Drilling Machines and Equipment

This section of the DSA Roadmap report describes the current state and expected outlook as a consequence of the development of machines and equipment capable of automation used to drill wells.

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Functional Description

Drilling machines and equipment refers to both surface and downhole systems. On the surface, the rig system includes power generation, rotary drive (top drive or rotary table), hoisting and pipe handling, and the fluids system, which includes the circulating pumps, fluids preparation and treatment and solids control. Downhole, the primary system is the bottom hole assembly (BHA). Collectively, these machines and equipment provide the power and control to fracture and remove rock and to create a borehole in a desired trajectory.

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Surface machinery was originally powered by direct drive diesel engines. These were supplanted by direct current (DC) electrical generating systems having electric motors connected to the machinery. In recent years this electric system has been supplanted by alternating current (AC) variable frequency drive (VFD) systems.

VFD systems are highly controllable and have enabled the traditional mechanical brake on the drawworks to be replaced with joy sticks for powering up and braking down. Programmable logic controllers (PLC's) enable operations of these machines to be programmed. For example, startup of a mud circulating pump can be programmed to ramp up in a predetermined manner when the start button is pressed. Because VFD drives are highly controllable, they provide industry with an opportunity to apply automation.

Drilling operations use a broad variety of equipment that is located on surface and downhole. This equipment performs many functions and currently ranges from independently controlled (e.g. shale shakers) to highly automated (e.g. rotary steerable tool). Because the typical telemetry loop to surface and back to downhole has historically been too slow or delayed for real-time control, downhole equipment is becoming autonomous; the downhole control receives supervisory control updates via telemetry then acts on its own. Surface equipment has traditionally not been automated. However, because it is very similar to industrial machinery, which has been automated to a high degree, surface equipment automation may be easily automated. opportunity.

Performance targets

Performance targets for drilling machines and equipment fall into two higher level categories: nonproductive time (NPT) and productive time (PT). Nonproductive time is the duration of activities that do not correspond to progressing the borehole to a greater depth. Productive time are activities that correspond to progressing a bore hole to a greater depth. Productive time includes both the time necessary to progress the bore hole. It also includes time progressing the bore hole that is inefficient and can be reduced, which is typically referred to as invisible lost time (ILT).

Nonproductive time is defined as the reported time spent on activities that were unplanned and unnecessary in drilling the well. This includes lost time from problems and down time from equipment failure and may be caused by equipment failure, equipment inefficiency compared with a plan, human error and similar events. Some companies include drilling dysfunctions, such as whirl, stick slip and vibrations within NPT.
Invisible lost time is defined as time lost due to inefficiency while drilling a well and is typically reported as PT and therefore remains "invisible" to the record. [1]

Automation of drilling machines and equipment must address both components of performance KPIs. NPT may be addressed by designing robust machines and control systems that minimize failure and by incorporating control systems into machines that can prevent those machines from operating outside their own operating envelope and thus reduce failures. It is critical that control systems prevent operations from undertaking activities in the wellbore that create circumstances outside the wellbore stability envelope. For example, instigating tripping acceleration or speed that leads to borehole issues requiring remediation.

Mud pump controls must be 'tuned' to the mud and wellbore conditions such that the pump start-up minimizes potential wellbore damage. Machine condition monitoring enables predictive maintenance, and systems must minimize drilling dysfunction such as whirl, vibration, stick slip.
ILT can be addressed by designing mechanized systems that can extract activities from the critical path and perform them in an automated mode off the critical path. These activities may include stand building of drill pipe and other tubulars, pick up and installation of pre-made BHAs and automated pipe running. Other solutions include the development of mechanized systems able to perform more quickly than can humans doing the task manually or semi manually. These include such activities as tripping and making connections. Mechanized Onshore mechanized systems that occupy less space than manually operated systems reduces the rig system footprint, which creates an opportunity to reduce rig move loads and durations. Automated systems can replace varied human performance with consistent and repeatable performance, which usually delivers a faster result (Figure 1.)

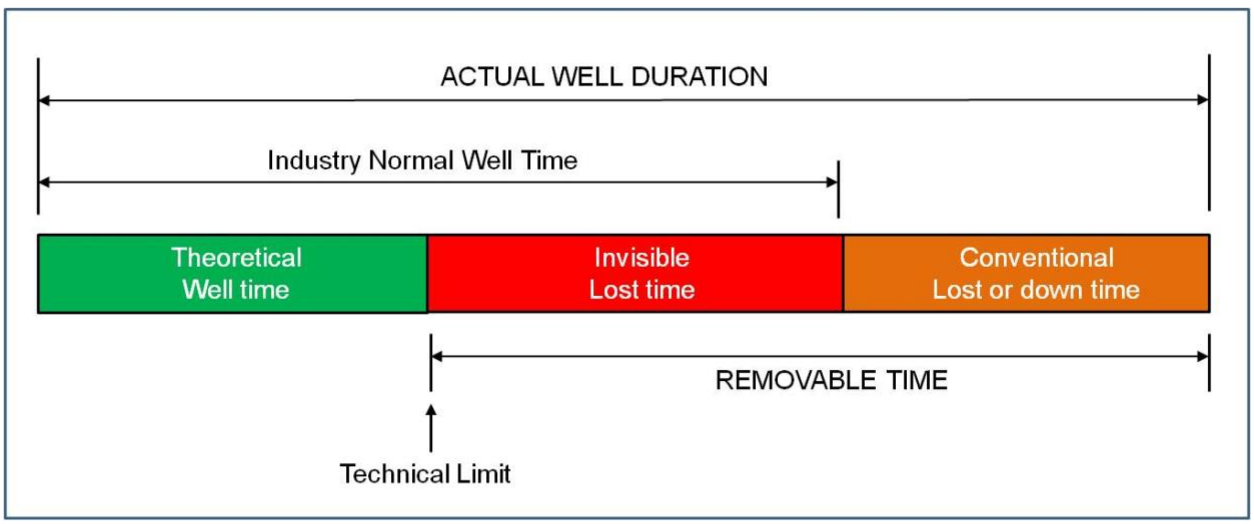

Figure 1 Representation of NPT and ILT

Drilling equipment is currently designed to address some ILT for both land and offshore drilling. For land drilling, designers are developing mechanized stand building equipment. Some designs use bucking units in the cat walk and range 3 pipe; others build and rack vertically. Because they are aimed at repetitive tasks that operate independent of the wellbore condition, these devices can be upgraded from mechanization to automated control.

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The industry has developed and implemented cradle systems that enable make-ups and off-line BOP tests. Because they remove the make-up and test time from the critical path, these systems are becoming increasingly common. Mechanization of the cradles for placement of the BOP on the wellhead further advances this process toward automation.

Drilling rig designs that offer the potential for continuous tripping into and out of the borehole are emerging. These systems require automation to control the interrelated and to synchronize various equipment and machines involved in the process. An offshore drilling tower has demonstrated tripping speeds of 6,000 feet per hour with robotic handlers and automated control.[2] A retrofit system for modern offshore drilling rigs has been prototype tested to implement continuous tripping.[3]

Drilling machines are responsible for three key drilling process parameters: weight on bit (WOB), rotation (RPM), and fluid flow and fluid horsepower. These parameters directly impact the rate of penetration (ROP). In today's environment, these values are measured by and controlled from the surface equipment and friction, deflection, control latency and many non-linear effects create significant uncertainty in the reported downhole values.

The performance targets for a new land rig must:

- Minimize ILT by using mechanization and automation to maximize offline (non-critical path) activities
- Minimize ILT through machines and equipment designs based on automation rather than automating current designs.
- Include downhole tools that act autonomously to tune the drilling process at the rock face through minimizing drilling dysfunction, such as vibrations and incorrect parameters.

Current Situation

Although available, technologies such as auto drillers and ROP optimization, operate under conditions of significant uncertainty, low data rates from downhole tools, high latency in signals and system response, and poorly performing physical models. Often, the driller is in the control loop because the level of uncertainty in the state of the well requires intuition and experience to make decisions. The net result is higher risk operations, greater downtime and poorer performance resulting from suboptimal control of the drilling subsystem.

Many components on modern drilling rigs have mechanized processes that were previously performed manually. In many cases, this provides a step towards automation. But a look at each of the components individually reveals significant disparities as to their relative readiness to be part of an automated drilling system. For example, the topdrive is a comparatively recent innovation when compared with shale shakers, the basic design of which has been in place for many years.

Nevertheless, to take advantage of the precision and reaction speed that automation will bring to drilling operations, one feature must be universal in all top-side drilling package components; all the drilling equipment should be controlled electrically, or electro-hydraulically. The advent of VFD on AC electric rigs is certain to encourage the adoption of automated drilling systems.

The primary functions of drilling machinery on modern rigs are to provide rotation, hoisting and fluid-pumping power. The ability to apply automated control to the topdrive has been demonstrated by the torque-control algorithms used in stick-slip mitigation. The potential for the topdrive and other major components to be controlled automatically via supervisory control algorithms driven by downhole data has also been established in the field.[4] These algorithms aim to maximize drilling performance by controlling rig machines with fewer direct inputs from humans.

Hoisting mechanisms have also demonstrated the ability to react with precision to the same control algorithms. Electric hoisting systems, including rack and pinion hoisting systems on some singles rigs, are already available. Such systems allow downward pressure on the drillstring. Similarly, the weight of a large topdrive also provides up to 100 klb of potential pressure, combined with heavy weight pipe placement some record wells with a horizontal reach of over 38,000 feet have been drilled with current hoisting technology. Therefore, available downward pressure does not appear to be an impediment to automating a current drilling system. Electric hoisting with permanent-magnet motors ensures that the system locks solid upon failure. These are the type of winches used on many cranes and would provide a safer system than currently used on most rigs in the event of power loss to the drive.

For full automation, fluid handling demands considerable improvement. Automated fluid transfer has been installed on the most modern offshore rigs, in which the source and destination of the fluid are chosen and used by the automated system to find the most efficient route, open and close required valves, and start up transfer via electric drive centrifugal pumps. Mixing of fluids in these systems is semi-automatic using bulk storage of barite and bentonite and cement and smaller quantities of other chemicals that must be input manually. The sack-slitter may be automated, but the sacks are still loaded manually. A fully automated sack room, possibly using robots, is necessary to achieve a fully autonomous system.

New mud pump designs are also an option, but triplex pumps with AC motors can be finely tuned and programmed to, for example, ramp-up at a rate that mitigates pressure spikes when breaking circulation.

Arguably the most repetitive drilling process that potentially lends itself to the type of automation applied to industrial manufacturing processes is tripping pipe. Currently, singles rigs are available that can pick up individual joints from horizontal and stab, make-up and trip-in a string of pipe. Using range 3 pipe, some rigs achieve tripping speeds of up to 1,300 ft (400m) per hour and can drill to depths of 19,000 ft (5,800 m). These systems may be fed by joints of pipe provided in cassettes.

Many industry members suggest that the machines currently used on a traditional triples rig can also do the work in automated mode if more and better sensors are added in strategic locations. Currently, pipe-handling on the rig floor can be accomplished using a single joystick and catwalks feeding the drillpipe are automated. However, machines and automated processes on most rigs still require human input, such as locking elevators or locking a stand in the finger board or identifying the top of the box when in-slips tripping in, and the tool joint when in-slips tripping out.

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Automated connections are now possible by providing consistent stick-up height. However, additional correctly placed quality sensors will enable more extensive tripping automation on current machinery. Pipe tallies can be maintained automatically using radio-frequency identification (RFID) tags that detect a joint passing through the rotary table to be used in maintaining pipe history and, in conjunction with documented inspections, mitigate failures. Doping, however, remains a challenge; some systems have been implemented but it remains one area in which new hardware may still be required to ensure continuous replacement of the human contribution.

Robotic pipe handling systems are also in development today. One unmanned system utilizes autonomous robotic operations that can be remotely controlled from an interactive 3D interface. Centralized control means that all robots can 'see' each other without the need for cameras or other sensors. On a modern rig, this robotic system can integrate with and use current, state-of-the-art drawworks and topdrives. Enhancing current pipe-handling systems with the addition of sensors will enable automation of modern rigs in the field today. When fully developed, a robotic system may be retro-fitted to those same rigs.

BHA make-up is an intensive and complex procedure that is unlikely to be automated. However, making up the BHA off-line and delivering the assembly to the rig in known sections will enhance the ability to automate the tripping process. Premade BHAs have proven to be significant time savers and are becoming common in some high-performance drilling areas.

Projects are underway to use automation, initially in data analysis, to improve well shut-in using well-control equipment. Emergency disconnect system (EDS) sequences automate complex pressure control processes involving the BOP stack. This equipment has been proven to respond as required.

A typical EDS sequence has about fifty commands to close rams and choke and kill valves and to unlatch the lower marine riser package (LMRP) and choke and kill connectors. This can all be accomplished in less than a minute following a single command. Although the industry must reach a consensus on a contractual model for automated well control, most of the technical challenges have been addressed.

Managed Pressure Drilling (MPD) has become well established as an automated process. MPD enables wells to be drilled using a closed loop fluid system that continuously adjusts the surface pressure to manage the downhole pressure. These systems can include a fast-automated system that reacts quickly to pressure build-up in a well that is caused by an influx and thus offers a potential solution for automated well control.

Solids control leaves room for improvement. For optimal efficiency, a shale shaker should have 80% screen coverage so an automation system could switch individual shakers on and off according to the fluid flow rate. More recent separation technology that uses a combination of high air-flow and vacuums, or large centrifuges, may be more readily integrated into an automated system.

Cuttings weight and volume requires new sensor technology to generate signals suitable for automated control. Mass volume and flow-through Coriolis meters are a significant improvement over counting pump-strokes to estimate flow-in and relying on a flow-line paddle to indicate changes in flow-out used by most rigs today. Sonar-based multi-phase flow meters are also available.

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Ideally, as a guide to the efficiency of hole-cleaning, the in-out delta as a measure of cuttings volume should be monitored constantly and tracked against hole-size and penetration rate. A true indication of hole-cleaning could save many hours pumping sweeps and circulating prior to running casing.

Current sophistication of downhole steerable systems and logging tools will enable automated drilling by offering both geometrical and geological precision. The Rotary Steerable Tool (RST) is a closed-loop robotic system that can be operated with periodic updates from surface.

One piece of automated drilling system equipment that still requires development is the human-machine interface (HMI). Experience from other industries confirms that the need for vigilance by an on-site or remote human operator remains, no matter how advanced automation becomes. The success of that vigilance depends on the level of involvement that can be maintained despite the lack of participation in the ongoing operation so the operator remains situationally aware.

HMIs able to illustrate clearly every vital parameter of the process without the need for constant interpretation of streams of data will be essential. Simulators that mirror operations on specific rigs and allow bespoke training programs are also essential to engender familiarity with all automated processes and to ensure any demand for intervention, particularly during emergencies, does not come as a surprise to the human in the loop.

Many drilling machines and equipment components have been developed to a degree of technical excellence that has prepared them for automated control. Automation requiring interconnectivity of various drilling machines has been significantly enhanced by the concept of the 'drilling package' wherein all major topside components and the control system across these machines have been supplied by a single manufacturer. The key to further development often lies in technologies available in other industries. Today's hardware does not present any insurmountable barriers to a fully automated drilling system.

Problem Statement

Fundamentally, the rig system must deliver energy to the down-hole environment to fracture rock and progress the bit towards its target. Today, this is executed by torque transfer and weight management of the drill string from the surface. This model is challenged by the fact that the system actuators (drive and draw works) are far removed from the control point (bit). This problem is accentuated in deeper wells and long-reach high-angle wells.

Two paths forward exist. One path is the ubiquitous adoption of high-rate hard-wired drillpipe telemetry systems; the other path is intelligent closed loop downhole (BHA) equipment, including smart drill bits. Hard-wired pipe offers a higher bandwidth control model in which the control inputs, actuators and sensor feedback are closed in a tighter loop with lower latencies and less measurement uncertainty to the surface machinery. Downhole intelligent tools remove the requirement for high-data rate low-latency surface connectivity.

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The drilling industry has traditionally relied on generational development of existing types of equipment with increased power, higher responsiveness and less downtime. Traditionally, the industry has been reluctant to make obsolete older less efficient equipment when replacements would require significant investment. Recently, the reduced rig count and operator demand for much higher drilling performance has resulted in active drilling contractors implementing rig upgrades that provide modern equipment with controllable drives. This response has created a landscape ripe for automation.

Radically new equipment designs which can, for example, significantly reduce pipe tripping times into and out of the well, are struggling to gain acceptance and secure funding. That is because the gap between current equipment performance and the envisaged performance of these new designs may be insufficient to reward investors.

Barriers

Cost

A primary hurdle to drilling machine and equipment automation is cost. Pricing pressure in 2019 makes a return on investment a challenge. In addition, the business model that includes typical dayrate contracts do not swiftly or directly reward improvements in performance from investments in equipment, sensor and control systems required to advance automation.

Equipment design

Although automating current equipment, such as automated driller, has resulted in improved performance, equipment designed for automation will be required to realize the full benefits and not simply automating current designs. Current assets limit the desire and financial wisdom to make such a significant investment, which will result in the obsolescence of current assets.

Needs

Drilling performance

The unconventional (shale) drilling market in the USA has become highly performance focused as measured in terms of release-to-release. Drilling contractors are shifting from a backlog of contracted-rig-days focus to a performance focus. Automation has assisted the improvement in performance with such innovations as rig controls and directional drilling systems. The next step forward will require equipment redesigns based on advantages offered by automation that reduce non-rotating drilling durations and enable rigs to move faster using such methods as continuous tripping, automated offline activities, reduced rig footprint and others.

Mud systems

Mud systems need to be designed for automation such that the costs of adding multiple valve controls and control treatment equipment is not prohibitive. Automated mud systems create opportunities through improved rheology control, continuous control and reduced labor for mixing and treating muds. Land drilling systems require automated systems that do not incur long hook up times or significant maintenance from the rig-up and rig-down activities.

Offshore well cycle time

Drilling costs are a significant portion of offshore development costs. Past high oil prices encouraged an expansion of traditional drilling equipment, but competitively priced wells require a significant reduction in total well durations. Equipment designed for reduced cycle times on many activities in drilling can generate this opportunity, particularly when the equipment incorporates automation for consistency, speed of operation, and the ability to multitask without additional crew.

Critical Success Factors

In order to deliver optimal value, drilling machines and equipment must be designed to take advantage of the highest feasible degree of automation. Automating current designs has already been shown to improve drilling efficiency but may yield insufficient improvements to warrant investment in regions that have already established high drilling performance. A systems engineering approach will be required to achieve maximum benefit, but may be a challenge to prove commercially in the near term when compared with the sunk investment in current rigs.

Less complex solutions may lead to reduced costs and enhanced performance. Changing the business model to reward improved well functionality and quality and leading to lower operating expense and improved production revenues is a means to further stimulate value from a combination of equipment and machine design automation.

Way Ahead

Historically, control automation has been applied to equipment that was, or was similar to equipment, already in service. Consequently, the development of control systems and automation applications has incrementally followed the rig equipment designs. Accepting that this was a good strategy for the industry, an opportunity exists to reassess the situation and develop machinery that is radically changed in design to take advantage of a truly automated system.

The challenge in envisioning the future for drilling machines is that traditional development has been slow and repetitive in many aspects and the application of advanced sensors and automation has appeared expensive compared with manual operations. The shale boom in the USA that demands fast high-value wells now provides the opportunity to innovate and deliver a high-value, lower-cost product.

Downhole drilling tools are envisaged to become increasingly intelligent and will provide fast feedback control in the BHA environment, including aspects currently primarily controlled from surface, and will include smart bits. These advances will be a combination of sensor placement, closed loop control and equipment attributes specifically designed for automation, such as bits with a continuously controlled standoff.

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Cassettes

Pipe cassettes are in vertical or horizontal use on some rig designs. Cassettes may be preloaded with measured tubulars that rack into the drill string path efficiently using automated control on mechanized systems.

Vertical racking

Effective automation will need to significantly reduce flat time associated with drill pipe, casing and tubing make-up. Companies have developed methods to create vertical pipe racking in stands ready to run into the bore hole. One such system uses a make-up head in the catwalk before raising two sections of range 3 pipe. Another system employs two centers, one for make-up and the other for drilling. These systems will become mechanized and then automated to operate in parallel to the drilling activities with limited crew involvement.

Prebuilt BHAs and completions

Begun in Norway with Lean Drilling™ in 1997, prebuilding BHAs has become common among high preforming drillers. Suppliers pre-make BHAs in accordance with agreed pipe and tool torque ratings for ready running into the bore hole. Pre-made BHAs offer the opportunity for mechanized systems to simply pick up and assemble pre-defined lengths of tubulars instead of suffering the inefficiencies of making up various components of varying diameters and lengths. Pre-made BHAs will enable less flexible, more specific mechanization on the rig, which will lead to further automation of the pipe handling in support of drilling systems automation. Pre-made BHAs will avoid the need for the more complicated and expensive designs of robotics that are required to pick up small items on the rig floor. On offshore rigs, bucking machines have been used to pre-make assemblies on the pipe deck.

Premade pressure tested completions are already in place, which again negates the need for a complex robotics solution on the rig floor.

Access to control

Control of machinery from third parties using their own algorithms creates a major challenge for the drilling industry. It has been envisaged that this control would be through a common communication method such as OPC UA and that machines would accept the directives into their own proprietary controller and return advice as to their ability to conform or to not conform to the instruction. An automated control system is not expected to override the internal controls and limits within machinery and equipment. The quid pro quo between the machinery and the control equipment is that the former advises the constraints under which it is operating and the latter acknowledges these constraints and acts accordingly.

The conflict between proprietary owners avoiding access to their machinery control and an open system that enables interoperability will become the future groundwork for Drilling Systems Automation. Industrial automation offers a view on past practices and successful implementation that can influence the development of drilling systems automation.

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John Berra offered the following perspectives on the future of drilling systems automation to SPE DSATS:

- End users have interoperability in the manually operated world. They want to maintain this interoperability in an automated world. Some competitors see the digital changes as a way to bundle their products and systems using proprietary communication. In industrial automation in the 1990s, chaos emerged with multiple standards efforts and proprietary schemes.
- Recognize that the pie gets bigger for everyone if communication is open and you get a bigger piece of the bigger pie by being the best in the open environment

Minimization of rig dimensions

A major opportunity offered by fully automated and mechanized drilling rigs is the footprint required by human operations diminishes significantly. Reduction of drilling rig footprint reduces the amount and quantity of steel supporting the operational envelope. For land drilling rigs, this reduces the material required to be moved between locations, enabling fast rig moves.

MPD Systems

Managed pressure equipment will become the norm for well control. Initially applied on land drilling, primarily to reduce hydrostatic pressure on the formation and increase rates of penetration, it is now being deployed offshore to drill undrillable wells. MPD systems deliver higher value through performance, mud cost reduction, and by minimizing complex casing schemes. As a consequence, the industry recognizes its value in the same manner as it recognized the value of top drives. More recently, adding an MPD system has positively impacted insurance premiums.

Well Control Equipment

Automation of well control has become a focus of an initiative[5]. It is likely that MPD will become more common and the first line of automated defense for a well influx.

General Outlook

Equipment development will focus on technologies that add value to the drilling process. Much of this development will occur in subsystems, where sensors and data processing can realize improved results from the new technology. These closed system tools will in many cases act autonomously.

A list of equipment items to be developed includes:

- Pipe doping systems that is fully effective and automated and works for building stands as well as for tripping
- Pipe tripping mechanization that is automated to achieve high tripping rates as automation accelerates, runs and decelerates the string according to swab surge models, or avoids this effect by enabling continuous tripping
- Drilling fluids treatment systems that employ machine drives controlled by an automated system
- Offshore recipe-driven fluid mixing systems engineered for lower cost application to onshore rigs such that a control system can auto mix.

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