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Recipe for Digital Change: A Case Study Approach to Drilling Automation

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Abstract

As margins tighten, players in the modern O&G landscape are being forced to reimagine their business models and re-evaluate their strategic direction to maintain a competitive edge. This often means doing more with less and spreading ever slimmer margins across increasingly complex well operations. Fortunately, with the wave of digital innovations that are sweeping the industry, most E&P organizations have a wealth of opportunities to streamline activity and increase efficiency while reducing the resources required. However, with the increasing array of digital opportunities, the gauntlet is set: those who adopt quickly and reap early benefits will undoubtedly be tomorrow's leaders. Laggards slow to adapt will fall progressively further behind as leaders successfully navigate through the learning phase and accelerate into new standards of efficiency. This combination of urgency and opportunity will undoubtedly be the force that propels the industry into the fourth great revolution; digital transformation.

As observed in a variety of industries, automation has proven to be one of these instrumental digital levers to unlocking the next level of efficiency. Across the O&G industry, we are beginning to see a number of applications in which tasks are not only becoming less labor-intensive but also faster, safer and with increased levels of precision. This ensures that repetitive tasks which often drain and distract workers are re-allocated to automated processes while ensuring that employees remain concentrated on prioritizing safety and operations integrity. The value proposition for automation in drilling is especially compelling as human operators can easily become overwhelmed with the volume of competing priorities and the pressure to make immediate decisions. By carefully delegating some of the decision-making to an intelligent drilling system, the cognitive burden on human operators is reduced resulting in a safer working environment conducive to increased performance and engagement.

In this paper, a detailed case study is presented to document the effort of a major service company to deploy a full drilling automation system in the Middle East implemented to autonomously operate rig surface equipment. A detailed description of the system's intelligent management system will be provided to communicate its capacity to interpret and autonomously respond to changing well conditions. A case study approach will be used in attempt to specifically identify the areas where automation delivers a step change in results compared to manual operations. Additionally, given the complexity inherent to executing a digitalization project in drilling, insight will be shared on the strategies leveraged to navigate the intricacies

of deployment and adoption. Throughout this paper, it will become evident that automation is quickly becoming a reliable solution for the consistent delivery of top quartile performance by unlocking new levels of consistency and procedural adherence.

Introduction

Due to the repetitive nature of drilling activities and the high level of risk to which workers are exposed, drilling has long been recognized as a prime candidate for automation. Documented endeavors as far back as the 1950s (H.G Allen et al, 1966) have catalogued the efforts made to take advantage of the efficiency gains offered by automation. However, in the decades since, even as a variety of other industries have seen breakthroughs in digital technology, the value added by drilling automation has been confined to mechanized, predetermined actions which only marginally reduce the cognitive burden on the driller.

The reality is that the sector faces a unique set of challenges that make it difficult to advance the implementation of digital technology. The conservative nature of the industry built on a history of fit-for-purpose solutions and detailed planning has stunted the industry from keeping pace with more agile industries well-adjusted to the fail-fast, learn faster design approach. In addition, the complex layers of stakeholders often coming together from five or more enterprises integrated by the well operator to deliver a well, stymies efforts to push forward digital change. Generally, digital systems rely on fluid data flow between all systems, and standardization becomes a critical component to the success. Finally, the health and safety risk inherent in large, mechanical operations sets a very high standard for the reliability of new technology. However, when pragmatic design and deployment practices are paired with the rapid innovation principles learned from the tech industry, a tremendous amount of value can be unlocked.

In this paper, a comprehensive case study is presented to illustrate how these challenges were overcome to deploy an intelligent, autonomous drilling system capable of independently prioritizing and responding to simultaneous events, to execute all drill-a-stand activities without human intervention. Throughout this document, it is shown that automation has proven to be a critical lever in shortening the learning curve of a deployed rig, as well as delivering performance and efficiency gains beyond the capacity of a well experienced crew. A comprehensive look is also given into the specific strategies adapted for a successful digital implementation in an oil and gas digital deployment.

Project Scope

In early 2018, the service company partnered with a major Middle Eastern NOC on one of the world's largest lump-sum, turn-key gas well delivery projects. Given the multiyear scope of the project and the deep existing relationship among the service company, the rig contractor, and the operator, it was a unique opportunity to deploy the drilling automation solution for pilot testing.

This project would result in a significant increase in drilling activity for the service company with the number of deployed rigs tripling and many new rig crews coming together for the first time. Following a progressive deployment plan, two rigs were selected as initial candidates for automation and would be operated on identical wells in identical fields alongside their manually operated counterparts. As all rigs were deployed in a similar time frame, it became possible to isolate the performance improvement introduced by the traditional learning curve compared to the improvement introduced directly by automation. To minimize the bias related to the start-up learning curve, the system was scheduled to deploy nearly 1.5 years after the project start up once each of the rigs established a solid foundation for expected performance.

Performance Benchmarking

Given the long history of the service company in the region, nearly a decade of performance data was collected with the company's well performance evaluation digital solution. This ensured that comprehensive insight could be captured throughout the deployment to compare performance with other rigs drilling similar well profiles in the same region with a comparable trajectory from a database of hundreds of previously drilled wells. Benefits of using this digital solution have been described in detail in different publications such as L. Ouahrani (2018) and S. Raza (2019).

Prior to the automation system deployment, a comprehensive benchmark analysis was conducted to identify the present performance of the candidate rigs, as well as their ranking in comparison with the manually operated rigs in the project. The analysis covered a variety of metrics related to the areas in which automation was expected to introduce value. This included standard metrics such as drilling rate of penetration (ROP), duration of pre and postconnection activities, spud-to-well TD (total depth) KPIs. However, given the unique nature of the implementation, additional metrics were also evaluated including downhole tool communication accuracy, BHA tool failure statistics, number of bit trips per well section, and drilling dysfunction mitigation metrics. These were established on a single rig level as well as a fieldwide comparison for comparable well types.

As the value-added analysis would be a critical component to direct the focus throughout the pilot period, it was essential that the results could be measured and communicated as soon as possible. This would allow stakeholders to identify potential bottlenecks for fast resolution to maximize the value added with automation. To enable this, an automated data reporting system was customized to allow automation specific insight to be extracted on a daily basis from exported rig data. Automated reports could then be shared with all stakeholders involved with minimal manual input to track automation utilization, performance, and any software bugs encountered. Throughout the implementation process, field benchmarks were updated to ensure that relevant, up-to-date comparisons were available.

Table 1—Automation Evaluation Metrics

Measured Category	KPI	Calculation
Performance	ROP	$\frac{Footage\ drilled\ in\ control}{Total\ section\ hours}$
Consistency	% of time of postconnection in control	$\frac{Time\ of\ postconnection\ in\ control}{Total\ postconnection\ time}$
	% of time of pre-connection in control	$\frac{Time\ of\ preconnection\ in\ control}{Total\ preconnection\ time}$
Accuracy	Success ratio of AutomatedDownlinks	$\frac{AutoDownlinks\ accepted\ by\ the\ tool}{Total\ AutoDownlinks}$
Utilization	% of footage in control	$\frac{Footage\ drilled\ in\ control}{Total\ footage\ of\ the\ run}$

Technology Overview

As discussed earlier, the system focused on autonomously executing all the drilling steps beginning from when the slips were removed after connection until the slips were replaced at the end of the stand. Throughout this workflow, the system would make decisions-not on a small number of predefined scenarios but would intelligently interpret the drilling environment to decide on the best course of action without human oversight or control. This capability can best be described as a collection of interlinked modules that work in parallel in a dynamic sequence to achieve the drilling objective.

The primary feature is described as "Drill-a-Stand," which replicates the actions taken by the driller while perfectly adhering to the limits and recommendations laid out by the operator. This includes standard activities such as preconnection and postconnection sequences but also includes additional activities such as "work-the-pipe" and "friction tests" used to identify differential sticking risk. The remaining features operated as a subfeature in the Drill-a-Stand workflow and added additional functionality while drilling including ROP optimization, drilling dysfunction mitigation, and directional automation (Fig. 1). Further details on these features can be found in B. Goodkey et al (2020).

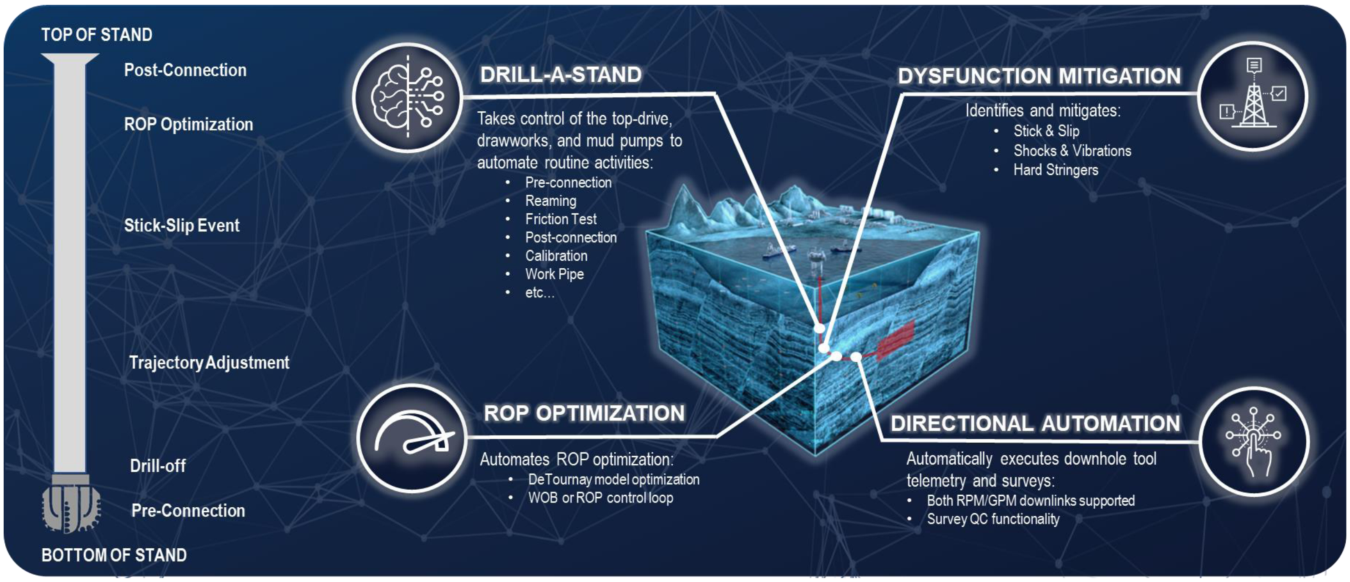

Figure 1—Automation System Features

Autonomy in Action

To properly prioritize and plan each operation, the system leveraged an intelligent planning engine to independently identify and schedule the operation sequence. This capacity to autonomously perceive and react to the dynamic drilling environment is a distinct departure from traditional automation systems which are confined to fixed sequences and simply mechanize a series of pre-programmed, repetitive actions. In order to take an active role in decision-making, the system utilized rig sensor data to determine the current drilling operation or "rig-state". From this reference datum, the system would autonomously plan and execute all remaining activities required to achieve the desired end-state selected by the driller (e.g., "Finish drilling the stand."). If any additional activities became necessary while drilling, the system would independently identify and incorporate the required activity in the planned sequence to accommodate the action. Examples of this include implementing a drilling dysfunction mitigation sequence once deemed necessary by the system or sending an automated downlink sequence while drilling once requested by the directional driller.

As recognized in industry literature (Fig. 2), this transition from predefined sequence automation to self-regulated, machine workflows signals an inaugural transition into the realm of "drilling autonomy". This ability to identify and adapt to unplanned events dramatically widens the scope of automation compatible activities and reduces the number of "hand-back" events in which a human is required to take control. In this new way of operating, the system assumes control of certain workflows and possess' the intelligence to make certain decisions independently. This effectively reduces the cognitive burden on the driller and ensures more concentration can be focused on operations and crew safety. In addition, this new foundation sets the groundwork for the future of automation systems in which multiple workflows will be performed consecutively without human intervention (ex. drilling, tripping, casing running, etc.).

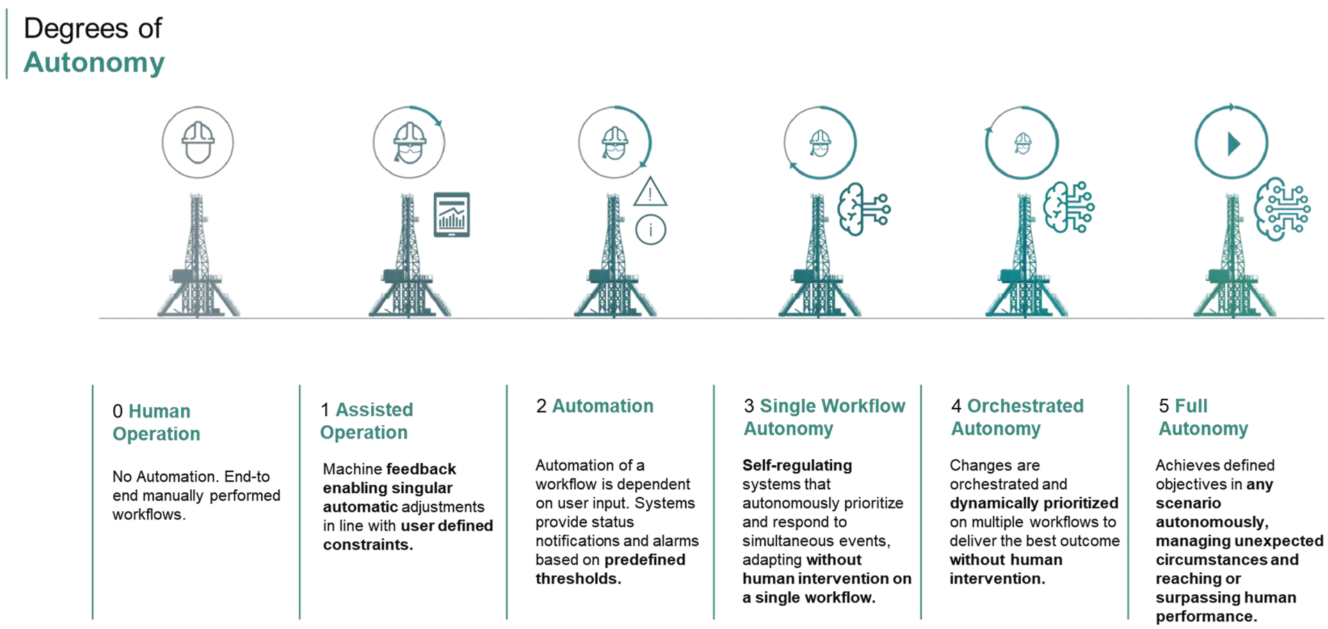

Figure 2—Levels of Automation (World Oil — January 2021)

Foundation of Success

As with many new technologies, the success of the automation system depended as much on a strong implementation as it did on the technology itself. This was well understood prior to the deployment, and a comprehensive strategy was defined long before deployment. Several key elements were identified as priorities, which can be divided into the following three categories:

Project Ownership

Instead of relying entirely on personnel from the product development team, responsibility for the deployment was placed in the hands of the project's business line itself. This included operations personnel already integrated into the project as well as experts from the drilling business line to interface between the development team and operations. By enabling the team from the inside out, it ensured that the power to bring change resided with the same unit directly responsible for the system's success. This was crucial for accurate judgement on where and how innovation was required.

Staircase of Change

Due to the strong focus on precision solutions and risk avoidance, the oil and gas industry tends to be very conservative when integrating new technology. This is especially true for a drilling automation system where the driller is expected to entrust an external agent with critical tasks generally reserved for the most experienced crew members. To encourage a higher level of trust and enhance adoption, a staged deployment strategy was planned to introduce increasing levels of automation control. This began initially with simulator training sessions to give the driller an idea of the scope of automation and expected behavior of the system. Once the driller became familiar, three ascending levels of automated control were introduced beginning with shadow operation (advise only, no control), Incontrol Mode (single machine automation), and finally Optimization Mode (full workflow automation).

Manufactured Dependence

When introducing a workflow that dramatically changes the way of working, it is often difficult to gain full commitment from users who oftentimes are entrenched in decades of previous experience. Breaking this inertia of habit can be exceptionally difficult especially when the direct user possesses the primary responsibility for utilization but is far removed from those driving the change. To encourage adoption, a performance coach was scheduled to remain on location during the management of change period to advise and support the driller in adapting to the system. To measure the level of adoption, utilization was thoroughly monitored and reported on a daily basis to all stakeholders involved. In the event that utilization was lower than expected, the root cause could be identified and addressed with minimal delay.

Key Challenges

Custom Sequence Execution

Prior to deployment, it became apparent that several routinely performed actions specific to the project could not be executed by the automation system. Given that these limitations would limit the utilization and effectively the value added, they were quickly logged and prioritized as action items for the development team. An agile software update approach was implemented to ensure that the updates would arrive at the rig site as soon as possible.

Users Competency Assessments

Despite allowing for several months of on-premise support from performance coaches, it became evident that the driller's competency had begun to stagnate before they had become fully independent. Due to immediate access to the coach, they became highly reliant on the available support whenever any issues were encountered even if they had routinely faced the incident previously. To encourage this growth of competency, routine assessments were introduced to give a clearer idea of where additional training was necessary and to give the drillers more insight on their progress so far. This was implemented in coordination with the service company and the rig contractor to ensure their effort was recognized. Throughout later periods of remote operation, it became clear that the drillers had progressed to the point of autonomy. At this stage, they were not only comfortable to operate independently but also preferred to use the system rather than relying on manual operation.

System Bug Resolution

As with any new technology deployment, system bugs on some level are nearly unavoidable. To ensure fast resolution, all bugs were immediately recorded in an online portal by the performance coach in charge. For any high priority issues, a member of the development team remained on "pager duty" for immediate support. For any issues that could not be resolved immediately, a resolution case would be prepared and added to the queue of required updates. The project team and development team would then review and prioritize resources so that fixes and "nice-to-have" features could be included in future updates.

Results

In the year and a half since implementation, drilling automation has delivered significant value in almost all measured metrics across the board. This is evident not only in increased performance but also through reductions of nonproductive time (NPT), improvements to safety, and remarkable improvements to consistency. This has enabled the rig to deliver top-quartile performance with crews of all levels of experience independent of the crew motivation level or dexterity. These results are summarized in four major categories including performance, consistency, reliability, and accuracy. Throughout each category, a case study approach is taken to share some context of where value is introduced with automation.

Performance

The mechanism of performance improvement relied on the automation system's intelligent "ROP optimization" algorithm, which constantly adjusted drilling parameters to identify the best combination to maximize ROP while remaining within the operators recommended limits. An excellent example of this is included in Fig. 3 in which two wells were drilled 300 ft apart by the same rig: one with automation in control and the other operated manually. In the manually drilled section, it is evident that parameters were conservative with the WOB (weight-on-bit) setpoint limited far below to maximum limit defined for the section. In the automated case, parameters were maximized throughout the section leading to an average ROP improvement of nearly 60%.

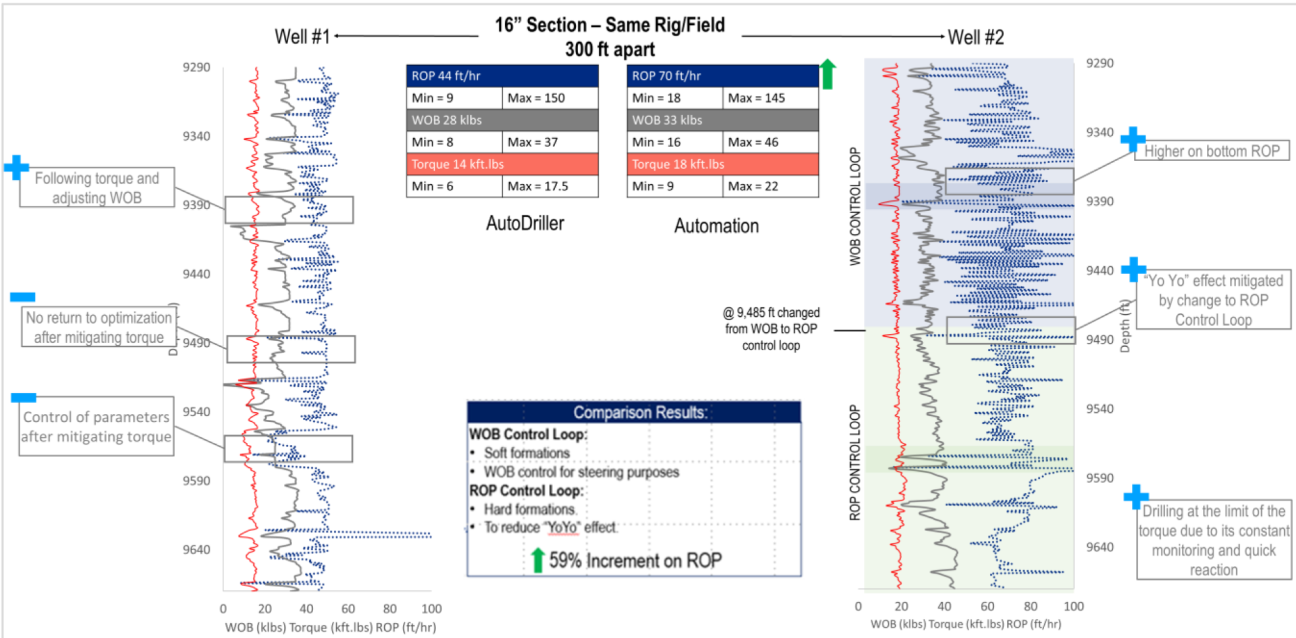

Figure 3—Manual vs. Automated ROP Case Study

As mentioned earlier, performance improvement was measured by comparing field ROP of identical wells (field location, well type, and BHA). Overall, significant improvement was evident with a 16.4% year-on-year increase in ROP relative to the field while previously, the rig had underperformed compared to the field average. In addition, four section ROP records for the field were achieved while in control with automation in the first year.

Consistency

While it's true that a machine cannot always outperform a top-ranking crew, the true value of automation resides in its ability to execute recommended procedures with near-perfect precision every single time. When analyzing the top-performing crews in the project, it became evident that to deliver outstanding results, certain elements of the procedures were often compromised. This exposed potential areas of operational incidents, which systematically lead to extended periods of NPT or even worse, health and safety incidents resulting from the increased trips required for equipment repair and high-risk remedial operations (string jarring, acid operations, fishing operations, etc.). Another reality of manual operation is the susceptibility of personnel to fatigue, distractions, and inexperience that threaten not only performance but the safety of those working in the vicinity. Automation ensures that no deviations occur while allowing the driller to focus on the critical areas of safety and operational integrity related to instrument monitoring, crew supervision, and alarm management, which often becomes a secondary priority in manual operations.

As an excellent example of the consistency introduced by automation, a case study is included below of the preconnection sequences executed throughout a section (Fig. 4a). In this section, 12 h of operation were executed by the driller (shown in grey), and 12 h of operation were executed with the automation system in control (shown in blue). In the figure, the full preconnection sequence can be seen with the block position rising through the backreaming sequence, before reaming down and stopping at the connection point. In total, 55 preconnections are shown: 38 performed with automation and 14 performed by the driller. Although the driller occasionally executed the action faster by violating the recommended practices, automation was on average far more efficient in reducing the average connection time and minimizing exposure to major incidents.

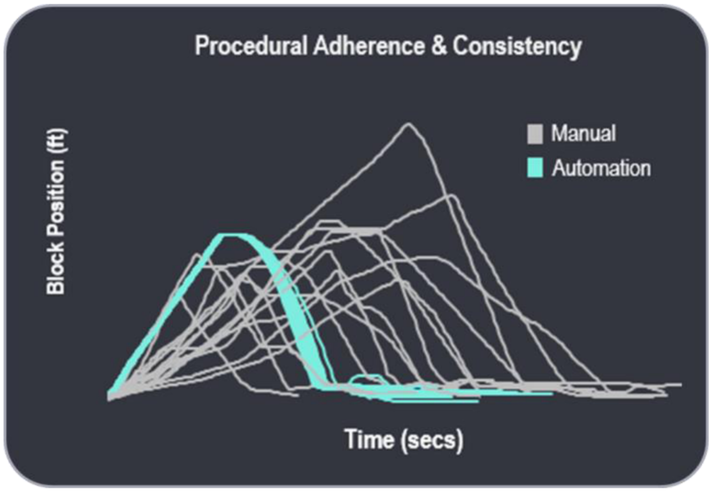

Figure 4a—Fingerprint chart of block position for pre-connections (Blue for automation, grey for driller)

As shown in Fig. 4b, when executing pre-connections with automation in control, the variability in connection time is drastically reduced. This summary displays the distribution of 533 pre-connections executed with automation in control. When compared to manual operation, the pre-connection time is decreased by 23% with a consistency increase of more than 3 times.

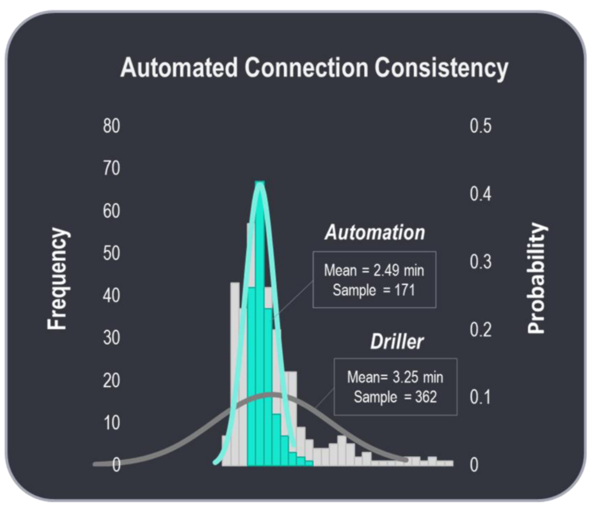

Figure 4b—Normal distribution of preconnection times

Tool Reliability & Endurance

Drilling dysfunctions such as shock and vibration and stick-slip-if unmitigated can quickly lead to days' worth of non-productive time and costly tool repair bills. As such, correct mitigation procedures are generally top-of-mind for drilling organizations in order to minimize the premature failure of downhole tools and bit damage. However, although these strategies are generally clearly laid out in the well plan, correct detection and implementation when required is far more infrequent. In a review of more than one hundred downhole tool failure events in the project in question, it immediately became clear that in most recorded drilling dysfunctions, mitigation measures were either applied late, or not at all. In cases were mitigation procedures were implemented, deviations in recommendations were frequent and only partially compliant to the planned steps.

To increase the adherence to mitigation recommendations, the automation system was configured to detect as well as automatically mitigate events immediately after identification. The mitigation sequence could be configured based on each client's preferred method of mitigation as well as adjusted based on the event's severity and event type whether it included shock and vibration, stick-slip, or hard stringers. Once mitigated, the automation system would return immediately to ROP optimization to minimize the performance lost to mitigation prevention. This ability to balance on the limit of mitigation and optimization is a major step forward for tool failure prevention and performance.

To illustrate the system's response to drilling dysfunctions, an example has been included in Fig. 5. In this diagram, erratic torque—indicative of a stick-slip event—can be identified in the lower half of the plot. The event is immediately detected by the drilling automation system (1) and the WOB and RPM recommendations are adjusted. After two minutes of drilling with stick-slip at level two, the system triggers the "torsional mitigation mode" and proceeds through the client defined mitigation strategy; in this case a stepped reduction in WOB and an increase in RPM (2). After failing to mitigate with the initial reduction, the system continues through three successive steps of parameter adjustment until the erratic behavior subsides (3). The drilling automation system then enters a "post-mitigation mode" by returning to ROP optimization while maintaining a margin below the setpoints which initially triggered the event. In the case that the dysfunction could not be mitigated within the configured time frame, the system would have re-planned, picked up off bottom, stopped rotation, and dissipated the string energy before returning to drilling.

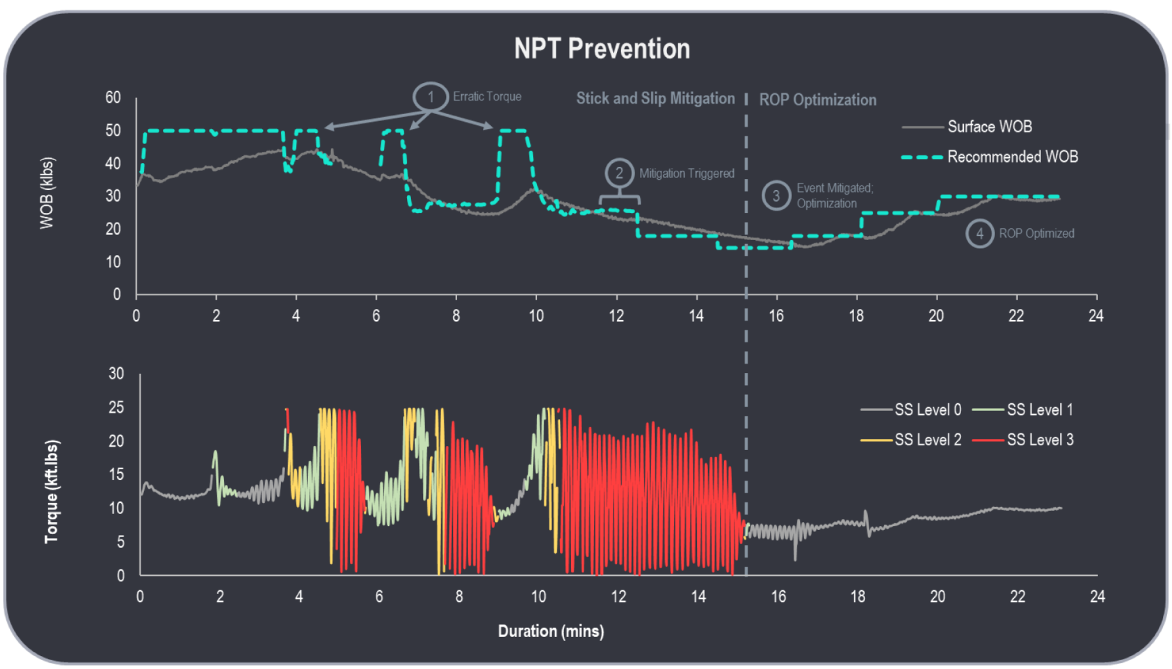

Figure 5—Stick/Slip Mitigation Example

This immediate response to drilling dysfunctions has proven to be a critical element in lengthening tool reliability and extending the footage of drilling runs. An example of this is included in Fig. 6, where the drilling automation system was leveraged to successfully drill a section in a single run with record ROP while previous wells had taken a minimum of two runs with lower performance. This example highlights the advantage of an automated system where driller attention and exhaustion do not play a factor in mitigation and optimization. In the case of a human driller, the perpetual adjustment of parameters is not feasible meaning that parameters are often left too low compromising performance, or too high decreasing tool reliability. Instead, the automated system can perform the mitigate/optimize cycle hundreds of times, as often as necessary to ensure that the drilling parameters continuously straddle the boundary of performance and tool reliability.

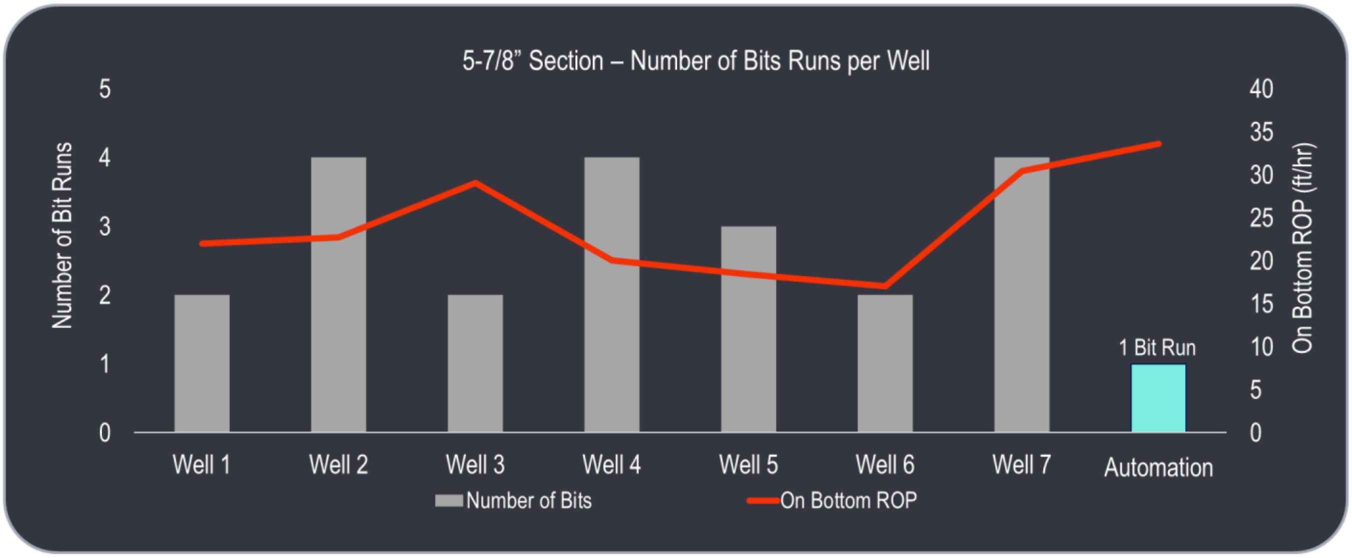

Figure 6—Mitigation Functionality Case Study

Accuracy

Manipulating the drilling parameters—rotations per minute (RPM) and gallons per minute (GPM)—as accurately as possible is critical for a downhole tool to successfully identify and accept a command sent via downlink. As a result of the variability of human operation, a common downlinking strategy includes picking up off bottom as shown in to increase the likelihood of success.

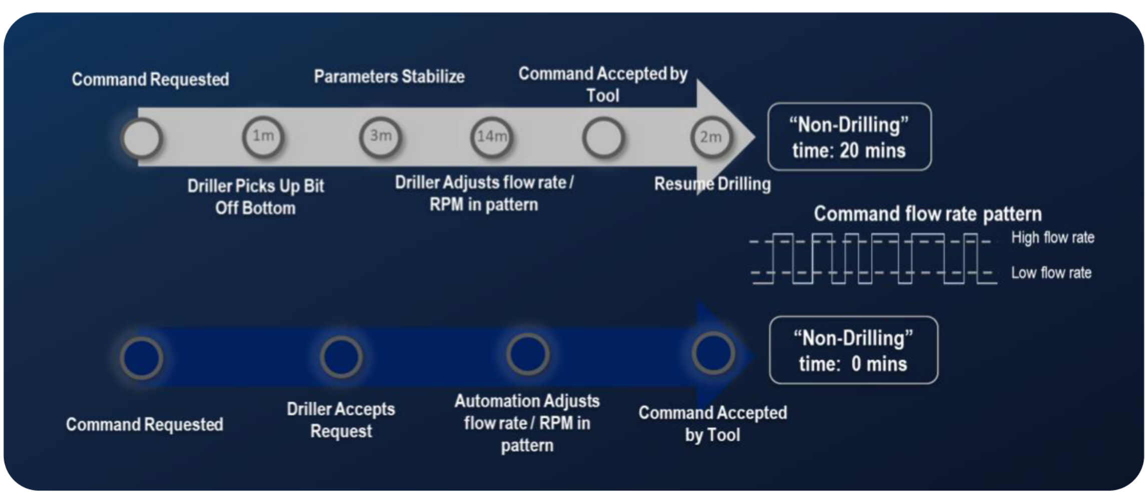

Figure 7—Downlinking Process Comparison

Once the command is requested, the driller will pick up off bottom, wait for the parameters to stabilize, and manually manipulate the mud pumps or top drive to send the requested signal. Once the command is accepted, the driller returns to bottom to continue drilling with the entire sequence taking approximately 20 minutes of nondrilling time. In cases where the signal is stronger and precision is not as critical, the driller can execute the downlink while on-bottom drilling, albeit with reduced attention to the drilling operation resulting in an increased risk of operational incident. In the case that a downlink is sent with automation, a single confirmation message is sent to the driller's interface with no additional intervention required. If the driller chooses to accept the downlink, the system will autonomously adjust the flow rate or RPM in the requested pattern while the driller remains focused on operations. Due to the increased precision of the automation system in contrast to a human operator, downlinks can typically be performed on bottom without the need to come off bottom and stop drilling to increase the accuracy.

In summary, by automating downlinks, improvement was observed across the board when compared to manual operations as shown in Fig. 8 (n=1,341). Beginning with downlink success rate, the frequency of downlinks correctly identified by the downhole tool increased to 95% effectively reducing the number of repeated downlinks. In addition, given the increased accuracy of the automation system, 93% of downlinks could be performed while drilling instead of compromising performance and picking up off bottom for execution. Finally, the total time spent downlinking was reduced by increasing the number of fast downlinks. This avoided reliance on the more stable slow downlinks commonly used in deeper sections of the well. Overall, the increased downlinking efficiency proved critical in reducing well time in addition to increasing directional control throughout the sections where precise navigation is required.

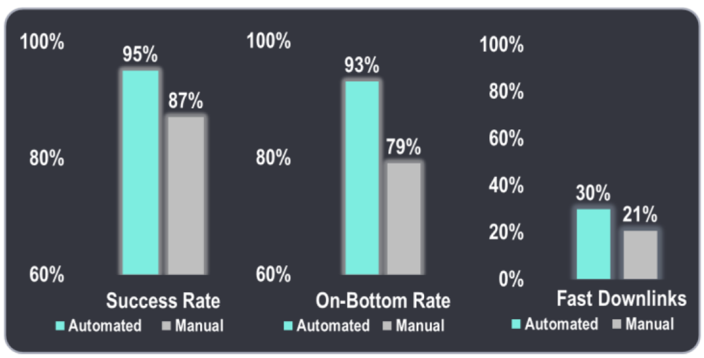

Figure 8—Automated downlink results compared with field benchmark

Overall Results

In this example, the case for automation is clear. In less than a year, a rig went from being a performer in the bottom half of the project to becoming tied with the top performer in less than a year. Two key indicators that capture this progression are operational integrity measured as total NPT per well shown in Fig. 9, and footage per day (to well TD) shown in Fig. 10. As can be seen in Fig. 9, when comparing seven consecutive wells, the total NPT per well showed a dramatic reduction following the full deployment of automation even in similar well types with identical tools.

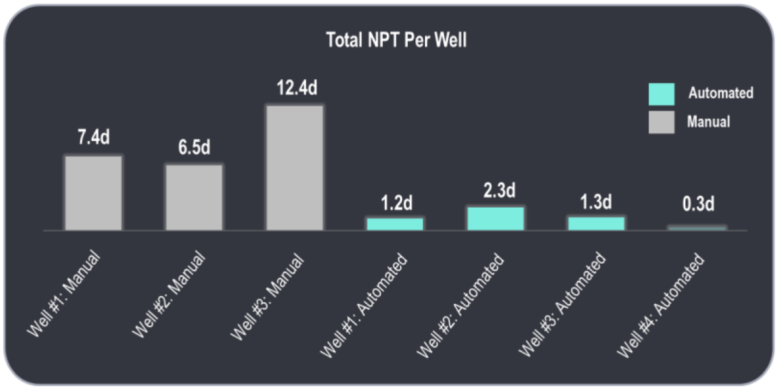

Figure 9—Manual vs. Automated NPT Comparison

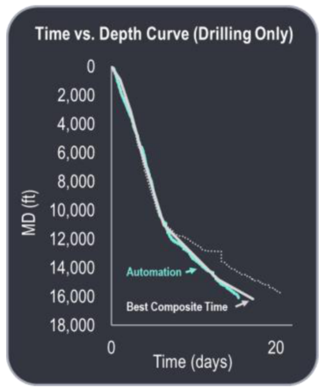

Figure 10—Automation Drilled BCC

As the majority of incidents resulted from non-compliances to recommended procedures and premature tool failures, automation played an important role in minimizing the time expended resolving operational incidents. In addition, with an improvement from 233 ft/day to 347 ft/day since implementation, there is clear evidence that progression is consistent and can be sustained through each successive well. An example of this is included in Fig. 10, which provides an example of a well that was drilled ahead of the best composite curve time (BCC) time by optimizing ROP and eliminating a bit trip in the final section.

Conclusion & Way Forward

As the oil and gas industry transitions to a new era of operating, embracing digital technology has become more crucial than ever before. The case study presented in this paper identifies intelligent drilling automation and specifically "drilling autonomy" as a persuasive candidate for delivering the next step in drilling efficiency, consistency, and safety. In the implementation detailed, there were clear step changes in most drilling performance metrics as well as operational integrity and safety. The most active contributor to these results is clearly extracted from an increase in operational consistency.

In an industry traditionally recognized as a slow adopter of change, this detailed roadmap indicates that with adequate planning and change management tools, major transitions in the way of operating are entirely possible. In the specific context of "drilling autonomy" the foundation has been tested and proven setting the stage for increased levels of autonomy eventually spanning across drilling operations. Overall, this exercise has provided conclusive evidence that drilling automation is the way forward for drilling organizations looking to remain competitive in today's economic climate. With the ability to provide step changes in performance, safety, and operational integrity out of the box, the new era of digital drilling has begun.

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