The Benefits of Stochastic Subsurface Uncertainty Assessment in a Complex Greenfield LNG Development

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Decision Challenges in Field Development

• **Uncertainty**
  • Production forecasts

• **Decision**
  • LNG-Train capacity
  • Offshore development

• **Objective**
  • Maximize economic return

**CHALLENGES with Probabilistic Decision Making Analysis**
1. Process
2. Tools
3. Training
4. Communication

**Optimization**

**LNG Design**

**Risked-based Economic Return**

**Subsurface Development**

**Production Forecasting**

**Risk**
Paradigm Shift – Adopt an Alternative Methodology

A. Initial field development decisions were based on a deterministic assessment (the Base case)
   • Develop an initial well count and locations with large amount of redundancies (what if reservoir is poorer than base case or poor completion or well failure...)
     • $AOF_{well} \rightarrow \text{Max}(\text{Rate}_{well})$
     • $N_{wells} \times \text{Max}(\text{Rate}_{well}) > 2 \times \text{Avg}_{LNG\ \text{throughput}}$
   • Subsea gathering system with dedicated 1Bscf/d trunkline per train
   • Simple workflow: G&G interpretation $\Rightarrow$ reservoir model $\Rightarrow$ dynamic model $\Rightarrow$ production forecast

B. Alternative methodology from management’s motivation to quantify risks (gas contracts in form of SPA = production obligation) and reduce cost in a low commodity price environment (capital efficiency)
   • Provide probabilistic production forecasts and reserves
   • Can we reduce well count and differ wells to future drilling campaign?
Key Learnings

• Making decision under uncertainty is difficult and requires careful and thoughtful framing
  • Move from an aspiration (minimize cost & maximize production) to a quantifiable risk tolerance goal - P(Max(Gas Rate) < X years) < 0.05

• Science of uncertainty assessment is complex
  • Statistics and modeling knowledge

• Importance of workflows, software and hardware
  • Integrated multi-disciplinary workflows
  • Modeling tools with probabilistic assessment modules, ideally running realizations in parallel
  • Tool capable of gathering data from multiple platforms, software and disciplines for data integration and analysis
Quantitative Stochastic Uncertainty Assessment

1. Large number of stochastic realizations using Monte-Carlo sampling of uncertain parameters
2. Dynamic model screening of each static model using a fast proxy
3. Model selection using distance-based technique, multi-dimensional scaling (MDS) and clustering
4. Dynamic model selection from stand-alone reservoir simulation
5. Full field simulation of selected model combinations
Deepwater Stratigraphic Complexity

- Giant deepwater clastic reservoirs with complex stratigraphy – impacts reservoir connectivity
  A. Amalgamated deepwater slope channel elements
  B. Channel complexes, imaged seismically
  C. Channel complex set

- Uncertainty in reservoir thicknesses and location / transmissibility of internal boundaries (channel, channel complexes and channel sets)

*from Campion et al. (2005), Sprague et al. (2005) and Di Celma et al. (2011)
An Efficient Strategy to Provide Probabilistic Forecasts

• Production is sensitive to connected hydrocarbon pore volume

• Probabilistic forecasts require large number of samples – stochastic spatial variables

• Number simulations from coupled models is unmanageable: $N_{FFM} = N_{OF1} * N_{OF2}$
  1. Create large sample of single reservoir static models (Monte-Carlo sampling)
  2. Screen models using dynamic connected volume, then dynamic simulation
  3. Compare all model pairs and measure the difference
  4. Multi-dimensional scaling, clustering and selection
Prediction – Communicate Probabilistic Results

• Improve communication and make informed decisions from quantitative uncertainty assessment

• Generate probabilistic prediction on many levels:
  • Field production, water breakthrough
  • Wells: Net Pay, HcPV, BHP(t)
  • Maps: P(Net pay > 30m)

• Provide management with calibrated values for portfolio models, planning, risk management and reserves
Benefits – Model Rejection, Fast Learnings and Updates

• Stop traditional history matching techniques with ad-hoc model changes to match history, which generally leads to poor predictivity
  • Most history matching problems are non-unique
  • Does not provide uncertainty assessment
  • Slow process

• Model rejection techniques with additional information provide
  • Instant update to prior distribution of uncertain parameters (posterior distribution - Bayes)
  • Learnings
  • Reduction of uncertainty
  • Additional matched models using resampling techniques

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<th>Scenario</th>
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<th>Posterior</th>
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<tr>
<td>High</td>
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Development of Efficient Visualizations & Analytics Tools

**Challenge:**
- Large amount of data from various sources
- Data stored in various locations
- Multi-disciplinary

**Solution**
- Create a central data store (SQL) linked to original data locations and properly managed
- Establish links between data tables
  - *Model parameters* – *static volume* – *connected volume(t)*
  - *Well location* – *static prediction* - *dynamic forecast*
- Develop dashboards to query and visualize the data in one common location
- Data analytics
Limitations of Tools Employed for this Study

- Pillar-based grids are not ideal to construct complex stratigraphic models where internal surfaces representing geologic boundaries are driving gas recovery. Evaluation of depo-grid underway.

- Inability to properly handle structural uncertainty near faults to preserve or modify fault throw.

- Sequential built of reservoir model – parallelization is hindered by tool and licensing structure.

- Model export for integrated subsurface-surface, coupled reservoir simulation.

- Limited access to cluster technology for faster delivery.

- Streamline simulation used in geoscreening is not a direct proxy to primary gas depletion.
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THANK YOU