This is the second version of the Drilling Systems Automation Roadmap Report for the Oil and Gas Drilling Industry. This report outlines the currently anticipated development of organizations, processes and technologies thro 2025. It is intended to help guide the industry forward without offering a prescriptive solution.

DRILLING SYSTEMS AUTOMATION ROADMAP 2019 – 2025

PHASE II STAGE II REPORT

John P de Wardt, Program Manager
Drilling Systems Automation Roadmap
Industry Initiative

www.dsaroadmap.org

DRILLING SYSTEMS AUTOMATION ROADMAP & BOK 2019 – 2025

PHASE II STAGE II REPORT

Version 19 05 31 Public Release

Revisions

The authors of this publication are aware that the nature of the subject matter covered will develop over time as new techniques arise or as current practices and technologies are updated. Therefore, it is the intention to intermittently revise this report to reflect these changes and to keep this publication as current and as complete as feasible.

This version is Version 19 05 31 Public Release.

This version supersedes the Phase II Stage I Version 17 04 06 report released to JIP Funders April 2017.

Anyone with expertise, techniques or updates that they wish to submit to the publisher for assessment for inclusion in the next revision are requested to e-mail their information in the first instance to:

info@dsaroadmap.org

Acknowledgements

John de Wardt, BSc, CEng, FIMechE, Distinguished Member SPE and President of DE WARDT AND COMPANY led this initiative as Program Chairman. This project was initiated and undertaken on a voluntary basis followed by a Phase II JIP funded stage.

Lead team Players

The DSA Roadmap leading team players that reviewed, debated and agreed the adopted process and debated the work as we developed the content included:

Amanda DiFiore (Qinetiq / AMD Consulting / Charles River Analytics)
Blaine Dow (Schlumberger)
Calvin Inabinett (Aerojet Rocketdyne / Aerodyne Industries,
Clay Flannigan (2013 – 2017) / Maria Araujo (SwRI) (2017 -)
Daniel De Clute Melancon (Halliburton) (2013 – 2014)
Ed Tovar (InTechSys) (2013 – 2016)
Eric Cayeux (IRIS)
John Macpherson (Baker Hughes a GE Company)
Mark Andersen (Shell / Anderson and Spillman)
Moray Laing (SAS / Halliburton)
Randy Mutch (Ensign)
Robin Macmillan (NOV)
Slim Hbaieb (Schlumberger)
Terry Loftis (Transocean / Loftis Offshore Oilfield Consulting)
Mario Zamora (Schlumberger / Retired)

Chapter Contributors

John de Wardt, as DSA Roadmap Program Manager, is the coordinator and main author of this work and maintains overall responsibility for its content. De Wardt participated as Program Manager, Lead Author and Lead Editor.

Sections of this report were generated by section leaders whose leadership is acknowledged below and whose teams are acknowledged at the beginning of each section. They include:

John de Wardt – Vision and Needs for a Drilling Systems Automation Roadmap
John de Wardt – Current State 2019 / Future State 2025
John de Wardt – Systems Architecture
Moray Laing – Communication
John Macpherson – Instrumentation, Measurement Systems
Robin Macmillan – Drilling Machines and Equipment
Calvin Inabinett & Ben Facker – Control Systems
Blaine Dow – Modeling and Simulations
Amanda DiFiore – Human Systems Integration
Mark Anderson – Standards and Certification

John de Wardt – Contingency Management
John de Wardt - Value Proposition for Drilling Systems Automation
John de Wardt – Summary Observations

Advisors

The advisors who provided feedback on some critical areas of the product include:
John Berra (Past Chairman of Emerson Process Management)
Eric Nettleton (formerly Rio Tinto – Mine of the Future™ project)
Tom Sheridan (Professor Emeritus at the Massachusetts Institute of Technology)
Luca Save (Safety and Human Factors expert, Deep Blue S.r.l)

Funding the DSA Roadmap Project Phase II Stage I & Stage II Reports

High Value Contributions

The time donated by the Program Manager, steering committee, the challenge team leaders and all their team members (encompassing fifty industry experts globally) far exceeds $600,000 before recognition of the JIP Funding and without including any value attributed to the knowledge they shared.

Joint Industry Project Funders – JIP 1 and JIP 2

The work was carried through the final phases (Phase II Stage I report, then Phase II Stage II report) with key contributions by Joint Industry Project Funders in JIP I and JIP 2 funding. JIP funding was approved by the IADC Drilling Engineering Committee in 2015. Funds raised were $215,000 over JIP1 and JIP2.

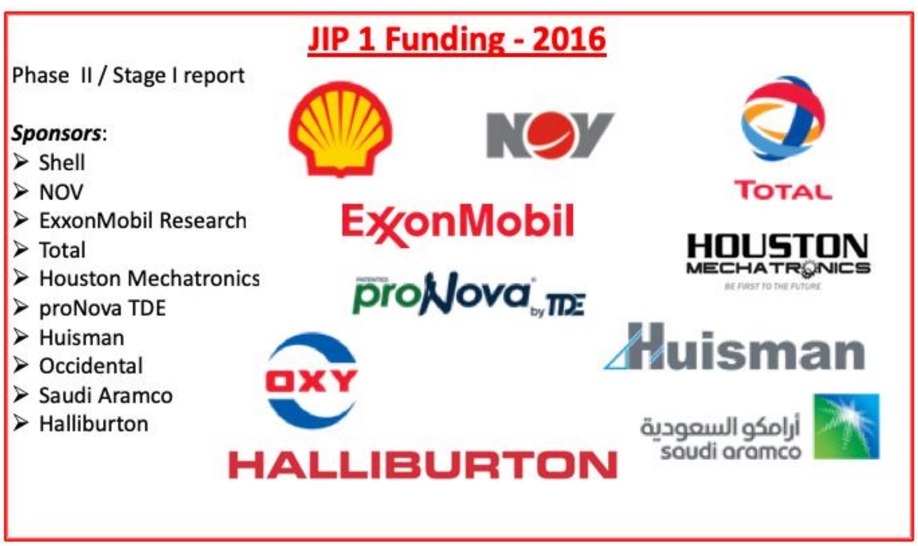

Figure 1: JIP 1 Funders Provided $100,000 at $10,000 each

Figure 2: JIP 2 Funders Provided $115,000 based on Returning Funders @ $5,000, Not for Profit Funders @$5,000 and New Funders at $10,000

Affiliations

The Drilling Systems Automation Roadmap Industry Initiative has operated as a stand-alone entity with multiple affiliations that ensure its relevance within the drilling industry. The considerable support provided by these affiliations is catalogued below.

IADC, IADC Advanced Rig Technology Committee (ART) & IADC Drilling Engineering Committee (DEC)

In 2014, IADC hosted early workshops in Vienna, Austria and Galveston, Tx, at which the plans and progress of the DSA – R initiative were presented and discussed. In January 2018, IADC hosted a major workshop in Houston, Tx, at which the key challenges were debated in parallel work groups; the feedback from this event was compiled into an action-oriented report for the DSA – R Report Stage II update. IADC DEC reviewed and approved the proposal to for the Joint Industry Project (JIP) to fund completion of the Stage I, Stage II reports and the industry workshop. IADC DEC contacts Mike Killalea, Linda Hsieh. IADC ART linkage through Terry Loftis and Robin Macmillan.

SPE Drilling Systems Automation Technical Section (DSATS)

SPE DSATS was informed on progress through its monthly meetings and provided a stage for industry updates through its DSATS Symposiums. DSATS also provided the banking mechanism for collecting funds and managing the distribution of approved payments under the JIPs. SPE DSATS linkage through Ed Tovar, John Macpherson, John de Wardt, Mark Anderson, Moray Laing and Robin Macmillan.

AUVSI: the world's largest nonprofit organization dedicated to the advancement of unmanned systems and robotics. AUVSI linkage through Lindsay Voss.

Southwest Research Institute: R&D problem solvers providing independent premier services to government and industry clients. SwRI linkage through Clay Flannigan and Maria Araujo.

Energistics: the industry standards organization for data and information transfer. Energistics linkage through Jay Hollingsworth.

OPC Foundation: the interoperability standard for the secure and reliable exchange of data in the industrial automation space and in other industries.

Preface

Launching and developing a roadmap in the upstream oil and gas drilling industry has been a major challenge. Similar roadmaps are common in Department of Defense (DOD) and other similar work environments, in which experts are typically funded to generate the product within 12 to 24 months. The DSA-R, launched as an all-volunteer initiative during a particularly challenging time in the oil and gas upstream industry, has produced a high value product.

We researched and identified the best process for road mapping and adapted it to drilling. This process—the publicly released version of the Sandia National Laboratories (SNL) Roadmapping—guided us as we stepped through the project's phases and stages. This report is the output of Phase II Stage II of that process. The SNL Roadmapping process envisages an update to this report every two years post publication, enabling updates of the current state of automation and the application of lessons learnt to be included in revised future projections.

We pulled together a strong steering committee, which expanded the input to some 50 industry experts globally. This broad reach drove the richness of the content.

We commenced this project as a group of industry experts volunteering both time and knowledge. It became apparent that the Oil and Gas industry volunteer initiatives struggle to deliver results especially in the tight financial environment after 2014. This led the leadership to secure funding for professionals to carry forward the planned program through the IADC Drilling Engineering Committee (DEC) process for Joint Industry Project (JIP) approval. We are thankful to the funding companies in JIP 1 and JIP2 who made it possible to transform a volunteer initiative of experts into a product for the industry and non-industry experts to access this knowledge base and deliver value themselves, for their companies and for the industry.

This report is intended to help any company within or outside the oil and gas industry understand the direction of drilling systems automation and to find an opportunity in which they may use their own expertise to profitably add value to this technology growth.

By John de Wardt, BSc Mech Eng Hons, CEng, FIMechE, Distinguished Member SPE. President DE WARDT AND COMPANY INC
Program Manager, Lead Author & Lead Editor of the Drilling Systems Automation Roadmap 2013 – 2019

DE WARDT & COMPANY
Global Management Consultant
Oil and Gas

Executive Summary

Purpose, Scope and Boundaries

The purpose of this report is to describe a vision for Drilling Systems Automation (DSA) and the steps that may be taken to move the industry forward and to affordably achieve this vision. Delivering on the promise of DSA requires a roadmap to describe the interrelations within a complex operation and to show how those interrelations can be advanced to deliver value.

The DSA roadmap addresses the full range of drilling operations and wells at a high level termed the 'Reference Architecture', which provides a framework for industry cooperation that forms an umbrella over actual DSA implementation at the 'Solutions Level', where innovation and competition thrive. The scope includes the full cycle from spud to completed well ready to connect and put on stream, across all varieties of drilling operations and across all well types.

Location construction (seabed surveying) and the arrival and installation of the drilling unit have not been included. Although they have an impact on the rate of adoption, business models were excluded. It is likely that lump sum and financially incentivized drilling operations will be accelerators of the application of DSA because of elements of DSA related to rate of penetration (ROP) optimization, advanced control of well bore steering that leads to a reduction in on site personnel and, recently, the advent of a major service company program to purchase a range of relevant companies and invest heavily to implement a fully integrated DSA program called "Rig of the Future".

Vision, Product Definition

The vision for the DSA roadmap was drafted at the applied technology workshop held in Vail, Colorado (de Wardt *et al.* 2012): "In 2025, well plans are uploaded into an interoperable drilling system that automatically delivers a quality wellbore into the best geological location, installs the casing and zonal isolation according to plan, installs the completion system according to the program and updates remote operators and experts in real time to changes in the situation, and identifies potential paths for success for the experts to input control. Deep, complex wells will rely more heavily on centers of excellence onsite and remote to provide real time and near real time updates. Routine multiple wells will rely on remote operations centers to monitor progress and react to alarms."

Current State, Future State

The current state and the perceived future state of drilling define the gap to be crossed by DSA. Much has been achieved by various companies in the oil and gas drilling sector. Significantly more achievement is envisaged as participants see maturing current technologies opening opportunities to the future. Through a high degree of automation, combined with advanced data analytics becoming the norm globally, DSA will progressively transform the way drilling operations perform. The transformation is advancing the quickest in the USA land drilling environment, which will provide both a platform and an understanding for future developments and global adoption.

Systems Architecture

Systems Architecture defines integration and physical interoperability of the drilling system, including prime subsystems, and includes the hierarchy of workflows, interfaces, definition of states, and other aspects that enable system functionality. This definition was recognized as a critical foundation for the successful uptake of drilling systems automation. The method to develop the Drilling Systems Automation Systems Architecture (DSASA) was based on Department of Defense Architecture Framework (DoDAF) and International Council on Systems Engineering (INCOSE). This approach provides a top down approach of systems that combine to deliver a well in a highly complex and often uncertain environment having multiple viewpoints. A hierarchy of architecture from Reference Architecture through Pattern Architecture to Solutions Architecture was identified as the most appropriate means to map the Systems of Interest (SoI) for the industry. The Reference Architecture is the focus of the roadmap and is the level of architecture used to define how the industry can cooperate using a common view. The Solutions Architecture is the detailed version developed for any project and is the level at which innovation and competition occurs. Solutions Architecture feedback lessons to Pattern Architecture that feedback interoperability updates to the Reference Architecture, which is anticipated to be maintained as a common view across the industry. Systems of Interest are described in terms of potential development and their consequences mapped to the roadmap challenges. This multi-dimensional approach combines the articulation of any SOI development with the associated development required in the challenges to ensure success.

Systems Architecture also describes the levels of decisions and control occurring up a hierarchy from sensors to business systems. ISA 95 framework was adopted and adapted to map the Decision and Control Framework for Drilling Systems Automation.

DSA Roadmap Challenges

The DSA Roadmap process identified eight interdependent challenges (technology and process streams) to describe anticipated advancements in drilling systems automation across the spectrum of expertise required to deliver a comprehensive solution. To achieve the vision of the roadmap, these advancements are anticipated to be both innovative and disruptive. The eight challenges, listed and summarized below, include:

1. *Communications* address links among the downhole, surface, remote operating centers, and distributed experts and standards for common protocols and interoperability, deterministic systems for hardware control and secure data transport at all levels.

2. *Instrumentation and Measurement Systems* (IMS) defines the requirements for delivering comprehensive, reliable, quality measurements of the downhole, and surface operations in a appropriately timely manner for DSA.

3. *Drilling Machines and Equipment* includes a wide range of surface and downhole drilling equipment and highly mechanized and semi-autonomous robotics.

4. *Control Systems* focusses on downhole, surface and remote systems directed at creating the wellbore and delivering various levels of automation, from monitoring through advisory control to autonomous systems.

5. *Simulation Systems and Modeling* covers planning, real-time, offline, remote and post-well modeling and simulation tools and systems.

6. *Human Systems Integration* addresses the interaction of automation systems with humans and mode issues including human displays, human machine interfaces, role competencies, training and distributed and decentralized control. It also introduces the application of a Levels of Automation Taxonomy (LOAT) matrix for the transition from manual to highly automated systems through the cognitive functions cycle of acquisition, assessment, decision and action.

7. *Industry Standards and Certification* identifies available standards and regulations that may be applied to define the operations of automation as well as to current and future impacts that can define the ultimate future of DSA.

8. *Contingency Managemen*t System is critical for safe, deterministic, trustable, deployable autonomy and for the system's ability to "get out of trouble" (added Dec 2015). This challenge is currently unaddressed.

Value Proposition for DSA

The value proposition for DSA has been difficult to articulate. Control systems for drilling have been enhanced and islands of true automation have been developed and implemented. Industry experts have inconsistent views of the value of automation that range from those who believe it will add value to those that maintain the business can only be run by experts in a highly manual mode. Proponents for automation are now engaging significant sums of money to prove their concepts while detractors believe conventional machinery already in the asset base combined with significant personnel training efforts will be a competitive business model.

The fundamentals for successfully applying automation also are aligned with improving inabilities within the industry today. One example of this failing is the quality of data from surface drilling sensors that the driller uses to operate the drilling rig; recent efforts to measure this quality has shown huge errors that can be remedied only by an approved and thoroughly adopted calibration and maintenance process. Additional issues arise as various companies install sensors of similar or differing physical models to measure and display data either to themselves or to multiple parties. This leads to significant confusion as to which measurement is accurate and timely for the purposes to which it is to be applied. The current array of sensors traverses the spectrum from high accuracy, high frequency and low latency to erroneous, infrequent and delayed, creating a challenge to the implementation of a comprehensive automation system. Some of the issues with current sensors can be simply remedied through upgrades while other issues cannot be physically or economically solved and require models to fill the gaps in data and information.

1 of 14: Overview & Executive Summary

High performance drilling in the USA land environment has created a small opportunity for automation to deliver value through faster drilling and hence lower well costs. At the same time, this high-performance drilling environment has created a need for automated acquisition, processing and decision making that is many times faster than human capability. Mile a Day (MAD) wells are being achieved in the vertical, build and lateral well sections with the application of various degrees of automation in the cognitive function cycle to support the human, who assumes a supervisory role. This automation is enabling experts to supervise multiple operations remotely and not be restricted to a single wellsite.

Rig designs developed in a manual era yield less value than automated mechanisms developed in an automated era. The value from automation can be significantly leveraged when the mechanical system is designed though a systems engineering approach from a basis of automation.

The value proposition exists and requires careful articulation in terms of well costs / quality impact and not simply speed of drilling.

Contents

