Design of Engineering Systems under Uncertainty via Real Options and Heuristic Optimization

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Addressing Uncertainty

Flexibility: the ability of the system to be actively managed against uncertainty by hedging risk and exploiting upside opportunities in order to maximize a system's value over its lifetime.

[inspired by RO literature]

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Flexibility = Active Management of Uncertainty

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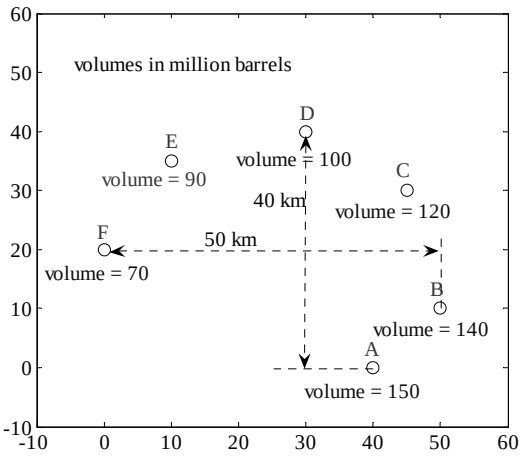
Flexibility addresses both Risk and Opportunity

Case Study

Embedding Flexibility in Off-Shore Oil Pipeline Network Deployment

Problem Statement

- Maximize NPV
- Determine
  - production facility location and capacity
  - pipeline sizes
  - production rates over 3 stages



The Genetic Algorithm

- The GA is an optimization approach that is modeled after Darwin's Theory of *Natural Selection*.
- An individual (design solution) is more likely to survive if it is adapted to its environment (design objectives and constraints).
- Designs with desirable traits (design characteristics) will evolve and remain in the genome composition of the population over designs with weaker traits.
- The GA works with a coding for the design parameters. This allows a combination of discrete and continuous variables.
- The GA uses a population-based search. Normally, this implies an expensive search.

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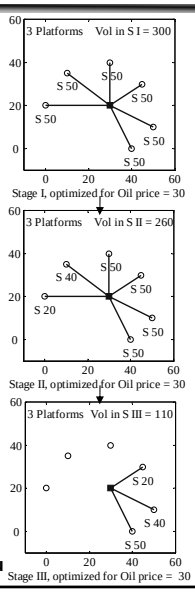
A Rigid Design - Optimized



Evolution of Design Optimized for Oil Price = 30

PV(Cost)	1006
PV(Revenue)	1828
NPV	822

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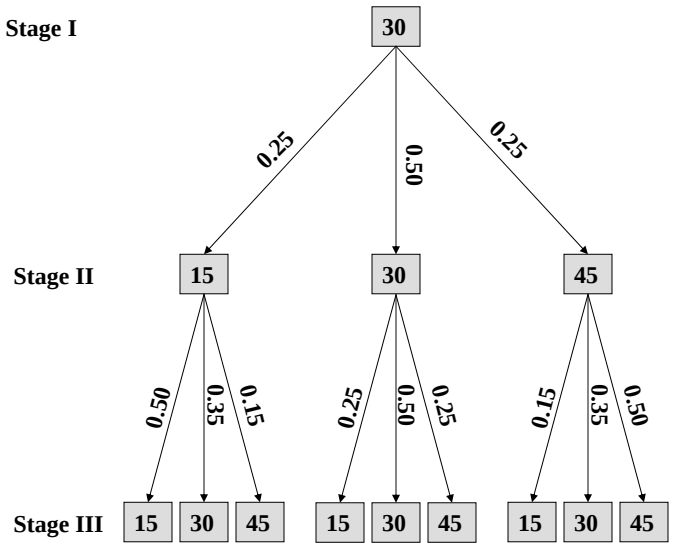
Recognizing Uncertainty in Future Oil Prices



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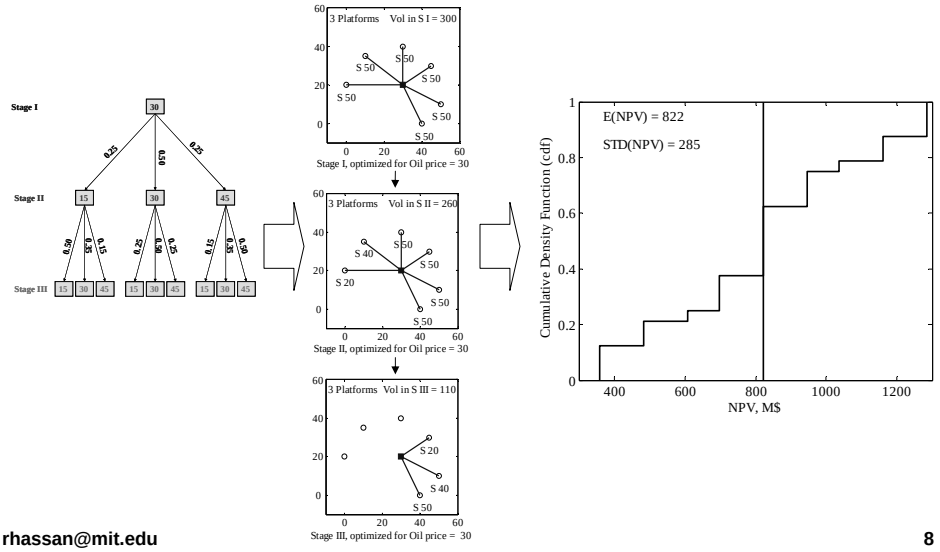
Rigid Design Evaluated under Price Uncertainty



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Designing for Flexibility Using Real Options

- In financial markets, options have been adopted as proven mechanisms for coping with uncertainty.
- A financial option gives its owner the right, but not the obligation, to take a particular course of action in the future.
- Options provide flexibility in the decision making process with the objective of limiting downside losses while capitalizing on potential upside opportunities.
- "Real Options" has been emerging as a discipline that applies ideas from quantitative finance to engineering projects.

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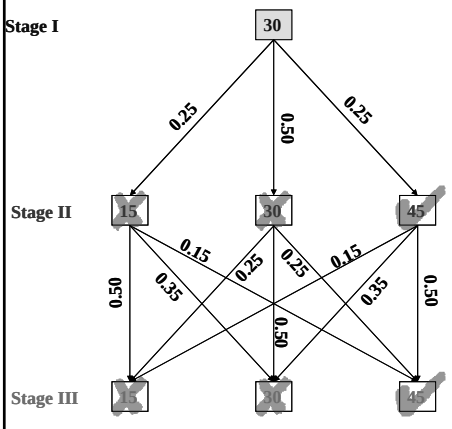
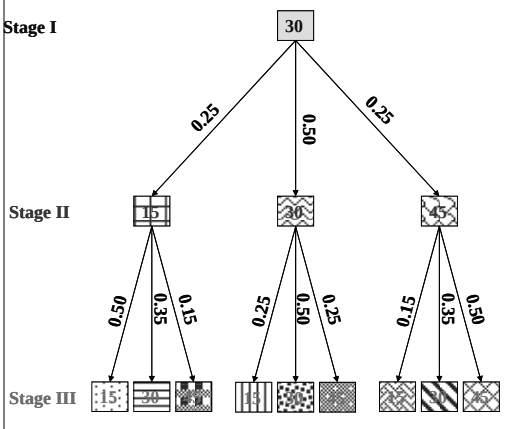
Designing for Flexibility Using Real Options

Financial Markets



Engineering Projects



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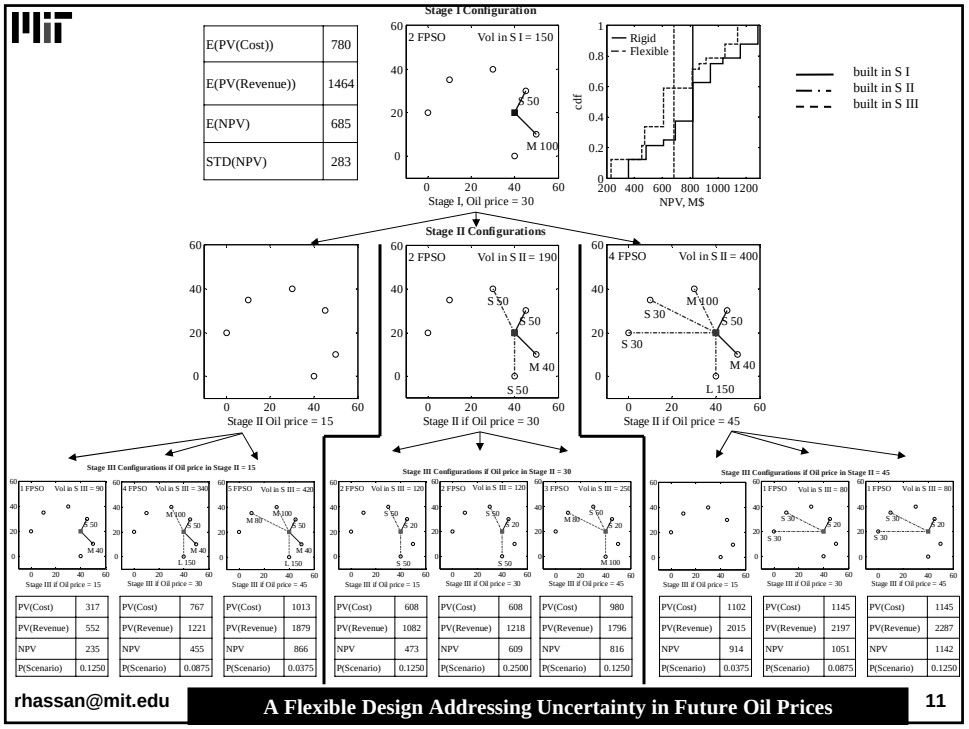

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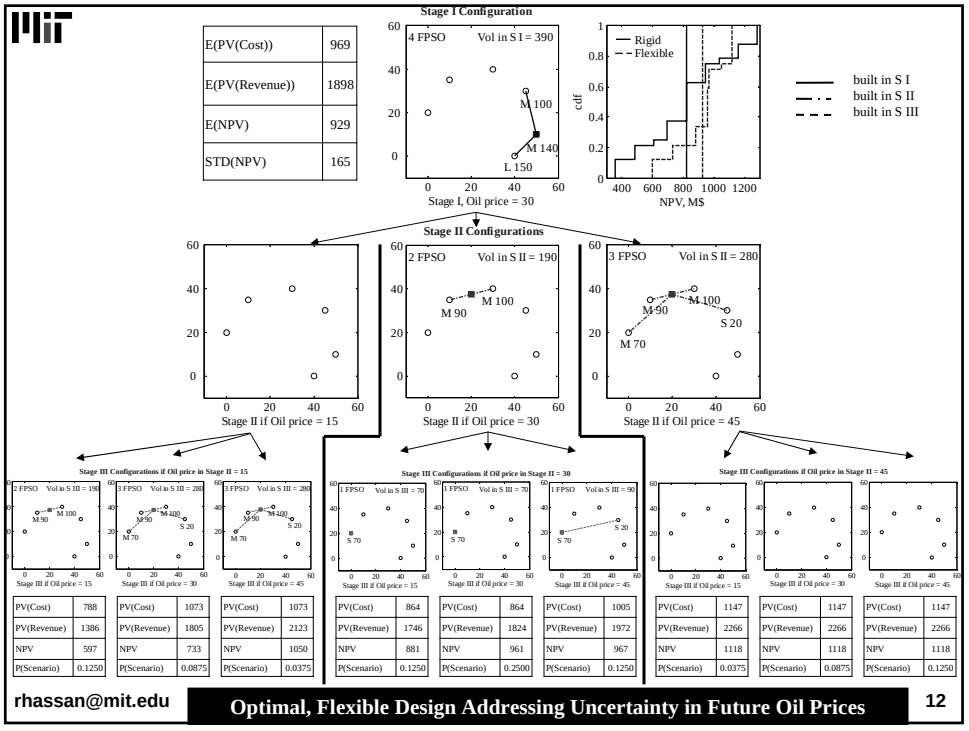

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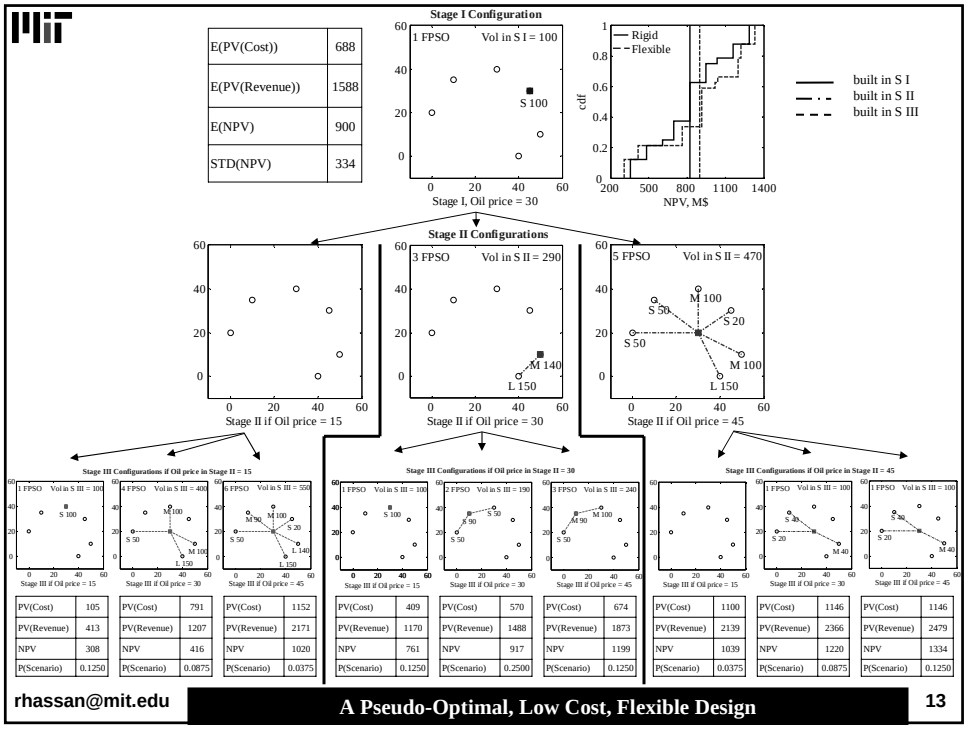

Solution Quality under Uncertain Oil Prices

Value Metric (millions of dollars)	**Rigid**	**Flexible Demo**	**Optimal, Flexible with Highest E(NPV)**	**Pseudo-Optimal, Flexible with Low Cost**
E(NPV)	822	684	929	900
STD(NPV)	285	283	165	334
Min Possible Gain	358	234	788	308
Max Possible Gain	1286	1142	1148	1334
E(PV(Cost))	1006	780	969	688

Computational Cost

Computational Cost Metric	**Rigid**	**Flexible**
Design Variables	19	91
Variable Coding in Bits	28	208
Exhaustive Design Space	268×10^{6}	411×10^{60}
GA Function Evaluations	14×10^{3}	17×10^{4}
GA Computational Time (mins)	< 1	150

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Words of Wisdom on Flexibility in System Design

- Flexibility is not an objective in itself; the impact of flexibility on system performance is the objective.
- Flexibility does not mean and is not only achievable via staged deployment
- Flexibility is not revenue management in engineering projects
- Traditional financial options analysis and valuation approaches, i.e. Black-Scholes formula and derivatives, do not apply to engineering design.
- Value-at-Risk analysis presents a simple, transparent, but powerful approach to valuing flexibility in engineering projects.
- Flexible designs do not necessarily require larger initial capital expenditure as compared to rigid designs.
- Flexibility is not the enemy of optimality.

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