Strategic Engineering of Large Infrastructure Systems:
Real Options, Staged Development, and the Role of Flexibility

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Dec. 4th, 2007

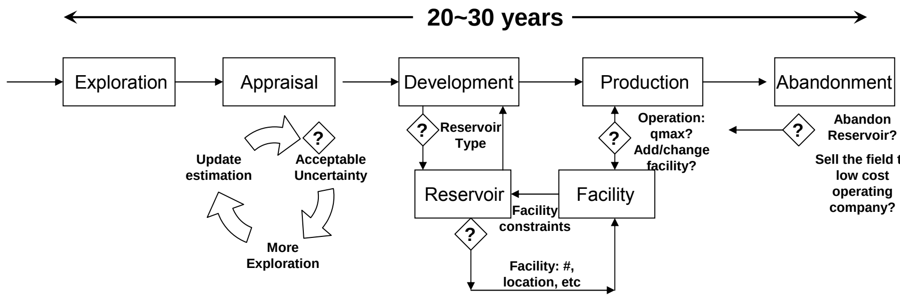
* This research work is sponsored through BP-MIT research program

Outline

- Background about offshore oil/gas field development project
- Motivation and research questions
- Integrated Matlab model of offshore oil/gas project
- Applications of the integrated model
  - Design optimization
  - Reservoir and market uncertainty modeling and simulation
  - Flexibility in oil/gas field development
  - Simulation case study of flexible staged development
- Conclusion and Future work

Background

❑ **Generic stages for oil/gas exploration and production project**



Exploration:
Geographical location
Reservoir identification (seismic)
Local environment politic, economic conditions, etc…

Appraisal:
Drill appraisal wells to learn more about reservoir and reduce uncertainty (reservoir volume, fluid properties, etc.)

Development:
Based on reservoir properties, selects reservoir type, facility concept designs
Reservoir and Facility Models capture link between physical dynamics and facility configuration
Estimate the production profile, field development cost
Select -> Define -> Execute

Production:
Actively monitor and manage reservoir production
Potential further field development

Abandonment:
Determines Abandonment Conditions
- Technical condition
- Economical condition

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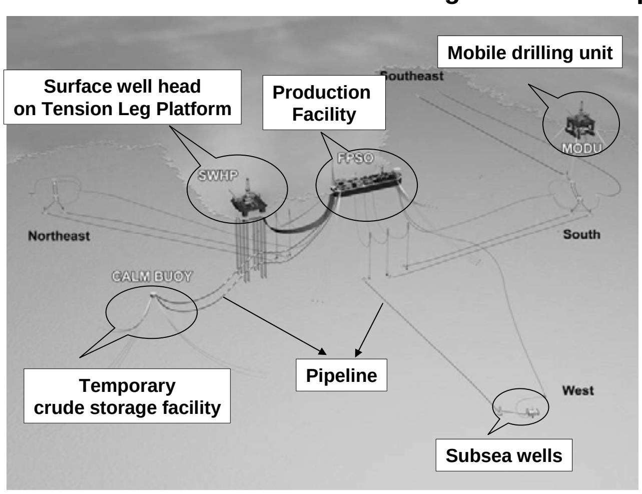
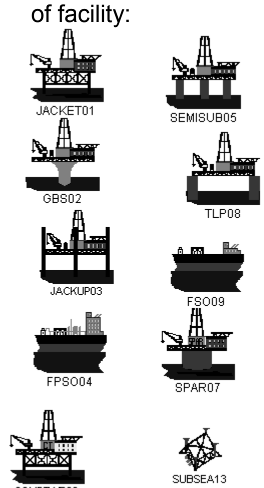
Background - cont.

❑ **An illustration of offshore oil/gas field in deep water**



Some other types of facility:



Motivation

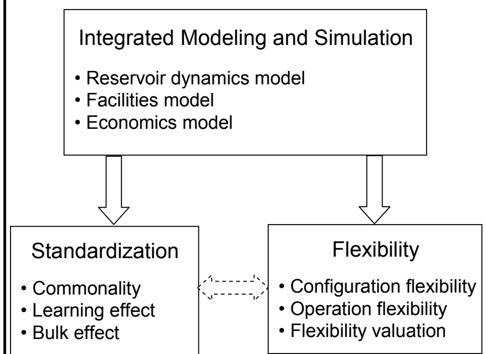
- Large-scale engineering systems, such as offshore oil gas platforms, are very complex in nature due to the interactions among multiple disciplines, such as reservoir engineering, facility designs, project economics, etc.
- Existing tools are very domain specific and a lot of integration effort is required from decision makers in the early field development stages.
- Furthermore, multi-billion dollars investment decisions on offshore infrastructure have to be made under a wide range of uncertainties such as reservoir, market conditions, and political environment uncertainties. Traditional practice of designing the “optimal” facility to the specifications potentially leads to undesired outcomes (e.g., opportunity loss, high risk).
- Therefore, there is a need for major oil companies to think more strategically in their offshore oil and gas development.

Research Questions

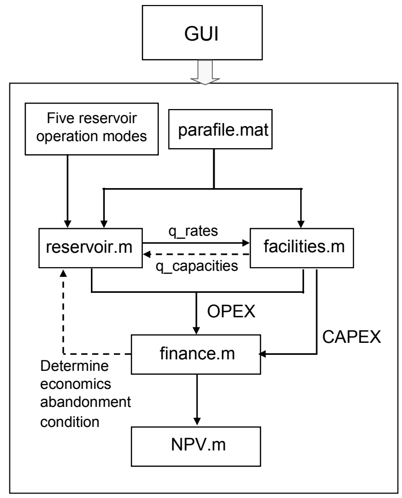
- **The key research questions are:**
  - **Modeling:** How to model the essential interactions among multiple disciplines for strategic decision making in offshore field development?
  - **Flexibility:** How can flexibility in design and operation improve projects expected value under uncertainties?
  - **Strategic Engineering Framework:** In the context of offshore oil and gas projects, how to develop a strategic engineering framework for field development which is robust and adaptive to future environment?

Overview of Model Structure

- Conceptual structure

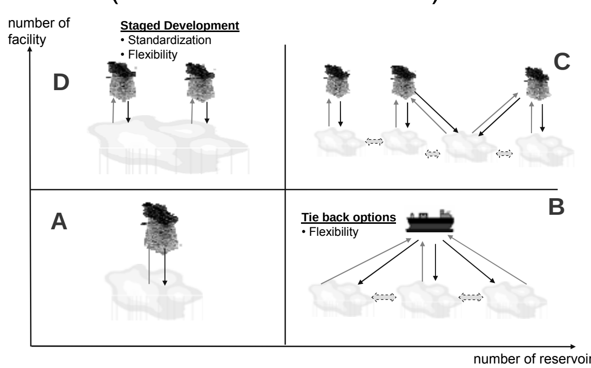


- Implementation structure



Model Capabilities

- The integrated model intends to consider following the scenarios (with focus on B and D)

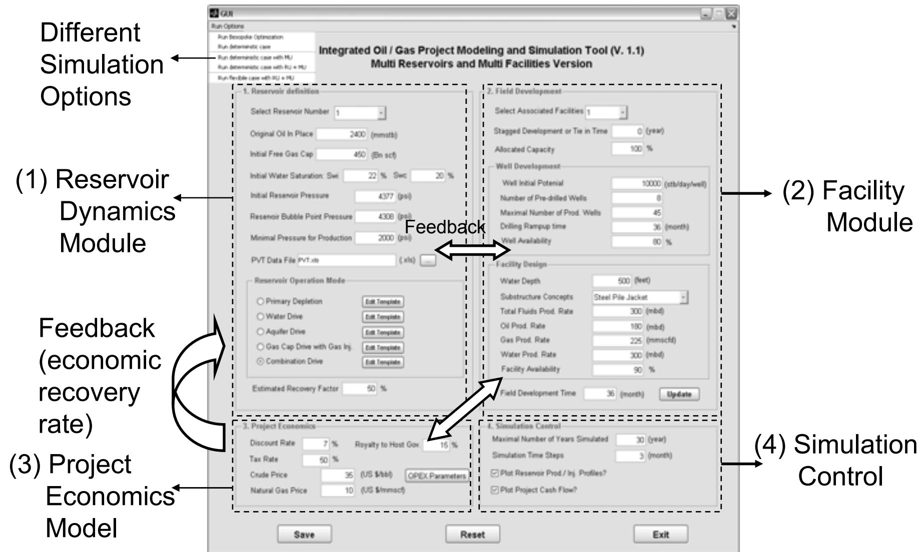


		# of Reservoirs				
		1	2	3	4	5
# of Facilites	1	1				
	2	1				
	3		1			
	4		1			
	5		1	1		
	6				1	
	7					1

Staged development of a large reservoir

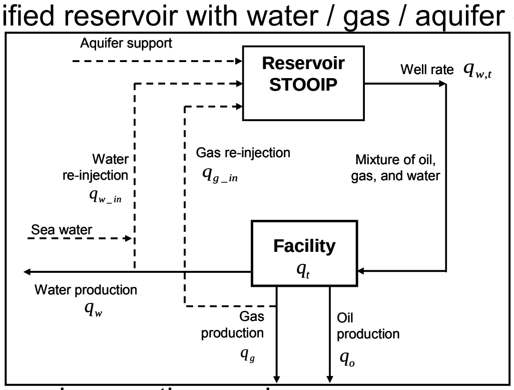
Tie-back a small reservoir 3
To facility 5 as capacity becomes available

Multi-reservoir Multi-facility Integrated Model



Reservoir dynamic model

- A simplified reservoir with water / gas / aquifer drive



- Five reservoir operation modes
  1. Primary depletion
  2. Water drive
  3. Aquifer drive
  4. Gas cap drive with gas injection
  5. Combination drive

Parametric facility cost model

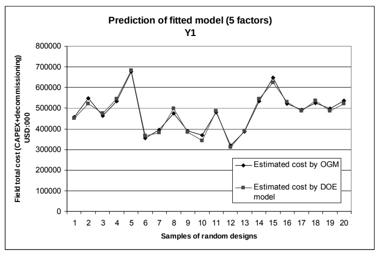
- Develop facility cost –capacity parametric model using OGM software and Design of Experiment (DOE) method for Steel Pile Jacket substructure

$$\vec{\mathbf{y}} = \mathbf{A}\vec{\mathbf{x}} + \mathbf{B}$$

Where

$$\vec{\mathbf{y}} = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \end{bmatrix} = \begin{pmatrix} \text{Field total unadjusted cost} \\ \text{Total topside installed cost} \\ \text{Total substructure cost} \\ \text{Total topside dry weight} \\ \text{Total substructure weight} \end{pmatrix} \qquad \vec{\mathbf{x}} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix} = \begin{pmatrix} \text{Sea water depth} \\ \text{Crude prod. rate} \\ \text{Water prod. rate ratio} \\ \text{Water inj. rate ratio} \\ \text{GOR} \end{pmatrix}$$

- A linear relationship seems to capture the facility cost - capacity model very well



- Compare predictions of facility model with OGM model outputs
- The average error for field development cost is less than 3%

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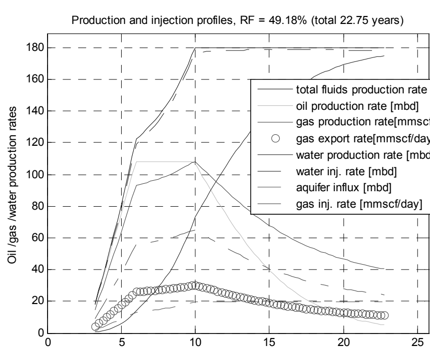
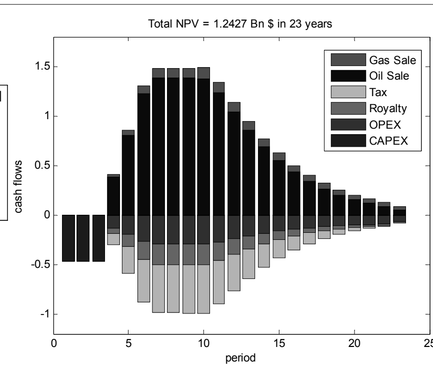
Typical flow rates and cash flow profile for oil/gas project





Some outputs:

```
Reservoir simulation stops: watercut out of limit (97%)!
Active constraint: platform total fluids production capacity
Active constraint: platform oil production capacity
Economics abandonment condition is NOT active!
The reservoir recovery factor is : 49.18 %
The total produced oil is : 393.4403 mmstb over 22.75 years.
This simulation took 0.969 seconds.
-------------------------------The end of ouputs--------------------------------
```

- CAPEX: equally spread out in project development phase
- Learning effect on CAPEX reduction for stage development : define learning factor internally (e.g., 90%)
- OPEX: fixed OPEX + variable OPEX

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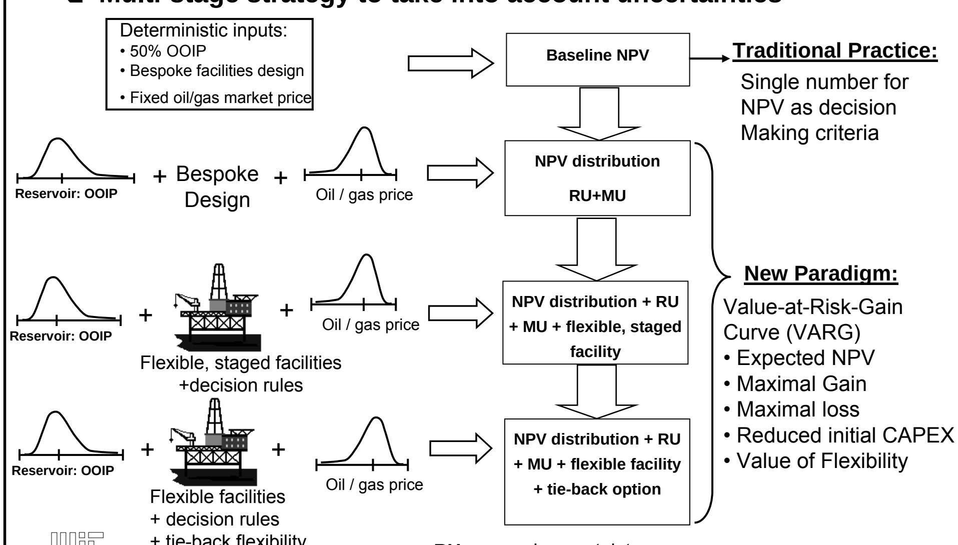
Applications of Integrated Model

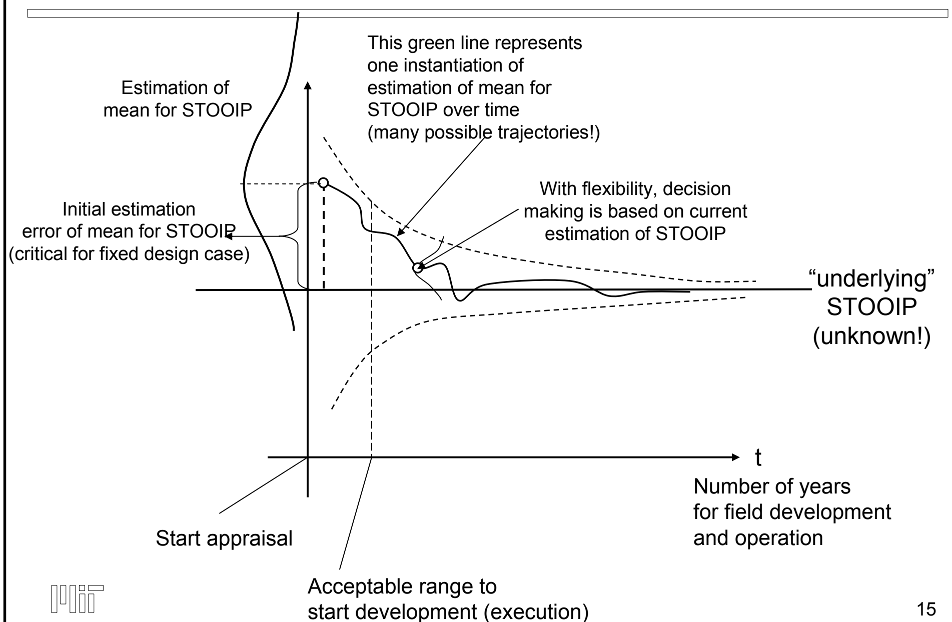
Uncertainty and flexibility in oil field project

- **Multi-stage strategy to take into account uncertainties**



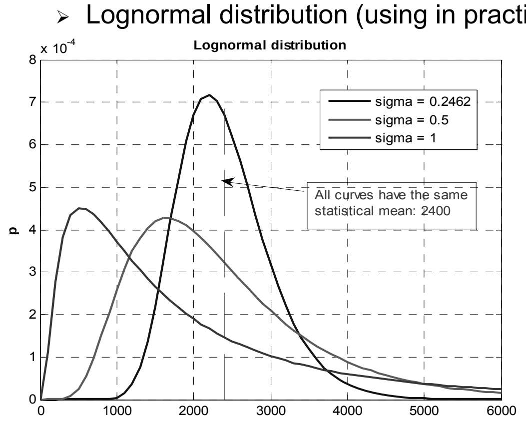
RU: reservoir uncertainty
MU: market uncertainty

Reservoir uncertainty



Distribution of reservoir volume estimation

- Assume initial estimation of reservoir volume follows some distributions, e.g.,
  - Normal distribution with negative tail cutoff
  - Lognormal distribution (using in practice)

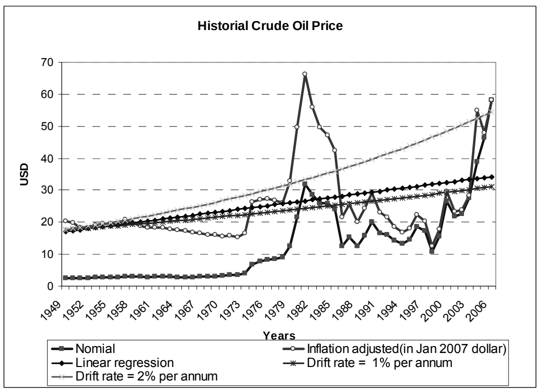


Learning processes will narrow the distribution of STOOIP over time.

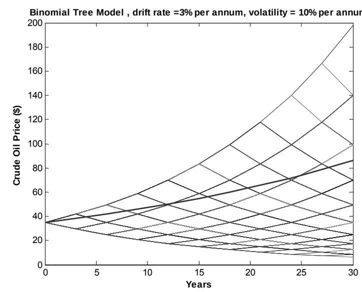
The standard deviations for blue, green, and red curves are: [600 1279 3146] mmstb.

Market uncertainty

- Crude oil price constantly changes over time
- Field development strategy needs to adapt accordingly
- Some mathematical techniques are available to model price evolution (e.g., binomial tree model)



Binomial tree model



Initial oil price: $35

$\mu = 0.02$ (per annum)

$\sigma = 0.1$ (per annum)

$\Delta t = 3$ years

$T_{\max} = 30$ years

$$u = e^{\sigma\sqrt{\Delta t}}$$

$$d = \frac{1}{u}$$

$$p = \frac{e^{\mu\Delta t} - d}{u - d}$$

$$p(scenario) = p^k (1-p)^{n-k}$$

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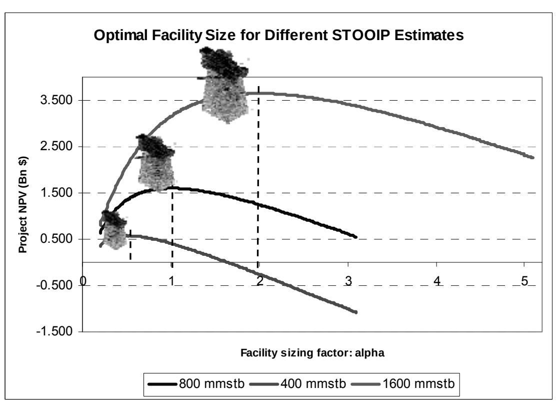
Bespoke design

- Given P50 estimation of STOOIP, design a facility to optimize project NPV
- Bespoke designs for different STOOIP estimations (400, 800, 1600 mmstb)



This figure shows that different STOOIP estimates can lead to different optimal facility sizes.

Single factor facility sizing: alpha* [200 150 150 200] mbd or mmscf/d for [Total fluid rate oil production rate gas production rate water production rate]

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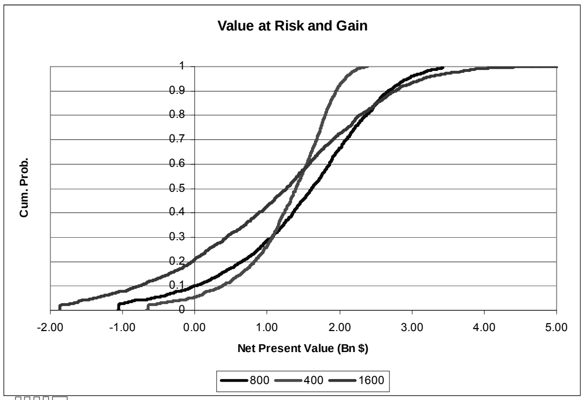
Bespoke designs + reservoir volume uncertainty

- Bespoke designs for three STOOIP estimates (800, 400, and 1600 mmstb)
- Monte Carlo simulation (2000 runs) for each bespoke design with OOIP uncertainty (normal distribution, mean 800, std 400, cutoff at 5)



This figure shows that different bespoke designs will behave differently under reservoir uncertainty

- Bigger facility can take larger upside opportunity but will potentially lose big
- Smaller facility is a relative conservative strategy

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Flexibility in oil/gas field development

- There are many possible ways to embed flexibility into oil/gas field development:

Field level

- Postpone, abandon field development.
- Add new platforms, tie-back other reservoir fluids to platforms, etc.

Platform level

- Capacity expansion (i.e., add extra water injection equipment)

Operational level

- Well and production management (i.e., shut down wells, increase / decrease water injection volume)

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Pre-determined vs. Flexible Staged Development

Compare three field development strategies:

1) Pre-determined staged development
   - Three identical stages (33% capacity each) in year 0, 2 and 4
   - 90% learning factor on CAPEX reduction

2) Flexible staged development
   - Stage options: 33%, 50%, 100% capacity
   - 1~2 stages (33%, 100%, 100% + 50%, 100% + 100%) depending STOOIP estimates
   - A decision rule has been coded in the program to determine when to add additional stage with how much capacity

3) One big monolithic facility development
   - Single stage in year 0 with 100% capacity

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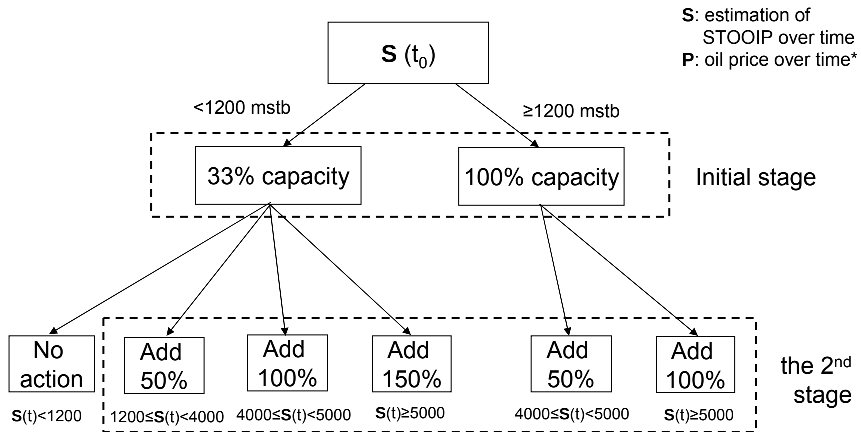
Decision rules for flexible staged development

- This is an example of the decision rule



*Adding stage can be made only when **P**(t)>$35

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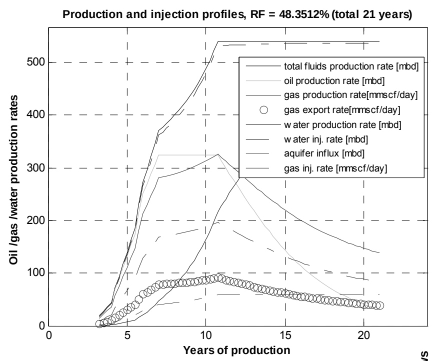
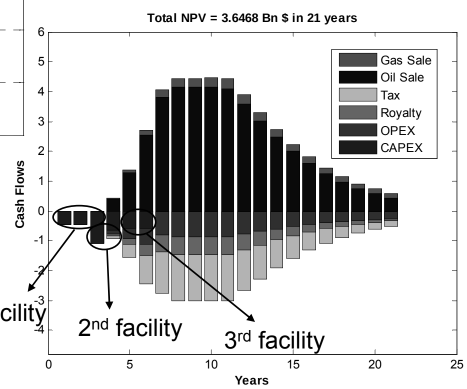
Pre-determined three stages development





Clone facilities

1st facility

2nd facility

3rd facility

Learning factor on CAPEX: 90%

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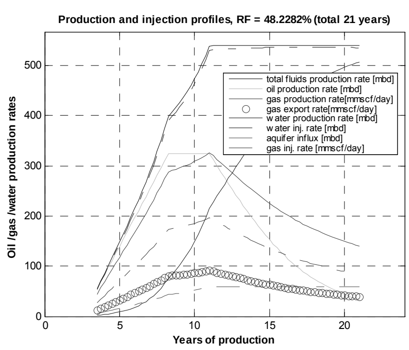
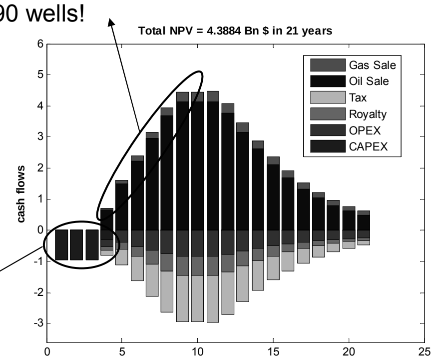
1 stage development (one big monolithic facility)



5 years for drilling ramp up
90 wells!



Assume 3.25 years development time

No learning benefit

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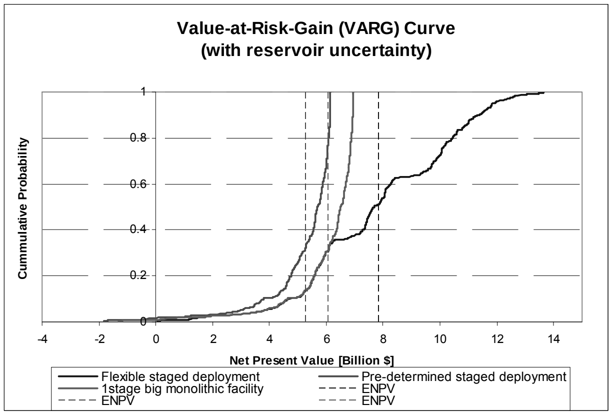
Comparison results



In this simulation case study, the flexible staged development strategy is better than the single stage big monolithic facility:

- Increases ENPV by 1.79 Bn.
- Allows to increase capacity when it is needed, as a result, it can take significant amount of upside opportunity (6.71 Bn).
- Decreases maximal downside loss by 1.34 Bn.
- Decreases minimal initial CAPEX by 1.72 Bn.

	ENPV	Min NPV	Max NPV	Minimal Initial CAPEX	Expected Initial CAPEX
Flexible staged development	7.87	0.05	13.65	1.41	3.10
Pre-determined staged development	5.28	-1.82	6.15	1.41	1.41
1 stage big monolithic facility	6.08	-1.29	6.94	3.13	3.13

Mean	4500 mmstb
STD	1500 mmstb
# of Runs	600
Learning factor for CAPEX:	90%
Assume normal distritution for STOOIP	
100%, 50%, 33.3% staging capacity for the flexible case	

Initial CAPEX is the CAPEX for the first stage without discounting

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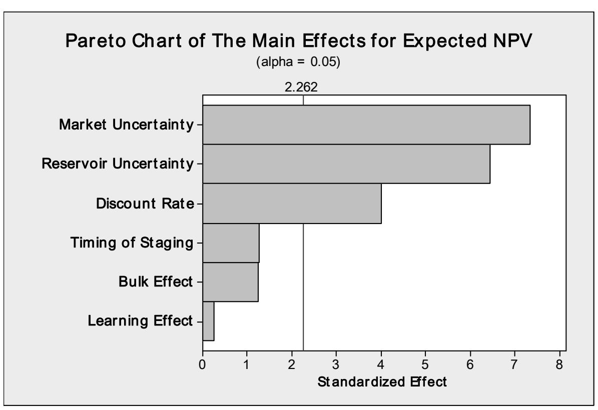
Key factors for Expected NPV



The figure on the left shows the relative importance of several factors on project ENPV. The top three factors are:

- Market Uncertainty
- Reservoir Uncertainty
- Discount rate

- A design of experiment is conducted to study the relative importance of these factors contributing to ENPV.
- The exact sequence or relative importance scale will depend on the various assumptions and range of levels for each factor.

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Contributions and Future Work

- The main expected contributions are followings:
  - Operationalize Strategic Engineering (system design for uncertainty environment, flexibility in design) in the context of oil/gas field development project.
  - Demonstrate the integrated technical / economical modeling and simulation as an approach for Engineering Systems design.
- Future work
  - Apply the models and approaches to a real offshore oil/gas field development.
  - Propose a generic Strategic Engineering framework to be applicable to large-scale infrastructure systems

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Back up slides

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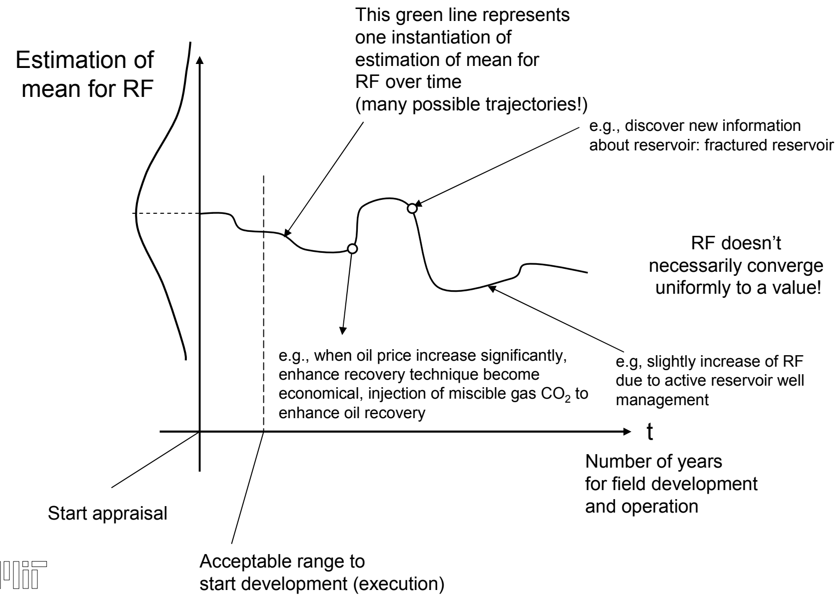
How does estimation of Recovery Factor (RF) change over time?



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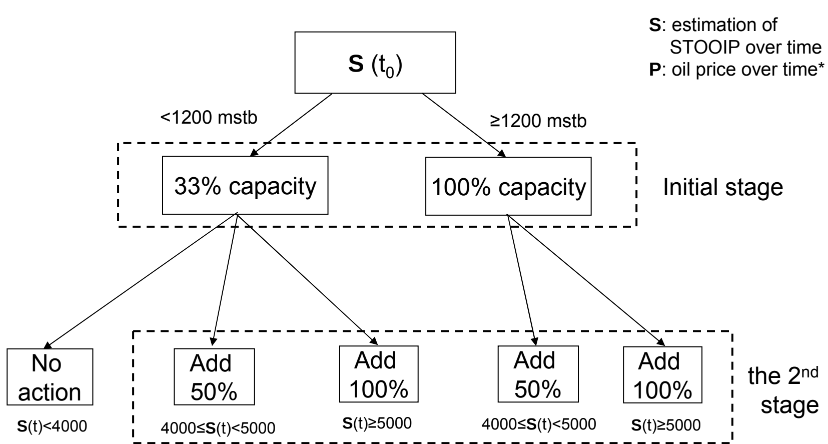

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