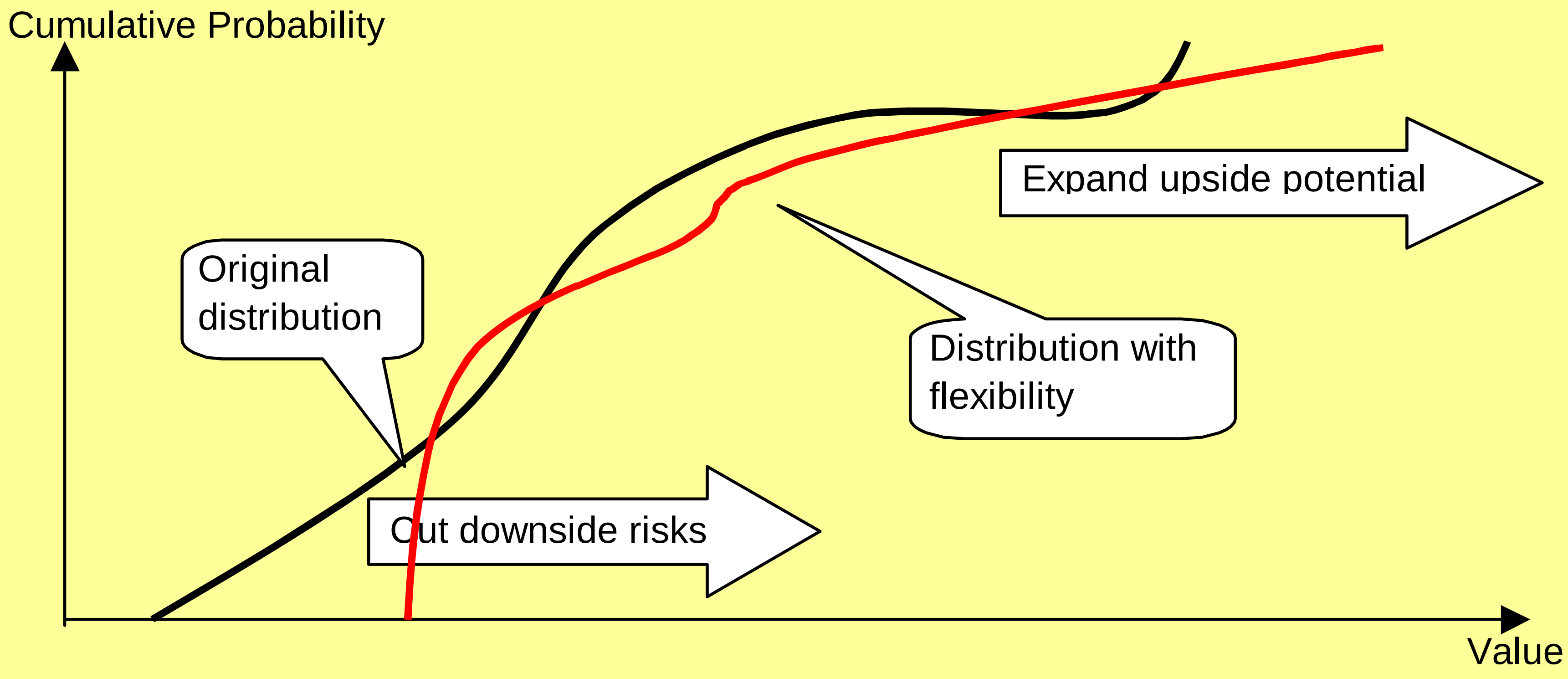
VAR and Flexibility

- **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



Excel Analysis Sequence to illustrate value of flexibility

1: Examine situation without flexibility

- **This is Base case design**

2: Introduce variability (simulation)

=> a different design (in general)

3: Introduce flexibility

=> a even different and better design

Parking Garage Case

- **Garage in area where population expands**
- **Actual demand is necessarily uncertain**

- **Design Opportunity: Stronger structure**
  - **enables future addition of floor(s) (flexibility)**
  - **Requires extra features (bigger columns, etc)**
  - **May cost less !!! Because can build smaller**

- **Design issue: is flexibility 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 may be 250 more spaces**
  - **could be 50% off the projections, either way;**
  - **Annual volatility for growth is 10%**

- **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 ground level**

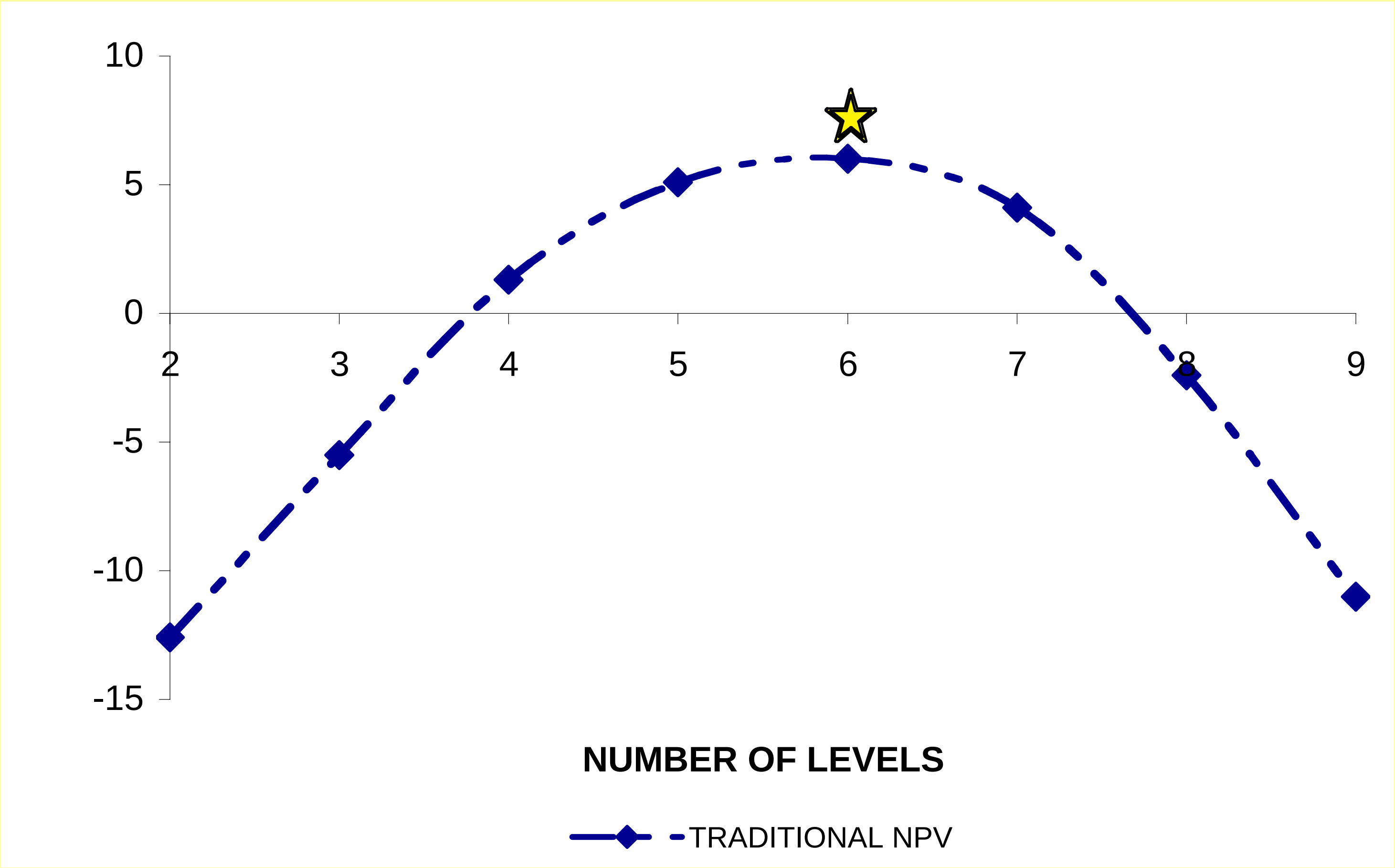
- **Site can accommodate 200 cars per level**

Step 1: Set up base case

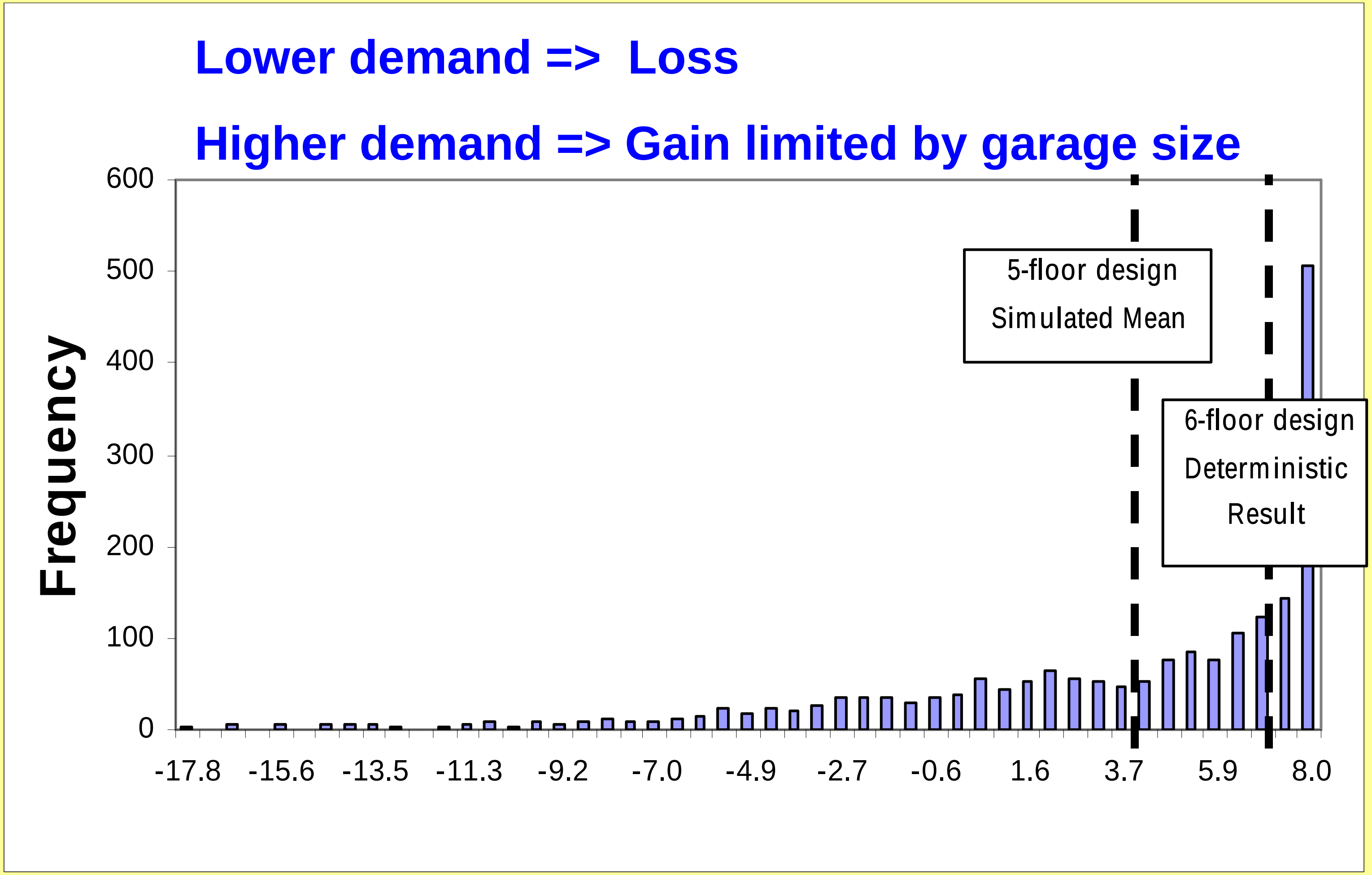
Demand growth as predicted, no variability

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**					

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

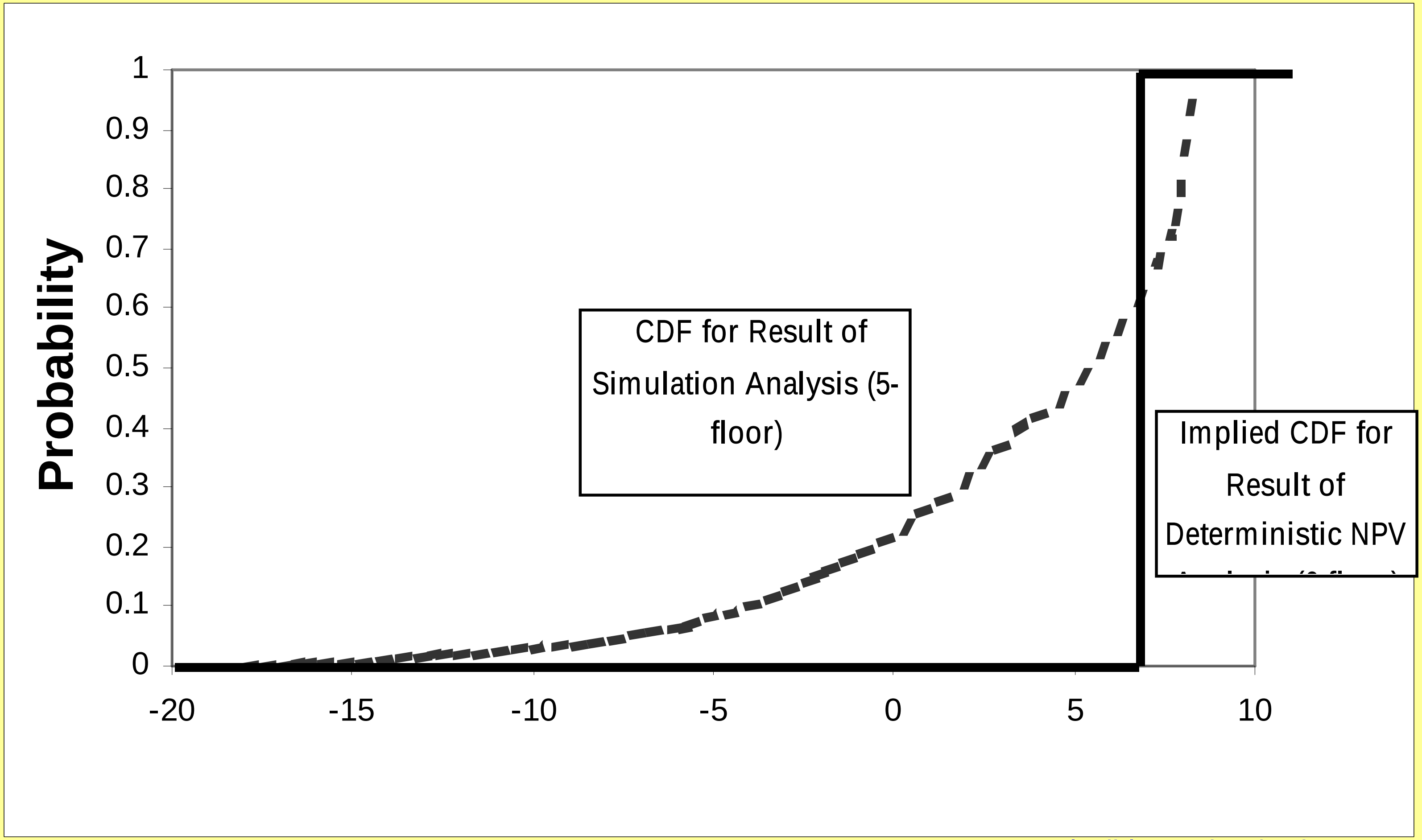


Step 2: Simulate uncertainty

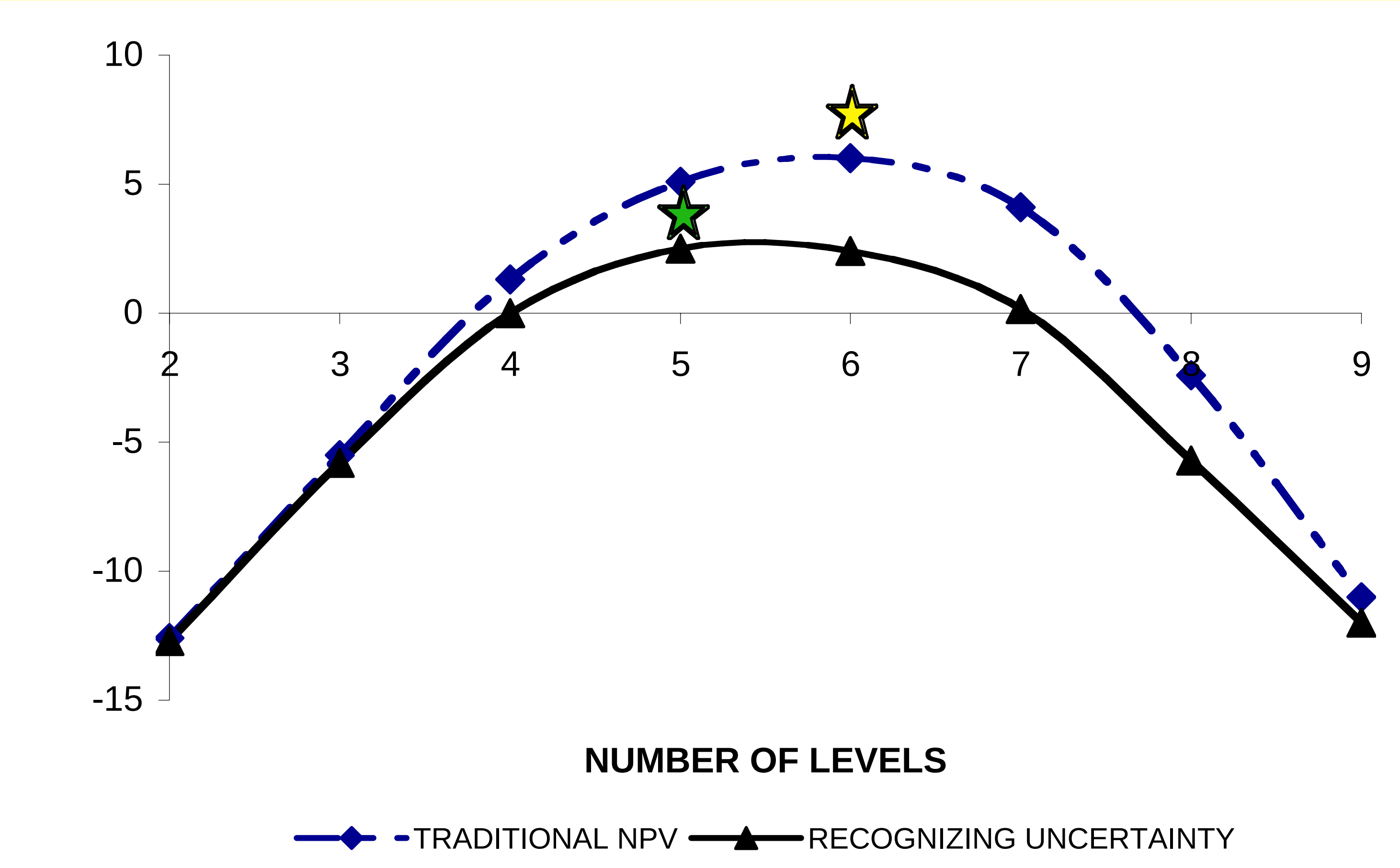


NPV Cumulative Distributions

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 Fl with stronger structure enabling expansion

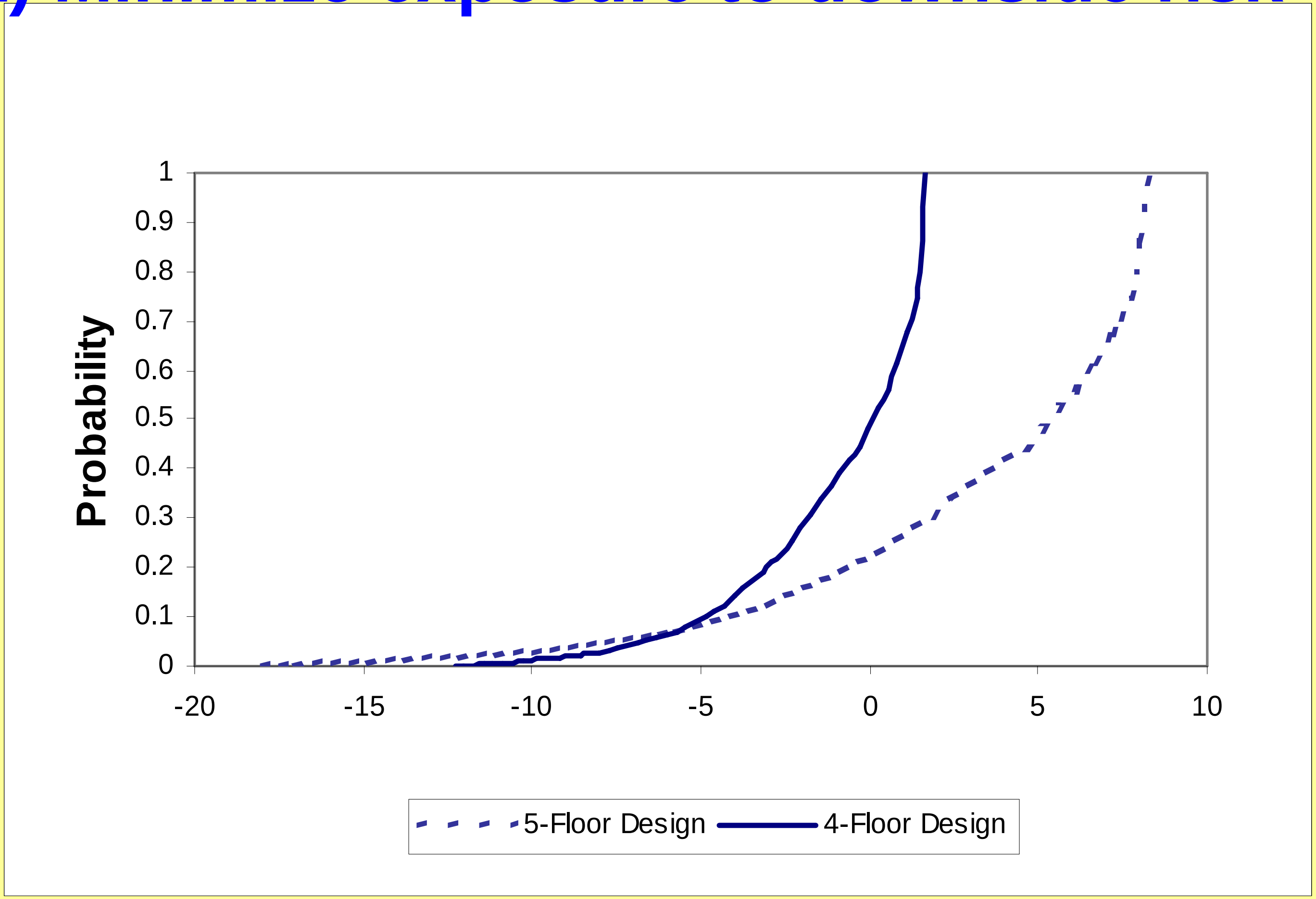
Summary of design results from different perspectives

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?

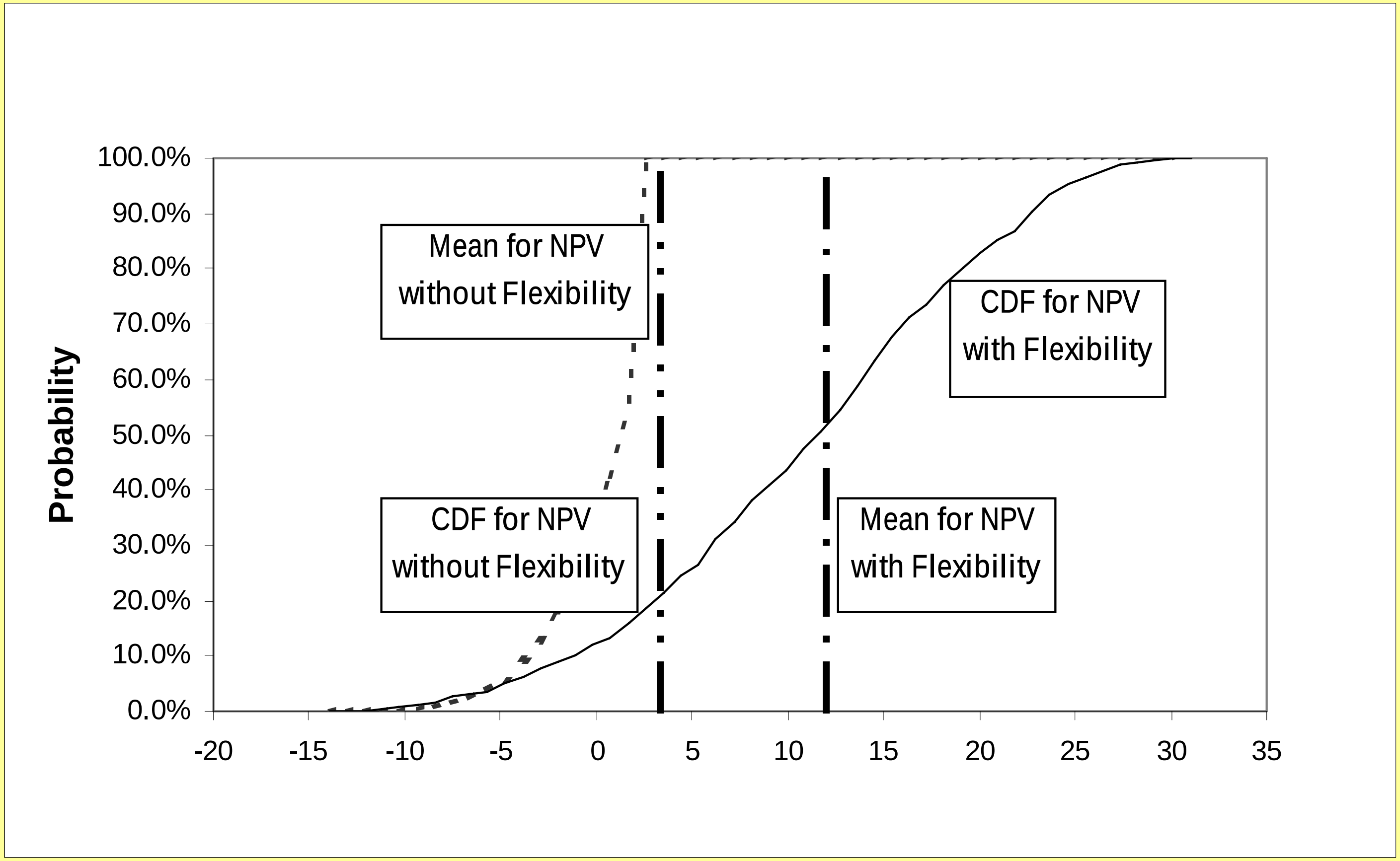
Sources of value for flexibility:

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 design problem

From: focus on a (mythical) forecast or set of specs

To: managing (realistic) uncertainties by flexibility

Summary

- **Flexibility Adds great value**

- **Sources of value for flexibility**
  - **Cut downside risk; Expand upside potential**

- **VARG chart is a neat way to represent the sources of value for flexibility**

- **Spreadsheet with simulation is a powerful tool for estimating value of flexibility**