Controls

The Drilling Systems Automation Roadmap Controls section provides guidance to the future development of controls that are activated by a supervisory automated system.

Table of Contents

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Introduction

Drilling Systems Automation requires interoperability between various companies and various sensors and equipment, which necessitates data sharing. The segmented business created by current contracting practices is not conducive to such interoperability. Successful application of drilling systems automation across these various entities requires an integrator who has a leadership role to drive the application. It also requires a Systems of Systems architecture that provides the framework for automation application described earlier in this report.

The need to move people out of harm's way was the primary driver of drill floor mechanization, which laid the foundation for the application of surface control systems. The value of improved borehole steering, combined with the inherent latency effects of downhole-to-surface and surface-to-downhole communications, led to the development of advanced downhole control systems for rotary steerable tools.

The adoption of variable frequency drives (VFD) for the primary drilling machines (drawworks, top drive, mud pumps) enabled the application of advanced control systems to these machines. This resulted in joy stick and push button operations replacing the mechanical brake and rheostat controls. Looking ahead, reducing the drilling cost will be an important differentiator for operators and automation is a key parameter in this regard.

It is likely that the greatest drilling cost savings will come from applications that not only use control to automate the drilling machines and equipment, but also to automate decisions in the supervisory control of these machines and equipment. Drilling operators need to be aware of the opportunities that current technology can provide and be prepared to revisit traditional views of how drilling operations are being conducted in terms of systems, human roles and new business models.

Functional Description

Drilling control systems are fundamental to drilling automation. Composed of independent devices, control systems use electrical, mechanical or hydraulic energy to operate and self-regulate processes and equipment, typically with minimal human intervention. Control systems are devices that control machines using input data from the rig machines and equipment, downhole sensors, and, where available, along-the-drillstring sensors. Human operators' interface with the control systems to control the machines through Human Machine Interface (HMI), which also displays information from the drilling process.

The role of control systems in the drilling automation roadmap can be illustrated in the Decision Making and Control Framework (DMACF) presented earlier in the Data and Information Viewpoint of the Systems Architecture (Figures 1a and 1b). The control system is represented by:

- Level 1 machine Control
- Onsite Control Center (Figure 1b, yellow)
- Remote Operations center (Figure 1b, yellow)
- SCADA (Figure 1b, yellow).

Control systems will be heavily integrated with:

- Models and Simulations
- Data Acquisition
- Well Construction Execution System.

The control system forms part of the DSA DMACF hierarchy from the machine level to the enterprise level. The controls at various levels required to effect automation can be described as (Figure 1a):

- Level 0–Physical processes are the actual physical processes of the drilling and completion operation (well construction).
- Level 1–Machine and equipment control are the machine level controls that sense and manipulate the physical processes and are typically proprietary and built into the equipment and machines.
- Level 2–Execution management includes supervising, monitoring, and controlling the physical processes with real-time controls and software. The controls at this level execute the input to the machine and equipment controls according to the desired performance and quality (e.g. ROP Optimization, wellbore steering). Initially this is highly dependent on human input but will be transitioned to a greater degree of automation as implementation develops.
- Level 3–Operations management is managing workflows to drill, protect the hole and complete the well. The controls at this level are supervisory and direct the next level controls with the intent of the operations.
- Level 4–Enterprise management is managing business-related activities of the drilling operation.

9 of 14: Control Systems

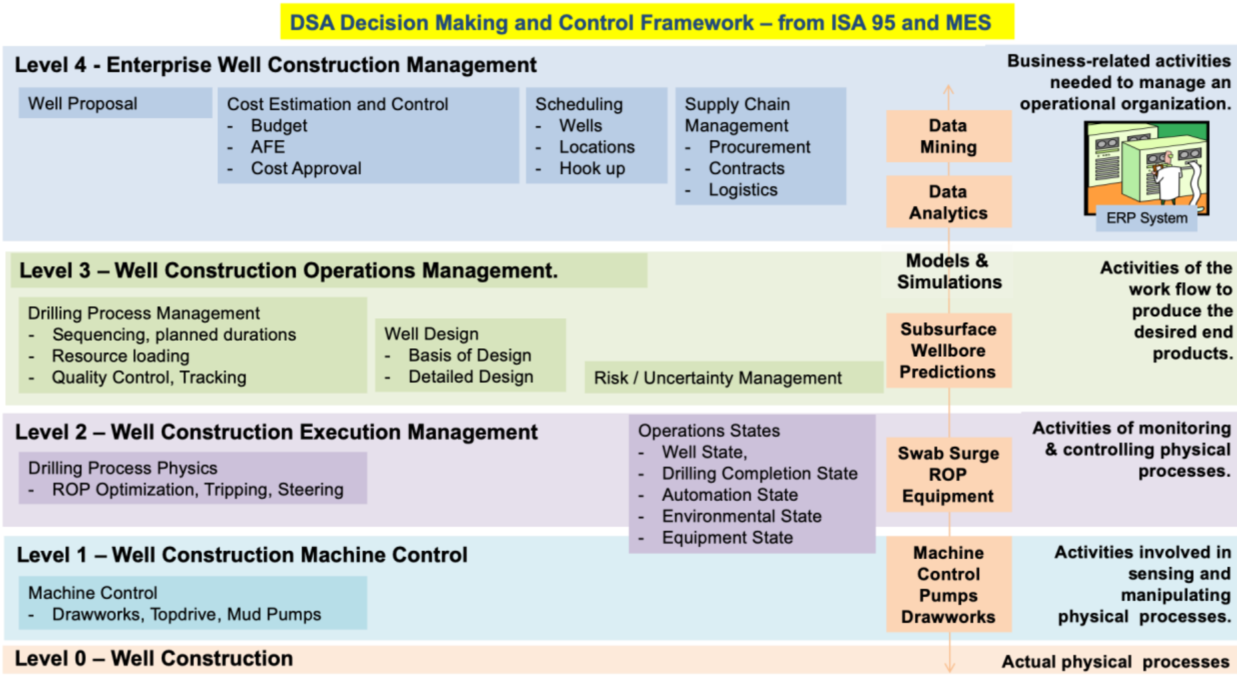

Figure 1a: Decision Making and Control Framework from ISA 95 for Drilling Systems Automation

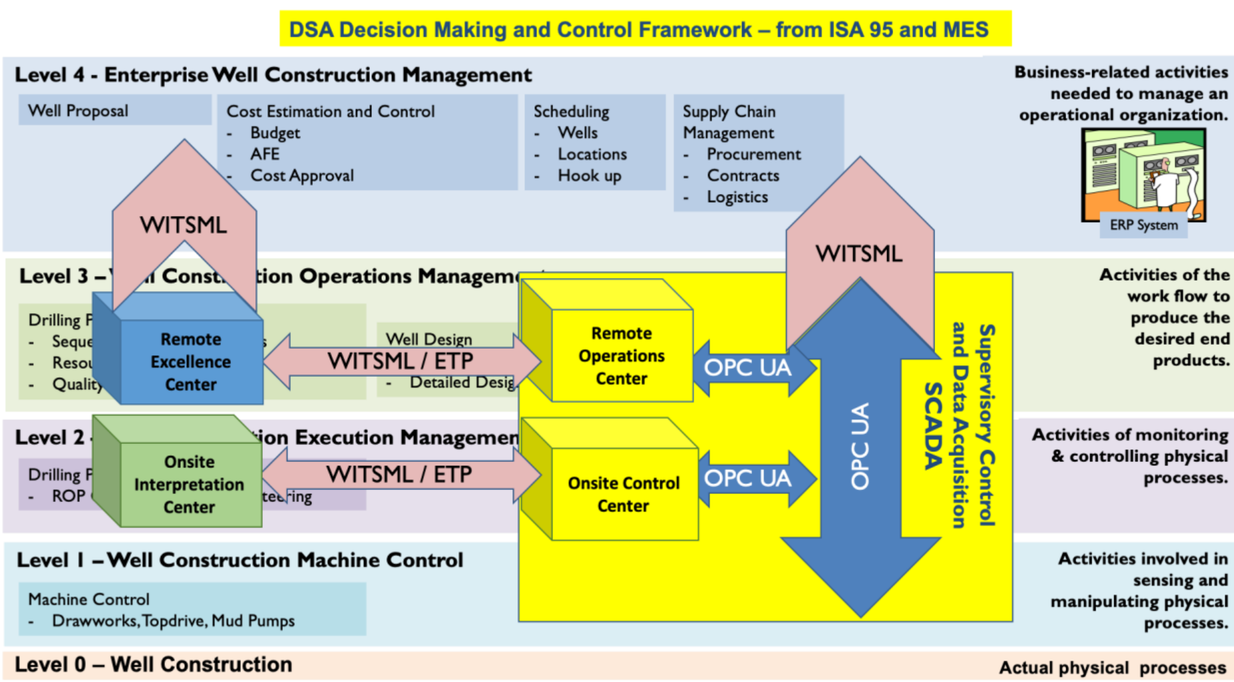

Figure 1b: DMACF Showing SCADA, Control and Operations Centers

Performance Targets

The scope for drilling control systems in this roadmap is derived from the Roadmap Vision. Capabilities such as well plans are uploaded into an interoperable drilling system", "updates remote operators and experts in real time" and "Routine multiple wells will rely on remote operations centers drive the need to include all layers of the DMACF in the assessment (DSA Roadmap Vision).

The application of control systems must add value to the drilling cycle from rig-release to rig-release for land and platform drilling and spud-to-release for offshore floater drilling. The values delivered are direct and indirect.

Direct value add will be achieved through:

- Removing risk to humans by removing them from dropped objects, heavy manipulation and chemical handling zones
- Removing risk to the well by controlling the envelope of operations and acting on early signals of a well control event without possible human error
- Improving performance of a controlled operation whether this is a hole making, steering process or mechanized activity
- Reducing costs and risk by reducing labor
- Ensuring reliability of the system being controlled and the applicability of algorithms that are managing the operations.

Indirect value add will be achieved through:

- Redesigning equipment for automation in a manner that improves its efficiency
- Redesigning equipment that has a smaller dimensional footprint and reducing the loads to be transported to the dimensions to be walked and skidded
- Ensuring parallel (offline) activities are performed in repeatable and predictable durations so that they do not become critical path (online).

Interoperability

The whole control system for drilling operations must be interoperable to maximize economic effectiveness. The industry will need to address challenge this through standards applied to control system communications and through agreements on sensor data ownership and usage. Failure to create an interoperable system on an industry scale will result in 'islands of automation.' These islands may add value in their own subsystems or may add no value if they simply control a component and are not able to influence a subsystem (System of Interest). The drilling industry's penchant for closing control systems in the interest of competitive advantage will hinder progress.
The DSA Roadmap target is that standards will be established enabling full plug-and-play interoperability between all systems and subsystems in the drilling operation because, based on other industry experience, this will create the greatest value for all.

Current Situation

Systems of today are designed around the human operator; the human verifies that equipment is reacting per applied set-points and interprets sensor readouts to decide proper actions. The equipment controls are preprogrammed to act repeatedly based on defined inputs and known states, such as the auto driller that senses deadline tension and automatically adjusts a derived WOB.

Future drilling control systems must be able to conceptually understand the drilling process in order to provide advice to the human operator and must even have a high level of "machine intelligence" to augment or provide adaptive levels of human-machine interaction. This design will need to address the current operational liabilities and business models of drilling operations, including roles currently covered by drilling operators, contractors and service companies.

Today, most control systems are programmed to act repeatedly based on defined input and known states. These systems are designed primarily to enable the human to control the drilling equipment when performing various operations.

Currently available drilling control systems do not contain significant amounts of data generated from the well planning phase. These data are conveyed to the drilling team through written reports and charts, typically called a Drilling Program and Detailed Operating Procedures. Data captured during drilling are not usually fed back to the well planning tools. This means that when things do not progress per plan, decisions must be taken immediately by the drilling crew, with minimal support from systems or remote experts in real time.

Remote expert systems do exist that support drilling operations at the wellsite. However, these systems often exhibit latency such that they cannot be incorporated into a drilling control system loop. The potential exists to integrate the contents of the Detailed Operating Procedure into the drilling control system and thus enable data to flow back to the well planning tools for decision support (Figure 2).

9 of 14: Control Systems

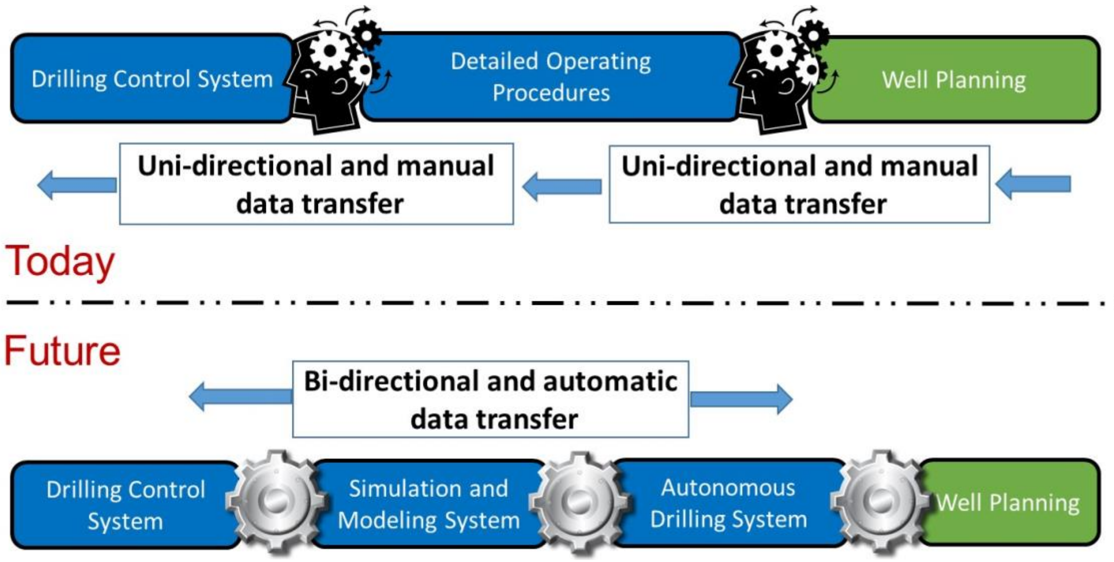

Figure 2: Data flow scheme to better support automated well planning update and data collection

Initiatives, both within individual companies and within the drilling community, are targeting standardization of interfaces for control. SPE DSATS created the 'Drill-a-Stand' use cases and has commenced building an OPC UA based guideline for technical integration and for common nomenclature applicable for the drilling domain. The guideline is called the Rig Information Model and, more recently, Drilling Systems Information Model when it was expanded from the rig to all the controlled systems.

Another approach, taken by an original equipment manufacturer (OEM) in its next generation drilling control systems, is based on an integration platform that allows third party applications to be deployed within the control system. The applications need to be built using a provided Software Development Kit (SDK). This system operates readily on two control systems previously designed and built by the same OEM.

In recent years, advanced automation has given the drilling industry some new wins. Rotary steerable drilling systems are advanced closed loop automation systems that operate autonomously (downhole) with intermittent supervisory input. Soft torque damping systems on top drives is a surface system that uses algorithms and control at the surface to mitigate downhole generated torque fluctuations.

Bit/BHA vibration detection and mitigation is a high value control opportunity that is being realized through advisory control systems. Current solutions are either based on mathematical models for the drill string or based on downhole measurements transmitted via hard-wired pipe or retained in memory. Common to these solutions is that their ability to compensate for the vibrations pattern detected by manipulating topdrive speed or torque set-points at a sub-second rate.

Within drilling optimization, advanced automation is being used in commercial products (Figure 3). These systems go beyond traditional autodrillers, which operate only on surface sensor input. The new systems include mathematical models or downhole measurements that enable algorithms to set surface equipment operating parameters that produce optimal BHA/bit operating conditions. ROP optimization, through improved WOB, is the most common use case for these systems.

Directional drilling systems have advanced to advisory control whereby the automated analysis produces advisory parameters for the directional driller to accept and act upon or to modify and act upon. Because the advice from these systems is now routinely accepted by the directional driller, the loop on numerous systems has been closed to control the set points of the rig machinery directly.

Managed pressure drilling (MPD) systems have become advanced to the point they are able to automatically control and adjust the back pressure to maintain a desired downhole pressure.

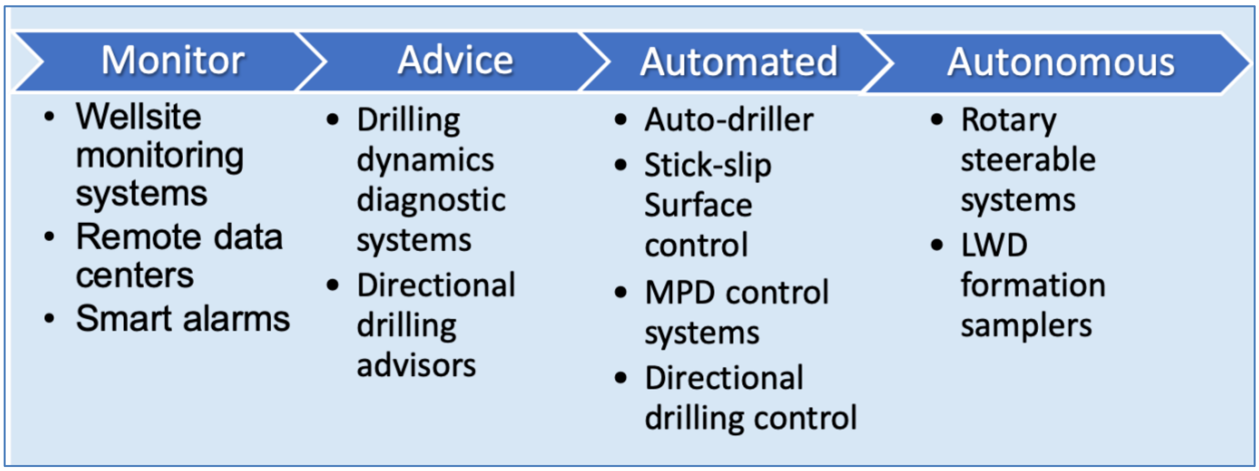

Figure 3: Examples of current control systems (see "Levels of Automation Taxonomy" in "Human Systems Integration Section")

Rig control systems are typically set when the rig is assembled for the first time in a rig up yard. The performance of drilling control systems (auto driller and stick slip) can be improved by tuning the systems on site according to the situation being drilled.[1] This requires detailed procedures and training to allow the drill crew to make the necessary adjustments. This tuning can be automated through self-diagnostic, self-tuning control systems.

Similarly, the startup of mud pumps is being programmed in the rig up yard and rarely adjusted on site. The mud pump startups need to be adjusted to the mud rheology and hole conditions at hand to minimize negative impacts on the borehole from undesirable pressure surges.

Problem Statement

The capabilities of control systems will extend beyond being tools for mechanization. How far the automation will be developed depends on the capability of the equipment to control processes that contain uncertainty and require modelling of some data inputs that cannot be measured. Furthermore, levels of automation will be decided on the balance of human interaction as mapped in the Levels of

Automation Taxonomy (LOAT) matrix in the Human Systems Integration section of this report. The level of automation achieved will depend also on the understanding of all the normal and off-normal scenarios that are factored into the system design that concern environmental, operational and situational conditions.

Drilling systems have not been designed using a requirement-based system engineering approach. This has led to systems that do not maximize the best combination of efficiency, safety, cost, availability or maintainability. Likewise, without traceability of all work products throughout all aspects of the systems development, gaining 100% trust from end users cannot be achieved. Without that trust, these systems will be suspect to end users, which will lead to adoption delays.

The systems must be documented and validated for design philosophy, basis of design, redundancy, reliability, availability, long term environmental resistance and fault tolerance. This mandate includes software, electronics, hardware and man-machine interface (see Systems engineering for solutions architecture subsection, in “Systems Architecture” section).

Control systems must be robust, able to be formally updated using management of change (MOC), and re-tested for compliance. Some challenges that control systems will need to address include:

- Validation of the system.
- A holistic approach to control systems
- Current Rigs (Machines) are not capable of achieving the vision from a control perspective
- Designing a control system to manage the drilling process vs. managing the drilling equipment.
- Orchestration of various capabilities
- Determining the health and operating conditions of all system machines and equipment.

To further advance automation requires the development of capabilities in control systems that extend beyond those of traditional controller and SCADA system rig architectures. New Control Systems Architectures will need to be based on the Decision Making and Control Framework (Figures 1a and 1b).

While traditional systems could easily be documented using ladder logic of state diagrams, complex systems are more difficult to describe and understand. The internal logic becomes hidden from anyone outside the development team.

Configuration management is required to ensure that all interconnected automated systems can perform interdependently, without which system failure may lead to unsafe situations or financial losses. The perception of failure of configuration management will become a barrier to adoption. If ignored, an early catastrophic failure will become a significant and long-lasting barrier.

Life cycle management of automation is a concern. If companies disappear or lose the ability to support fielded systems, operators and drillers need to own the source code so that they can maintain and update the systems under their supervision. Without those capabilities, maintenance and updates could come at a huge expense and with major delays.

Barriers

Inadequate and incomplete data

Because they were installed for automation, sensors in specific, highly automated equipment are very good for implementing extensive control systems. However, most sensors collecting traditional data are inadequate and will require improvements and additions to be applicable for automation.

Access to data

Today, it is difficult to access data required for controlling a process as opposed to controlling just the machine. Because data necessary for process control are often treated as proprietary, owners of the data are reluctant to release data into an aggregator where it can be used for higher level process control.

Modelling speed and precision

Advancing control systems for broader automation applications will require the use of models to ascertain situations within the operation that cannot be measured and for prediction. Many models exist for drilling designs, planning and operations. However, these will need to be reassessed for speed and precision to support automation, and additional models will be required to ensure the required spectrum of input data.

Needs

Mechanization requires automation to ensure that the performance is consistent and that humans are removed from these operations. Automation can drive design solutions that differ from those based on manual control, which multiplies the advantage of automation when investment in new technology is undertaken. A well thought out automated rig solution will result in advantages, such as a smaller foot print, and lead to further financial gains.

Drilling performance on land in the USA has achieved very high levels and left a small performance opportunity to realize value from automation. The need is to design automated solutions that minimize cycle time rig-release to rig-release.

Many routine operations can be improved by developing a control system to undertake operations. This will realize a consistency that cannot occur when many humans are performing the operation. One example is drilling friction tests and setting WOB; another is bedding in a bit, which has already proven a performance differentiator.

Oil companies have recognized that well control can benefit from automation; subsea BOP stacks currently have control systems that are manually initiated. Advancements in sensing and analyzing well status can lead to increased control over well shut-in and the avoidance of human interpretations that may lead to critical delays.

Offshore rigs must achieve significant advances in performance for offshore projects to remain competitive. Advances in control systems leading to higher levels of automation can bring consistency to routine operations, remove humans from the process, and enable faster cycle times.

9 of 14: Control Systems

Critical Success factors

A combination of accurate sensors able to measure the right data at the requisite frequency, and models that can interpret data that cannot physically be measured, are critical to the success of drilling automation.

Likewise, industry desire to adopt interoperability between various systems (controls, machines, equipment) across the entire operation is vital to automating drilling. Technically, interoperability can be accomplished quite quickly but the rate of application is controlled by managers and companies and the business model (contracts) employed. Interoperability at the higher rig-to-service level is being achieved. However, there is significant reluctance by key players to open their systems and to enable interoperability at the machine control level. This situation is unlikely to change in the near term unless senior managers in major companies drive it. This situation is akin to the so called 'Field Bus Wars' that occurred in industrial automation in the 1990s.[2]

Way Ahead

The advancement of control systems will be driven by key industry goals, including:

- Adding value to drilling operations, which will occur most easily when a subsystem is transitioned to a higher degree of automation. This creates a requirement to upgrade or add sensors and to apply models and other attributes to effectively close a control loop.
- Enabling the driller to perform when the control system can outperform the human. An example of such a circumstance is changing from a focused soft torque system to a comprehensive system that continuously reduces all drillstring dysfunction, resulting in a smoother drilling operation without human intervention.
- Enabling operational improvements in locations where the human cannot perform, or the telemetry loop is inadequate for remote control. The rotary steerable system, which advances steering capability, improves bit performance, control weights on bit and mitigates drilling dysfunction downhole, is a prime example of this process for other subsystems to follow.
- Improvements in and availability of higher data rate telemetry systems from downhole to surface (and vice versa). Hard-wired telemetry offers the ability to run the control loop to surface, whereas current mud pulse technology requires downhole control loops with supervisory control from surface.

The achievable level of automation depends on the ability of the control system to properly handle the wide range of expected and unforeseen scenarios encountered during drilling operations. For maximum benefit, drilling control systems must:

- Be continually tested and validated in order to be trusted
- Take a holistic approach, leveraging available technology
- Be designed to be more easily incorporated into older drilling rigs
- Manage the drilling process instead of the drilling equipment
- Be schedule driven such that parallel activities are initiated from the schedule according to the drilling states (and other states) and time

- Use data-driven approaches and physics-based algorithms that address the uncertainty inherent in drilling
- Integrate detailed operating procedures and specifications from the well plan and facilitate the flow of data back to the well planning tools for decisions
- Seek a route out of trouble when unexpected or unplanned situations occur while continuously informing the driller of the situation

To make intelligent decisions around commanding rig devices, the control system must be aware of the system and subsystem states of those devices, and how command will affect the overall impact on the drilling system and its external environment.

Supervisory Control and Data Acquisition

Supervisory Control and Data Acquisition systems (SCADA) that incorporate monitoring with hierarchical control and human systems interfaces are common in industrial environments. SCADA systems distinguish themselves from other industrial control systems by being large-scale processes that can include multiple sites across large distances.

Industrial processes controlled by SCADA systems include manufacturing, production, power generation, fabrication and refining. Because they may run in continuous, batch, repetitive, or discrete modes, SCADA systems are applicable to drilling systems automation bringing with them the experience gained in industrial automation.

A SCADA system typically contains the following subsystems:

- Remote terminal units (RTUs) connect to sensors in the process and convert sensor signals to digital data. RTUs do not support control loops or control algorithms but can alter the state of a connected object.
- Programmable logic controllers (PLCs) connect to sensors in the process and convert sensor signals to digital data. PLCs are digital computers capable of localized control of the monitored process.
- A telemetry system is typically used to connect PLCs and RTUs with control centers, data warehouses and the enterprise.
- A data acquisition server is a software service which uses industrial protocols to connect software services, via telemetry, with field devices such as RTUs and PLCs. The server allows clients to access data from these field devices using standard protocols.
- A human–machine interface, or HMI, presents processed data to a human operator and through which the human operator monitors and interacts with the process.
- A historian is a software service which accumulates time-stamped data, boolean events and boolean alarms in a database that may be queried or used to populate graphic trends in the HMI.
- A communication infrastructure connects the supervisory system to remote terminal units.

SCADA systems are expected to transition to the next generation as cloud computing becomes established and the internet of things becomes common. This will enable near real-time reporting of state and the implementation of more complex control algorithms than is feasible today.

As the action arm of a SCADA system, PLCs are inexpensive but are limited in function. They are not interoperable and require unportable, "specialized" code. Although this is acceptable within a device using OPC UA comms for external device communications, it is not suitable for connecting devices.

The control systems for drilling systems automation are expected to develop into SCADA systems at the drilling operations level and across the integrated or multiple companies involved in the operations and to not remain as islands of controls.

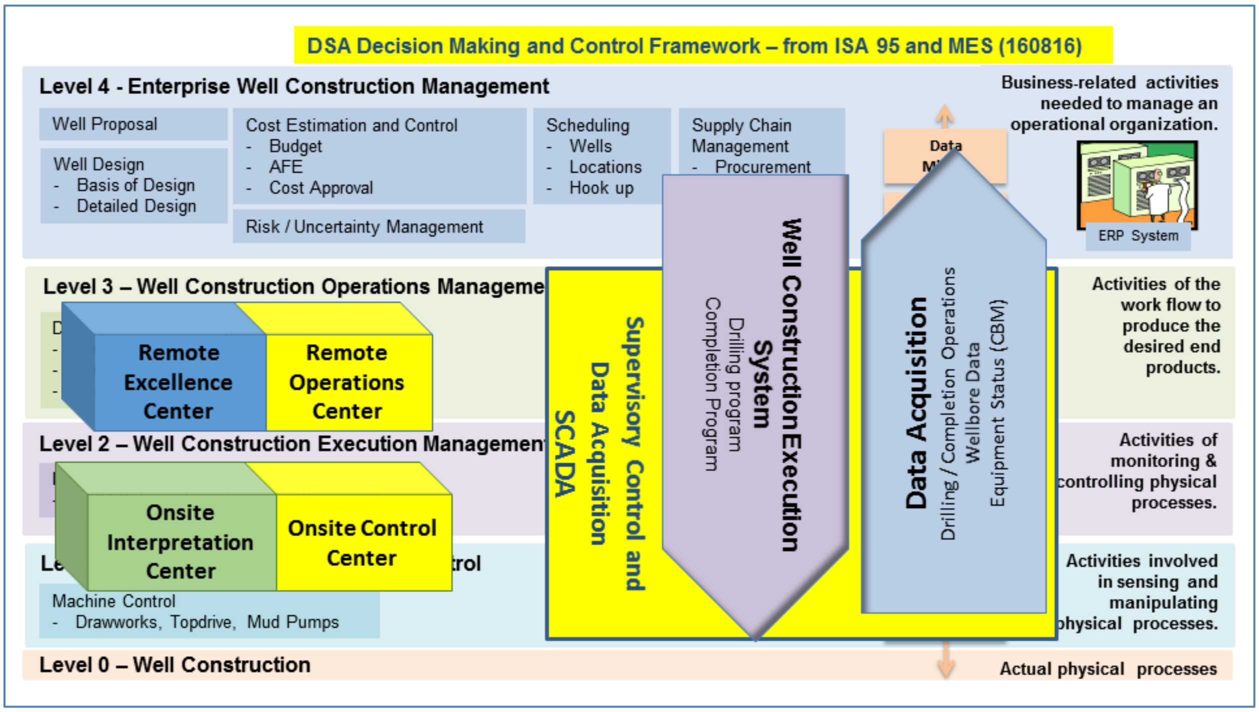

Figure 4: Evolution of Decision Making and Control Framework incorporating SCADA

The drilling industry has employed real time operations centers (RTOC's) to monitor and advise on drilling operations. As drilling systems automation application advances, the RTOC's will be replaced by a center for control and a center for excellence (Figure 4). The distinction between control and excellence centers is modeled on the set-up employed by Rio Tinto in their automation program called Mine of the Future™, Rio Tinto distinguishes the control activities from the analysis activities.[3]

Onsite Control Center

Today, the onsite control center is the driller's console. As automation advances, the driller's console will transition into a true integrated control center that controls all machines and equipment regardless of owner or vendor. In the offshore deepwater exploration environment, this will be a rig-based center having all key players participating alongside the driller. In an onshore, multiple well pad drilling environment, this integrated control center will be a pad-based center that controls one or more drilling machines. The control room will have minimal manning because expert support will be connected in real time from the remote operations center. This control center will also be responsible for managing the distribution of power to various activities and choices regarding activities limitations. It will also be responsible for zone management when it impacts the workflow and for tools or machine maintenance to the extent that they impact the execution of the operations.

Onsite Interpretation Center

The onsite interpretation center will provide regional interpretation from operator and supplier subject matter experts (SMEs). This center is defined as onsite to differentiate it from the remote Excellence Center. It will be regional and could be virtual, which means that the operator may have a regional office that is the focus of this center, but suppliers will virtually link in from their own regional offices. The onsite interpretation tracks the drilling operation and provides input to the onsite control center for implementation in the control hierarchy. These SMEs are regional experts and have the regional knowledge to directly support the onsite control center.

Remote Operations Center

The remote operations center is the highest level of the SCADA system and provides the highest level of control input to the hierarchy of control. Business decisions are made by the various disciplines supporting the development of an asset at this center's operating level For example, it is where the well-placement-in-the-reservoir decisions are made and communicated to the onsite control center for implementation.

Remote Excellence Center

The remote excellence center is where the data from multiple similar drilling operations is processed and interpreted. This is where new insights that improve the results of drilling including drilling performance, wellbore quality, and completions functionality are generated. The analysis is fed back to the remote operations center for conversion into new directives to the onsite control center. The remote excellence center may become partially or fully virtual in the future.

Inter Level Interfaces

A major attribute that requires management in the future for automation is the interfaces between the various levels in the Decision Making and Control Framework. Currently, many of these interfaces are undertaken by humans, using written documentation and following various paths that involve HMI. As automation advances, these interfaces will transition to more digitalization. Already, digitized drilling programs are emerging as a tool to improve lessons-learned capture and are being readied for adoption into an automated drilling system.

Human to Control Transition

The transition from human to automated control is described by the LOAT in the section "Human Systems Integration." This transition requires the control systems to develop in a sequential mode that back fills where the humans will hand off to the control system. It defines the depth of the control system development within the breadth of the systems architecture.

9 of 14: Control Systems

To be able to provide advice to the human operator, low level and advisory control systems will need conceptual understanding of the drilling process. To perform tasks, high-level action-oriented control systems must have conceptual understanding of how to operate the drilling equipment.

Failure Detection, Isolation, and Recovery

Systems are designed to eliminate or lessen the likelihood of hazards and their impact on the environments in which they operate. However, because inevitably they all encounter problems, systems should be designed to limit the effect of such problems. Because these problems are caused by physical or logical failures in the system, to assess their impact those failures must be detected by the control system. Failures should be well described and ferreted out by rigorous performance of failure modes and effects analysis (FMEA).

Detection may be performed by real-time measurements of device outputs, such as voltage levels or loss of subsystem pressure. These predicted failures are identified during the FMEA failures may exist that are not known, which may lead to an unknown systems state. These unforeseen failures must be accounted for also.

Isolating them is necessary to prevent failures being replicated throughout the system. The system must be designed to not allow unacceptable degradation at the higher level. Failures that can be isolated at the component and subsystem level will result in faults at the system level. Redundant and fault tolerant systems have been in existence for 20 years, particulalry in banking and credit card computer architectures.

Recovery from failures allows systems to remain functional with some level of autonomy. The likelihood and consequence of a failure should be strongly considered when determining what level of recovery to include in the system. This will limit unnecessary expense and complexity. Table 1 illustrates the guidelines for determining the level of FDIR to include in the system.

		Consequence	
		LOW	**HIGH**
Likelihood	**HIGH**	*Detection* – Slow Loop *Isolation* – Prevent higher consequence *Recover* – Recovery at a higher level Only address if failures stack up to move consequence to a higher level. These failures are quite often handled through redundancy.	*Detection* – N/A *Isolation* – N/A *Recover* – N/A Must be designed out of the system. Autonomous systems with failures of this type cannot be trusted.
	LOW	*Detection* – Post Operations *Isolation* – No accommodations *Recover* – No accommodations needed	*Detection* – Real Time *Isolation* – Limit to lowest level possible *Recover* – Recover to a safe state

		It should be sufficient to allow these failures to happen and address during a planned maintenance period.	Until sufficient verification and validation is performed on the system and demonstration through field use, failures of this type should recover to a safe state only.

Table 1 - Failure Detection, Isolation, and Recovery

Sequential Controls Development

Successful development of advanced controls follows a logical pattern required by hierarchical development and subsystem development for effective application. Hierarchical development requires a transition from human interface to automated controls that can be more effective. Subsystems development suggests that controls within a subsystem can add value, whereas controls development across multiple subsystems without closing loops within any subsystem cannot.

Applications are being developed that offer subsystem type applications that have not been verified to adhere to a mapped subsystem in the systems architecture. These applications will not generate value unless they close a loop in a subsystem of interest that does deliver end user value. Currently this haphazard approach misses the value from a mapped implementation.

Deterministic Systems

To command the next operation with certainty, the exact state of the system must be known. Although not everything in the entire system must be, each element should be analyzed to determine whether it needs to be deterministic. A gage for determinism may be items that can cause a safety issue or cause the system to miss KPIs.

This determination is relevant for hardware and for software. Data used in decision making must also be qualified for use in decision making. For instance, the software controlling a drilling process must act on data that are known to be valid, and dispel data that are made invalid by communications errors, sensor problems, latency, etc. The software must know the state of the hardware to know the level at which it can be commanded to affect the overall operation of the system. A deterministic system is one without randomness.

The current state of drilling systems sensors varies from those that deliver high-quality, low-latency data to many that deliver poor data of unknown quality with low latency. This adverse situation will negatively impact the uptake of advanced control system in drilling operations.

Robust Decision Making

The control system must be able to make accurate and timely decisions to meet safety and KPI objectives. As the levels of automation advance, the level of detailed use cases and state transitions will have to be more robust. Automation will only move at the speed of trust. If the automation applied cannot be trusted to make the right decisions on time, every time, it will never be enabled.

Environmental Condition Monitoring

An automated drilling system acts in an environment that is subject to randomness. However, most environmental variables are well known, and mitigations can be planned to address changes in the surrounding environment. The drilling system itself is interconnected to the environment as a whole and specifically to the subsurface environment defined by the earth model. Advancements in subsurface environmental detection that reduce future uncertainty, such as ahead-of-bit formation detection, can revolutionize drilling performance.

Operational Conditions Monitoring

Operational Conditions Monitoring deals with knowing what operations are going on throughout the system and having a plan to deal with their interactions. Detailed operating procedures traditionally carried out by humans will need to be programmed into the automated system to support this capability. When a change in system operations is necessary, the automation system should leverage preprogramed system state transitions logic.

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