# Record Breaking Optimization Results in Oman

Halliburton Project Management's innovative approach to drilling optimization resulted in a new field record in Oman, in part by utilizing Pason System's automation solutions, real-time drilling optimization, and high-quality data for enhancing well construction rates.

As a global leader in the management and delivery of lump-sum turnkey (LSTK) projects, the Halliburton Project Management (HPM) team deploys a suite of technologies, engineering services, and industry expertise to deliver wells safely and efficiently. LSTK projects are often outsourced to vertically integrated service companies due to the complexity or size of the drilling program, and Halliburton has been awarded several projects worldwide based on their proven record of meeting or exceeding customer's expectations.

In Oman, HPM was presented with challenging targets from the NOC, and HPM responded with a structured, targeted strategy for success. Over the first 12 months, HPM's primary focus was on deploying the proper personnel and services, identifying challenges specific to the drilling field, and reliably identifying and tracking invisible lost time (ILT) and non-productive time (NPT) to better control and reduce off-bottom time. The second phase was to explore improvements in on-bottom performance and rate of penetration (ROP) using new technologies and collaborations with other industry leading specialists.

This paper describes the challenges and step-by-step chronology of solutions deployed to achieve continuous performance improvement and merits of integration amongst Halliburton and Pason for maximizing drilling performance. By effectively focusing on process execution, the project team was able to achieve field records for best composite time for oil-producing wells and for water-injector wells.

## Establish Control, Automate, Eliminate Limiters… Repeat

After working in Northern Oman for approximately 9 months, HPM drilling teams struggled to find a consistent and repeatable roadmap for significant ROP improvements.

During the initial +9 months, the drilling teams were relying on the driller to manually control ROP, weight-on-bit (WOB), differential pressure, pump pressure, and torque. Regardless of the driller's experience, it is difficult for a single person to successfully monitor and adjust for multiple, continuously changing variables in real-time. The results were unpredictable variations in ROP, WOB and drilling processes that could not be repeated from well to well. Although the drilling plan was

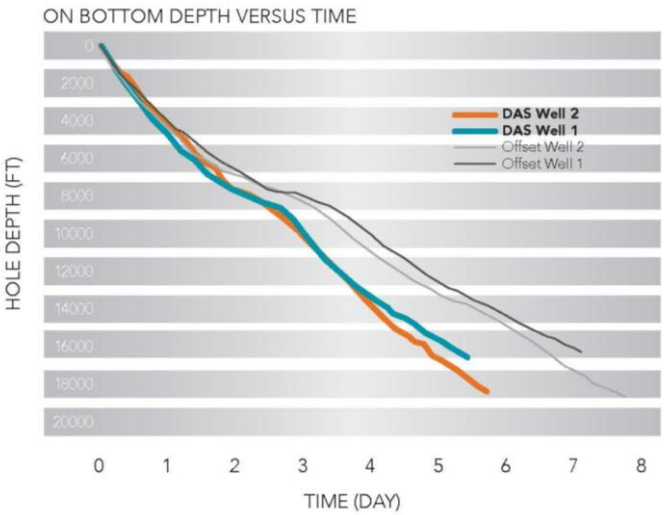



*Figure: Record breaking ROP performance in N.America*

sound, the team was unable to achieve significant improvements in ROP due to the extreme variation and lack of control.

To help solve this problem, the Halliburton Project Management team tasked Pason Systems to first augment the rig's existing Electronic Drilling Recorder (EDR) and sensor set installation to improve data quality and real-time visibility, and second to integrate the Pason ADR and DAS technologies into the rig's existing PLC system.

The initial objectives of the trial were to:

- Optimize the 12 ¼" section of the well that is drilled with TCI and motor (resulted in 6.9% on-bottom ROP improvement)
- Optimize the 6 ⅛" section of the well initially drilled with Geo-Pilot® Rotary Steerable Systems and iCruise® Intelligent Rotary Steerable System and PDC bit (resulted in 17.9% on-bottom ROP improvement). With customer approval on select wells, significant savings can be achieved by transitioning to a mud motor through this section
- Achieve further benefits by utilizing Pason's Data Delivery and Analytics Services throughout the well planning and well execution phases, with a focus on real-time data, drilling key performance indicators, and enhanced rig activity tracking through advanced IADC tour sheet time codes

DAS Target Based – Pason Drilling Automation System (DAS) is an automatic drilling system designed for use on both Brakehandle and AC rigs with programmable logic controllers (PLCs). DAS Target Based controls the drawworks to maximize rate of penetration (ROP) by automatically adjusting the control limits (ROP control, WOB control, torque limiting, target differential pressure) based on the well plan.

Pason DAS Boundary Based – Based on Mechanical Specific Energy (MSE) Optimization and Stick-Slip Mitigation technologies, Pason Drilling Automation System (DAS) Boundary Based utilizes patented algorithms to identify and implement optimum drilling parameters in real-time while working within specified technical limits or boundaries unique to the rig, formation, or BHA.

*DAS is a trademark of and contains technology licensed from ExxonMobil Upstream Research Company

The pilot program was organized in 3 phases.

- Phase 1: Installation of the Pason system to gain further insights on the drilling performance through improved data quality and access to real-time data in 1-sec resolution
- Phase 2: Installation of the DAS Target Based (AutoDriller) to improve control of drilling operations and better identify ROP limiters

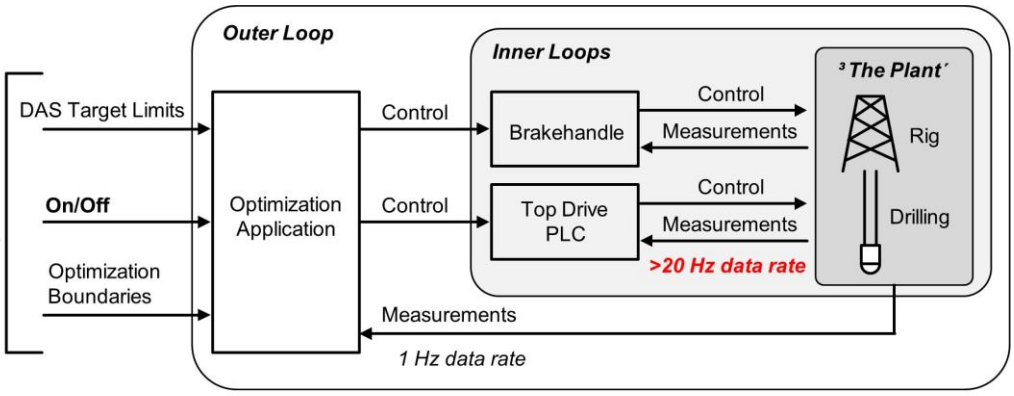



*Figure: WOB control scheme – Process Flow from Driller to Drill Bit*

- Phase 3: Integration of DAS Boundary Based technologies into both the planning phase and drilling phase

Training on Pason system was completed both in the office and the rig site, and the goal of the project was communicated to the entire team. Drilling engineers, RTOC engineers, driller, rig manager, company man (DSV), and directional company all received a common message: set the drilling parameters and let Pason DAS control block speed and WOB.

Six trial runs using the Pason AutoDriller (DAS Target Based Drilling) were deployed for each of the 2 selected rigs. During each run, the Pason EDR was able to record the active DAS control limit (ROP control, WOB control, torque limit, or target differential pressure).

During drilling operations, this information encouraged conversations around modifications to the existing well plan. During post-well analysis it allowed the Halliburton optimization team to clearly identify the limiter of each well section for changes in future well planning.

Using the data collected, aggregated, and stored by Pason, Halliburton was able to identify several ROP limiters:

- Surface torque
- Geological uncertainty
- High density formations
- Drilling bit limits
- Differential pressure

Once the team understood and was able to quantify the ROP limiters, the Halliburton optimization team was able to create their plans for drilling parameter optimization for the upcoming wells.

To successfully achieve high levels of ROP optimization using automation, Halliburton focused heavily on good data. This meant a requirement for and reliance on high quality and high-resolution data.

## High Quality / High Resolution Data

- Halliburton Project Management team's analytics tools require high quality data to yield consistent and repeatable drilling plans
- Data accuracy and reliability are key
- High resolution (1-second) real-time data allows real-time monitoring and real-time analysis of drilling performance, allowing for the revision of current drilling plans as needed
- Sensor data that is fit for purpose eliminates the need for data cleaning real-time

## Focus on "Good Data"

Similar to other technology companies, both Halliburton and Pason have invested millions of dollars and countless man-hours developing industry leading Artificial Intelligence (AI) and Machine Learning software solutions focused on drilling safer and more efficiently. While many of these solutions deploy leading edge technology, the reality is they rely on accurate, high quality, reliable data to produce an output that is valuable and meaningful.

Recognizing this need, Pason's R&D department spent several years redesigning the way in which Pason's systems receive, store, and manage data, including several initiatives focused on predictive and preventive maintenance of Pason's equipment through remote diagnostics and 24 hour monitoring of component level and overall system health. The

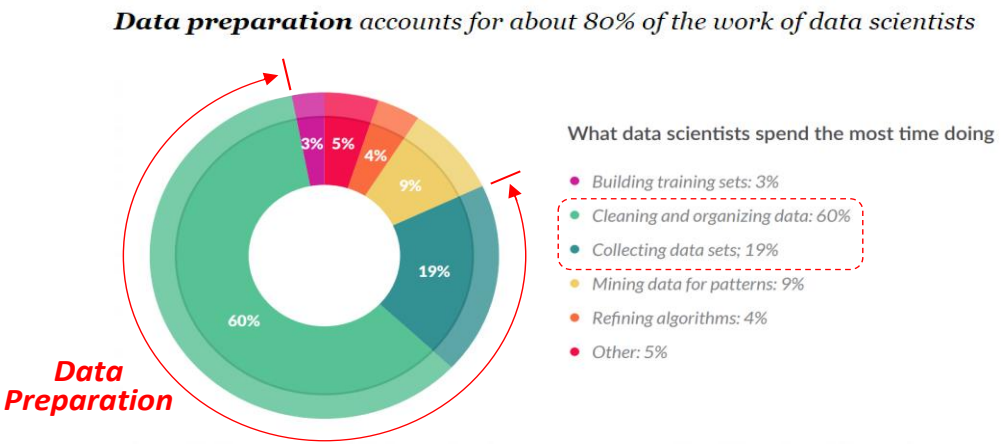



*Figure: SOURCE: CrowdFlower 2016*

results have been an overwhelming success towards Pason's goal of creating a standardized, scalable, and secure data delivery system from raw sensor data to analytics and AI solutions.

"We noticed that in previous projects with other 3rd party sensors, data quality was sub-optimal. We were looking for a data provider that did not suffer from gaps or issues with data quality," stated Khaled Abdelaal. "We solved this problem with the Pason system."

Halliburton's optimization team performed minimal data cleaning to ensure accurate on-bottom ROP and ROP limiters. The data was analyzed on over 40 wells stored in Pason's DataHub and found less than 2% data accuracy issues which were negated by running certain data cleaning algorithms. For reference, other data recording systems have demonstrated up to 30% errors in data accuracy and / or reliability.

## Importance of Variation Reduction and Proper Control Parameters

- Variation reduction is critical for the following reasons:
  - To more easily and accurately identify performance limiters; drilling system control state is needed to properly identify

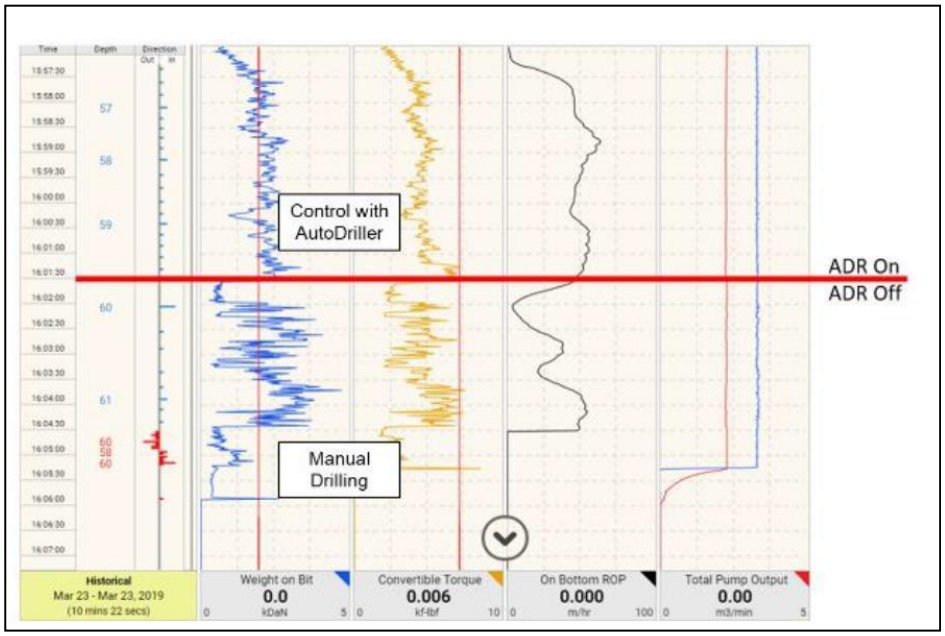



*Figure: AutoDriller Impact*

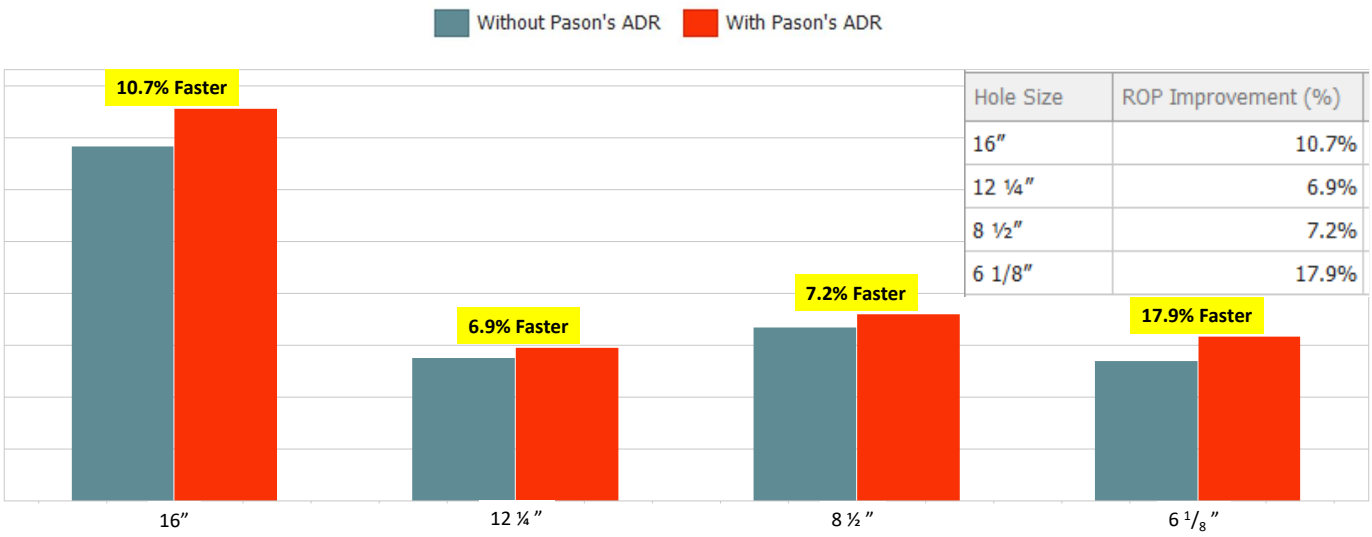
and quantify performance limiters in each section
    - To reliably deploy improved drilling strategies
    - To accurately attribute improvements to a specific change in the well plan
- This continuous improvement cycle of "Identify – Plan – Execute – Review" can then be used to create an optimization roadmap for subsequent wells

As more wells were drilled utilizing the Pason system, additional efficiency improvements and cost savings opportunities were discovered.

## Improvements In On-Bottom ROP and Beyond

It is common for customers to focus solely on ROP improvements as their measure of Return on Investment (ROI). ROP is easy to quantify and quick to compare from well to well. However, there are several other areas where cost savings and significant drilling improvements can be achieved; they are simply more difficult to measure and for this reason are often ignored.

- Maximum average ROP times and remarkable reduction in the drill-out times
- Identify sections where further increasing ROP is not possible with current system restraints. This detailed understanding of the main ROP limiters per hole section provides the basis for developing mitigation plans to remove those limiters.
    - Bit selection, BHA configurations, mud weights, torque limits, target differential pressure, and other factors can be revised to further optimize drilling operations.
- Reduced vibrations results in less wear and tear on the rig and downhole equipment:
    - Decreased stress on the drill string, motor, and bit
    - More consistent Depth of Cut (DOC) or bit engagement, which can significantly reduce bit wear and hole quality
    - Minimized opportunities for motor stalls
- Toolface easily held by directional hands
    - The smoother the WOB, the smoother the delta p, which in turn helps motor efficiency and helps hold toolface
- Minimal bit wear by reducing drilling dysfunctions
- Potential for longer runs




| Hole Size | ROP Improvement (%) |
|---|---|
| 16" | 10.7% |
| 12 ¼" | 6.9% |
| 8 ½" | 7.2% |
| 6 1/8" | 17.9% |

*Figure: Average on-bottom ROP performance*

## Improved connection times achieved by eliminating overtorque in the drill string joints

One specific area to be highlighted is the improvement in connection times following the deployment of the Pason system, as this significant cost savings was not expected.

Before the first well was completed, the company man was already commenting that the tripping out performance had improved. Post-well analysis of the data proved what the rig crew had observed: removing the driller and replacing him with the DAS system resulted in **10% to 20%** faster breakout connections. The consistent, controlled application of WOB reduced the occurrence of overtorque along the drillstring. This alone saved 108 minutes.

** NOTE - Similar results were achieved on another Pason trial in Oman, where the Customer recognized a total reduction of over 1,000 minutes in connection times alone.*

Led by the HPM team, Halliburton and Pason worked together in Oman to achieve a significant contribution to ROI using automation, high-quality data, and a proven planning process to create a blueprint for success.

## Failing to Plan is Planning to Fail

Pason has worked with several partners over the years and recognizes that changing customer workflows can be challenging. Empowering skilled crews through a well-planned training program can have a dramatic impact on the success of automation efforts at a rig site. A robust trial plan is key. The project management team should include all people in the drilling operation, must have a champion, and must define measurable results. It should include the drilling contractor and other service companies and take into consideration any existing Contractor/Operator's best practices.

### Conservative operating parameters

When drilling manually, drillers often stay well within rig equipment limitations. This can reduce drilling optimization opportunities. For optimal drilling performance, the drill string and rig equipment limitations should be documented as operating boundaries, allowing the driller to search for optimum performance without the risk of damaging equipment. Setting the correct boundaries may require buy-in from multiple vendors (bit vendor, directional company, etc.). Once the parties were trained and the correct boundaries were established, the DAS Boundary Based AutoDriller system could be fully utilized to ensure the optimization space was maximized.

### An Accurate Roadmap Leads to an Efficient Journey

The planning phase should challenge existing limiters and highlight potential areas open for continuous improvement. Upon review, the Oman optimization team identified the following areas for improvement:

- Overly conservative operating parameters
- Inability to consistently follow roadmap limits

When following roadmap limits, it is important to utilize a wide limit window, make infrequent system changes and allow the system to optimize.

### On-Bottom Drilling Performance

The average on-bottom ROP improvement was 10.5 %.

- On-bottom ROPs shown above are based on average ROP delivered by both Rig 1 and Rig 2 from 5 wells drilled before and after system deployment

- On-bottom ROPs improvement delivered by the AutoDriller system in Rig 1 is 9.2% and 11.9% in Rig 2

### Off-Bottom Drilling Performance

- 31% reduction in shoetrack drill-out time
- 27% reduction of DC/HWDP overtorque issues in the 16” hole

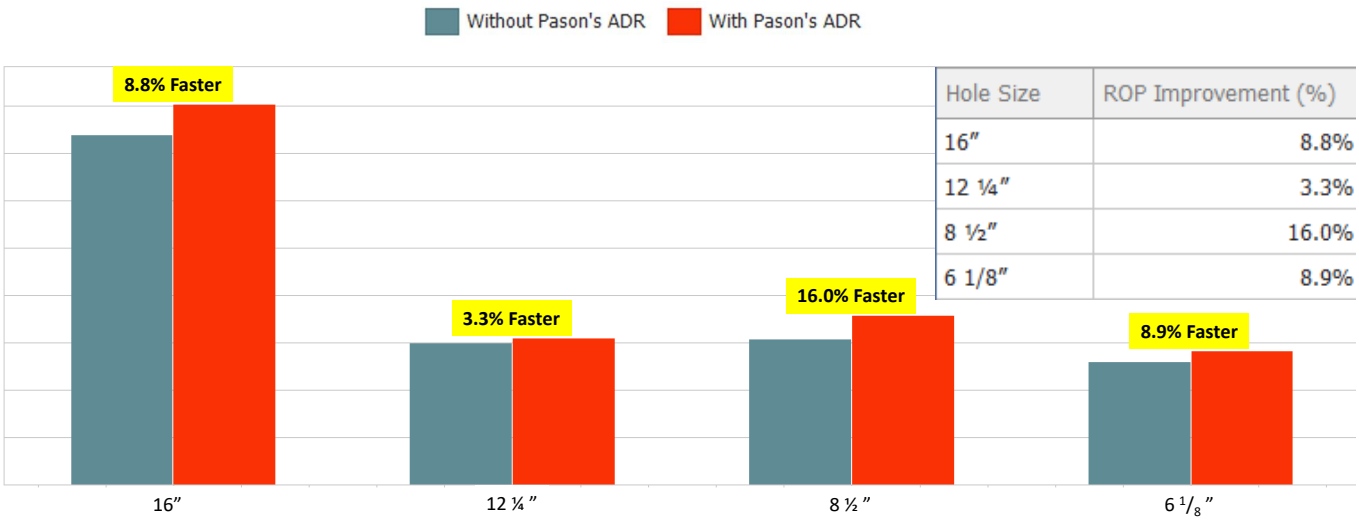
### Total Time Improvement

- 4% improvement in total well time
- 12% improvement in well construction rate

## What Gets Measured Gets Managed

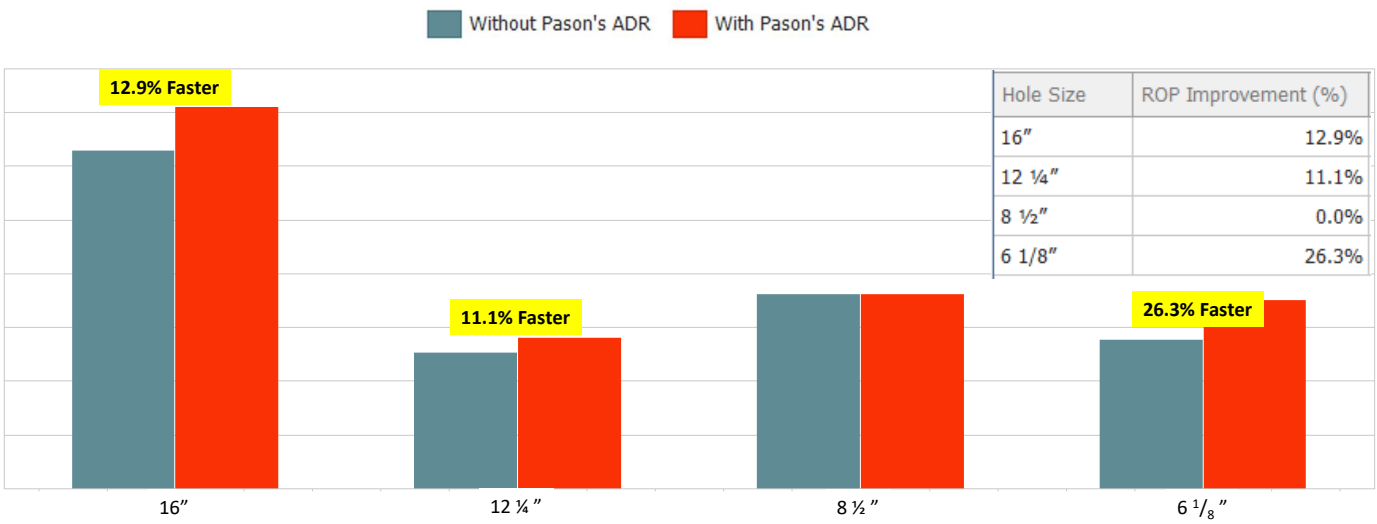
During the trials, consistent and repeatable success was achieved. The Pason multi-parameter AutoDriller operated off Halliburton’s roadmap that included targets and limits for ROP, WOB, differential pressure, and torque. The AutoDriller automatically adjusted the active control state according to the roadmap targets and limits. Real-time optimization through automation helped to further quantify and visualize the limiters. The limiters could then be safely pushed higher. These new limits were used to remodel the drilling plan that would ultimately achieve success in ROP optimization. Successful deployment of the AutoDriller system assisted in improving the on-bottom ROP of Rig 1 by an average of 9.2% and of Rig 2 by an average of 11.9%.

Halliburton achieved significant ROP optimization by integrating Pason’s unique automation technology with their innovative drilling optimization process. They will continue to create value for their customers using this record-breaking approach.




| Hole Size | ROP Improvement (%) |
|---|---|
| 16″ | 8.8% |
| 12 ¼″ | 3.3% |
| 8 ½″ | 16.0% |
| 6 1/8″ | 8.9% |

*Figure: Rig 1 ROP performance; improvement of 5.9 hrs (average)*




| Hole Size | ROP Improvement (%) |
|---|---|
| 16″ | 12.9% |
| 12 ¼″ | 11.1% |
| 8 ½″ | 0.0% |
| 6 1/8″ | 26.3% |

*Figure: Rig 2 ROP performance; improvement of 13.0 hrs (average)*

**Halliburton Optimization Team**: This team is led by Khaled Abdelaal. He has been in the drilling industry for 18 years with a proven track record in optimizing well designs, implementing new technology and improving operational procedures. He has worked in Austria, Egypt, and now in Oman as Principal Well Engineer for Halliburton Project Management. He holds BSc degree in Petroleum Engineering.

Khaled was successfully able to develop integrated models utilizing data analytics for drilling optimization as well recognizing trends in real-time data which relate to improvement opportunities and avoidance of drilling hazards through Pason's high resolution real-time data. He believes integration of machine learning, prescriptive analytics and lean ways of working can save cost, time and most importantly make industrial workplaces safer.

Contact Halliburton to learn more about how they can create and deliver your optimization roadmap. https://www.halliburton.com/en/integrated-services/project-management/integrated-well-construction

**Pason Systems Inc**: Pason is a leading energy services and technology company. We develop and deliver high-value hardware, software, and services, primarily for the oil and gas drilling industry in 12 countries. Our motto is: Technology Deployed Simply. Our mission is to improve the effectiveness, efficiency, and safety of drilling operations.

Contact Pason for detailed information on how to maximize your drilling ROI.
https://pason.com/contact-us/