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

Cumulative Probability

Value

Original distribution

Cut downside risks

Expand upside potential

Distribution with flexibility
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

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>19</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>750</td>
<td>893</td>
<td>1,015</td>
<td>1,688</td>
<td>1,696</td>
<td></td>
</tr>
<tr>
<td>Capacity</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
<td></td>
</tr>
<tr>
<td>Revenue</td>
<td>$7,500,000</td>
<td>$8,930,000</td>
<td>$10,150,000</td>
<td></td>
<td>$12,000,000</td>
<td>$12,000,000</td>
</tr>
<tr>
<td>Recurring Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating cost</td>
<td>$2,400,000</td>
<td>$2,400,000</td>
<td>$2,400,000</td>
<td>$2,400,000</td>
<td>$2,400,000</td>
<td></td>
</tr>
<tr>
<td>Land leasing cost</td>
<td>$3,600,000</td>
<td>$3,600,000</td>
<td>$3,600,000</td>
<td>$3,600,000</td>
<td>$3,600,000</td>
<td></td>
</tr>
<tr>
<td>Cash flow</td>
<td>$1,500,000</td>
<td>$2,930,000</td>
<td>$4,150,000</td>
<td>$6,000,000</td>
<td>$6,000,000</td>
<td></td>
</tr>
<tr>
<td>Discounted Cash Flow</td>
<td>$1,339,286</td>
<td>$2,335,778</td>
<td>$2,953,888</td>
<td>$696,641</td>
<td>$622,001</td>
<td></td>
</tr>
</tbody>
</table>

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

Lower demand => Loss
Higher demand => Gain limited by garage size

NPV Cumulative Distributions
Compare Actual (5 Fl) with unrealistic fixed 6 Fl design
Recognizing uncertainty =>
different design (5 floors)

Number of Floors

-15 -10 -5 0 5 10

Expected NPV ($, Millions)

Traditional NPV
Recognizing uncertainty

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

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>18</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demand</td>
<td>820</td>
<td>924</td>
<td>1,044</td>
<td>1,519</td>
<td>1,647</td>
</tr>
<tr>
<td></td>
<td>Capacity</td>
<td>800</td>
<td>800</td>
<td>1,200</td>
<td>1,600</td>
<td>1,600</td>
</tr>
<tr>
<td></td>
<td>Decision on expansion</td>
<td>expand</td>
<td>expand</td>
<td>expand</td>
<td>expand</td>
<td>expand</td>
</tr>
<tr>
<td></td>
<td>Extra capacity</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Revenue</td>
<td>$8,000,000</td>
<td>$8,000,000</td>
<td>$10,440,000</td>
<td>$15,190,000</td>
<td>$16,000,000</td>
</tr>
<tr>
<td></td>
<td>Recurring Costs</td>
<td></td>
<td></td>
<td></td>
<td>$3,200,000</td>
<td>$3,200,000</td>
</tr>
<tr>
<td></td>
<td>Operating cost</td>
<td>$1,600,000</td>
<td>$1,600,000</td>
<td>$2,400,000</td>
<td>$3,200,000</td>
<td>$3,200,000</td>
</tr>
<tr>
<td></td>
<td>Land leasing cost</td>
<td>$3,600,000</td>
<td>$3,600,000</td>
<td>$3,600,000</td>
<td>$3,600,000</td>
<td>$3,600,000</td>
</tr>
<tr>
<td></td>
<td>Expansion cost</td>
<td>$8,944,320</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cash flow</td>
<td>$2,800,000</td>
<td>-$6,144,320</td>
<td>$4,440,000</td>
<td>$8,390,000</td>
<td>$9,200,000</td>
</tr>
<tr>
<td></td>
<td>Discounted Cash Flow</td>
<td></td>
<td></td>
<td></td>
<td>$974,136</td>
<td>$953,734</td>
</tr>
<tr>
<td></td>
<td>Present value of cash flow</td>
<td>$30,270,287</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Capacity cost for up to two levels</td>
<td></td>
<td></td>
<td></td>
<td>$6,400,000</td>
<td>$6,400,000</td>
</tr>
<tr>
<td></td>
<td>Capacity costs for levels above 2</td>
<td></td>
<td></td>
<td></td>
<td>$7,392,000</td>
<td>$7,392,000</td>
</tr>
<tr>
<td></td>
<td>Price for the option</td>
<td></td>
<td></td>
<td></td>
<td>$689,600</td>
<td>$689,600</td>
</tr>
<tr>
<td></td>
<td>Net present value</td>
<td>$12,878,287</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Including Flexibility => Another, better design:

4 Floors with strengthened structure enabling expansion
Summary of design results from different perspectives

<table>
<thead>
<tr>
<th>Perspective</th>
<th>Simulation</th>
<th>Option Embedded</th>
<th>Design</th>
<th>Estimated Expected NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deterministic</td>
<td>No</td>
<td>No</td>
<td>6 levels</td>
<td>$6,238,416</td>
</tr>
<tr>
<td>Recognizing Uncertainty</td>
<td>Yes</td>
<td>No</td>
<td>5 levels</td>
<td>$3,536,474</td>
</tr>
<tr>
<td>Incorporating Flexibility</td>
<td>Yes</td>
<td>Yes</td>
<td>4 levels with strengthened structure</td>
<td>$10,517,140</td>
</tr>
</tbody>
</table>

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

![Graph showing CDF for NPV with and without flexibility]

Comparison of designs with and without flexibility

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

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