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

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

Intended "Take-Aways"

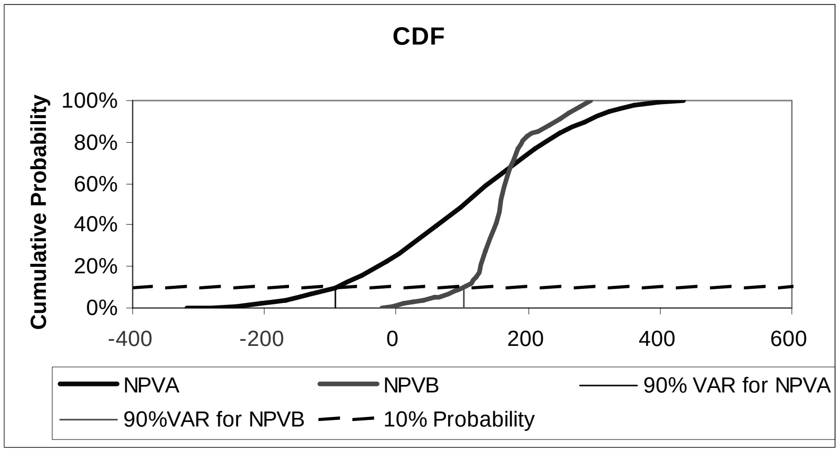
- Design for fixed objective (mission or specifications) is engineering base case
- Recognizing variability => different design (because of system non-linearities)
- Recognizing flexibility => even better design (it avoids costs, expands only as needed)

Value at Risk Concept

- Value at Risk (VAR) recognizes fundamental reality: actual 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 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 lose more than *V* dollars for this project."
- VAR easy to see on cumulative probability distribution (see next figure)



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

Notes:

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

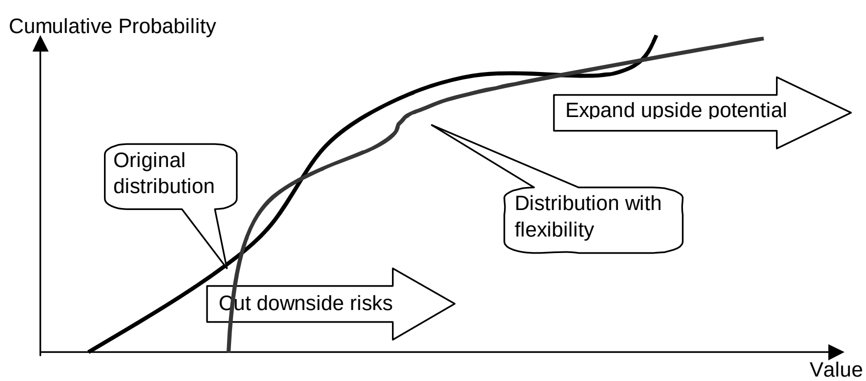
- VAR can be found on the CDF curve:
  - 90% VAR => 10% probability the value is less or equal
  - NPV corresponding to the 10% CDF is 90% VAR

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

- Note: Excel simulation techniques taught in ESD.70

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

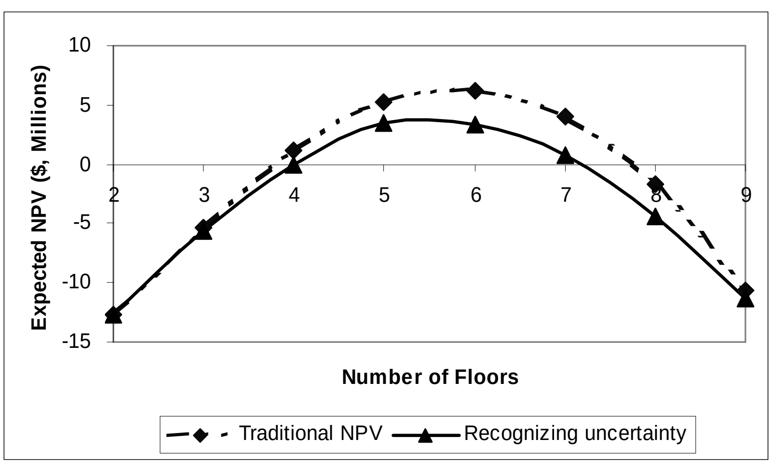
- Site can accommodate 200 cars per level

Step 1: Set up base case

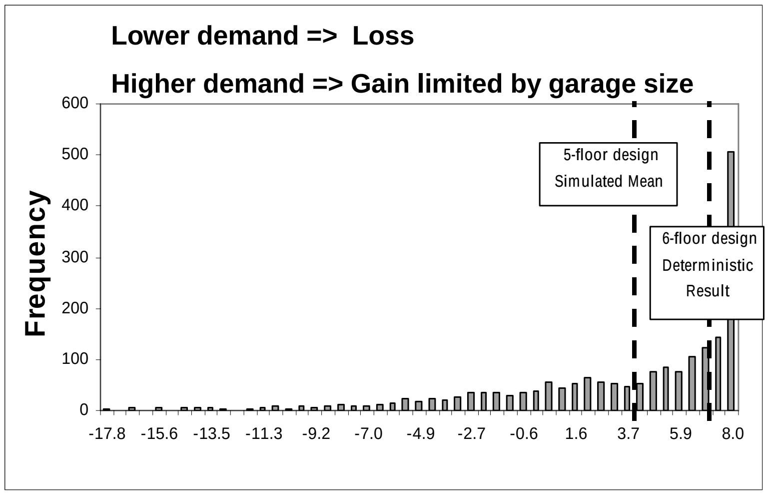
Demand growth as predicted, no variability

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



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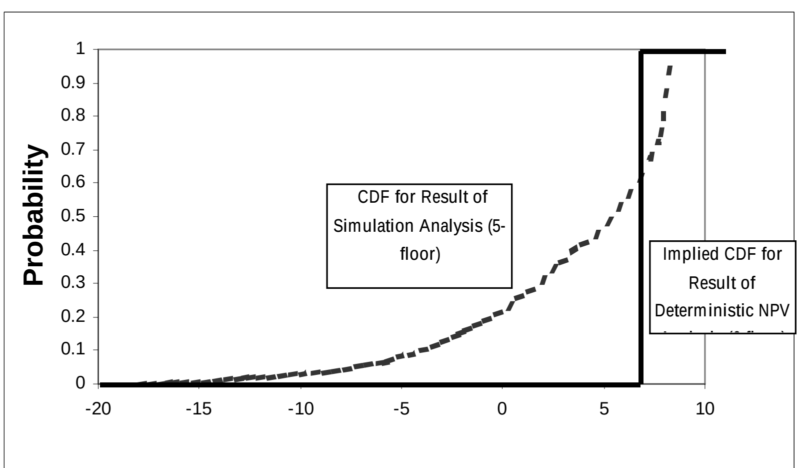
NPV Cumulative Distributions

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



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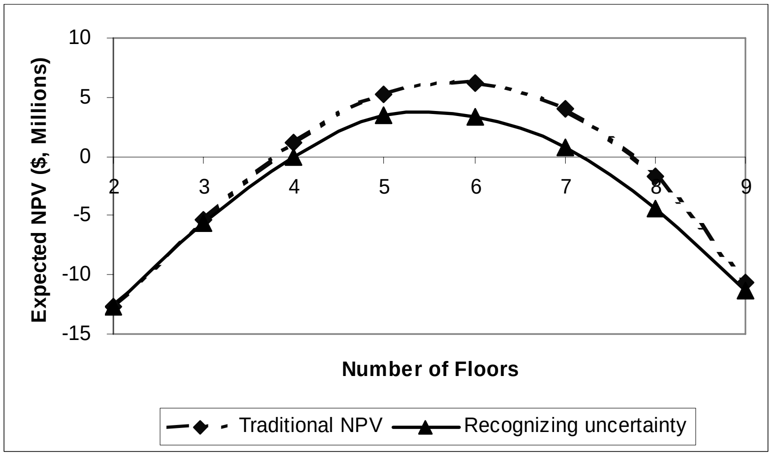
Recognizing uncertainty => different design (5 floors)



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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

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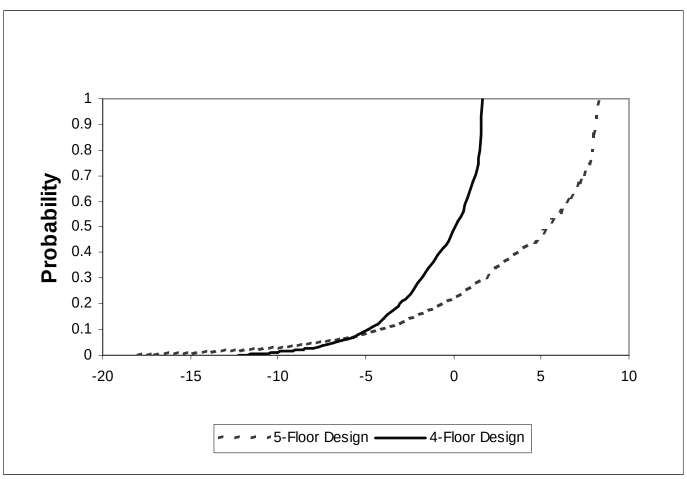
Summary of design results from different perspectives

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?

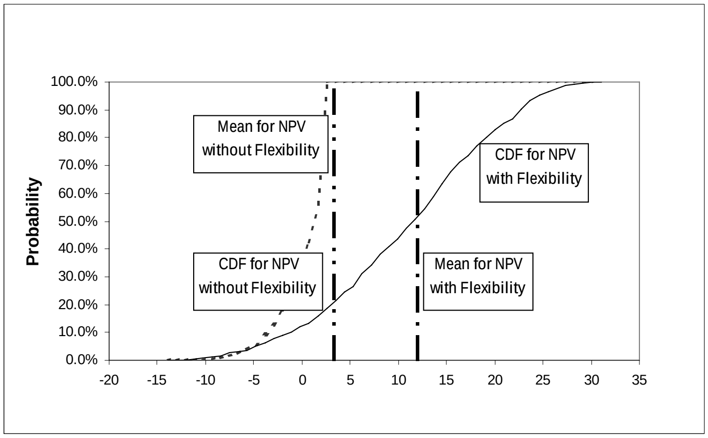
Sources of value for flexibility:

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

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