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

Tao Wang and Richard de Neufville

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)
Outline of presentation

• Value at Risk

• Analyzing flexibility using spreadsheet

• Parking garage case

• Mining case

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: Strengthened structure
  – enables future addition of floor(s) (flexibility)
  – costs more (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 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>860</td>
<td>1,015</td>
<td>1,688</td>
<td>1,696</td>
<td></td>
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<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>$12,000,000</td>
<td>$12,000,000</td>
<td></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>
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</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

<table>
<thead>
<tr>
<th>Number of Floors</th>
<th>Expected NPV ($, Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-15</td>
</tr>
<tr>
<td>3</td>
<td>-10</td>
</tr>
<tr>
<td>4</td>
<td>-5</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>-5</td>
</tr>
</tbody>
</table>

Recognizing uncertainty

Step 2: Simulate uncertainty

Lower demand => Loss

Higher demand => Gain limited by garage size
Recognizing uncertainty => different design (5 floors)
Step 3: Introduce flexibility into design (expand when needed)

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
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<th>2</th>
<th>3</th>
<th>19</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>820</td>
<td>924</td>
<td>1,044</td>
<td>1,519</td>
<td>1,647</td>
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<tr>
<td>Capacity</td>
<td>800</td>
<td>800</td>
<td>1,200</td>
<td>1,600</td>
<td>1,600</td>
<td></td>
</tr>
<tr>
<td>Decision on expansion</td>
<td>expand</td>
<td>expand</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extra capacity</td>
<td>400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<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>
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</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>$1,600,000</td>
<td>$1,600,000</td>
<td>$2,400,000</td>
<td>$3,200,000</td>
<td>$3,200,000</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>Expansion cost</td>
<td>$8,944,320</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<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>
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</tr>
<tr>
<td>Discounted Cash Flow</td>
<td>$2,500,000</td>
<td>$4,898,214</td>
<td>$3,160,304</td>
<td>$697,136</td>
<td>$653,734</td>
<td></td>
</tr>
</tbody>
</table>

| 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

<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
Comparison of designs with and without flexibility

Wow! Everything is better! How did it happen?
Root cause: change the framing of the problem
• recognize uncertainty; add in flexibility thinking

<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>

Cash Flow Simulation
Option to Abandon in Mining

For a Marginally Profitable Underground Mining Operation
Vassilios Kazakidis, Associate Professor
Mining Engineering, Laurentian University

Text refers to spreadsheet analysis used for demonstration

Draft Presentation: Do not quote or circulate without permission
Outline

- Cash flow simulation model created in Excel to model an abandonment decision in a marginally profitable underground nickel mine.
- The model was created using actual cost and production data from a currently operating mine.
- Nickel is a historically volatile metal (~35%/yr).
- Abandonment occurs when metal prices fall low enough to make the project unprofitable (the trigger).
- When metal prices fall low enough, this causes the operating costs to exceed the revenues generated.
- If this occurs during any period, an “IF statement” in the model triggers the abandonment, and an associated abandonment cost is incurred.

Revenue and Cost Simulation

- The Revenue generated during each period is determined by simulating the metal price based on an inputted initial value ($2.8/lb) and volatility (40%) and using the Brownian motion. The metal price is then multiplied by the number of lbs mined per period to give the revenue generated.
- The Operating cost is simulated for each period based on an inputted initial value ($1.412 M) and cost volatility (9.6%), again using Brownian motion. Cost volatility is caused by uncertainties due to ground problems or equipment failures which are common occurrences in underground mines, and which affect costs.
- The mine has the option to abandon at the start of any of the simulated periods if operating cost > revenue.
Model Layout

- The model is divided into 3 spreadsheet tabs:
  - Input Parameters
  - No Option to Abandon
  - Option to Abandon
- In the “No Option” tab, no abandonment can occur.
- In the “Option to Abandon” tab, shutdown may occur.
- Simulating NPV values for both of these spreadsheets will show that the NPV in the “option to abandon” is consistently higher than with “no option”.
- With the “option to abandon”, the very low (even negative) tail-end NPV values are essentially cut-off.
- The difference between the simulated NPV’s in both spreadsheets is the value of flexibility.

By Vassilios Kazakidis (Do not quote or circulate without permission)

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