Multivariate Statistical Analysis of Bakken Completions: Aiming for Optimal Design

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Background
CAPABLE OPERATORS WITH VARYING RESULTS

- Within Viewfield, the Estimated Ultimate Recovery (EUR) varies widely
  - 81 mboe is the median EUR
  - 20 active operators, 2,529 total wells

- Operators also see a range of recoveries.
  - Median EUR, mboe
    - CPG 100
    - PBN 74
    - TOG 62
    - MSO 111
THE BAKKEN IS MASSIVE
Considerable Variability

- The entire Bakken covers 200,000 mi² or 520,000 km²
  - Reservoir thickness at Viewfield ranges up to 65 ft or 20m

- Produces primarily light oil:
  - Significant solution gas
  - Waterfloods in place

- Over 3,500 wells drilled
  - TVD 2,400 ft to 10,500 ft
  - TVD 725m to 3,200m
  - Lateral lengths up to 8,600 ft or 2,630m
NOT ALL BAKKEN IS CREATED EQUALLY

Five Distinct Play Areas

- Facies
  - 4 stacked reservoir facies

- Temperature
  - Determines maturity of hydrocarbons
  - Oil window – migrated from ND – Thanks!

- Pressure > Hydrogeological Regimes
  - High Oil Saturation at Viewfield
  - Surrounded by Aquifers

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VARIABLE OUTCOMES
Uncontrollable vs. Controllable Factors

• Uncontrollable variables are beyond what operators can influence:
  ○ Reservoir characteristics: pressure, temperature, porosity, permeability
  ○ Rock properties: ductility, geochemistry, rock stress

• Controllable variables are design and operational decisions that influence outcomes
  ○ Drilling: fluid systems, well spacing, lateral length, casing system
  ○ Completions: technology, fluid (type, volume), proppant (type, blend, tonnage), stages (number, spacing)

Factors in All Completions Designs
Multivariate Analysis
Influential controllable factors
• Relationship between well performance and geologic/engineering variables is:
  - Non-linear
  - Dominated by complex interactions between variables

• Multivariate statistics aims to:
  - Identify variables that have the largest effect on outcome
  - Group wells according to similar inputs and outputs
  - Discover complex relationships in your data
AN OLD FASHIONED OPTIMIZATION PROBLEM

- Which completion variable(s) and in what amounts will most beneficially influence ultimate recovery
- Select a play area with a consistent subset of uncontrollable variables
- The analysis focuses on the impact of controllable completion variables
- Wells impacted by the waterflood have been excluded from the analysis
Step 1:
Is there dependence between EUR and any of the variables?
Yes: Go to Step 2
No: Stop growing the tree
Building a Decision Tree

Strongest Associations

Step 1:
Is there dependence between EUR and any of the variables?
- Yes: Go to Step 2
- No: Stop growing the tree

Step 2:
Find the variable that has the strongest association to EUR
BUILDING A DECISION TREE
Identifying The Impact

Step 1:
Is there dependence between EUR and any of the variables?
Yes: Go to Step 2
No: Stop growing the tree

Step 2:
Find the variable that has the strongest association to EUR (using a Chi squared test)

Step 3:
Find the split point of the variable that results in the largest difference between the mean of two groups
BUILDING A DECISION TREE
Finding the Next Factor

Step 1:
Is there dependence between EUR and any of the variables?
Yes: Go to Step 2
No: Stop growing the tree

Step 2:
Find the variable that has the strongest association to EUR (using a Chi squared test)

Step 3:
Find the split point of the variable that results in the largest difference between the mean of two groups

Step 4:
Repeat steps 1-3 on each of the sub groups
RECURSIVE PARTITIONING
Resulting Decision Tree
Outcomes
Path to Optimal Design
OPTIMAL PATH
Toward Maximum EUR

- The path to the group with the highest median EUR
- Three key factors to maximize EUR
  - Completions Technology – Coiled Tubing (packer)
  - Proppant Tonnage – > 4 tonnes/stage
  - Number of Stages - > 24 stages
The Viewfield Area has 2,052 wells

- EURs
  - P10: 201 Mbbl
  - P50: 63 Mbbl
  - P90: 11 Mbbl
Focus on the top 5 original operators out of 20 active in the area.
HIGH EUR EVOLUTION
1: Wells Using CT Cut/Port

- Wells completed with CT Cut/Port system, 701 wells
- EURs
  - P10: 231 Mbbl
  - P50: 92 Mbbl
  - P90: 17 Mbbl
Over time operators have gravitated to using CT completion systems.

EURs have increased.
2: Proppant – more than 4 tonnes per stage

- Wells completed using a CT completion systems and and more than 4 tonnes of proppant per stage, 408 wells
- EURs
  - P10: 251 Mbbl
  - P50: 103 Mbbl
  - P90: 21 Mbbl
As operators continue operations, higher tonnages have become the norm.

Median EURs are consistently higher than the lower tonnage pumped.
HIGH EUR EVOLUTION

3: Completed Stages – more than 24 stages

- Wells using CT completion system, pumping more than 4 tonnes per stage and more than 24 stages, 222 wells
- EURs
  - P10: 276 Mbbl
  - P50: 138 Mbbl
  - P90: 30 Mbbl
• One operators, Crescent Point, entirely dominates this group.

• The optimal completion has a P50 EUR significantly above the overall P50 and is approaching the P10 for the entire Viewfield area.
<table>
<thead>
<tr>
<th>Operator</th>
<th>CGP (optimal)</th>
<th>CPG</th>
<th>PBN</th>
<th>LEG</th>
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## Recent Activity

What have you done lately? (Since January 2014)

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<td>EUR, overall (2,052)</td>
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## Recent Activity

### How’s it working? (Since January 2014)

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<td>Half Cycle</td>
<td><strong>120</strong></td>
<td><strong>122</strong></td>
<td>179</td>
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<td>Efficiency, mboe / 100m hztl</td>
<td><strong>10.6</strong></td>
<td>6.2</td>
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</table>
LOW COST EVOLUTION
Designing For Low Cost

1. Technology
   p < 0.001

2. Prop per Stage (t)
   p < 0.001
   ≤ 4
   > 4

3. Stages
   p = 0.006
   ≤ 15
   > 15

4. Prop per Stage (t)
   p = 0.034
   ≤ 7
   > 7

5. Stages
   p < 0.001
   ≤ 24
   > 24

6. Ball & Seat, CT (Pressure), CT (Straddle)

7. Technology
   p = 0.036

8. Ball & Seat, CT (Pressure), CT (Straddle)

* Half-cycle cost (drilling and completion only) per boe of EUR
The path to the group with the lowest median half-cycle cost per boe.

- Lowest median cost is $10.03 per boe of EUR, half-cycle.

- Three key factors to minimize unit cost:
  - Technology – CT Cut/Port (packer)
  - Proppant – greater than 7 tonnes per stage
  - Stages – greater than 15 stages

- 96 wells in this group: operated by CPG (87 wells), Taqa (4), Shelter Bay (3), Pinecrest (1), Landex (1)

* Half-cycle cost (drilling and completion only) per boe of EUR.
Conclusions
Conclusions

• Multivariate statistical analysis can illuminate
  ☐ Completions practices to engage and avoid to maximize EUR
  ☐ Completion practices to engage and avoid to minimize cost per barrel
  ☐ The value of detailed data collection
  ☐ The variables to focus effort/money on
  ☐ Guide technical question – ie. Why is a certain fluid or proppant performing better than others?

• CDL’s MV analytics provides a method to test individual D&C design parameters against actual results.

• With tuning of design some operators have lifted their P50 results to what used to be the area P10

• Analysis can guide new entrants in an area to a higher point on the learning curve
Thank you to other contributors

- Joshua Lee – type curves/EUR data
- Meridee Fockler – organizer
- Zenith Phillips – graphic designer
- Candace Keeler – cartographer
- Alison Lane – administration

CDL products used for this presentation:

- DISCOVERY DIGEST
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