

Fully Automated Directional Drilling for Consistency and Improved Performance

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Abstract

With the high rates of penetration achieved by today's drilling contractors, directional drillers have little time to make optimal steering decisions in a continually changing environment. Even when proper directional drilling decisions have been made, flawless execution of each decision can be difficult to perform.

Performance related to drilling speed, accuracy, and tortuosity are often inconsistent and greatly determined by the experience, skills, and even the current state of mind of both the directional driller and the driller. These factors lead to increased drilling and lifting costs along with wells having inconsistent hydrocarbon production potential.

Today, directional drilling tasks are increasingly automated to deliver more consistent and improved performance in the field. Before automation can control the physical equipment on the rig, a foundation built upon automated decision-making is critical. An automated bit guidance system provides this foundation and has drilled more than 800 wells successfully across all of the major unconventional plays in North America.

Building upon the decision-making foundation, the next level of automation executes the steering decisions from the bit guidance system automatically. Slide sequences are initiated, executed, and terminated by directly linking the bit guidance system with the rig's existing control system.

This integrated system is coupled with oversight from expert directional drillers in a remote directional drilling command center. The collaboration between human and machine has resulted in lower drilling costs, lower lifting costs, and better hydrocarbon production potential.

The Path to "Fully Autonomous"

Fully autonomous drilling is a daunting task. It can only be completely accomplished by machines performing all tasks in the drilling process currently performed by people, but without direct human control. It is, however, important to note that autonomous drilling is not an "all or nothing" concept. On the path towards fully autonomous drilling, individual tasks can be automated while other tasks continue to be performed by humans. For instance, systems using MSE calculations to automate the control of drilling parameters while rotating have

been in use and have added significant value to drilling operations for years. While these isolated systems enhance value, many drilling tasks remain in the hands of the drillers themselves.

Task by task, it is important to determine what is best performed by humans versus what is best performed by machines. Machines add value by handling a greater volume of data, performing more calculations, and responding faster to unexpected variations in the drilling environment than a human. On the other hand, experience, intuition, and human interaction with the crew are valuable skills that drillers or directional drillers provide to the operation.

Directional drilling consists of following a prescribed well path identified collectively by the company's geologists, geophysicists, and engineers. While attempting to stay on this predefined path, drillers and directional drillers often fail to compensate for multiple parameters including variations in rotary build and walk, formation stresses, motor yields, hydrocarbon production potential related to drilling accuracy, lease boundaries, tortuosity risks, deflections, and BHA potential. The variables are simply too many for drilling personnel to optimally consider and react to in real-time. Increased automation in the human-machine directional drilling process can ensure greater consistency and improved performance.

Fully autonomous drilling may one day be achieved using a phased approach similar to driverless cars. For years, automobile manufacturers have installed automated anti-lock braking systems. Over time, models came to feature increasing levels of automation such as global positioning, cruise control, adaptive lane control, attention alerts, automated emergency braking, and automated parking. The incremental steps towards a driverless vehicle are analogous to the path towards an autonomous drilling rig.

Autonomous Directional Drilling

Autonomous drilling is not a new concept. Automated systems are already in use and adding value by optimizing and changing parameters in real-time. However, systems currently in place typically control the rig only while rotating the pipe from the surface. When adjusting the path of the bit by sliding with traditional BHAs, the driller or directional driller typically

takes over the manual process of drilling without automation. Precise orientation of the bit when sliding is a unique and valuable skill held by relatively few exceptional drillers and directional drillers.

Today, most wells drilled in unconventional plays use traditional BHAs due to their proven reliability and cost effectiveness. However, fully autonomous drilling using these traditional BHAs cannot be reached without automating two important directional drilling tasks:

1. Determining the start and stop depths of the required slides, along with the correct orientation of the toolface
2. Executing decisions to set and hold the toolface in the correct orientation while reacting to variations in formation and other subsurface parameters in real-time

Task 1: Autonomous Bit Guidance

Significant progress was achieved by automating the first of these tasks with an autonomous bit guidance system configured with operator-defined guidelines. Successfully drilling over 800 wells in the major North American unconventional basins and on rigs operated by every major rig contractor is evidence of the system's success. The bit guidance system goes well beyond traditional directional drilling methods by employing advanced computer algorithms to make steering decisions automatically, with more consistency, speed, and reliability than human directional drillers alone. The guidance system removes variability around the directional driller's decision-making and experience that leads to significant variations in performance often seen today. Instead, the bit guidance system provides high levels of consistency and performance somewhat independent of the directional driller's experience level by automating tasks best performed by a machine:

- Providing automated quality control and advanced survey calibration
- Performing standard directional drilling calculations with more accuracy, more detail, and faster than humanly possible
- Enhancing analysis using real-time data streams
- Advising the driller through step-by-step slide and rotate guidance

Quality control and advanced survey calibration includes automated correction for survey tool interference. It uses more accurate magnetic background models, further reducing uncertainty and improving accuracy.

Standard directional drilling calculations and reporting typically performed by directional drillers are now performed automatically, saving valuable time. This allows the directional driller to give his full attention to the current situation without distraction.

The data analysis is enhanced using real-time data streams, and the system automatically provides the driller with step-by-step slide/rotate guidance by pairing dynamic data analysis with the operator's parameters. The slide/rotate decisions are uniquely based upon the estimated costs to the operator associated with each decision. The financial impact of rig time,

risk associated with tortuous wells, and potential loss of hydrocarbon production are factors in each decision.

The bit guidance system uses edge computing installed at the wellsite. Directional drillers, located either at the wellsite or in a remote directional drilling command center displayed in **Fig. 1**, provide oversight of the guidance.

With remote oversight, the experience, expertise, and intuition of the directional driller is combined with the heavy computational capabilities of advanced algorithms in a truly collaborative and transparent environment. This human and machine collaboration leads to wells drilled with lower cost, lower risk, and greater hydrocarbon production potential. One directional driller can monitor multiple wells, saving personnel costs and making operations safer by reducing travel time and time on the rig floor. The remote directional drilling command center facilitates a hub of drilling knowledge and experience, and a network with which to share that expertise.



Figure 1: Remote Directional Drilling Command Center

For optimum performance, the system's guidance must then be executed on the rig. A review of over 12 million feet drilled with the bit guidance system shows many instances when the actions of the driller or directional driller does not match the guidance from the system. The inconsistency can be attributed to several scenarios:

- The initial orientation of the tool is incorrect;
- The driller is unable to set and control the toolface from the start of the slide; or
- The initial toolface is oriented correctly, but the driller has difficulty maintaining a proper toolface orientation.

Each of these occurrences require experience and skills to remediate, whether it involves realigning, setting, controlling, or holding the proper toolface orientation. Two examples are shown in **Fig. 2** and **Fig. 3**. The green spikes in these figures indicate the toolface orientation during the slide sequences, so a more consistent toolface orientation is displayed by a series of spikes extended in a straight line from the wellbore. Erratic spikes or a rotation of spikes indicate issues holding toolface.

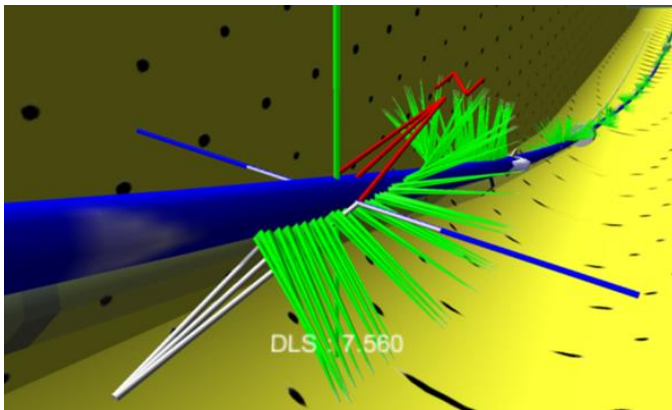


Figure 2: Incorrect Initial Toolface Orientation

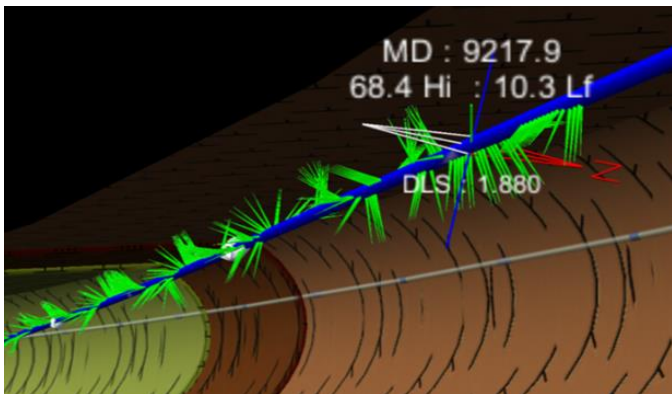


Figure 3: Unable to Hold Toolface

In each of these cases, continual adjustments to drilling parameters requires alertness, experience, and skills that many drillers and directional drillers have acquired over years of drilling in a specific basin. The drilling personnel possessing these desirable traits are in high demand but often unavailable on all of an operator's rigs, particularly during times of increasing rig count.

Task 2: Autonomous Sliding

An automated digital control module was designed, fabricated, and introduced in the field to augment the skills of drillers and directional drillers through automated proactive control of rig equipment while sliding. The system receives the instructions directly from the bit guidance system and executes the slides, continuously compensating for formation variability and for the continual effects of reactive torque.

The initial control module for deployment was designed to be integrated onto a fleet of super-spec rigs with uniform equipment, enabling the development, testing, upgrades, and crew training to be scaled consistently across a fleet of over 200 fully compatible rigs. These rigs include 7,500 psi mud pump systems, increased setback capacity for longer measured depth wells, walking and skidding capabilities for larger pads, and digital platforms to facilitate autonomous drilling. In addition, the control module is fully compatible with other automation systems that are currently deployed on these rigs. The system is currently being fine-tuned for continued autonomous

directional drilling with these rigs in the Permian Basin.

Field Implementation

The results show that automated decision-making, together with automated machine control of the sliding, can reduce drilling time, reduce slide percentage, and deliver a smoother, more accurate wellbore.

Results from wells drilled with the slide control module are compared to wells drilled without this automation. The wells were drilled in the Permian Basin with the same rig, with similar drilling parameters, and in a comparable drilling environment, with the following well program details:

- Upton County, Texas
- Wolfcamp B formation
- Bit: 8 ½" 5 blade, 5/8" cutter PDC
- Motor: 6 ½" 7/8 lobe, 6.4 stage, 2° bend, 4.05 bit to bend
- All surface locations within 3-mile radius
- Lateral lengths ranged from 10,300 ft to 10,700 ft
- Total of 8 wells drilled between October 2017 and June 2018

When implemented, the automated slide module contributed to an average of 14% less drilling hours to drill the lateral section than the average of the wells drilled using manual control, displayed in **Fig. 4**.

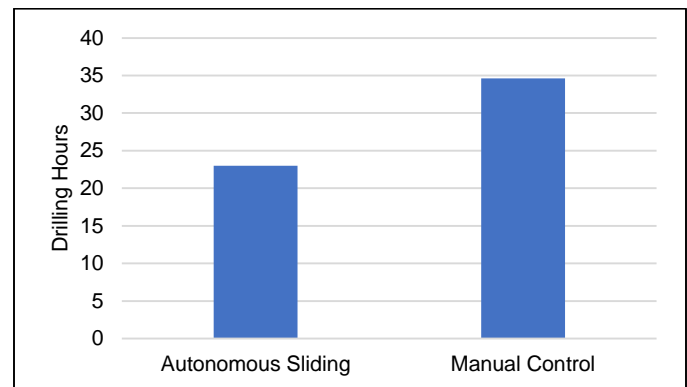


Figure 4: Total Lateral Drilling Hours

The primary reason for the reduction in drilling hours was a reduction in sliding percentage in the lateral section, shown in **Fig. 5**, due to more precise toolface control. With sliding ROPs much lower than rotating ROPs, reductions in slide percentage not only leads to a less tortuous well, but also directly lowers costs associated with the reduced drilling time.

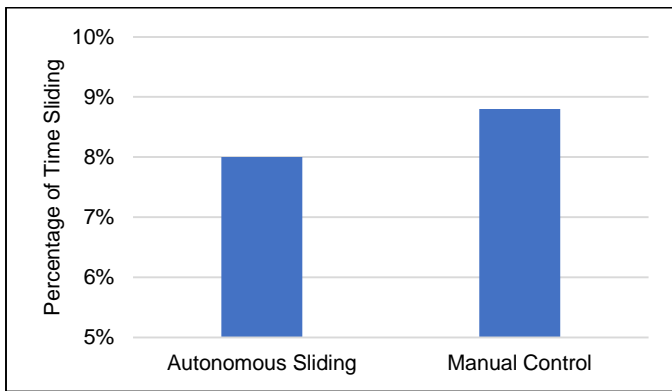


Figure 5: Percentage of Time Sliding in Lateral Section

Slide reductions can come from two sources: better identification of when to slide, and better execution of the slide. In the wells studied, the automated control module delivered a 3.4% increase in slide quality, shown in **Fig. 6**.

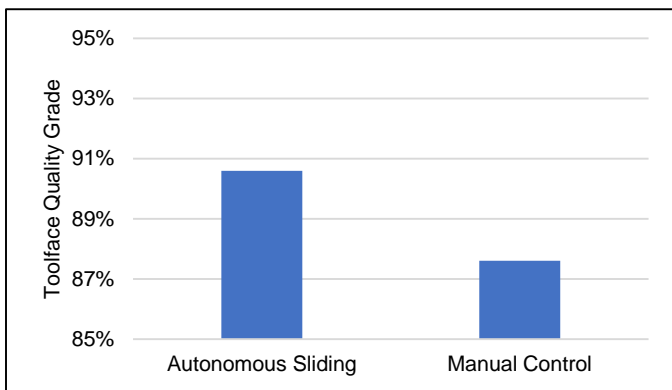


Figure 6: Toolface Quality Grade

The reduction in sliding also helps to deliver wells with less doglegs. Application of autonomous sliding technology delivers factory-like precision to the slide process, shown in **Fig. 7**.

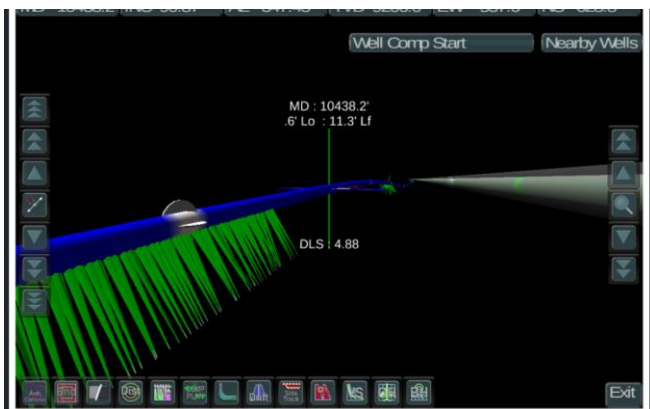


Figure 7: Slide Execution Using the Automated Slide System

Automated Decision-Making

Expert drillers and directional drillers are in high demand. The design of the autonomous bit guidance and sliding systems

provides consistency to operations and allows drillers and directional drillers with less experience to deliver consistent results. It was also found that even the performance of expert drillers can be improved, because even they too can be overwhelmed by data at times.

Nobel Prize winning author Daniel Kahneman's book *Thinking Fast and Slow* presents numerous examples of situations where high performers and experts perform poorly during certain situations due to the way the human brain processes information. Kahneman explains that humans have two modes of thinking associated with decision-making:

- System 1 operates automatically and quickly, with little or no effort and no sense of voluntary control
- System 2 allocates attention to the effortful mental activities that demand it, including complex computations

As it pertains to directional drilling operations, directional drillers continuously absorb data and information in real-time (continuous GR readings, hook load, surface torque, pump pressures, flow rates, trajectory measurements, etc.) and must make quick decisions such as determining toolface orientation, start and stop depths for slide sequences, anti-collision measures, risks associated with dogleg severity, and consequences related to distance from the target. Good directional drillers have developed their expertise over many years under the apprenticeship of more experienced drillers, often in a specific basin.

System 1 describes how most directional drillers make decisions: quickly and intuitively. The best directional drillers also know when to shift to System 2, where effortful geometric computations must be performed while incorporating additional data.

Kahneman provides evidence that people tend to depend on System 1 thinking too frequently in many situations. They are not willing, or do not have the time or energy, to switch to System 2, even when it is necessary for better decisions. Both the bit guidance system and the automated slide control module described in this paper provide much of the heavy lifting associated with System 2 thinking and augment the skills, intuition, and experience of even the best drilling personnel to take performance to the next level.

Conclusions

Just as the turn by turn decision-making of Google Maps is necessary prior to fully automating a driverless car, a similar decision-making foundation is critical to automating the control of rig equipment.

As demonstrated, autonomous drilling is not an "all or nothing" concept:

- Automation of individual tasks on the rig provide significant value to the operation on their own, without the need for full automation
- The data shows an already top performing rig improving its performance by combining the prior successes of automated directional drilling decision-making with the capability to execute those decisions using an automated slide module

- The combined system delivers both higher consistency and improved performance

In a cyclical industry, communicating best practices and establishing experience is not a small undertaking. Automating tasks such as bit guidance and sliding can harness best practices and expertise of experienced rig personnel; drilling success then no longer depends solely on the skills and knowledge of a specific person.

Acknowledgments

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Nomenclature

<i>BHA</i>	= <i>Bottomhole Assembly</i>
<i>GR</i>	= <i>Gamma Ray Log</i>
<i>PDC</i>	= <i>Polycrystalline Diamond Compact</i>
<i>ROP</i>	= <i>Rate of Penetration</i>
<i>MSE</i>	= <i>Mechanical Specific Energy</i>

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