Quantifying the Value of Flexibility in Design and Management of Onshore LNG Production System

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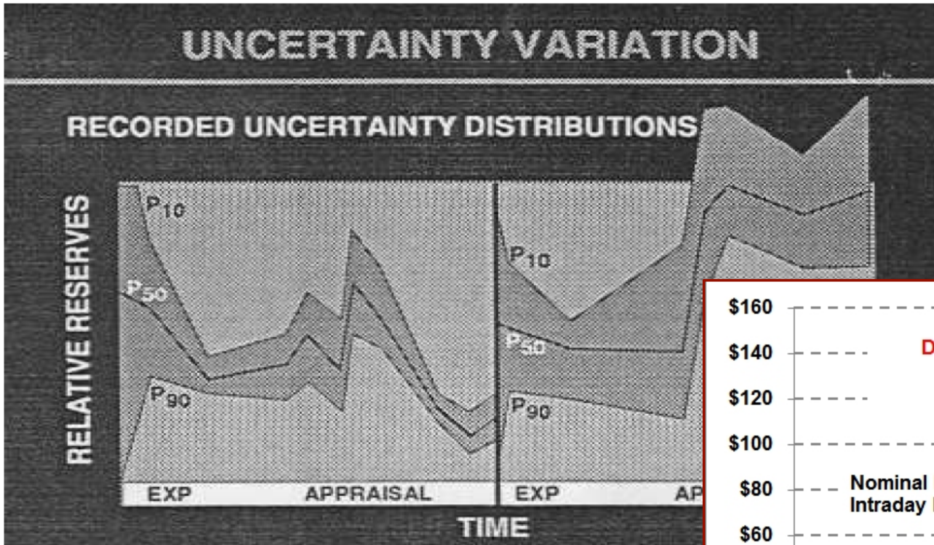
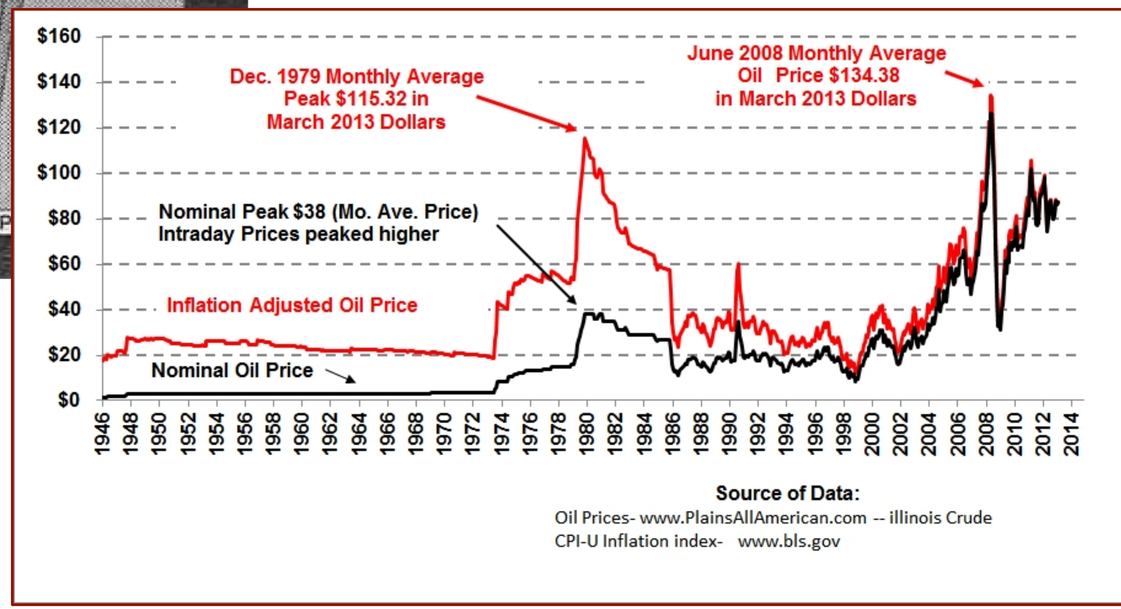
Motivation: Uncertainty



Source: Lin (2009) from BP sources



Motivation: Flaw of Averages

- Jensen's inequality

$$E[f(x)] \neq f(E[x])$$

- For systems with non-linear response (**most**), upsides do not balance downsides!
- Deterministic optimization may lead to incorrect capacity deployment, and design selection
- Standard stochastic optimization may not capture full benefits of pro-active adaptation

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What is Flexibility?

- Provides "right, **but not obligation**, to change system easily in face of uncertainty"
  - Abandon
  - Defer
  - Expand/contract
  - Phase
  - Switch
  - Etc.

- Also known as Real Option
  - "In" system: requires engineering design considerations
  - "On" system: from managerial standpoint

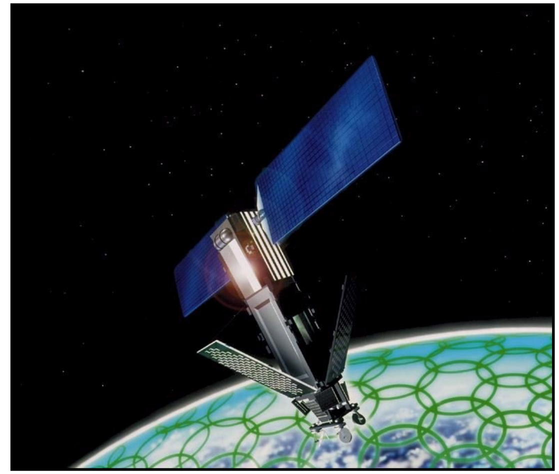
City Group Building, NYC

Source: Guma et al., 2009

Why Flexibility in Systems Matters?

- Engineering discipline increasingly complex
  - Need socio-technical considerations
- Uncertainty affects lifecycle performance
  - Markets volatile, regulations change, technology evolve
- Flexibility **can improve performance by 10%-30%** compared to standard design and project evaluation approaches
  - Protects from downsides (e.g. insurance)
  - Position for upsides (e.g. stock option)
  - **Net effect: better expected performance!**
- Design **rigidity** may lead to system failure
  - Iridium satellite/cell phone system
  - Convair B-58 Hustler

Source: www.comlinks.com

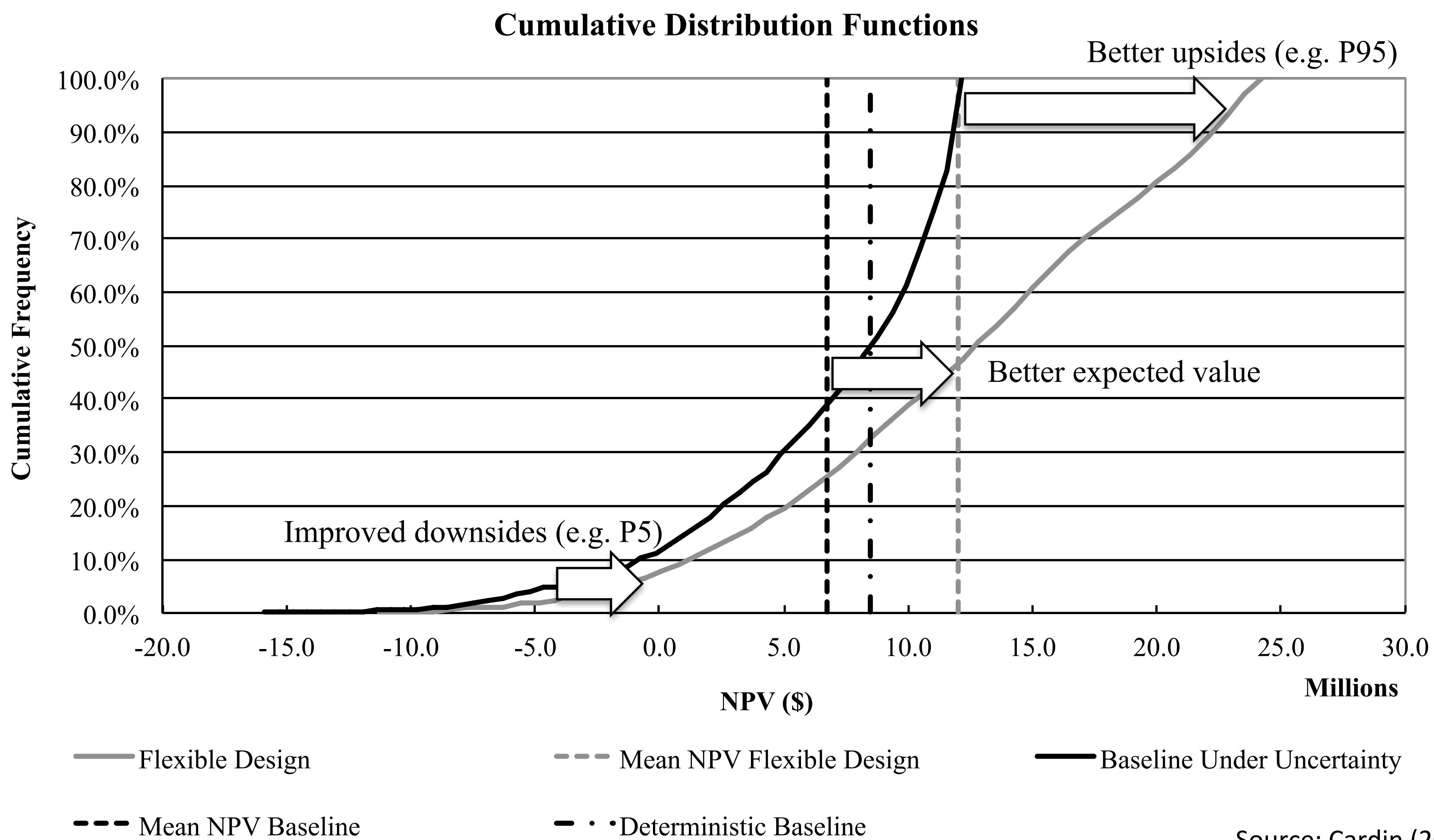


Iridium System:
Demand forecast over optimistic, too much capacity deployed at once ➔ filed for bankruptcy (de Weck et al., 2004)

Source: en.wikipedia.org

B-58 Hustler:
No contingency for Soviet surface-to-air missiles ➔ quickly obsolete, only 10 years of service (Saleh and Hastings, 2000)

Impact on Lifecycle Performance



Source: Cardin (2014)

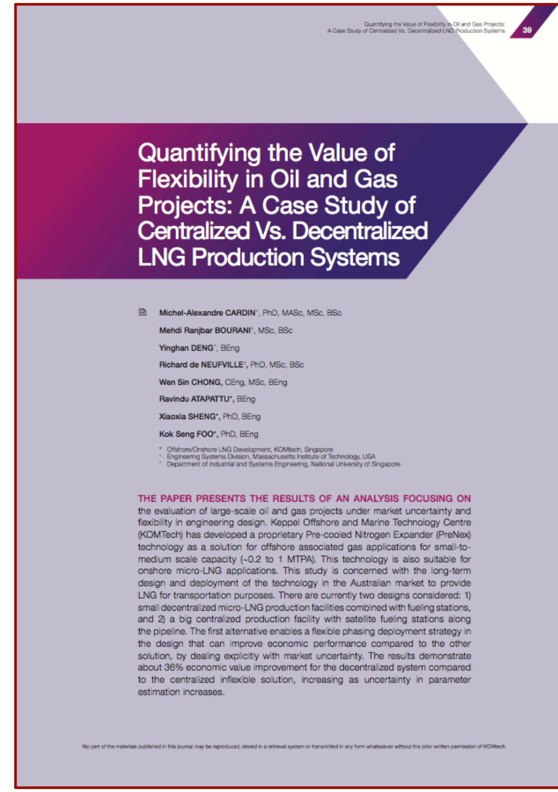
Challenges

- Flexibility not easy, need guidance
  - How much is flexibility worth?
  - How much flexibility costs?
  - What are major uncertainty sources?
  - What are the best flexible strategies to design?
  - Where to focus design effort to enable flexibility?

- Design thinking **NOT** widespread in industry practice and engineering education
  - Some do (and very successful), **MANY** don't

- **NEED TO ILLUSTRATE FLEXIBILITY ANALYSIS THROUGH CONCRETE CASE APPLICATIONS**

EXTENDED LNG STUDY



Quantifying the Value of Flexibility in Oil and Gas Projects: A Case Study of Centralized Vs. Decentralized LNG Production Systems

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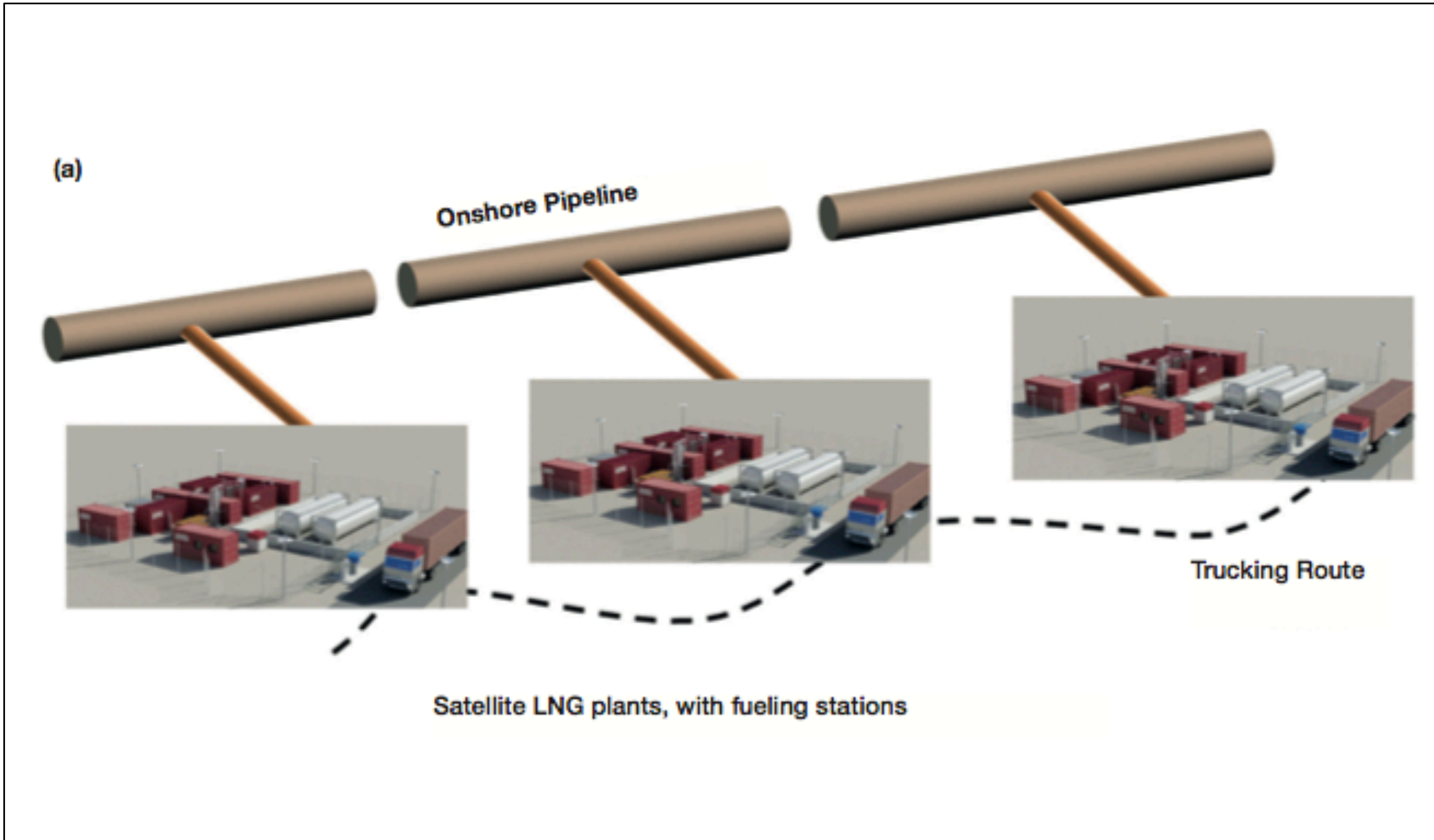
THE PAPER PRESENTS THE RESULTS OF AN ANALYSIS FOCUSING ON the evaluation of large-scale oil and gas projects under market uncertainty and flexibility in engineering design. Keppel Offshore and Marine Technology Centre (KOMTech) has developed a proprietary Pre-cooled Nitrogen Expander (PreNex) technology as a solution for offshore associated gas applications for small-to-medium scale capacity (~0.2 to 1 MTPA). This technology is also suitable for onshore micro-LNG applications. This study is concerned with the long-term design and deployment of the technology in the Australian market to provide LNG for transportation purposes. There are currently two designs considered: 1) small decentralized micro-LNG production facilities combined with fueling stations, and 2) a big centralized production facility with satellite fueling stations along the pipeline. The first alternative enables a flexible phasing deployment strategy in the design that can improve economic performance compared to the other solution, by dealing explicitly with market uncertainty. The results demonstrate about 36% economic value improvement for the decentralized system compared to the centralized inflexible solution, increasing as uncertainty in parameter estimation increases.

Inspired from paper by M.-A. Cardin, M. Ranjbar Bourani, R. de Neufville, Y. Deng, W. S. Chong, R. Atapattu, X. X. Sheng, and K. S. Foo, "Quantifying the Value of Flexibility in Oil and Gas Projects: A Case Study of Centralized Vs. Decentralized Lng Production," Keppel Offshore and Marine Technology Review, Singapore 2013.

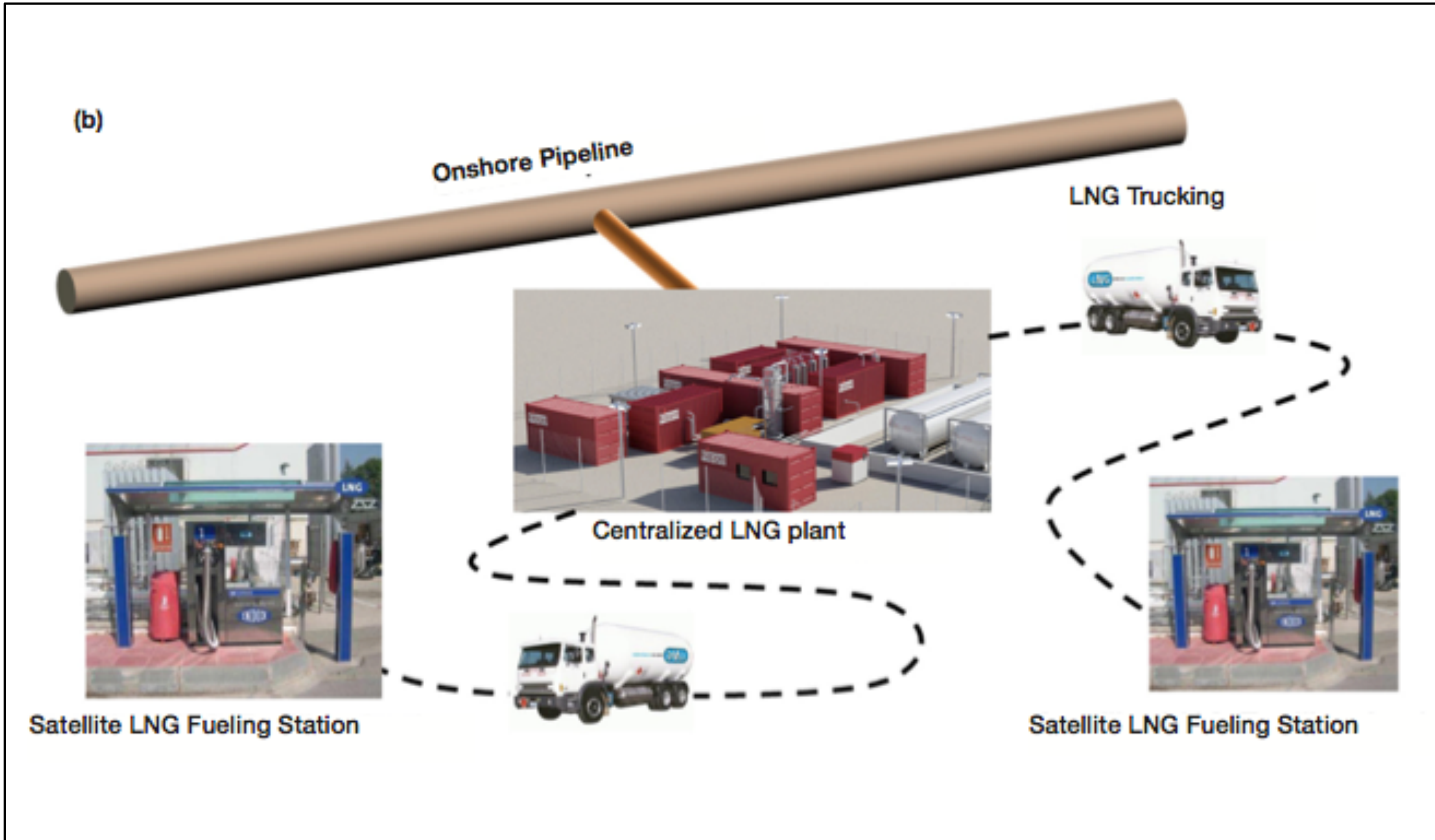
Analysis

- Step 1: Standard DCF Analysis
- Step 2: Uncertainty Analysis
- Step 3: Flexibility Analysis
- Step 4: Sensitivity Analysis

LNG study – Solution 1 (Decentralized)



LNG Study – Solution 2 (Centralized)



Net Present Value (NPV)

- NPV = PV (Revenues) - PV (Costs)

$$NPV = \sum_{t=0}^{T} \frac{R_t - C_t}{(1+r)^t}$$

NPV ≥ 0 ⇒ valuable project

‘r’ expressed as required rate of return – or discount rate – captures risk in project

Step 1: Standard DCF Analysis

- NPV Solution 1 (decentralized): $24.13 million
- NPV Solution 2 (centralized): $41.66 million
- Based on deterministic demand forecast:
  - $NPV_{centralized} > NPV_{decentralized}$
  - Centralized solution benefits from economies of scale
  - In Solution 1, transportation cost savings negligible
- Conclusion: **Solution 2 (centralized) Better**

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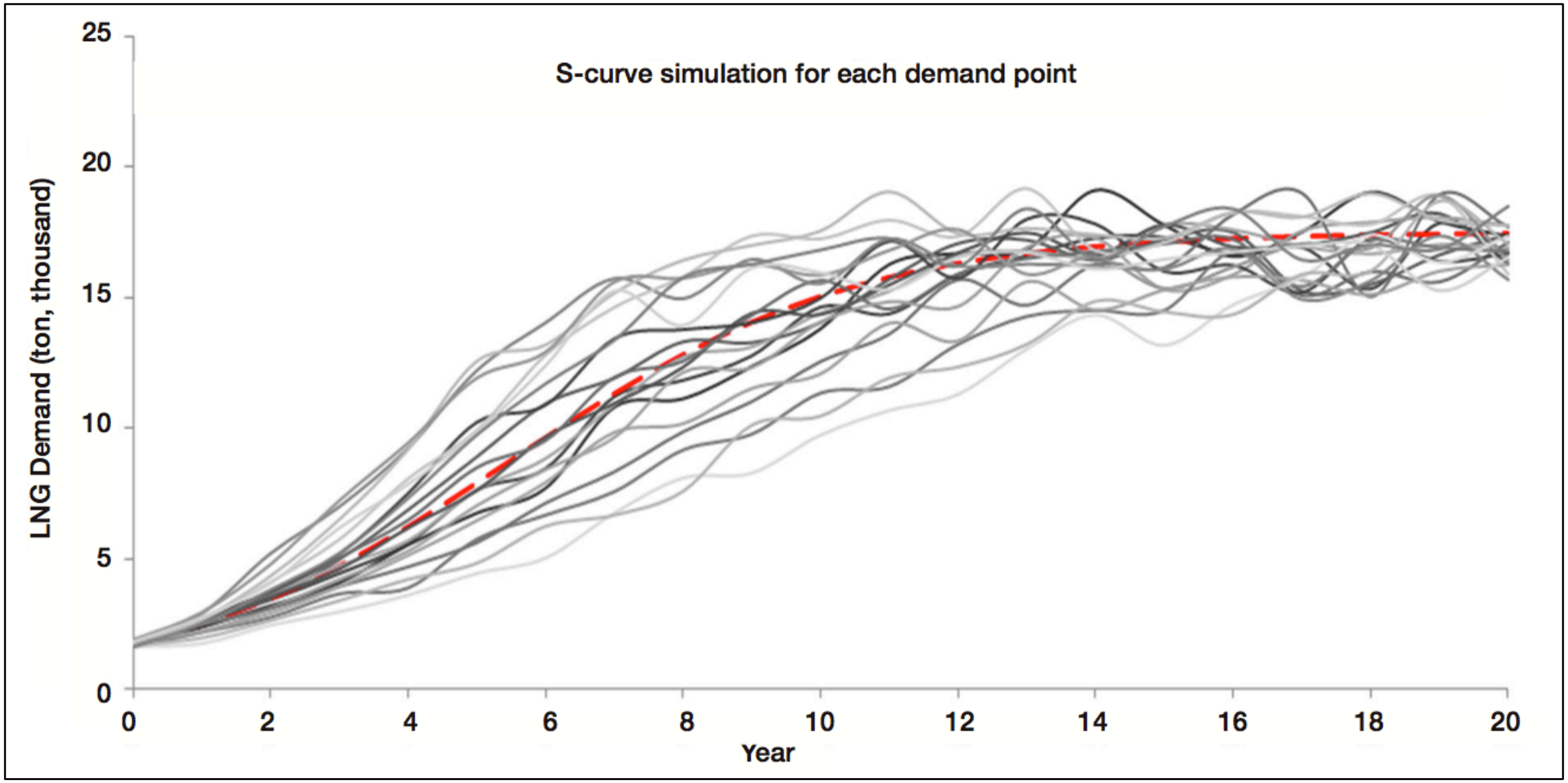
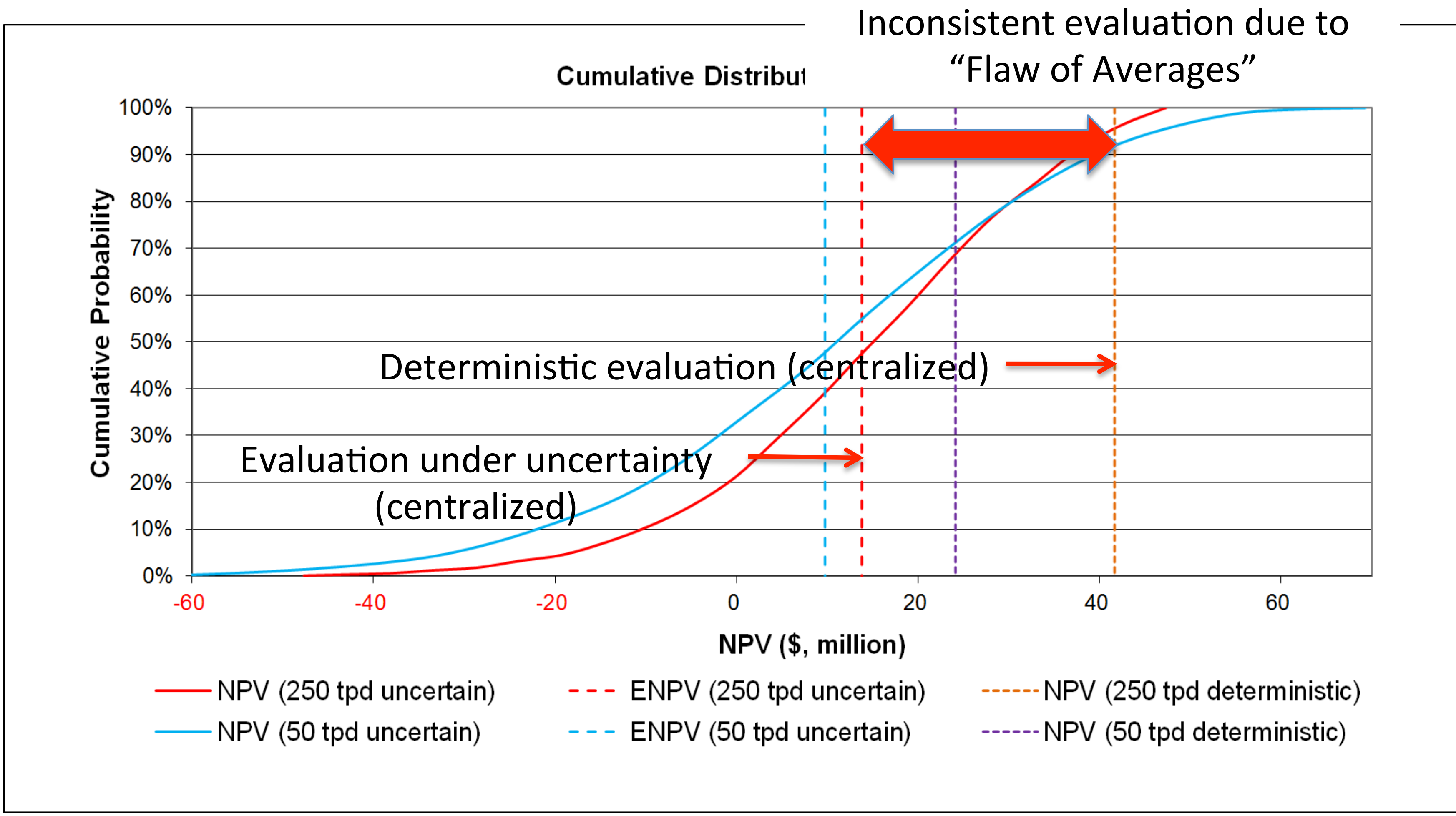
Step 2: Uncertainty Analysis

- Simulate LNG demand growth



Step 2: Uncertainty Analysis



Step 3: Flexibility Analysis

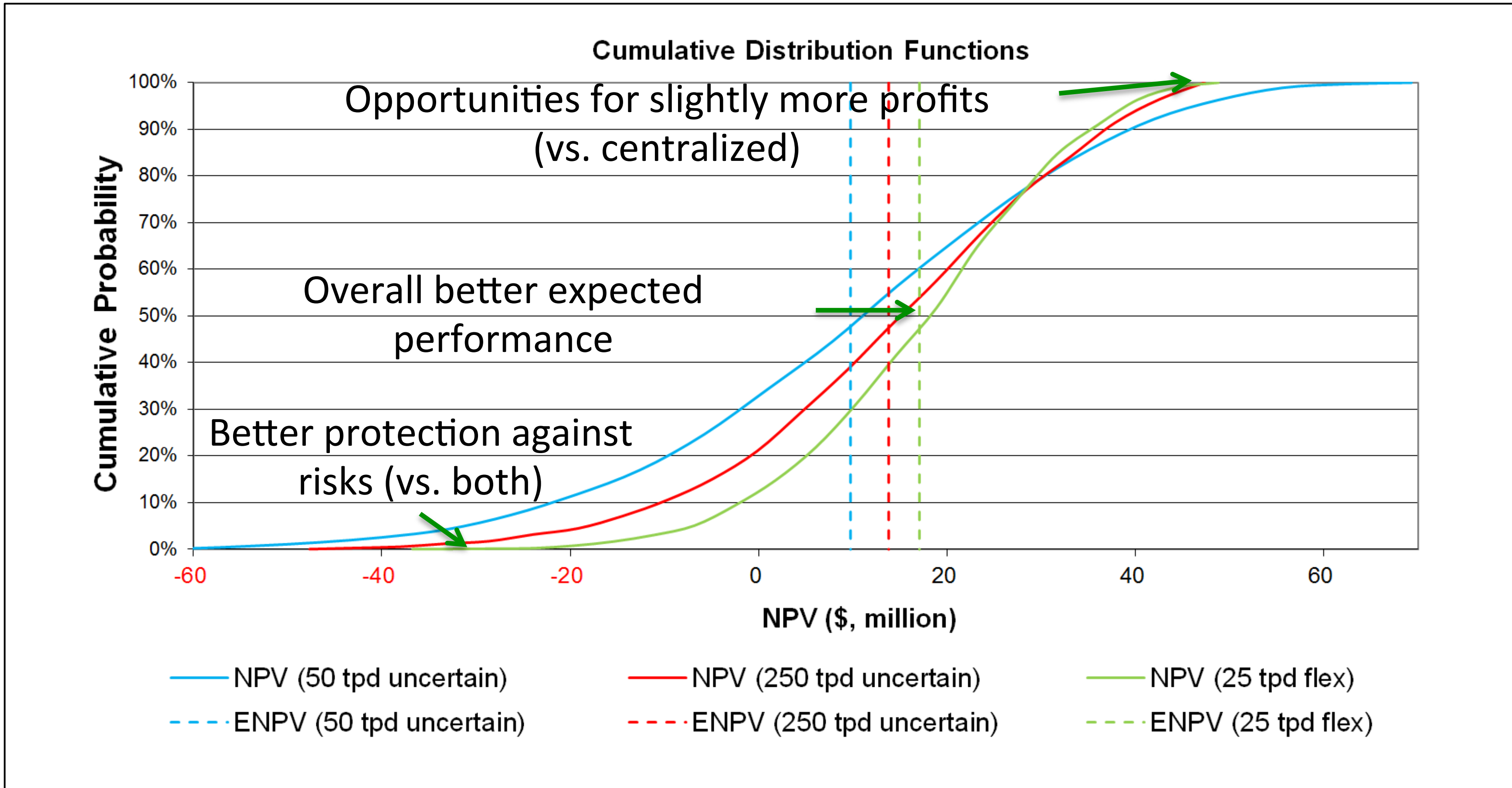
- In Solution 1 (decentralized), recognize flexibility to deploy additional modules only when demand is strong enough

- Captured in model by decision rule "*if demand > threshold X, add one more module, else do nothing*"
  - Applied at each site independently, for each demand scenario

- Strategy improves project value in three ways:
  - Defers costs capacity deployment to later ➔ lowers NPV cost
  - Avoids unnecessary deployment costs when demand is low
  - Provides contingencies to add more modules if demand is high, and generate more profits

- Above strategies **cannot be exploited** under solution 2 (centralized)

Step 3: Flexibility Analysis



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Step 3: Flexibility Analysis

Note decision reversal from standard DCF analysis!
Flexible decentralized solution now better; analysis more realistic

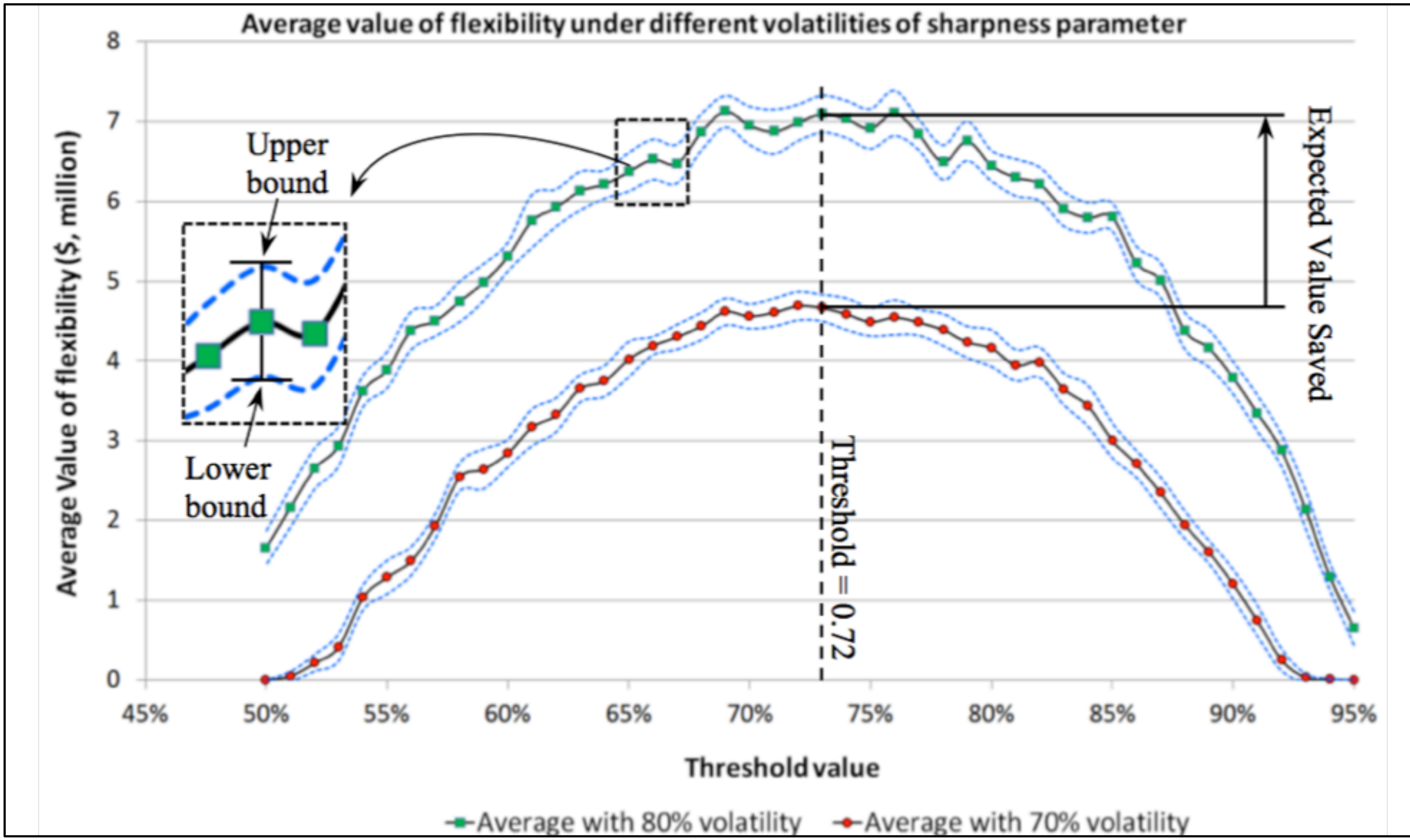
Value added by flexibility

Metric	Centralized Design Under uncertainty	Decentralized Design Under uncertainty	Flexible Design	Best Design?	Flexibility Value	Value Improvement [1]
Initial capacity (tpd [2])	250	250	125	N/A	N/A	N/A
Mean NPV	$13.60	$9.52	**$18.45**	Flexible	$4.85	35.66%
P5	-$20.00	-$30.09	**-$5.81**	Flexible	$14.19	70.96%
P95	$41.00	**$45.45**	$40.73	Decentralized	$0.00	0.00%
Standard deviation	$18.56	$23.33	**$14.29**	Flexible	$4.27	23.00%
Initial CAPEX	$154.36	$185.25	**$125.00**	Flexible	$29.36	19.02%

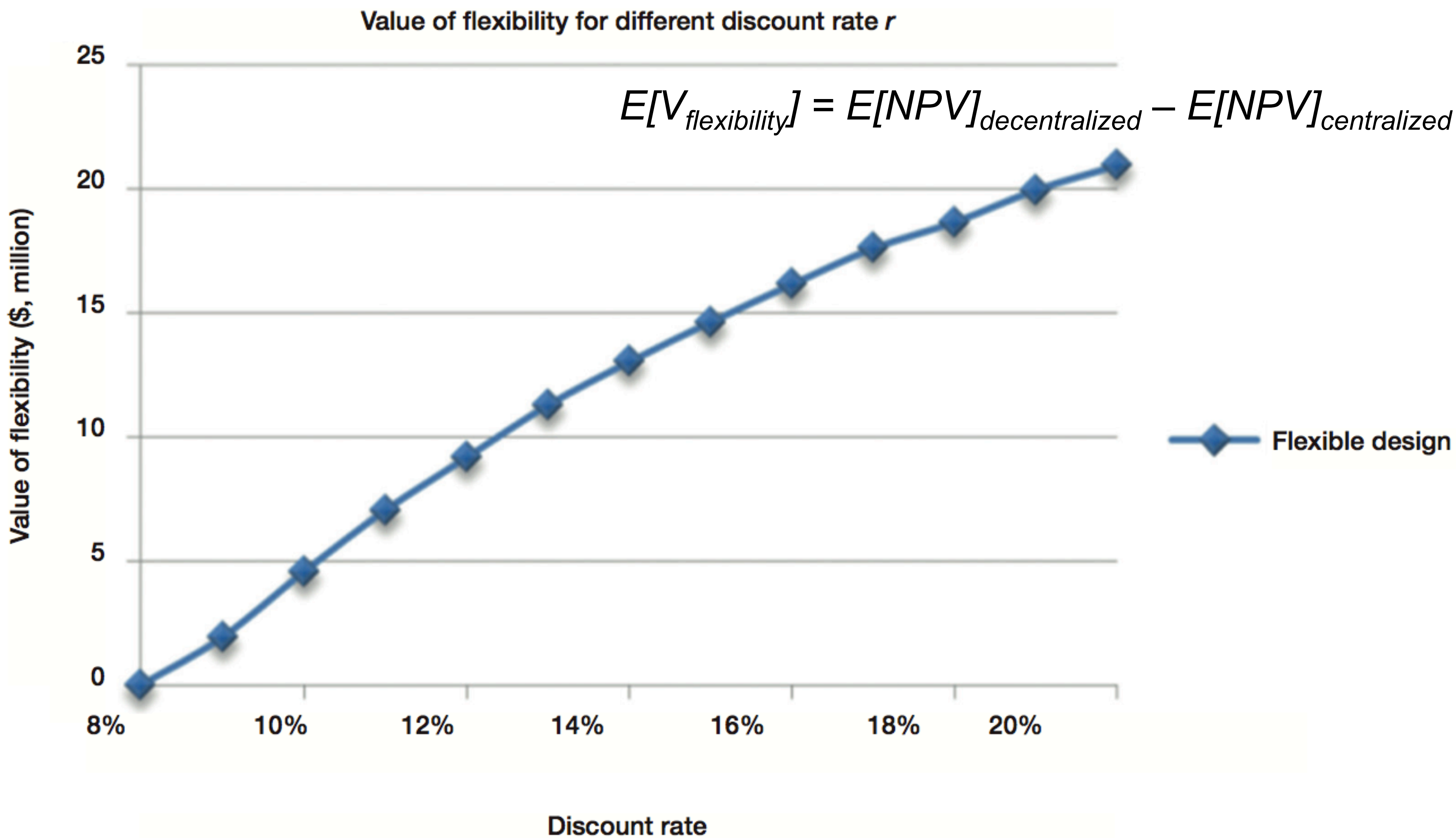
Evaluation based on different performance metrics

Best solution for each metric

Step 4: Sensitivity Analysis

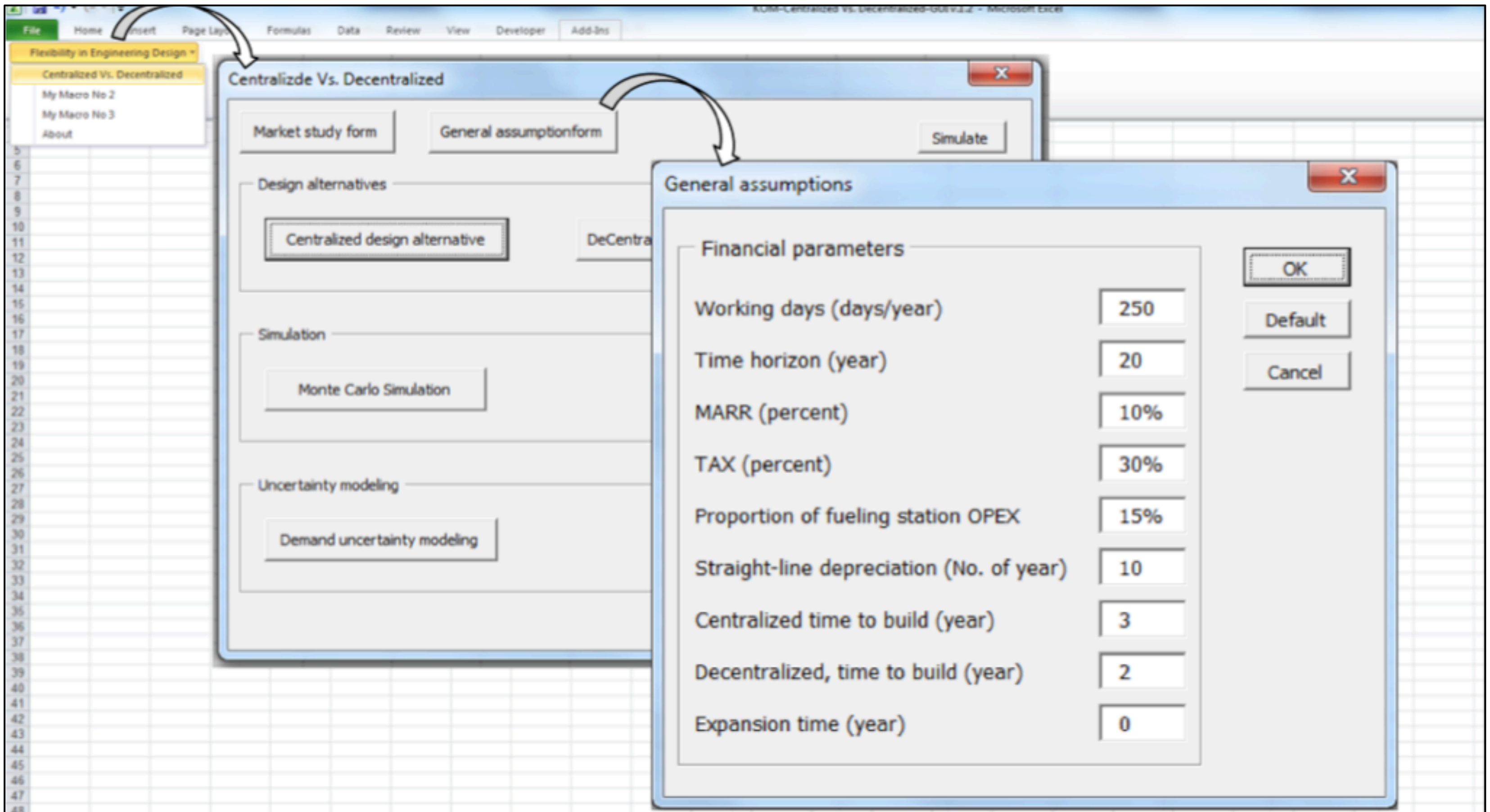


Step 4: Sensitivity Analysis



$$E[V_{flexibility}] = E[NPV]_{decentralized} - E[NPV]_{centralized}$$

Graphical User Interface



Conclusion

- Introduced systematic four-step methodology to analyze uncertainty and flexibility in complex infrastructure investment projects
- Demonstrated application to LNG production system
- Flexible decentralized system design enhances economic performance by 36% compared to centralized system – typical solution!
- Methodology applicable to other engineering systems

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