SPE 199601

Large-Scale Deployment of a Closed-Loop Drilling Optimization System: Implementation and Field Results

Stephen Lai, James Ng, Aaron Eddy, Sergey Khromov,
Dan Paslawski, Ryan van Beurden, Lars Olesen, Pason Systems

Gregory Payette, Benjamin Spivey, ExxonMobil Upstream Research Company
Introduction

• Reduce well cost:
  • Minimize spud-to-TD time.
  • Maximize ROP / minimize flat-time.
• Rotary drilling optimized by continuous adjustment of process parameters (WOB, RPM).
• Challenge: Formations can change rapidly.
• Automation solution:
  • Closed-loop system based on proven advisory application.
  • Field results from 270 rigs and 1700 wells.
Control Scheme

Driller supervises process and manages parameter limits.
Main Optimization Loop

Main loop runs once per second:

- If drilling dysfunction is detected, mitigation protocol is executed.
- If autodriller (ADR) is not in good state, ADR management protocol is executed.
- Otherwise, perform ROP/MSE optimization.
ROP/MSE Optimization

Challenges:
- Formation variation is random and non-stationary.
- Drilling process is difficult to model accurately.
- Scalability – must work at all rigs/ formations/ basins.

Solution:
- Extremum Seeking Control (input signal dithering):
  - Simple – minimal tuning parameters.
  - Adaptable – continuously seeks the peak.
  - Robust – no model-based assumptions.
ROP/MSE Optimization

- ROP increase
- WOB increase
- RPM increase
- constant MSE
Dysfunction Mitigation

When drilling dysfunction is detected, an automated protocol is used to remove the condition.

Stick-Slip Protocol

1. Stick-slip exceeds threshold.
2. Optimization stops to focus on stick-slip. WOB decreased.
3. Stick-slip reduced below threshold.
4. RPM increased. WOB is returned to original value.
5. Optimization resumes.

- Stick-slip protocol
- Stringer protocol
- RCD protocol
- Motor stall protocol
- Etc.
Autodriller (ADR) Management

• Operating state of ADR is critical for closed-loop optimization.

• ADR control issues\[1\]:
  • Poor setpoint tracking.
  • Control loop oscillations.

• ADR should be in a favorable control state for optimization.

<table>
<thead>
<tr>
<th>ADR Condition</th>
<th>System Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control loop oscillations</td>
<td>Adjust setpoints to put ADR back in WOB-control mode</td>
</tr>
<tr>
<td>Torque limiting</td>
<td></td>
</tr>
<tr>
<td>DIFP limiting</td>
<td></td>
</tr>
</tbody>
</table>

Deployment Challenge #1: Human Factors

- **Organizational buy-in** is needed\(^2\).

- **User trust** is needed:
  - Driller must have confidence that system operating as designed → notifications/alerts.

\(^2\) Behounek et al. “Change Management Challenges Deploying a Rig-Based Drilling Advisory System”. SPE-194184.
Deployment Challenge #2: Conservative Parameter Limits

For optimal drilling, true equipment limits should be used.

- **Upper WOB Limit**
- **Lower WOB Limit**
- **Upper RPM Limit**
- **Lower RPM Limit**
- **DIFFP Limit** (Autodriller)
- **ROP Limit** (Autodriller)

The diagram shows the reduced optimization space within the constraints of the equipment limits.
Deployment Challenge #3: Following the Limit Roadmap

**Bad Practice:**
- Small optimization window
- Frequent, ad-hoc changes

**Good Practice:**
- Wide limit window
- Infrequent changes
- Allow system to optimize
Field Deployment

![Graph showing the number of rigs and wells over time with data points for Total (North America), Canada, and the United States.]
ROP Improvement

*Each drilling trial has 3 consecutive wells.*

1\(^{st}\) well
No system

2\(^{nd}\) well
No system

3\(^{rd}\) well
With system

~90 trials

Each drilling trial has 3 consecutive wells.

**Top quartile ROP improvement = 18.1% and 17.4%.**
Conclusions

• Formations change rapidly → need closed-loop optimization:
  • Simple (no model) algorithm is best for scalability.
  • Mitigate dysfunction with triggered protocols.
  • Create a good limit roadmap and follow it.
• Large-scale deployment: 270+ rigs, 1700+ wells, 8 countries.
• Average rotary ROP improvement of 7% (top quartile = 18%) in 90 drilling trials.
Acknowledgements / Thank You / Questions

Special thanks to:

The staff at ExxonMobil Upstream Research Company.
The many field and office personnel who contributed to deployment of this system.
Mark Pawson, David Holoboff, Abdulkareem Dolapo, and Usman Farooq.