Valuing Flexibility Using a Catalog of Operating Plans

Michel-Alexandre Cardin, PhD Candidate

Engineering Systems Division

Outline

- Issue:
  - Too many combinations to analyze
  - Traditional approach: very simplified
- Analytical Problem:
  - How do we take more realistic approach, within available analytical resources (time, modeling complexity)
- Proposed Solution:
  - Concept: use of “Catalog of Operating Plans”
  - Implementation: depends on nature of industry
- Example application: parking garage

The Analytical Issue

- A complete analysis of an engineering system involves modeling and optimizing:
  – Basic infrastructure (plant, network, etc)
  – Considering possible evolutions of several factors over many periods (price and demand for products; quality and quantity of mineral in deposit)
  – Along with many modes of operations (routing of vehicles on network, allocation of production lines to products, etc)
  – Provide a range of measures of merit (NPV, Capex, Return on Investment)

- IMPRACTICAL TO DO EXHAUSTIVELY!

The Full Problem

Stage for System	**Element**	**Possibilities**
Initial Design	Configuration of Infrastructure	Many
Periodic Data on Context Factors	Price, Demand, Quantity, etc	Many, over many periods
Periodic Management Adjustments	Work Plans for Existing and New Facilities	Many, over many periods
Performance Metrics	NPV, ROI, Capex, etc	Many

Traditional Design Approach

Although complex, very simplified overall

Stage for System	Element	Possibilities	Traditional Design Practice
Initial Design	Configuration of Infrastructure	Many	Many
Periodic Data on Context Factors	Price, Demand, Quantity, etc	Many, over many periods	One Vector (Each 1 value)
Periodic Management Adjustments	Work Plans for Existing and New Facilities	Many, over many periods	None Not considered
Performance Metrics	NPV, ROI, Capex, etc	Many	One (the focus)

Analytical Problem

- We know we can increase value by
  - Recognizing uncertainty
  - Dealing proactively with it, by creating flexibility
  - … and enabling management to adjust
- How do we take this more realistic approach, within available analytical resources (time, modeling complexity)?
- Specifically, how do we
  - Focus effort on most productive parts?
  - Expand variables considered – and stay within limits of capability (this session)

Size of Problem: Astronomical!

- Full analysis of variations is impractical
- Example 1: possible price variations over 20 periods, if the price could be low, medium or high. The total number of combinations would be 3^{20} ~ 3 ½ billion…

  And this is for only 3 price levels!

- Example 2: possible decisions rules for expanding a facility (as in parking garage). One could expand with 1, 2, or 3 units (say); at different times; under different conditions.

  Over 20 periods, the possibilities are orders of magnitude greater than above!

Concept of Solution

We want a

- Middle ground between:
  - The simplest possible assumption typically used (e.g., price of copper is fixed over project life)
  - Complete set of possibilities
- Representative range of possibilities:
  - Small enough to be manageable analytically
  - Broad enough to cover all major situations

Outline of Solution

- Use "Catalog" of possible conditions, with associated responses or "Operating Plans"
- The "Catalog" provides a limited number of scenarios and responses intended to describe relevant patterns designers might wish to anticipate
- Instead of 3^{20} combinations of 3 price levels over 20 periods, we consider a "handful" of scenarios:
  - Steady rising and falling prices
  - High prices at beginning, low at end
  - Low prices at start, surge in prices at end
  - High volatility of prices around trend

A "Catalog" Approach

Stage for System	**Element**	**Possibilities**	**"Catalog" Approach**
Initial Design	Configuration of Infrastructure	Many	Many
Periodic Data on Context Factors	Price, Demand, Quantity, etc	Many, over many periods	**10 to 20** Representative Scenarios
Periodic Management Adjustments	Work Plans for Existing and New Facilities	Many, over many periods	**10 to 20** possible responses
Performance Metrics	NPV, ROI, Capex, etc	Many	Several E(NPV), Capex, Value at Risk and Gain, etc

Benefits of Catalog Approach

- Enables consideration of major scenarios
- Avoids intractable exhaustive design analysis
- Encourages deeper investigation of situations with greatest impact on performance
  – Additional scenarios and responses easily added
- Can be tailored to design problem
  – Catalog can be larger or smaller, focused on specific uncertainties
- Using modern computers, expanding analysis effort factor is easy

Benefits of Flexibility

- Changes expected economic value in two ways:
  – Recognizes value added by manager's ability to adjust to changing uncertain conditions
    - Value can be large, should not be ignored
  – Adds value through explicit consideration of flexibility in design and operations
    - Several case studies support this
    - E.g. satellite systems, mining, real estate development, automotive, etc.

Unknowns

- Validity: Only a few applications so far (real estate, mining). Seems promising, but more validation needed
- Definition of Catalog: How is this best done?
  - All at once at start?
  - Incrementally? from a starter set to more scenarios determined according to their effect on performance
- Detailed Characteristics: What level of detail appropriate to this approximate approach?

A RESEARCH TOPIC !

Research Questions

- How to find a Catalog of Operating Plans?
  - what is a good way to define members of the catalog?
  - How should search be expanded to more members of catalog?
  - When should search be terminated?
  - Others?
- What is the role and value of flexibility in this approach?

Parking Garage Example

http://www.flyhia.com/images/inset_parking-garage.jpg

Traditional Design Approach

Stage for System	**Element**	**Possibilities**	**Traditional Design Practice**
Structural Design	Number of Floors	Many	Many
Periodic Data on Context Factors	Price, Demand, Quantity, etc	Many, over many periods	One Price, Demand Profile
Periodic Management Adjustments	Price Changes; More Floors	Many, over many periods	None Not considered
Performance Metrics	NPV, ROI, Capex, etc	Many	One (the focus)

Design for Flexibility

- Analysis expanded to consider:
  - Several demand scenarios
  - Expansions with simple decision rule
  - Target curves

Stage for System	**Element**	**Possibilities**	**"Garage Case Design"**
Structural Design	Number of Floors	Many	Many
Periodic Data on Context Factors	Price, Demand, Quantity, etc	Many, over many periods	One Price, **1000s** of Demand Profiles
Periodic Management Adjustments	Price Changes; More Floors	Many, over many periods	**Some** Simple decision rule
Performance Metrics	NPV, ROI, Capex, etc	Many	**Several** NPV, VARG

Catalog Application

- Can look at expanded range of design variables and decision rules:
  - How many years before expansion?
  - Periods avoiding expansion?
  - How many floors to add on each expansion?

Stage for System	**Element**	**Possibilities**	**"Garage Case Design"**
Structural Design	Number of Floors	Many	Many
Periodic Data on Context Factors	Price, Demand, Quantity, etc	Many, over many periods	One Price, **1000s** of Demand Profiles
Periodic Management Adjustments	Price Changes; More Floors	Many, over many periods	**CATALOGS** of decision rules
Performance Metrics	NPV, ROI, Capex, etc	Many	**Several** NPV, VARG

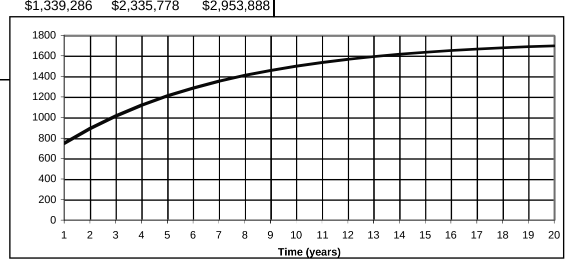
How to Find A Good Catalog?

- Suggested methodology
  - Step 1: build basic economic model (traditional approach)
  - Step 2: find representative uncertain scenarios
  - Step 3: identify potential sources of flexibility in design and operations
    - How we "add" value to the system
  - Step 4: for each scenario, find the best operating plan
    - This creates the "flexible" catalog
  - Step 5: assess value added by the catalog approach
    - How we "recognize" the value of managerial adjustments

Step 1: Build Basic Model

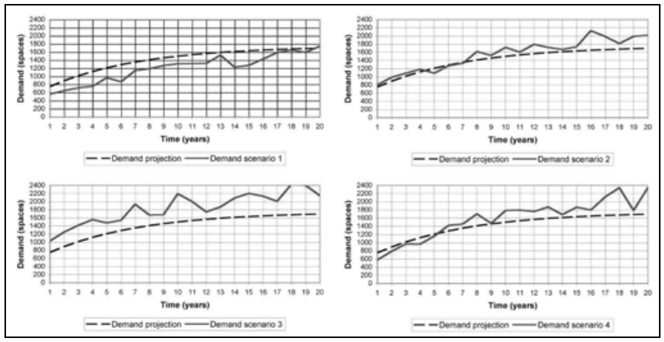
- Take deterministic demand projection and price
- Build cash flow model, get initial value of system

Year	0	1	2	3
Demand		750	893	1015
Capacity	0	1200	1200	1200
Revenue	$0	$7,500,000	$8,930,000	$10,150,000
Operating costs	$0	$2,400,000	$2,400,000	$2,400,000
Land leasing and fixed costs	$3,600,000	$3,600,000	$3,600,000	$3,600,000
Cashflow	$0	$1,500,000	$2,930,000	$4,150,000
DCF		$1,339,286	$2,335,778	$2,953,888
Present value of cashflow	$32,574,737			
Capacity cost for up to two levels	$6,400,000			
Capacity costs for levels above 2	$16,336,320			
Net present value	$6,238,417			



Step 2: Find Representative Scenarios

- Determine sources of uncertainty (e.g. **demand**, price)
- Incorporate fluctuations around deterministic projection
- Produce a few demand scenarios (10 to 20) and look at representative properties. Any idea?

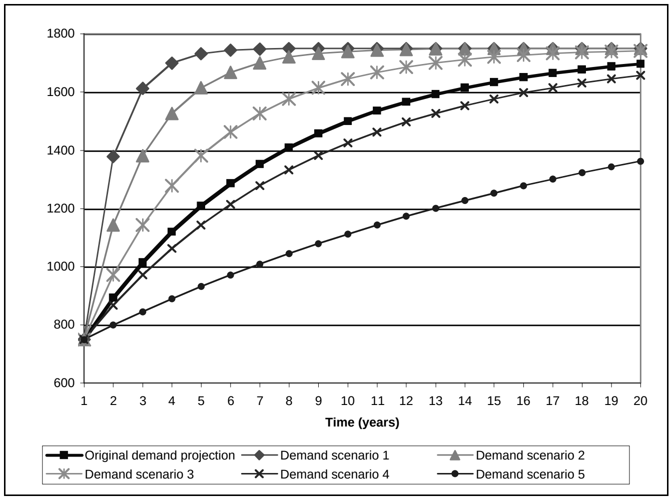


Finding Representative Scenarios

- Take demand growth between years 1-5 as criterion
  - Create five representative scenarios differentiated by early growth level
- How to differentiate categories?
  - Use mid-value between two categories
  - E.g. simulated scenario with growth above 123% similar to scenario 1, between 100%-123% scenario 2, etc.

Demand scenario category	Percentage increase from first to fifth year	Mid-value
1	131%	123%
2	115%	100%
3	84%	68%
4	52%	38%
5	24%	

Representative Scenarios



Step 3: Identify Flexibility

- Demand is uncertain, how to adapt?
  - Reduce losses: build fewer floors initially, reduce initial CAPX
  - Increase profits: expand as demand increases
  - Other sources of flexibility?
- Every system is different. Not obvious where to find flexibility!
  - Brainstorm, experts' opinions, etc.
  - Topic of doctoral research

Step 3: Identify Flexibility (2)

- Many ways to exploit flexibility to expand, in design and operations

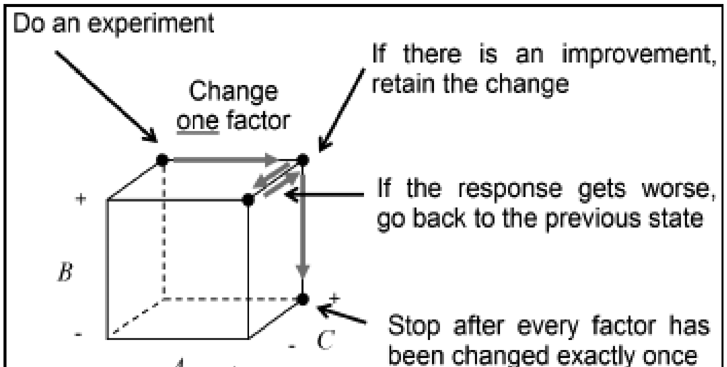
Design Elements and Management Decision Rules	Description	Levels		
A	Expansion allowed in years 1-4	No		Yes
B	Expansion allowed in years 9-12	No		Yes
C	Expansion allowed in years 17-20	No		Yes
D	Expansion decision rule (years)	2	3	4
E	Number of floors expanded by	1	2	3
F	Number of initial floors	4	5	6

  – "Levels" correspond to specific choice of design element of management decision rule
  – Note: $3^3 \times 2^3$ possibilities: 216 combinations!

Step 4: Catalog of Operating Plans

- Introducing adaptive One Factor At a Time (OFAT) algorithm (Frey and Wang, 2006)
  – Used in design of experiments (DOE)
  – Applied to design of engineering systems to effectively search best design combinations
  – Provides shortcut to full factorial analysis
  – Cost-effective way to explore the space of possibilities
- Method inspired from adaptive OFAT…
  – We do not perform statistical experiments while exploring the space of possible combinations
  – Consider one scenario at a time

Adaptive OFAT Algorithm

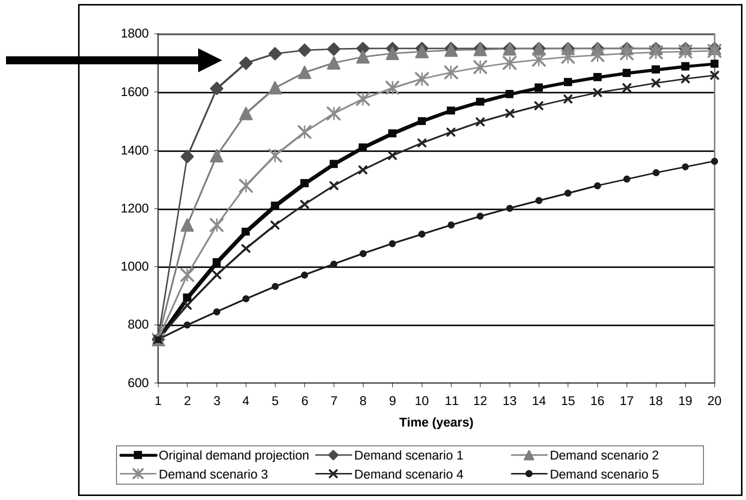


(Source: Frey and Wang, 2006)

Step 4: Setup Search

- Pick one representative scenario (e.g. scenario 1)
- Choose one combination of design elements and management decision rules $\Rightarrow$ Baseline condition
- Choose OFAT sequence arbitrarily
  - Determines sequence in which combinations of design elements and decision rules are explored
  - No need to be arbitrary
- Measure NPV for each combination, following OFAT sequence

Representative Scenarios



Step 4: Setup Search (2)

- Example:

DEs and Management DRs	Description	Baseline Experiment	OFAT Sequence
A	Expansion allowed in years 1-4	Yes	F
B	Expansion allowed in years 9-12	Yes	C
C	Expansion allowed in years 17-20	Yes	E
D	Expansion decision rule (years)	2	D
E	Number of floors expanded by	1	B
F	Number of initial floors	5	A

- Management DR: management decision rules (represented here by letters A to E in OFAT sequence)
- DE: design elements (represented here by letter F in OFAT sequence)
- Baseline experiment: set of design elements and management decision rules chosen for 1^{st} experiment

Step 4: Explore Possibilities

- Measure NPV ⇒ Baseline value
- Change one “level” in the combination:
  – If NPV is higher, keep change; if lower, go back to previous state
- Explore all levels at least once, keep best combination
- Notice: only 10 combinations explored instead of 216!

Experiment	DE and Management DR changed	Level changed to:	Output = NPV	Best output before step	Keep change?
1 (baseline)			$ 13.4		
2	F	4	$ 10.9	$ 13.4	No
3	F	6	$ 15.1	$ 13.4	Yes
4	C	No	$ 15.1	$ 15.1	No
5	E	2	$ 15.8	$ 15.1	Yes
6	E	3	$ 15.7	$ 15.8	No
7	D	3	$ 14.6	$ 15.8	No
8	D	4	$ 13.5	$ 15.8	No
9	B	No	$ 15.8	$ 15.8	No
10	A	No	$ 13.5	$ 15.8	No

Step 4: Get the Catalog

- Repeat same procedure for remaining 4 representative demand scenarios
- Get one operating plan best suited for each representative scenario
  – Now have a Catalog of Operating Plans!

DEs and Management DRs	Description	Op. Plan 1	Op. Plan 2	Op. Plan 3	Op. Plan 4	Op. Plan 5
A	Expansion allowed in years 1-4	Yes	Yes	Yes	Yes	Yes
B	Expansion allowed in years 9-12	Yes	Yes	No	Yes	Yes
C	Expansion allowed in years 17-20	Yes	Yes	Yes	Yes	Yes
D	Expansion decision rule (years)	2	2	2	2	4
E	Number of floors expanded by	2	3	3	1	1
F	Number of initial floors	6	5	5	4	4

Step 5: Assess Catalog Value

- Simulate operator's ability to choose operating plan depending on demand scenario (2,000 scenarios)
- Recall, simulated scenario categorized using mid-value between categories; then assign associated operating plan
  - E.g. scenario with growth between years 1-5 above 123% is given operating plan 1, between 100%-123% operating plan 2, etc.

Demand scenario category	Percentage increase from first to fifth year	Mid-value
1	131%	123%
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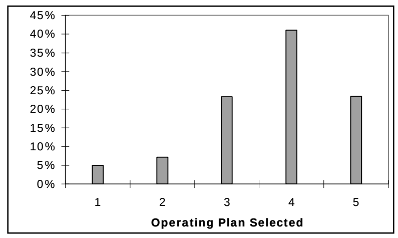
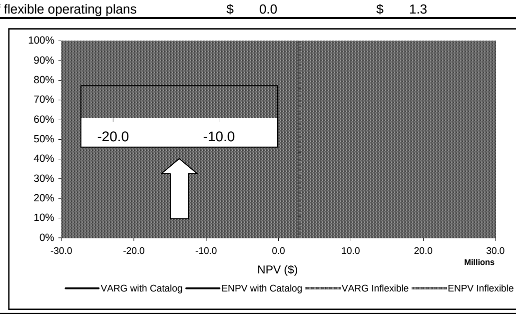


Step 5: Assess Catalog Value (2)

- Each assignment produces one NPV $\Rightarrow$ represent distribution with target curve!

	Inflexible Design	Flexible Design with Catalog of Operating Plans	Which is Better?
Expected initial investment	$ 18.1	$ 16.3	Flex. and Catalog Better
Expected NPV	$ 2.9	$ 4.9	Flex. and Catalog Better
Expected NPV minus expected cost of flexibility	$ 2.9	$ 4.2	Flex. and Catalog Better
Minimum NPV	$ -19.5	$ -18.8	Flex. and Catalog Better
Maximum NPV	$ 8.3	$ 20.5	Flex. and Catalog Better
Value of catalog of flexible operating plans	$ 0.0	$ 1.3	



Summary

- Methodology improves current practice significantly, which is simplistic regarding exogenous factors affecting value
- Not exhaustive! It does not use an “optimal” plan for each simulated scenario. This would:
  - Take far too long
  - Be very expensive
- Method uses a “Catalog of Operating Plans” prepared ahead of analysis, designed to be “representative”
- Recognizes value from operational adjustments, and adds value through use of flexibility in design and operations

References

- Cardin, M-A. (2007), “Facing Reality: Design and Management of Flexible Engineering Systems”, Master of Science Thesis in Technology and Policy, Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA.
- Frey, D., Wang, H. (2006), “Adaptive One-Factor-at-a-Time Experimentation and Expected Value of Improvement”, *Technometrics*, 48, 3, pp. 418-431.