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Data-Driven Optimization of Drilling Parameters

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Outline

- ❑Introduction
- ❑Formation Tops Detection
- ❑Drilling Optimization Method
- ❑Results
- ❑Conclusion

Objective

- ❑ Optimization of drilling parameters using surface parameters, borehole assembly, and lithology information

Drilling Time ↓

Dysfunction ↓

Rate of Penetration ↑

Consistency of Drilling ↑

Evolution of Optimized Drilling Parameters ↑

Project Philosophy

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Parameters that are in our control

Surface parameters

Parameters that are partially in our control

Borehole Assembly

Parameters that are not in our control

Lithology

Drilling Process

Drilling Performance

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Overview

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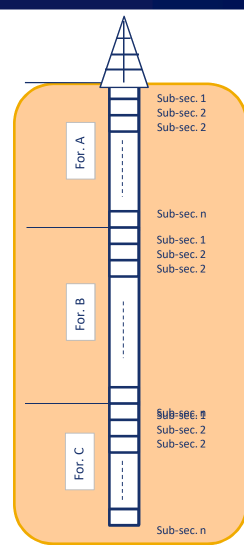
Offset Well Data

Analytical Techniques

Subject Matter Expertise

Suggested set-points for auto-driller and top-drive



- The optimizer has been run on a number of the wells in the US with satisfactory results

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Inputs-Outputs

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Inputs

- Offset Well Data
- Formation Tops
- Motor & Bit Information
  - Start Depth
  - End Depth
  - Max Diff P
  - Max Torque
  - Perf. Curve
  - Rev/Gal
  - Bit Diameter

Outputs

Recommend:

- Opt ROP
- Opt WOB
- Opt RPM
- Opt Bit RPM
- Opt Flow Rate
- Expected OXY
- MSE
- …

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Block Diagram

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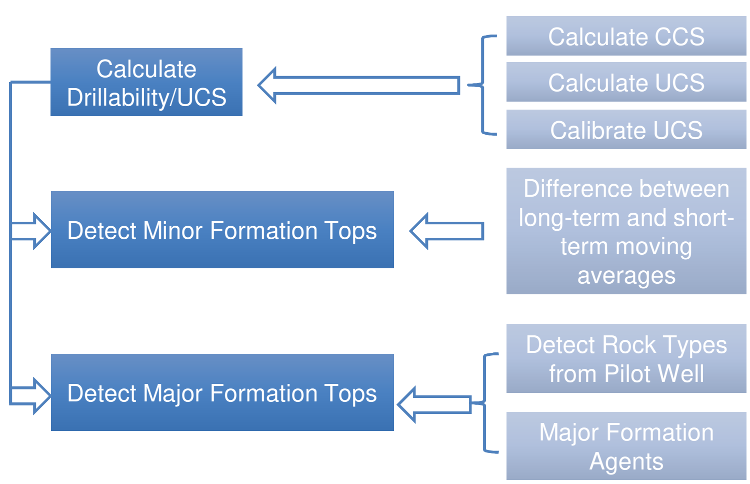

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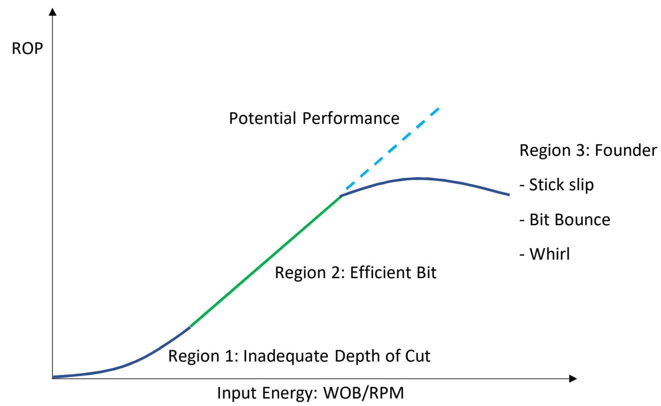
Calculating UCS/Drillability



Calculating UCS/Drillability

$$ROP = k\_drillability \times k\_bit\_wear \times k\_bit\_aggressiveness \times k\_bit\_cutter\_engagement\_wth\_rock \times k\_dysfunctions \times \frac{Torque\&Drag(WOB_{surface}) \times (RPM_{top\_drive} + RPM_{motor})}{diameter_{bit}}$$

Formation effect

Drilling is in the efficient zone	⇨	$k\_bit\_cutter\_engagement\_wth_{rock} = 1$
No dysfunction is present	⇨	$k\_dysfunctions = 1$
Bit aggressiveness is not taken into account All offset wells use similar bits	⇨	$k\_bit\_aggressiveness = 1$
Surface WOB is same as downhole WOB	⇨	$Torque\&Drag(WOB_{surface}) = WOB_{surface}$

⇩

$$ROP = k\_drillability \times k\_bit\_wear \times \frac{WOB_{surface} \times (RPM_{top\_drive} + RPM_{motor})}{diameter_{bit}}$$

$$\boxed{k\_drillability = \frac{ROP \times diameter_{bit}}{k\_bit\_wear \times WOB_{surface} \times (RPM_{top\_drive} + RPM_{motor})} \propto \frac{1}{CCS}}$$

Motor Performance Curve Model

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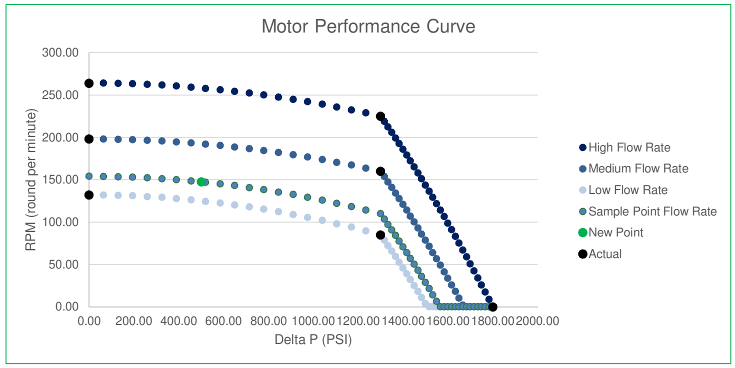
Inputs

Motor Specifications
- Max Diff P
- Stall Diff P
- Rev/Gal
- 6 Points from Graph
- Flow Rate
- Diff P

Drilling Data
- Flow Rate
- Diff P

Outputs

Motor RPM



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Calculating UCS from CCS

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Step 1 : Calculate UCS

$$UCS = \frac{CCS}{(P_{borehole} - P_{pore}(GR))}$$

Step 2 : Calibrate UCS

The maximum possible UCS in every region is used for calibration.

$$UCS = \frac{UCS}{UCS_{max,}(between\ TVD_{x1} and\ TVD_{x2})} \times maximum\ possible\ UCS$$

$TVD_{x1} and\ TVD_{x2}$ are selected based on geographical regions.

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Identifying formation zones where non_drillibility is changed

$$k\_non\_drillibility = \frac{1}{k\_drillibility}$$

$\Delta TVD_{short\_term}: 10ft$ Short term moving window size, user-defined, default is 10ft

$\Delta TVD_{long\_term}: 90ft$ Long term moving window size, user-defined, default is 90ft

$$k_{non\_drilibility}^{short\_term} = \text{moving\_window\_average}(\Delta TVD_{short\_term}) + \text{moving\_window\_std}(\Delta TVD_{short\_term})$$

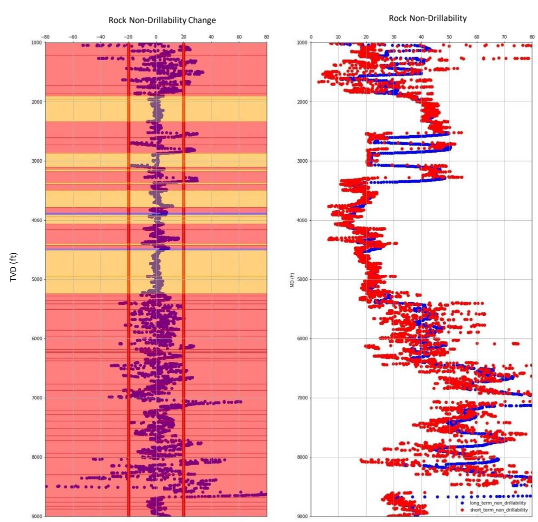
$$k_{non\_drilibility}^{long\_term} = \text{moving\_window\_average}(\Delta TVD_{long\_term}) + \text{moving\_window\_std}(\Delta TVD_{long\_term})$$

$$k_{non\_drilibility}^{change} = k_{non\_drilibility}^{long\_term} - k_{non\_drilibility}^{short\_term}$$

$Non\_drillbility\_change\_limit: 20$

- When the difference between long term and short term non_drillibility is above this limit, it is considered a change in formation and TVD is recorded.
- Non_drillability_change_limit is a user defined parameter, default value is 20.

Example, CCS change plots



Identifying Major formation zones

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PEF
Density
Gamma Ray

Detect Rock Types from Pilot Wells

Agent 1
- Detect when UCS AVG increases

Agent 2
- Detect when UCS AVG decreases

Agent 3
- Detect when UCS STD changes

Agent 4
- Detect when GR changes

Agent 5
- Detect spikes

Detect Major Formation Tops

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Analysis of Formation Top Detection Results

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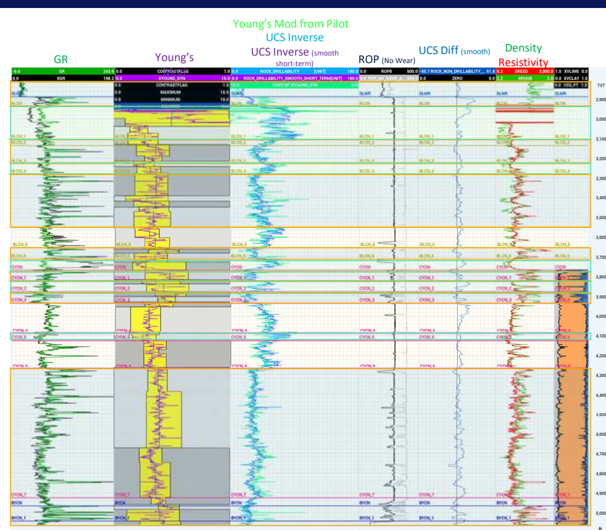

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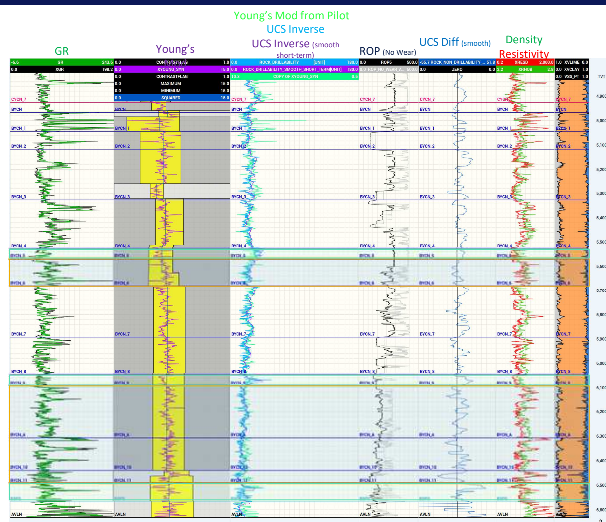
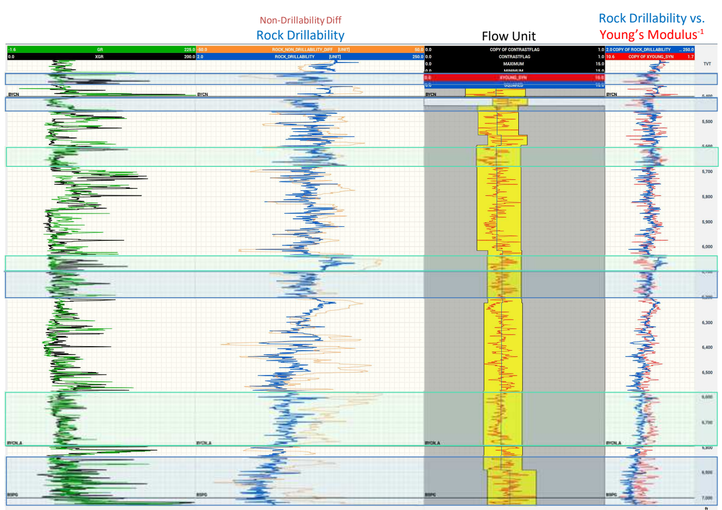
Analysis of Formation Top Detection Results Cont.



Analysis of Formation Top Detection Results Cont.



Find matched formation tops between multiple offset wells

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a. Select the first offset well as the basis well.

b. Select formation change TVDs in all offset wells that are:
   a. Closest to formation change TVDs in the basis well.
   b. Within a proximity limit (default 250ft).

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Example Result

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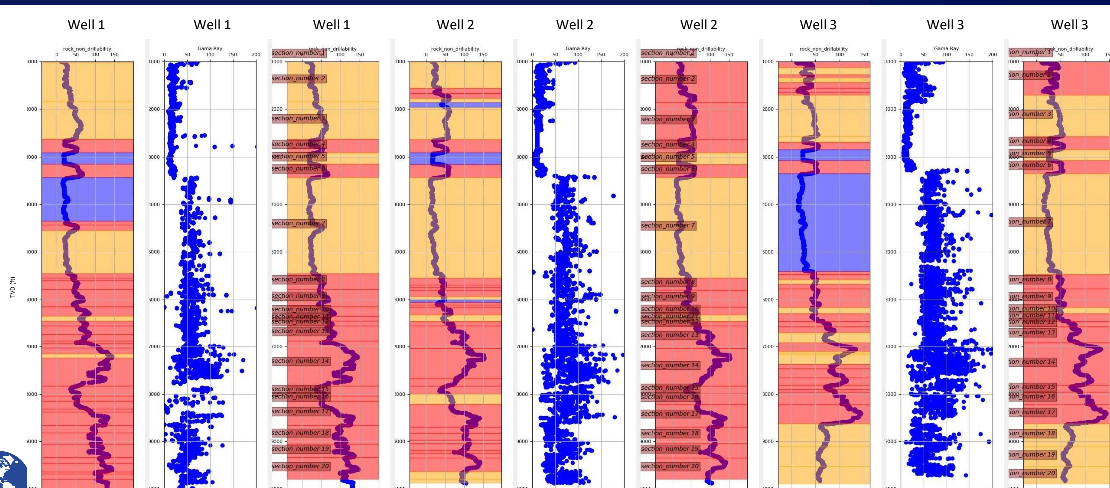

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Formation Top Detection Features

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- Can run in real time.
- Can run in horizontal section.
- Detects formation top using drilling data.
- Drillability/Calculated UCS can be a useful parameter for geologists in identifying formation tops.

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Data Processing

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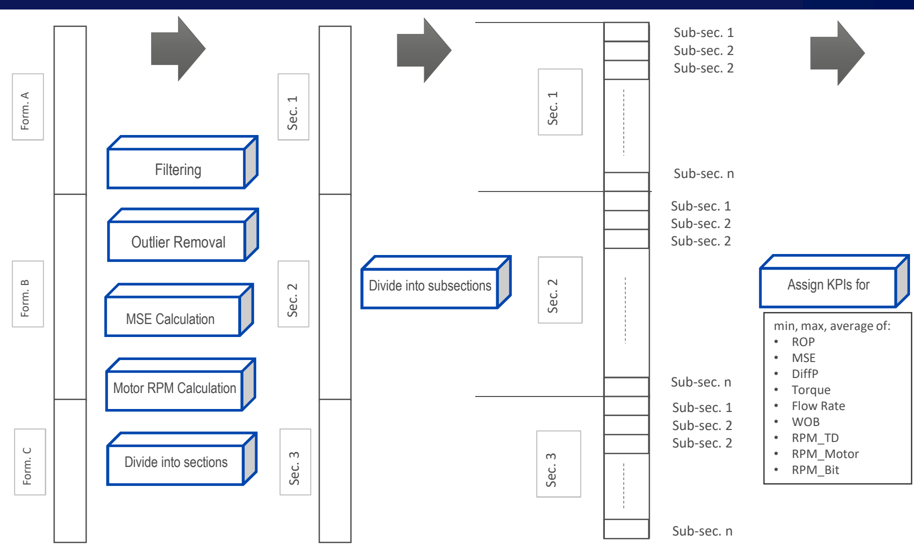

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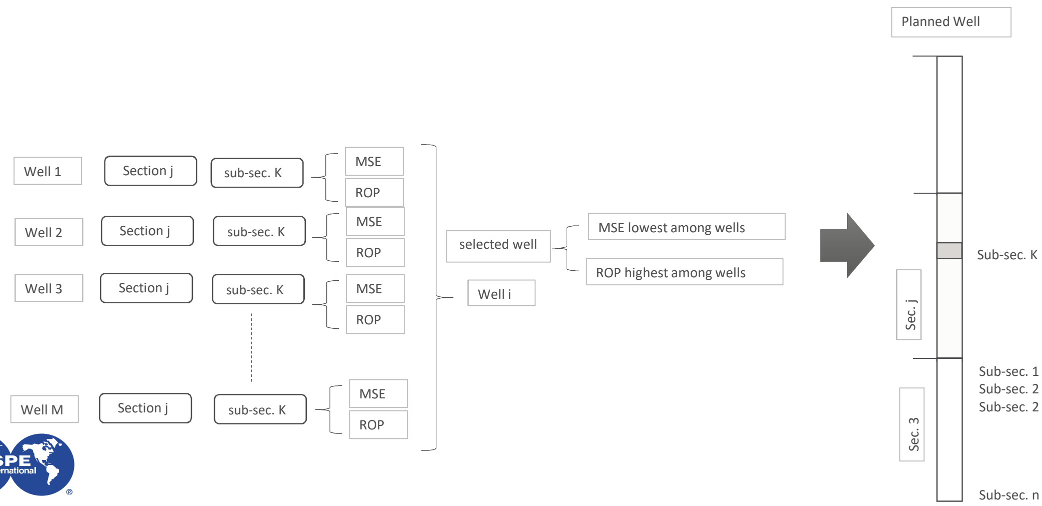
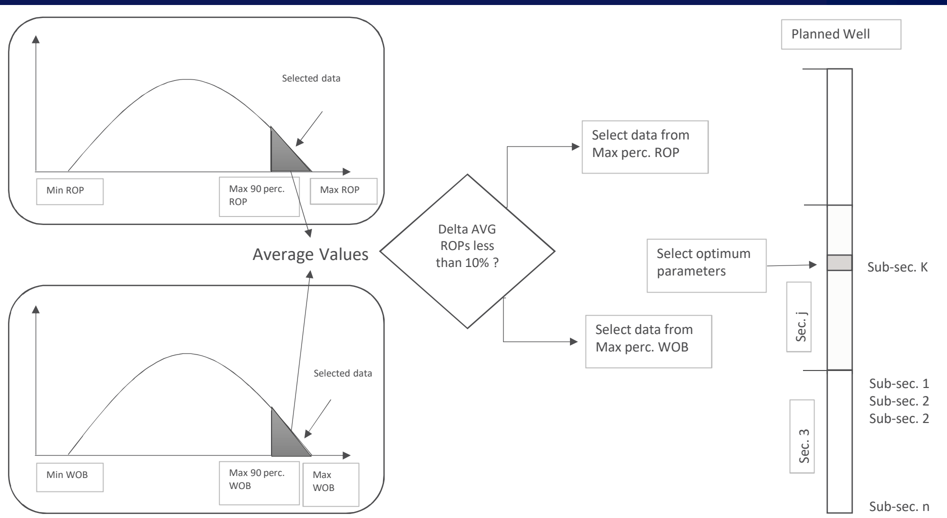
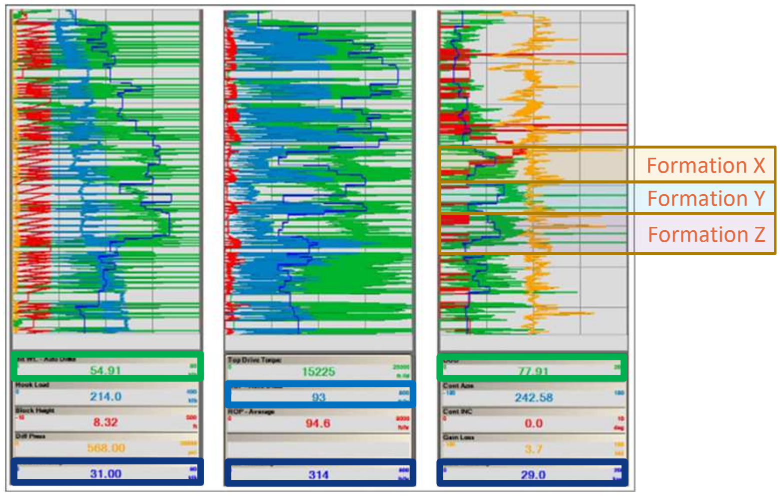
Best Well Selection



Suggested Drilling Parameters



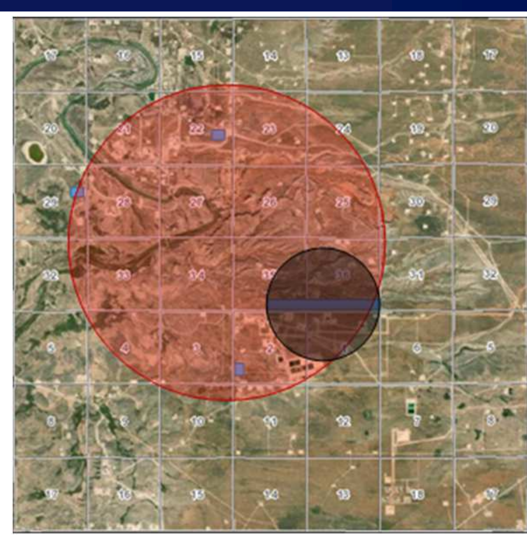
Algorithm Transition and Parameter Agreement



Expansion of Trial Area

When
- Area is increased by 688%
- Raduis is increased four miles
- Sample size is increased 83%

Does Algorithm
- Maintain depth control?
- Retain best demonstrated data?



- Initial population
- Expanded population
- Well surface location

Retained Information Post Expansion

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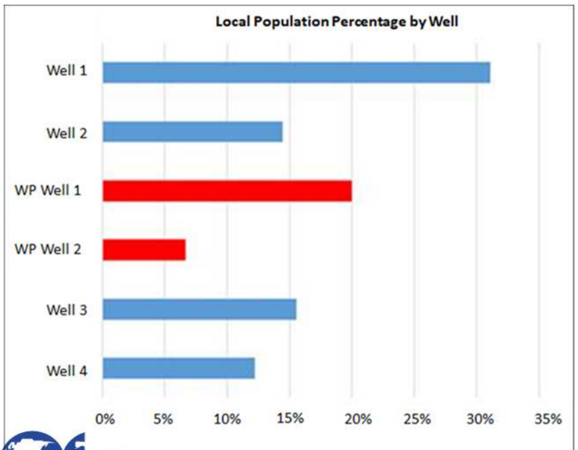

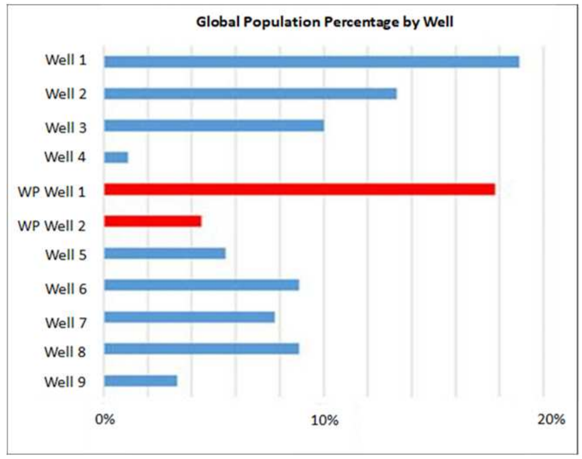

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* Red color corresponds to wells which used wired drillpipe.

Intermediate Drilling Performance for 9-7/8” Hole

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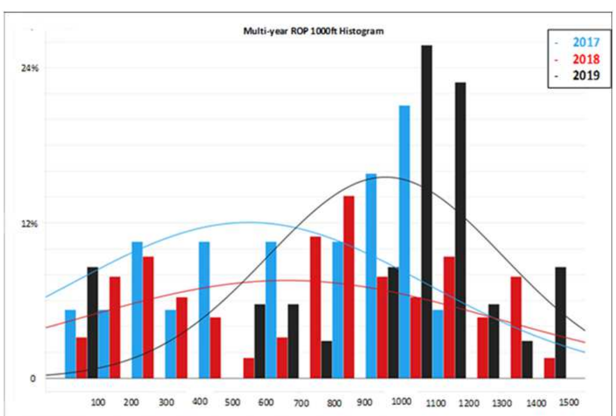

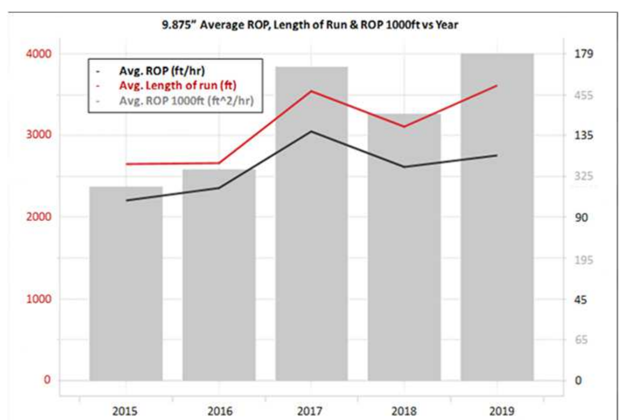

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$$ROP\ 1000\ ft\ = Average\ ROP\ \times \left(\frac{Run\ Footage}{1000}\right)$$

MSE Analysis of Past & Present Process

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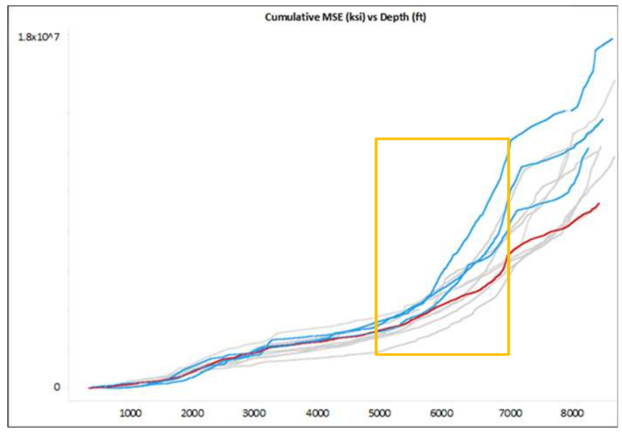
- Lowest cumulative MSE was achieved.
- Improved consistency.
- Minimal variability post trip.
- Wells optimized based on manual statistics method failed to match.

- Base population
- Outgoing process
- Algorithm well



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Delaware Group ROP Analysis

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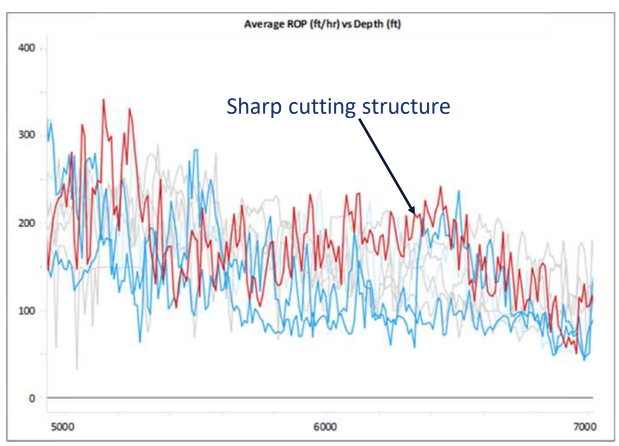
- Retained cutting structure for the longest drilling duration.
- Used high peak ROP when advisable.
- Restrained ROP when warranted.
- Optimization can be further improved for 6,250-7,000ft.

- Base population
- Outgoing process
- Algorithm well



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Conclusions

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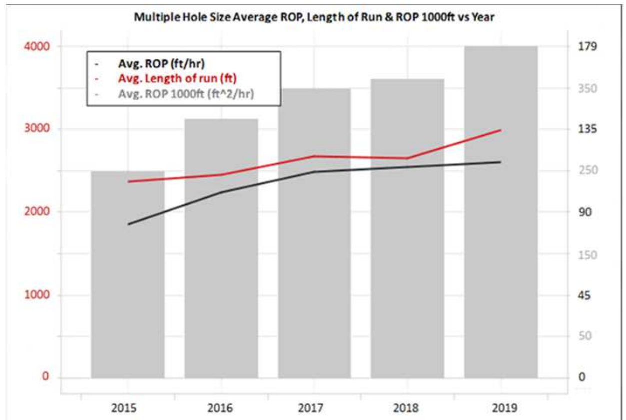
1. An optimization algorithm that utilizes MSE can be widely used and adopted by drilling experts.
2. Considering the effects of surface parameters, BHA, and lithology in optimization improves performance.
3. The data-driven technique used for optimization is flexible and practical.



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Thank You

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