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Before I start let me acknowledge the role played by the SPE Foundation, Offshore Europe, and my employer in making this presentation possible. We also wish to acknowledge the support of the American Institute of Mining, Metallurgical and Petroleum Engineers.



Automation of the Drilling System: What has been done, what is being done, and why it is important

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Society of Petroleum Engineers
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I will be talking about drilling systems automation – what has been done and what is being done in the industry. But most important I wish to communicate why it is important. If you come away willing to read the literature that I give at the end then I will have succeeded. If you come away and join one of the industry collaboration groups and start to contribute then I will be truly happy.

Presentation Outline



- Definitions and background
- The drivers for automation
- Technical and Business Challenges
- SPE Drilling Systems Automation TS
- A brief look into automation systems
- Conclusions
- Q&A

Drilling Systems Automation (DSA)

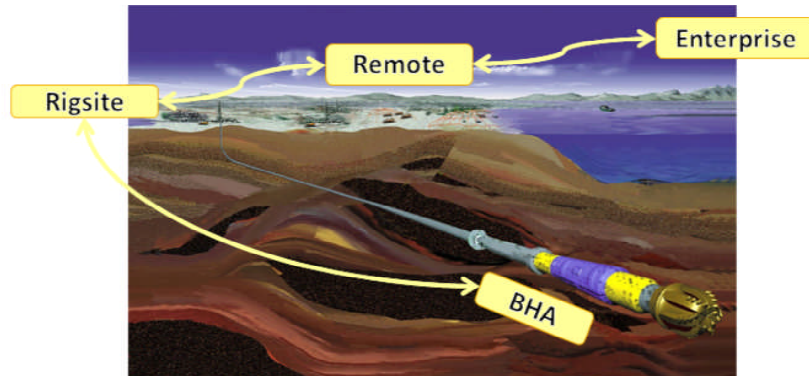


- **Systems Automation:** Involves the control of the drilling process by automatic means, ultimately reducing human intervention to a minimum.
- **Scope:** Includes all components downhole, on surface and remote to the drilling rig that are used in real-time to drill the wellbore.
- **Digital Backbone:** Employs control systems and information technologies

What is Drilling Systems Automation?



The process of creating a borehole with systems and sub-systems that are computer controlled, leading to reduced human intervention



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Current state-of-the-art is that we have isolated sites of automation: downhole in the MWD tools, on the surface at the rigsite, and remote in the data center. Each of these is discrete and is at a different level of automation. The objective of “Drilling Systems Automation” is to bridge these islands of drilling automation by creating an “automated drilling system” which delivers many productivity and safety benefits to all oilfield companies. There are many groups working to create the correct environment for drilling systems automation. But more about all this later, and let’s work on a few definitions first.

Levels of Computerization

Ref: Endsley and Kaber, 1999,
Ergonomics, Vol. 42

Functions

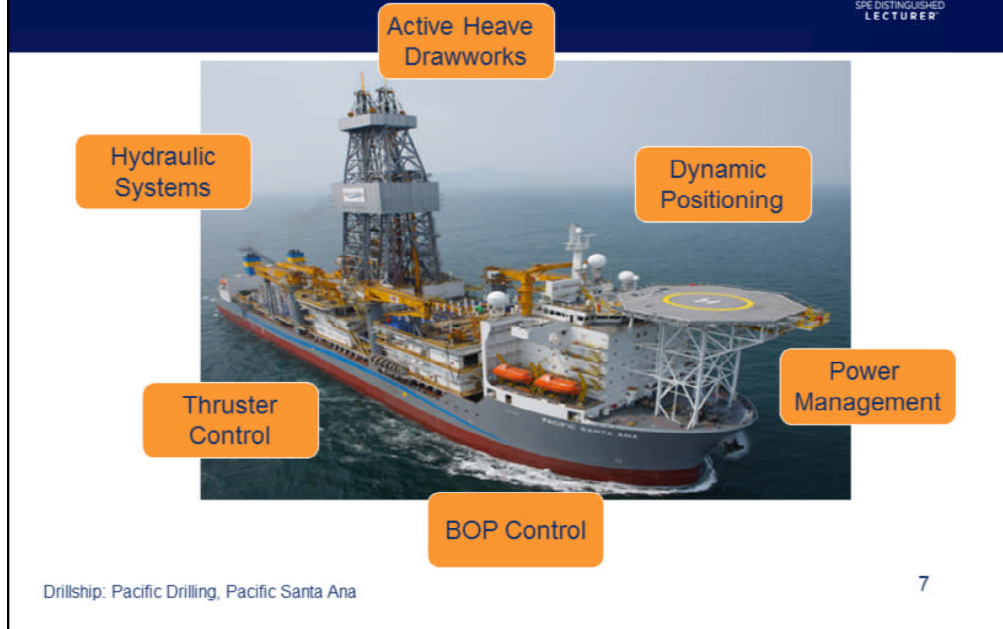


Levels	Functions							
	Monitor		Advise		Select/Decide		Implement	
1 Manual Control	H		H		H		H	
2 Action Support	H	C	H		H		H	C
3 Batch Processing	H	C	H		H			C
4 Shared Control	H	C	H	C	H		H	C
5 Decision Support	H	C	H	C	H			C
6 Blended Decisions	H	C	H	C	H	C		C
7 Rigid System	H	C		C	H			C
8 Auto Decisions	H	C	H	C		C		C
9 Supervisory Ctrl	H	C		C		C		C
10 Full Automation		C		C		C		C

H – Human C - Computer

Endsley and Kaber define levels of automation by function: monitoring, advice generation, selecting (decision making) and implementation (control). H corresponds to Human involvement in the function, while C corresponds to computer involvement. Note that each function, for example monitoring, is present over a wide range in levels of automation. However monitoring is the predominant computer function at lower levels of automation, and the progression is monitoring to advice to decision to control with increasing levels of automation.

Control Systems on Offshore Rigs

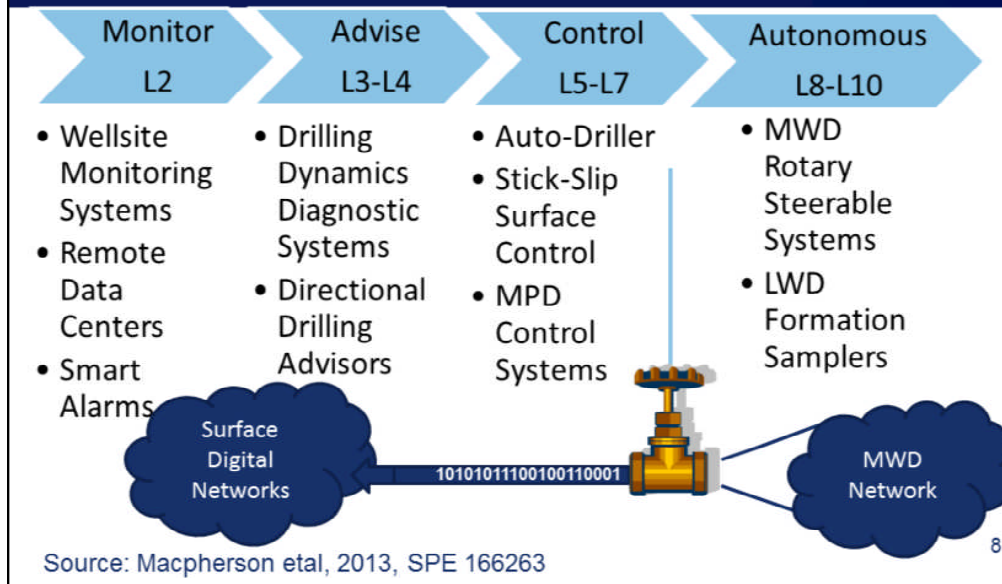


If we look at an offshore floating rig we see that there are many automated components. Each of these is quite sophisticated – the level of automation is high. But these are isolated components. In drilling systems automation we are interested in systems automation, which is the automation of the drilling process.

Drilling Systems Automation



The current level of automation in Drilling



The state of the art in drilling automation is actually quite impressive. For human and computer monitoring, both wellsite-based and remote systems are readily available, are quite advanced, and are being work on daily. For computer based advisory systems, a great deal of effort has been expended in interpreting data downhole and transmitting compressed diagnostics to surface. Directional drilling advisors (geosteering for example) are often executed remotely or at the wellsite, and control systems (auto-drillers are one example) are present at the wellsite. However, the highest degree of automation are downhole autonomous or semi-autonomous drilling systems, such as rotary steerable systems, which compare favorably with anything developed in any industry, especially considering their operating environment (high pressure, high temperature, high vibration).

The high degree of downhole automation is needed because there is (has been) a digital restriction between downhole and surface. With high bandwidth telemetry such as high-speed mud pulse and wired pipe, this barrier may be overcome in the near future.

Drilling Systems Automation



- The drilling industry has equipment that is highly automated (level 8+)
- Automation of drilling systems and processes is quite rudimentary (level 3)
- Why?
- What are the business drivers?

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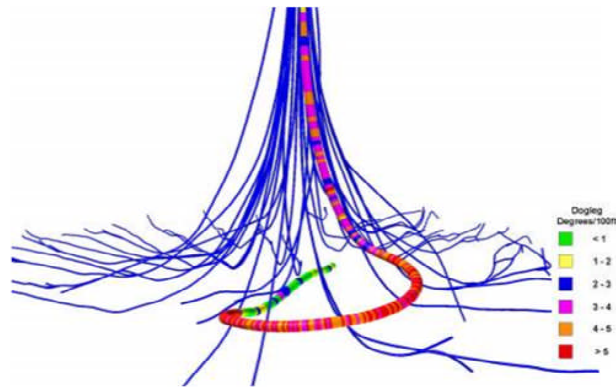
So to summarize, why are we so rudimentary in drilling systems automation? We have already seen one reason, restriction of the bandwidth available for digital communication. However, technically that barrier can be overcome, so it is worthwhile looking at the business drivers: are there business drivers for drilling systems automation?

DSA Drivers



Well Complexity

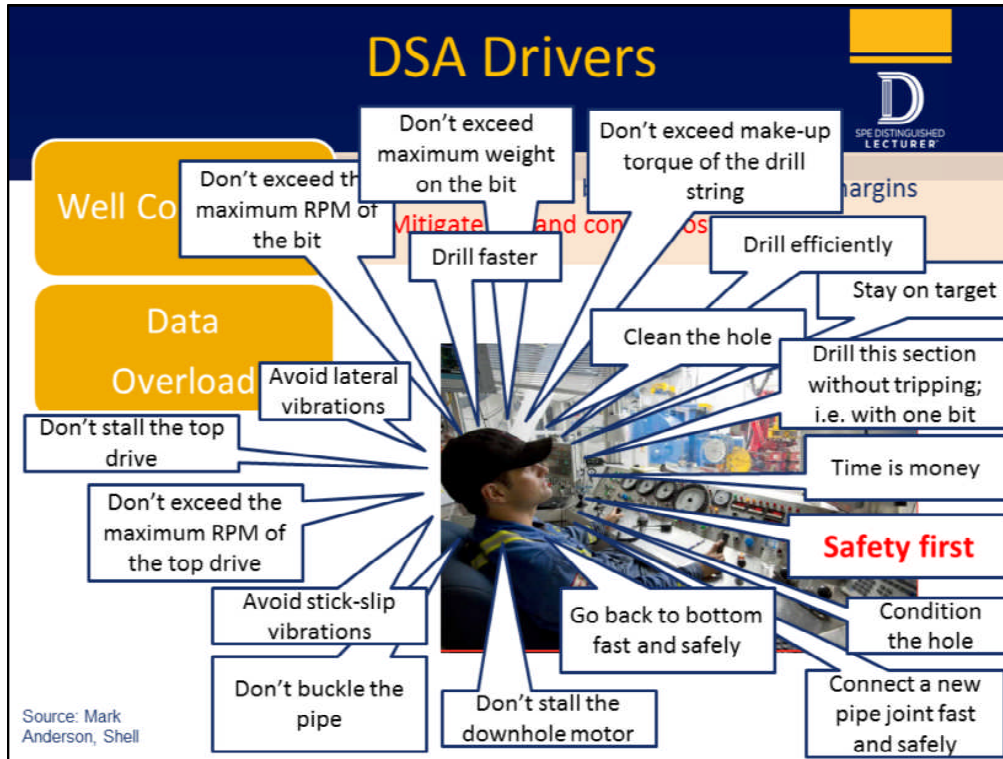
- Difficult profiles, bottomhole pressure margins
- Mitigate risk and control costs



Source: Baker Hughes


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The first driver is well complexity. The complexity of wells that we can drill has increased tremendously over the last couple of decades. This example shows a well drilled to tap reserves that lie directly under a drilling location. This profile is only possible with advanced steering technologies and sophisticated analysis and control systems. Systems automation makes feasible the control of such complex profiles by mitigating risk (such as steering risk and wellbore collision) while allowing operators to control and predict cost.



Another driver is data overload. We ask our drilling personnel to monitor and respond to an abundance of information, while maintaining focus on safety. Systems automation allows for monitoring and responding to many data and information sources, reducing the real-time data load on the driller, and allowing him to handle those which are more critical. As a side note this is “shared autonomy” – the computer-based systems are aides to the driller. It is technically a challenging area to develop. It is far simpler to develop systems that are wholly computer controlled, which are termed autonomous systems.

DSA Drivers



Well Complexity	<ul style="list-style-type: none">• Difficult profiles, bottomhole pressure margins• Mitigate risk and control costs
Data Overload	<ul style="list-style-type: none">• Real-time measurements, complex operations• Manage, interpret, act on large volumes of data
NPT Significant	<ul style="list-style-type: none">• 35 to 40% of deep-water drilling costs• Minimized by responding predictably to events

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On to the third driver, which is reduction in Non-Productive Time (NPT). Much has been said about NPT, but basically systems automation allow us to address NPT by being repetitive and predictable. Each task is repeated in the same way, each time, while maintaining the safety of the well bore and physical equipment. For example, the tripping speed is maximized by taking into consideration the swab and surge pressures in the wellbore and the fracture and pore pressure gradients; pumps are brought up at the correct rate to break mud gel strength without generating excessive pressure surges.

DSA Drivers

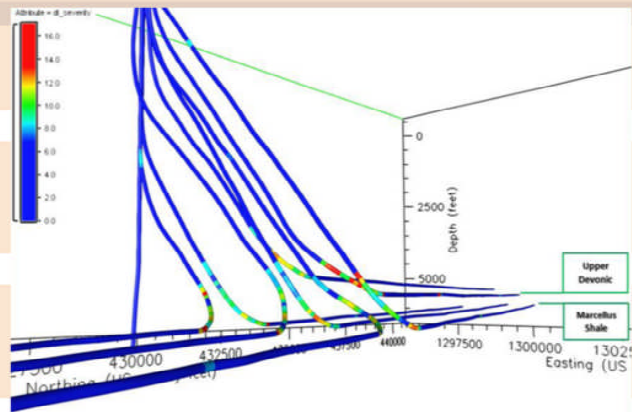


Well Complexity

Data Overload

NPT Significant

Well Manufacturing



- Drill many similar profile wells per field
- Repetitively drill to plan with minimal risk and cost

Source: SPE 178875, 2016, Livingston et al, Team Approach to Horizontal Drilling Optimization in the Marcellus Delivers Record Setting Performance

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Another business driver is well manufacturing – the repetitive drilling of many wellbores with the same or similar profiles. This is the practice in drilling wells in the US Land environment in shale plays (“unconventional plays”).



Another three drivers.

Systems automation constructions (the digital backbone) makes it possible to bring expert resources to bear on a problem or issue, no matter where the expert resources are located in the world. In the mining industry these resources are termed "centers of excellence" to differentiate them from remote monitoring centers.

Systems automation also helps transfer knowledge, or develop a repository of knowledge, as skilled employees leave the industry. The mode of knowledge capture varies from physics-based models and their use while drilling a well, through electronic procedures, to data-driven analytics techniques such as deep learning that can be applied in real-time as the well is drilled.

Finally in this list (which is not exhaustive), and most important, is HS&E. Drilling systems automation directly removes people from red zones. The red zone can be the rig floor or it can be the wellsite itself.

Technology and Business



- There are significant business drivers behind drilling systems automation
- But to make DSA happen we have to communicate the technology to the business

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So there are many significant business drivers behind drilling systems automation – why then have drilling systems automation products not already proliferated in the drilling industry? The issue is that we have to communicate the technology to the business - we have to let the business see what is possible, and how to implement it and how to innovate and compete in the drilling automation space.

And we have to realize that drilling systems automation is not technically trivial. To visualize this, it helps to place drilling systems automation in context with other systems automation products in other industries.

Technology: DSA is Challenging



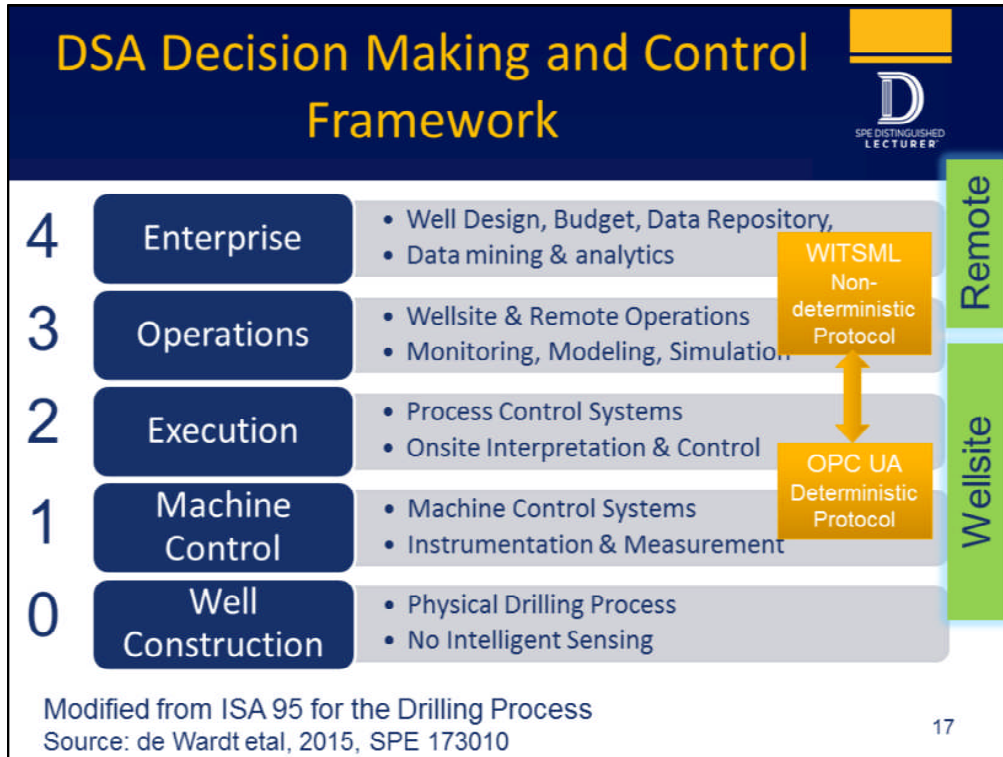
Source: UT Austin RAPID Consortium

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This slide is from Dr Mitch Pryor of the University of Texas at Austin, who graciously allowed me to use it. On the horizontal axis is the necessity of the automated components to have domain knowledge. On the vertical axis is a measure of task uncertainty – how difficult is it to automate the task.

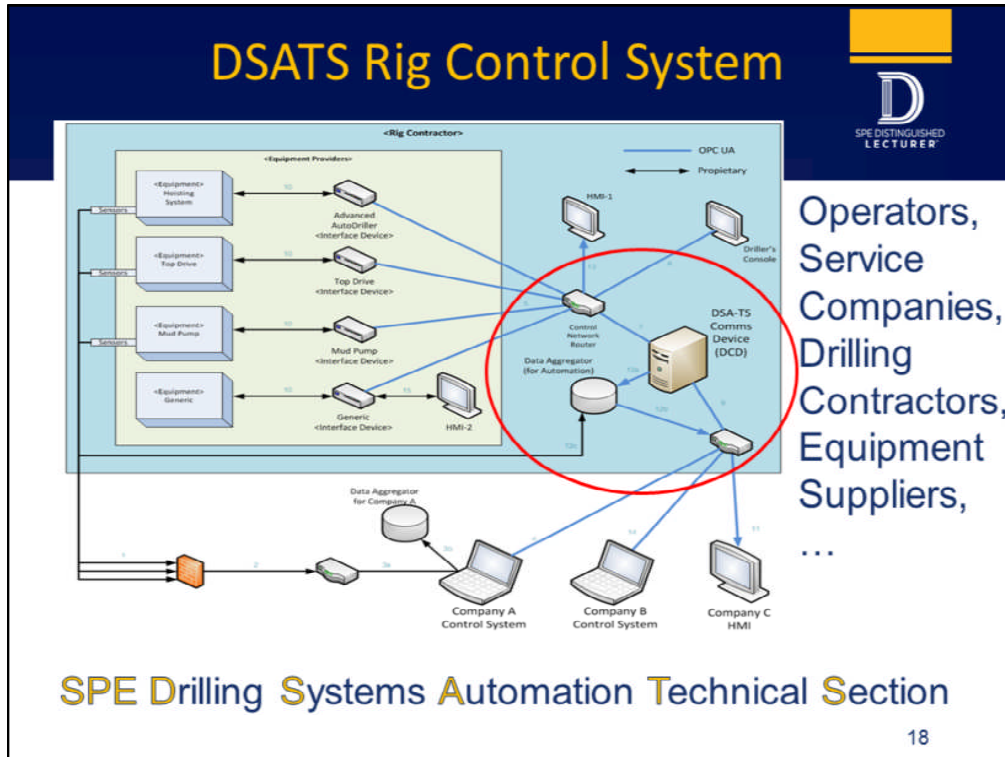
The first view is of robots in a car assembly line. The robots do not have knowledge of what they are assembling, and there is little uncertainty in the task – a hole must be drilled at a precise location in metal. The second view is of robots in an operating room. While task uncertainty is high, the robots have no knowledge they are operating on a human – indeed there is a bank of human “robo-surgeons” controlling the robots. The third view is of mining – here domain expertise in robots becomes more critical. For example in mining the shot holes are drilled by an autonomous drilling rig which can drill repetitively against plan. There is also a large digital backbone for logistics in moving the ore from the workforce to processing plant. The fourth view is of a robot for handling nuclear materials. Here it is important that the robot know what it is handling – if it is handling a “hot” item then it may not be able to move it through a barrier.

The last view is drilling systems automation. The task is technically complex. We drill holes in the ground, often with very limited information, and attempt to control the progress from far away. This complexity needs to be communicated to the business so that expectations are managed – but the same complexity opens a tremendous opportunity for collaboration and competition. We will now take a look at how collaboration is developing standards that allow DSA to be realized in a competitive environment.



The first collaborative construct we will look at is the “Drilling Systems Automation Decision Making and Control Framework”. This is modified from ISA 95, which is the automation standard for manufacturing (and other) industries. The lowest level represents the physical process – it has no intelligent sensing. The overlying layers extend from the wellsite, to remote systems, to the enterprise.

Connectivity between these layers relies on a digital protocol and language. These have been selected as OPC UA for deterministic high-speed communication, and WITSML, the industry standard for communicating data in a non-deterministic fashion. The mapping between these two protocols is currently underway, with the semantic model for WITSML 2.0 being merged or placed within the semantic model for OPC UA. Once this is finished, it will be possible to move seamlessly between the two protocols depending on need.



DSATS stands for drilling systems automation technical section, which is an SPE body of about 1,800 individuals who are collaborating on the guidelines required for systems automation of the drilling process. One of their first moves was to develop the communication layout for control of a drilling rig, so that service companies, equipment providers, and others, could all “play” within the automation space.

DSATS Communications Guidelines



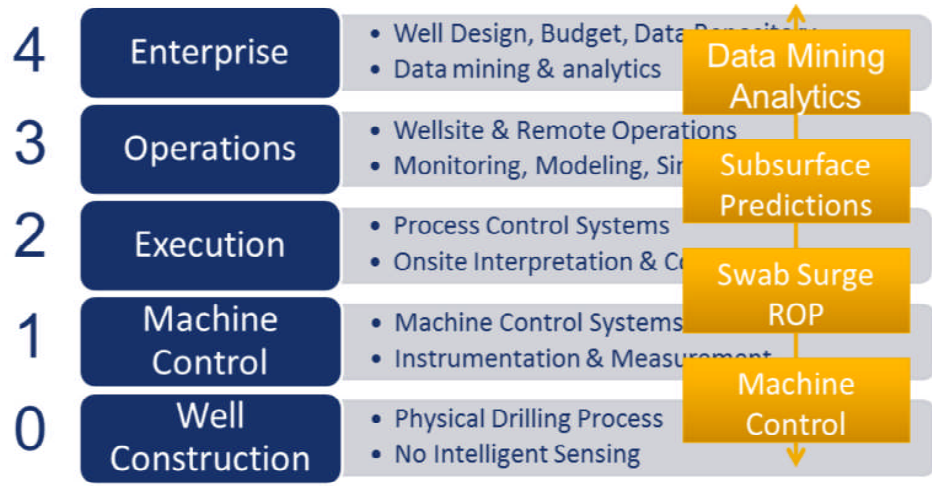
- OPC UA protocol for automation communications
- Interface to proprietary or other standards
- Machine independent software
 - data-to-information
 - control algorithms
- Standardized method for real-time drilling data
- Simplified device control architecture for drilling rigs
- Standardized units, security, rig-information-model

Next Step: Data

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The early main deliverable from DSATS was the recommendation to use OPC UA as the secure digital protocol, in line with other industries. OPC UA has existing bridges or adapters to other standards, and use of the protocol allows us to develop machine independent software, and to standardize on various aspects. Once the protocol is in place, the next development step is to focus on DATA

DSA Decision Making and Control Framework



Data flow between levels of the framework (NO SILOS)

The goal is to allow data to flow bi-directionally between levels in the DSA Decision Making and Control Framework. This links machines with models and controls in real-time, and most importantly it serves to breakdown barriers which have developed in the drilling industry. These barriers may be between companies, between entities within companies, or between technologies.

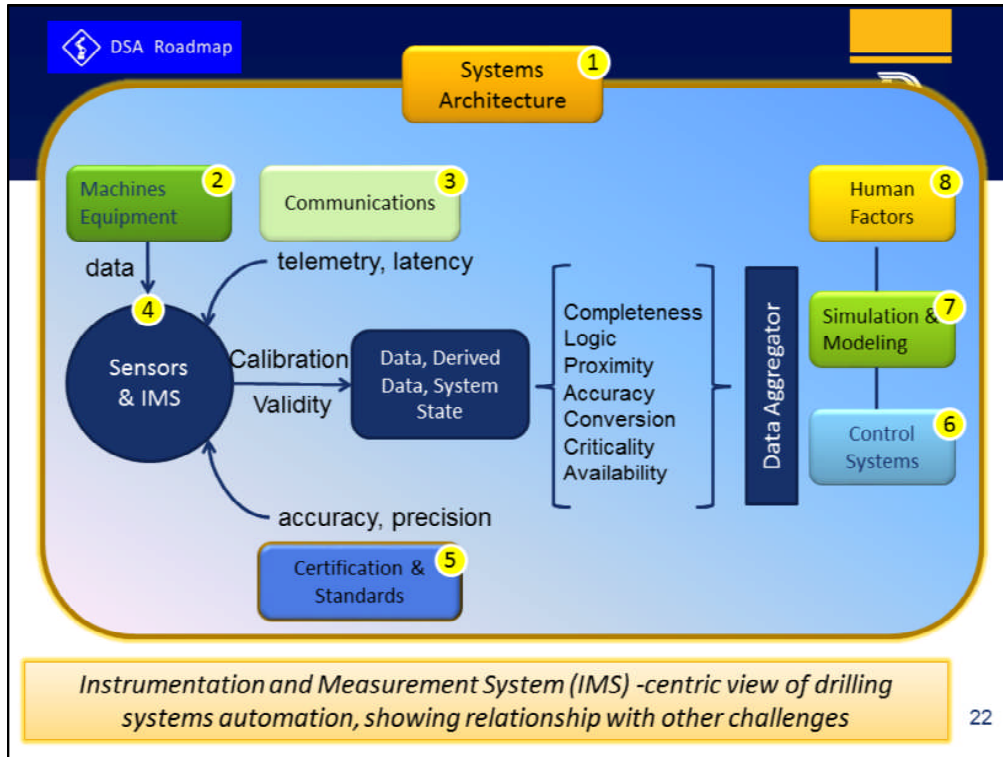
Data in Systems Automation



- Without data there is no automation
- “First comes data” (Lord Kelvin)
- Who owns the data?
 - Separation of Data Ownership, Guardianship and Confidentiality
 - Open System versus current Closed System
 - Data Model embedded in the Business Model

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Data is the most important element in drilling systems automation, and it must be reliable. There are data issues that the industry is working through, such as data ownership. Contracts typically place data ownership with the operator (he who pays for it owns it). However, ownership also means responsibility for data quality, and by paying for it one does not ensure data quality, so data providers and data compilers (aggregators of data) need to take responsibility or “guardianship” of data. At the moment there is confusion in contracts on the meaning of ownership and confidentiality. This needs to be resolved in a collaborative environment.

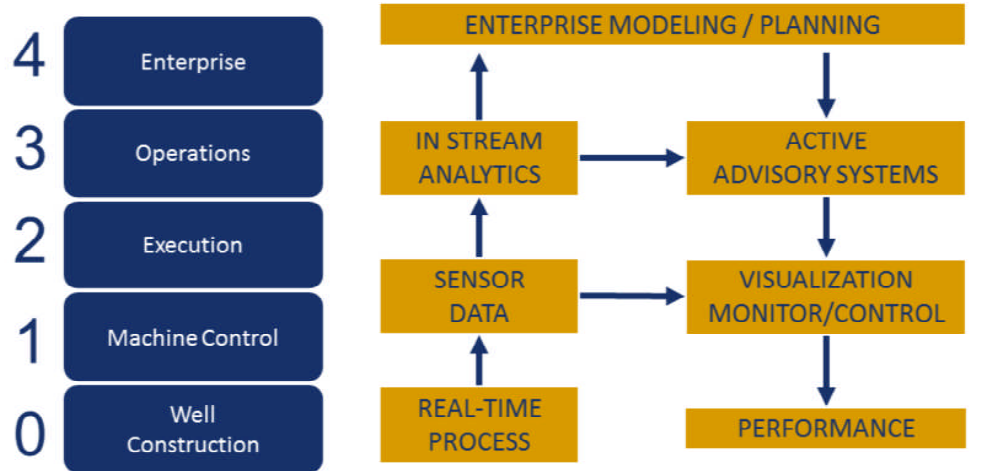


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Shown here is a data-centric view of drilling systems automation. This is actually a product of the drilling systems automation roadmap (DSA-R) that is being developed as an Joint Industry Project (JIP). The main components of drilling systems automation are shown numbered. The sensors and instrumentation and measurement systems (IMS) is expanded to give an idea of the criticality of data in the DSA construct. Basically sensors and IMS relate to machines and equipment, communications, and certification and standards. The product of data drives control systems and simulation and modeling. If you like, data is the blood of automation.

The rules shown (completeness, logic, proximity, and so on) were developed primarily by Dr Eric Cayeux to describe the needs of data in an automation environment. For example, they govern the level of automation that can be achieved by a weight-on-bit measurement at the end of the deadline, in a load pin, in a surface sub, or at the drill bit.

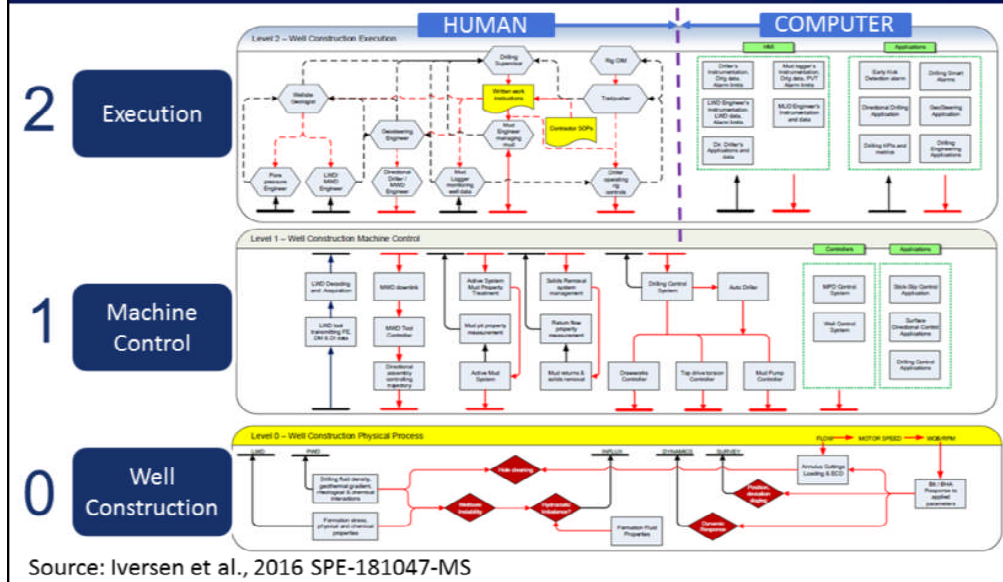
Real-Time Data Flow and Value



Source: DSATS Luncheon Presentation, 2015, SPE Digital Energy Conference 23

This slide is to reinforce the value of data in a systems engineering construct, which is essentially a nested series of feedback loops. So data gathered is monitored and fed-back to control performance. In a slower outer loop, data may be analyzed as it flows, and then fed-back through advisory systems to the control task to achieve an even higher level of performance. This series of nested feedback loops adds value to the drilling process. Without flow of data there is no incremental value achieved and the system is constrained by silos within and between the levels.

Data Flow: Shared Autonomy



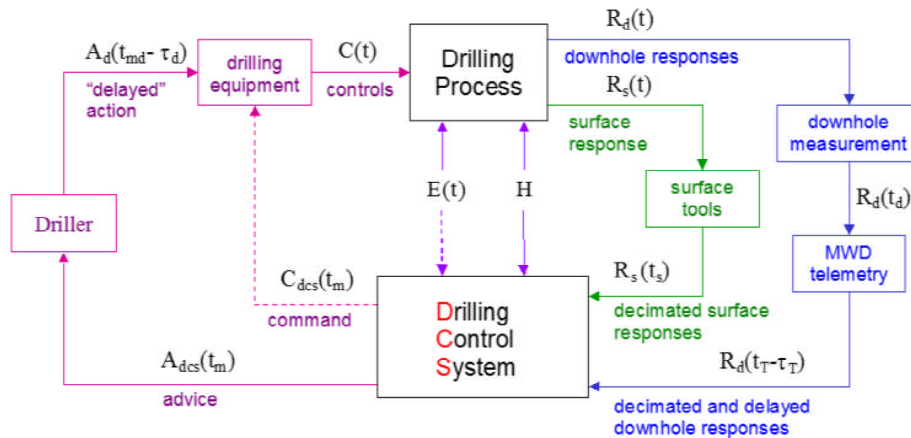
Don't expect to be able to read this slide. This is from a recent paper by Dr Fionn Iversen of the International Research Institute of Stavanger, and his co-authors. It shows what happens at level zero in the physical process, but more importantly, it shows the shared autonomy between human and computer systems at higher levels. Please read the reference (not just because I am a co-author) but because it illustrates the overall concept of what we are achieving in the drilling industry, and how "human-factors" play with computer systems in this "shared autonomy"

A BRIEF LOOK INTO SYSTEMS



1. Concept: Drilling Control System
2. Implementation: Real-Time Data Modeling
3. Implementation: Wired Pipe and DSA

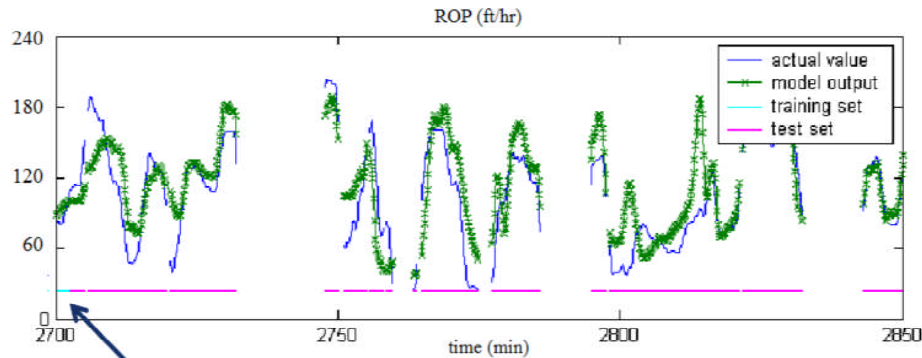




Source: Dashevskiy et al, 2003, AADE-03-NTCE-10

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In the early 2000's there was research being performed on drilling control systems. In particular, on the use of neural networks to function as drilling control systems. This construct shows the various data flow paths and the role latency and decimation of data play in the construct, depending on if the data is from surface or downhole, and if the system is used as an advisor or to directly control the equipment.



End of training set

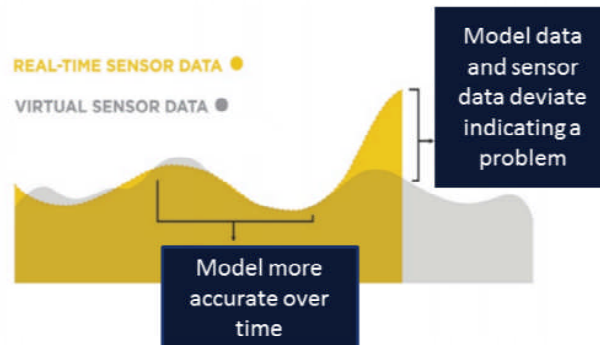
Source: Dashevskiy et al, 2003, AADE-03-NTCE-10

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The results with this concept were excellent, as shown here. It was possible to predict, for example, rate-of-penetration based on training sets of data. The prediction being performed here is ahead of the drill-bit – in other words, a prediction of what the value of ROP for the next drilled section will be.

Unfortunately, the downside is that such accurate predictions depends on data quality: how well does the training set define the control space? This level of data quality is difficult to achieve as drilling plans are tightly focused on offset recommended parameters. However, this approach does show the viability for neural nets and analytics. Similar techniques, on a new scale, are being practiced in “deep learning” methods by IBM and others in other industries.

Use of mechanical, hydraulic and thermal models, in real-time, to derive “virtual sensor data”

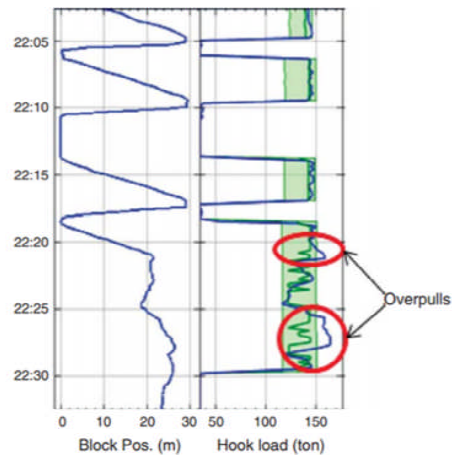


Source: Chmela et al, 2014, SPE 168018

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So turning away from data – driven systems, such as analytics and neural nets, another approach has been the use of physics-based models. In this case, the models are calibrated in real-time, and used to predict the likely value of a measurement – this prediction is termed a virtual sensor. Any deviation between the predicted and measured value may indicate an issue, which is then handled by an alarm, advising the operator, taking control, and so on.

- Example, models predict safe “pull-window” during tripping
- Set-points and operational constraints for safe, efficient operations
- Staged introduction: monitoring, shadow system, then control

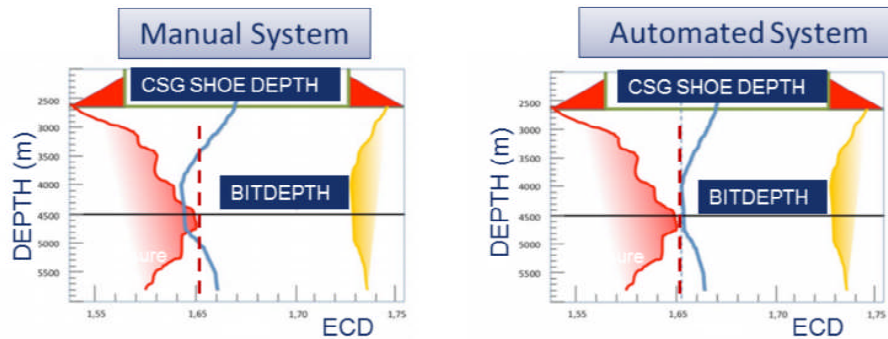


Source: Chmela et al, 2014, SPE 168018

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This example shows the use of the physics-based model to predict a safe hookload window, deviation outside it results in an alarm - but by feedback it also places a control on the amount of pull permitted. The horizontal axis is hookload and block position, while the vertical axis is time. This is active modification of constraints in automation. The rig can pull as fast as it is physically capable of, but the automation system modifies the constraints to prevent the operator from damaging the wellbore or the rig itself.

- Automated Tripping System

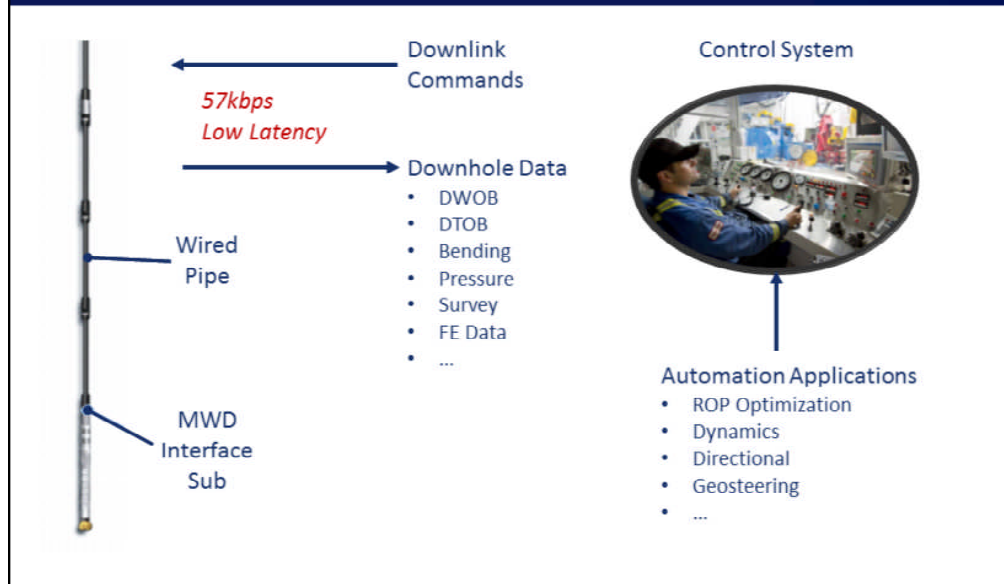


- System automatically adjusts running speed and acceleration to avoid swab

Source: Chmela, etal. 2014, SPE 168018

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This is an example of constraints in pipe running speed being modified to prevent damage to the wellbore, namely by keeping the running speed slow so that the downhole pressure does not drop and allow an influx of fluids. The horizontal axis is pressure scaled in terms of mud weight (ECD – Equivalent Circulating Density), while the vertical axis is depth.



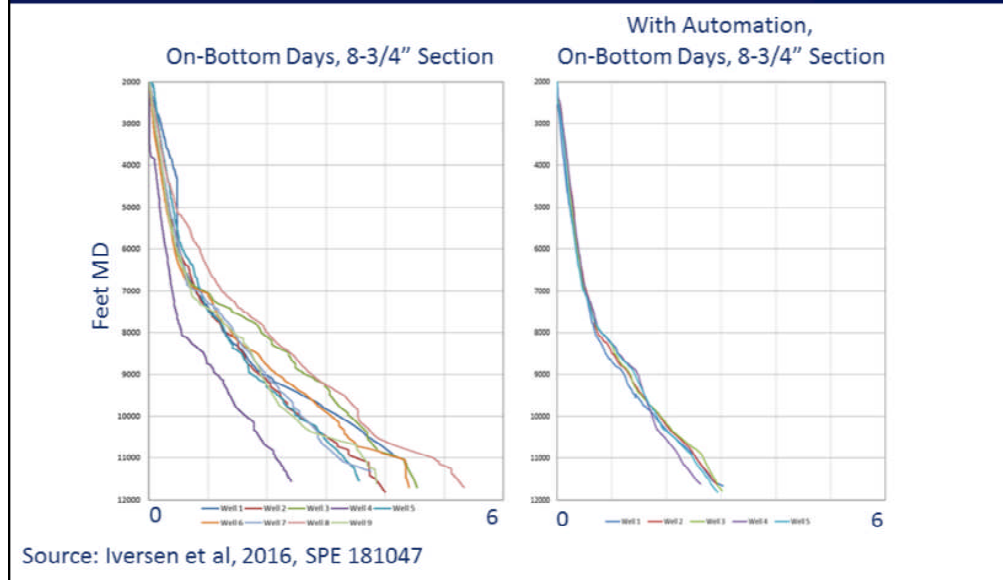
This third example is quite recent, from a 6-well test of drilling systems automation in the Bakken in US Land. In this case downhole MWD tools were linked with wired pipe to a drilling control system on surface. High-speed (low latency) data was delivered on surface to the drilling control system which could also downlink in real-time to the downhole tools. The drilling control system had the ability to run applications in real-time – the list shown here describes what is potentially available rather than what was actually used in the operation, which was focused on optimizing ROP and drilling operations.

Application of wired pipe, high-speed downhole data and closed-loop drilling automation in the Bakken:

- Drilling Efficiency: Real-time information improved awareness of drilling efficiency
- Standardizing connection practices reduces cumulative effects of back-to-bottom lateral vibrations
- Automation system shows promise to manage/mitigate downhole drilling issues
- Recommended to further develop drilling automation technology

Source: Trichel et al, 2016, SPE 178870

These notes are taken directly from the paper by Keith Trichel and his co-authors. The primary results were that drilling systems automation allows one to improve efficiency (more eyes and systems are focused on the operation), but most important, it brings standardization to the drilling process.



This standardization leads to being able to predictably drill wells. Shown here are the time-depth plots of the 8-3/4" sections of the 6-wells drilled with an automated system in the right-hand view, while the left hand view shows the manual operation. There are two points worth noting: (1) the best manual well remains the best well even after automation, and (2) the spread in time-depth profiles collapses in the wells drilled with automation. In other words, while systems automation may not (at least in early trials) deliver the fastest well, systems automation does deliver predictable performance. This is important: if drilling time can be predicted accurately then budgets, resources and equipment needs can all be predicted with accuracy.

Summary



- Drilling Systems Automation (DSA)
 - The process of creating a borehole with systems and sub-systems,
 - That are computer controlled, and which
 - Lead to reduced human intervention
- Impact is across the entire organization and drilling process: Drill Bit to Enterprise

Conclusions



While drilling equipment is highly automated, the drilling system/process is poorly automated.

Drilling systems automation is technically challenging, requires a holistic approach, and is rewarding with significant business drivers:

Performance, Safety and Cost

Further Reading



- SPE 166263, “Drilling Systems Automation: Current State, Initiatives and Potential Impact”, SPE ATCE, October 2013
- SPE 173010, “Drilling Systems Automation Roadmap - The Means to Accelerate Adoption”, SPE/IADC Drilling Conference, London, March 2015

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Sources of further information

Drilling Systems Automation Sources of Information



connect.spe.org/dsats/home/

connect.spe.org/dsroadmap/home/



www.iadc.org/dsroadmap



www.iadc.org/advanced-rig-technology-committee/#access

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Sources of information



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