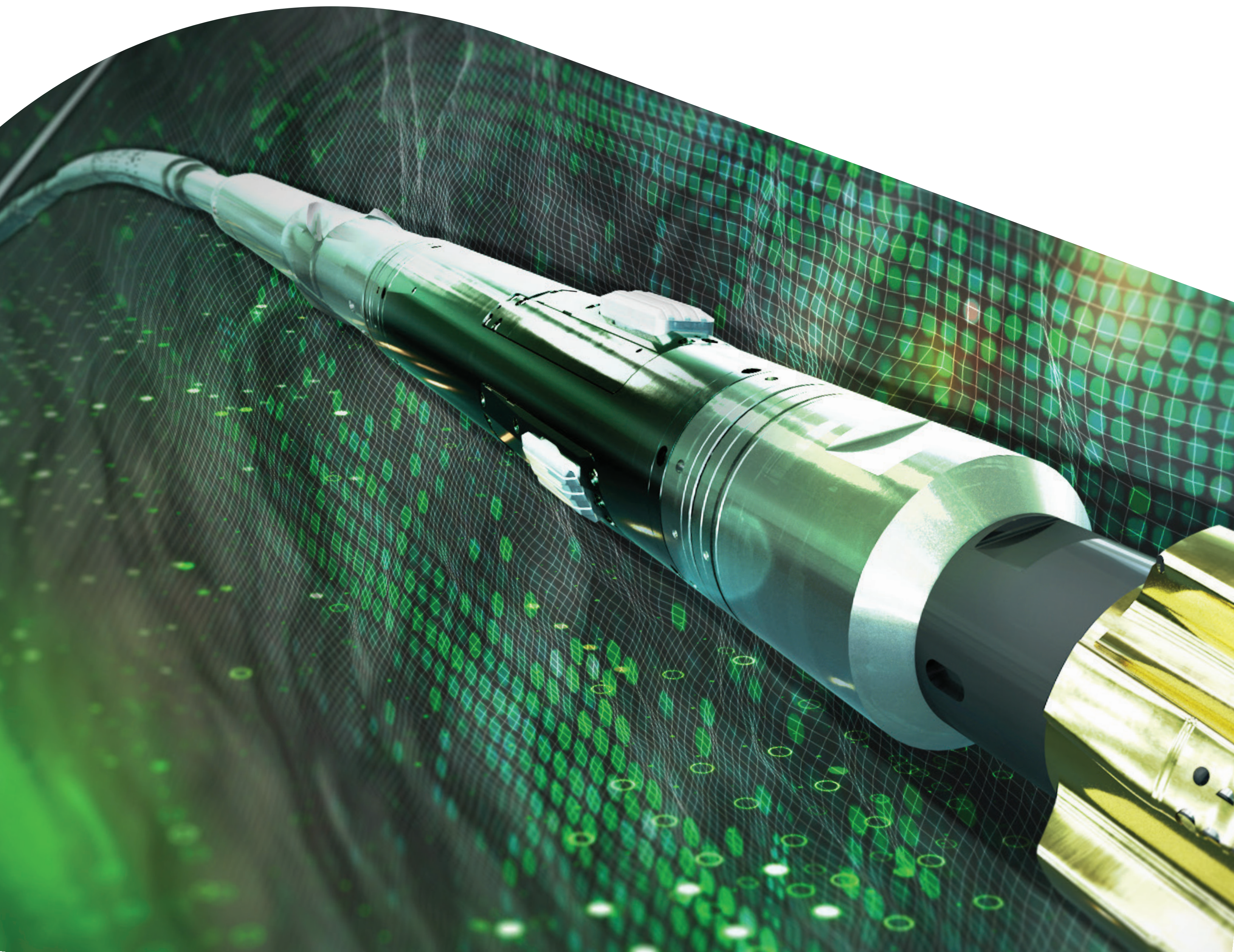
Making automated reservoir navigation a reality

How autonomous geosteering can unlock greater value from producing formations

Matthias Gatzen, David Holbrough, and Hamid Karimi



EXECUTIVE SUMMARY

In many fields—from aerospace to manufacturing—automation is a mature technology and an accepted component of day-to-day operations, improving consistency, enhancing efficiency, and increasing productivity.

Within the oil and gas industry, companies long ago recognized the benefits of automating activities to capture drilling efficiencies. Unfortunately, the industry has been slow to capture the maximum value from automation.

Baker Hughes has resolved this challenge by joining its unmatched drilling technology and expertise with cutting-edge digital advancements and AI. The result is a portfolio of automated drilling applications that include directional drilling capability, fluids monitoring, rate-of-penetration (ROP) and tripping optimization, stringer detection and mitigation and reservoir navigation.

As part of this initiative, the company recently introduced the i-Trak™ drilling automation system, the industry's first automated reservoir navigation service, elevating performance to the next level.

This paper will examine how i-Trak automation is being applied today and the value it is delivering right now for Baker Hughes customers.

Introduction

Airline pilots have relied on autopilot for decades. And every year, more and more self-driving cars enter the marketplace. But how well would automation work if the car or plane were navigating in complete darkness under extreme temperatures and pressures and with a fraction of the measurements they rely on for orientation?

These are the subsurface challenges drillers and geologists take on every day. So, automating the process means undertaking the complex task of linking hardware, software applications, and advanced algorithms with rig systems, real-time measurements, and closed-loop downhole control to deliver improved drilling performance.

The concept for drilling automation has existed for years, but moving from concept to reality has been a conundrum for developers because of the many technology elements that must function together to make it possible.

But now, a revolutionary automated reservoir navigation service (RNS) is overcoming these challenges—enabling an operator's RNS team to navigate just as successfully, safely, and efficiently below the surface of the earth as cars and planes do above ground.

Taking a complicated idea and translating it into a practical application takes **expertise**, an **ecosystem**, and **execution**.

In practical terms, this means assembling a team of experts who can work across disciplines, creating an environment that enables digital and physical components to be seamlessly integrated, and implementing game-changing technology to deliver measurable value at every stage of the process.

GREAT MOMENTS IN AUTOMATED STEERING HISTORY

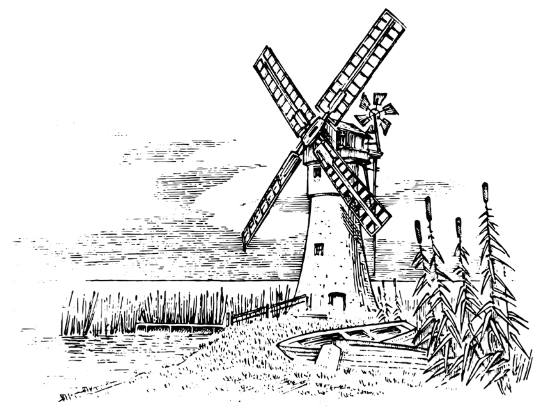


Illustration of a 17th-century windmill employing a version of Edmund Lee's automated steering device.

1745

Most blacksmiths spend a lot of time looking down at the job at hand. Edmund Lee must have spent a lot of time looking up. How else did he come up with the idea for what is widely recognized as the first automated steering device?

The windmill fantail.

The fantail, which Lee patented in 1745, is a small windmill mounted at the rear of a larger windmill and at right angles to its sails. This fantail automatically shifts (or steers) the larger windmill into the wind so that the main sails are in the optimal orientation to produce maximum power.

Lee's invention was so efficient and effective that variations of his design are still in use in the UK, Germany, Denmark, and other parts of Europe where changes in the wind direction are frequent.

1500
Leonardo da Vinci designs a self-propelled cart

1788
James Watt invents automatic regulation of steam into engines

Assembling the **expertise**

Building a system that can deliver automation in exacting conditions takes vision and coordination.

One of the biggest challenges in designing an automated RNS is assembling a team with the right capabilities. To develop the first-of-its-kind i-Trak automated RNS, Baker Hughes brought together drilling application experts who understand tool limits and drilling requirements, reservoir experts who know what it takes to build and maintain an accurate subsurface model, leaders in reservoir navigation who understand how to interpret subsurface logging data and make real-time decisions to maximize reservoir recovery, and hardware specialists with in-depth knowledge of surface and subsurface tools.

These experts were paired with digital team members who could build advanced digital twins for the reservoir and construct algorithms that can incorporate learnings and continually refine them to automatically steer a well path to a reservoir's most productive zones and keep it in that sweet spot.

Building the digital twin

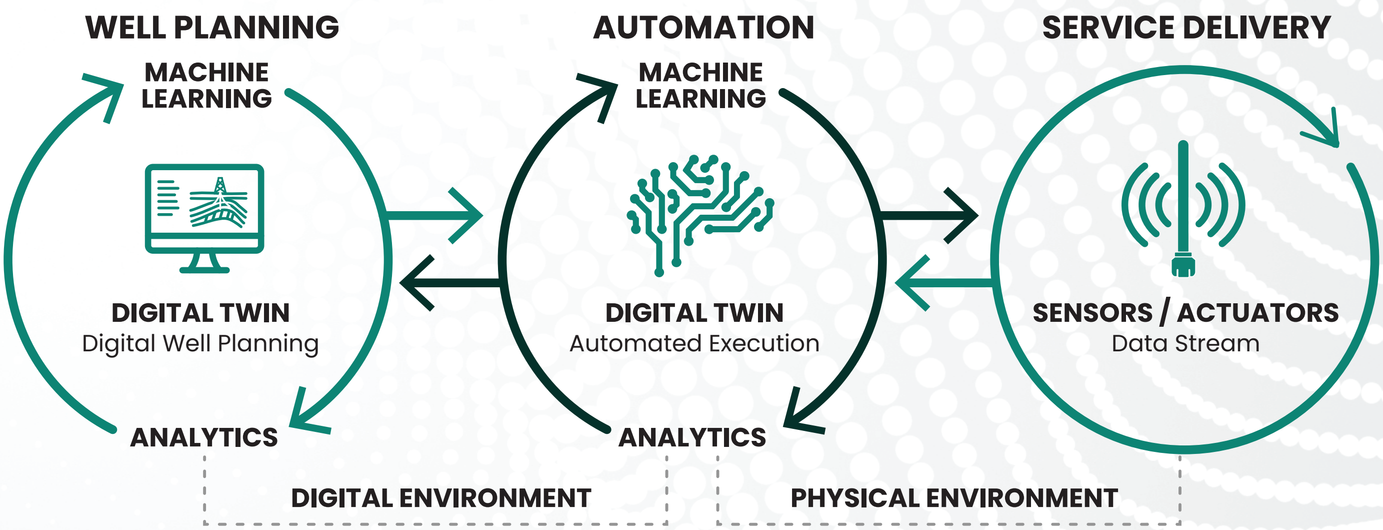
The foundation of the i-Trak automated RNS is a digital twin that is developed in the early planning stage. Once deployed, it receives real-time data from a variety of surface and subsurface sources. These data provide the crucial feedback needed to continually refine the digital twin and inform the algorithms so they can steer the well to the reservoir's most productive zones.

Without these digital tools, a well construction team—geologists, drillers, engineers, directional drillers, and the RNS supervisor—would have to manually process and review all the real-time data as it came in. Then, as a group they would need to identify and validate any potential changes to the well path before making any course corrections. This approach is incredibly inefficient.

With the automated solution, the team is able to simply approve or reject the recommendations that feed into an automated workflow — without manually managing and interpreting real-time data inputs. When a suggestion is approved, the i-Trak service automatically downlinks commands to the downhole directional drilling system to make course corrections in line with the new well path to optimize operations.

With this process, everything happens more easily and more quickly.

The results are increased ROP, which drive down drilling costs, and optimized positioning within the reservoir, which boosts production rates and improves ultimate recovery.



The digital twin connects the virtual environment with the physical environment. Using real-time streaming data, it continuously tests new models, cross-referencing risks to ensure safe operations and suggesting drilling modifications to deliver the best possible well plan for optimal production and minimal NPT.

Establishing an **ecosystem**

As important as the digital tools developed by the team of experts are, capturing maximum value remains an elusive goal without properly pairing that software-based solution with equally advanced hardware.

Harnessing the benefits of drilling automation is complex. It requires smart tools connected through a reliable network that enables the technology to react quickly and effectively.

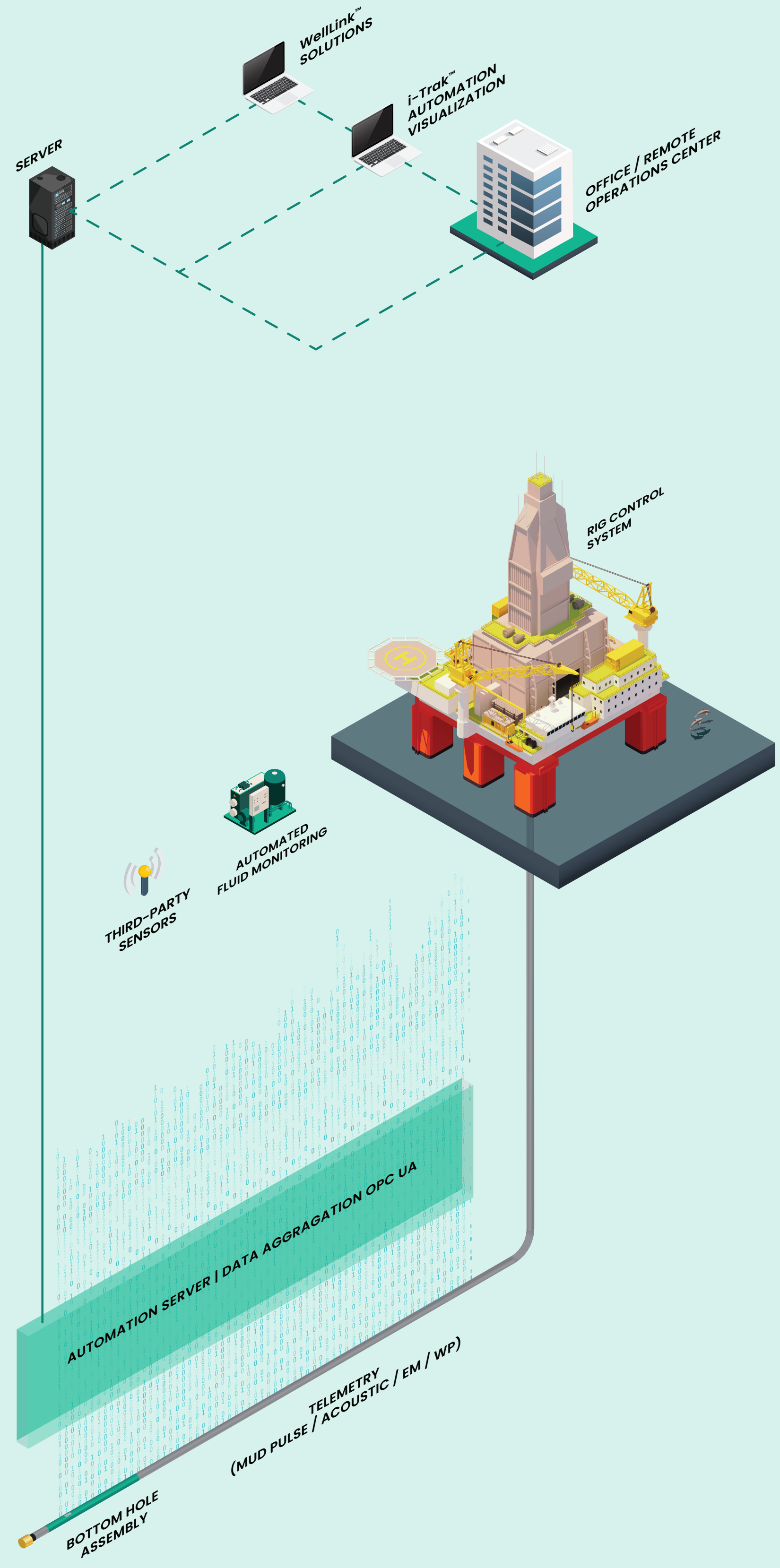
Improving production also requires a robust drilling ecosystem that seamlessly connects all stages of the operation—from downhole tools to surface systems to remote operations centers.

i-Trak automation is a paired hardware software service that allows automation microservices to be executed.

Downhole data, rig data, and data from third-party sensors are sent to the edge i-Trak automation server.

The edge i-Trak server hosts time-critical applications that cannot be executed in the cloud. The server executes micro-services that automate steps of the well construction process, sending commands to the rig control system to enable full closed-loop automation. This server is the mastermind of automated operations and coordinates decentral automation in the cloud as well as automation that is executed directly within the high-tech electronics downhole, such as automated steering.

This system is connected to the remote operations center, which is staffed 24/7 by a team of experts.



Delivering reliable **execution**

Like a self-driving car, automated geosteering maps a route and continuously makes adjustments as conditions change to ensure the best route is being followed. The i-Trak system optimizes well construction by changing drilling parameters automatically and in real time, integrating well-tested algorithms with rig systems, real-time measurements, and closed-loop downhole control to cut drilling days and deliver more productive and more profitable wells.

The result is literally groundbreaking, delivering:

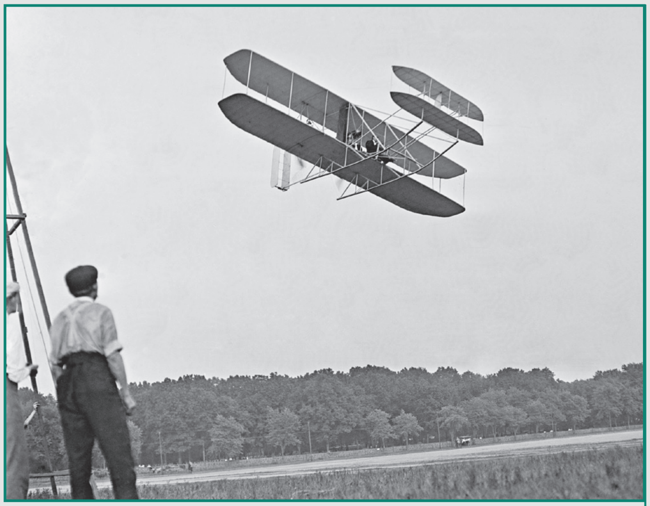
- Maximized reservoir contact
- Increased ROP and operational efficiency
- Greater predictability in well delivery and operations performance
- Lower well construction costs
- More precise wellbore placement for superior well performance for the duration of the drilling program

Although the tools are complex, using them is straightforward with the right execution plan, bearing in mind that a successful plan needs to take change management into account because integrating automated steps into a standard workflow can be disruptive.

To avoid compromising any of the potential benefits of an automated RNS approach, the service provider must work with field crews and the well team to help them acclimate to the new approach and track key performance indicators to ensure a smooth transition. This way, all the stakeholders can experience how automation works and gain trust in the process.

In many cases, the first step is to employ “shadow mode,” in which the system creates a well trajectory based on real-time data and proprietary algorithms while the customer’s crew drills the well using traditional geosteering. As the performance of the RNS is validated in the well and the various stakeholders become more comfortable with the technology, more steps in the drilling process can move from shadow-mode to full automation.

GREAT MOMENTS IN AUTOMATED STEERING HISTORY



1912

It might come as a surprise that the first autopilot capability was introduced by a man named Lawrence Sperry only nine years after the Wright brothers’ history-making flight at Kitty Hawk, N.C.

Sperry’s invention, called a “gyroscopic automatic pilot” (a.k.a. “George”), automatically balanced the plane in flight, which made it much easier for the pilot to control the aircraft. Use of the technology expanded in the 1920s and 1930s. An autopilot system was even installed on the plane Howard Hughes Jr. flew for three days and 19 hours to set a world record for circumnavigating the earth in 1938.

Companies started looking into using digital technology for autopilot in the 1970s, and as technology advanced, systems proliferated. Today, autopilot is mandatory for commercial airplanes with more than 20 seats.

1895
Self-steering torpedo

1920
First maritime autopilot system

1939
Self-driving cars previewed

Streamlining geosteering workflows

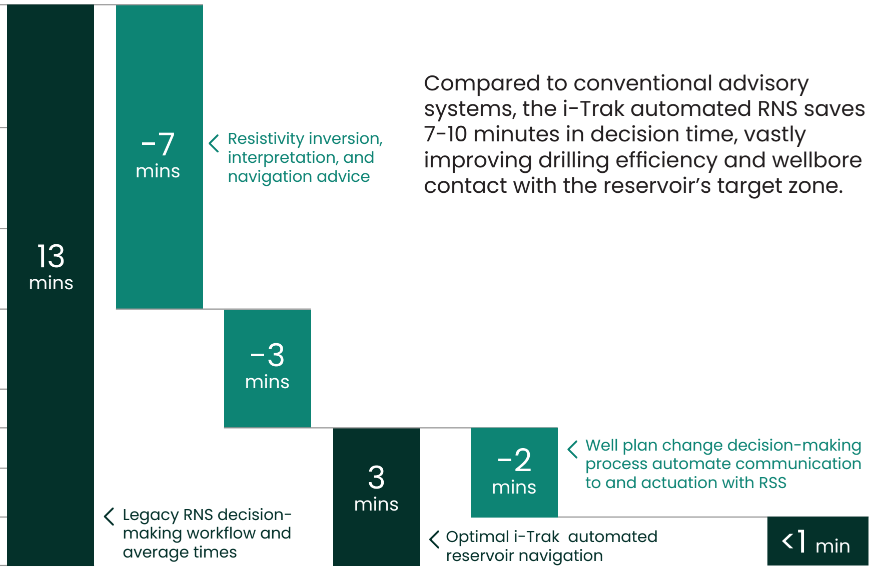
A comparison between the i-Trak service and a legacy reservoir navigation approach demonstrates how much time can be saved with downhole automation.

The decision-making workflow of a traditional system requires several time-consuming steps—including running inversions, interpreting results, discussing options, making decisions about well plan adjustments, and executing the final plan. On average, executing these steps takes about 13 minutes. And while the decision-making process is underway, drilling continues, and the wellbore moves farther away from its target.

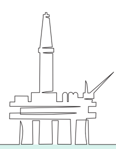
i-Trak automation changes this paradigm.

By automating inversions, determining the optimal boundary position, and making steering recommendations, the i-Trak system cuts the workflow to just three minutes. And with refinements to the system continuously improving that timeline, decision-making time can be reduced to less than a minute.

Run inversion with DAR/EDAR data	**2.5 mins**
Perform interpretation of boundary by RNS supervisor	**2.5 mins**
Determine target TVD/inclination based on boundary and standoff	**2 mins**
Discuss with Ops/Geology & Geophysics team	**2 - 15 mins**
Decide to adjust well plan	**1 min**
Discuss plan with Directional Driller	**1 - 10 mins**
Run anti-collision scan	**1 min**
Formulate downlink and initiate	**1 min**



Compared to conventional advisory systems, the i-Trak automated RNS saves 7-10 minutes in decision time, vastly improving drilling efficiency and wellbore contact with the reservoir's target zone.

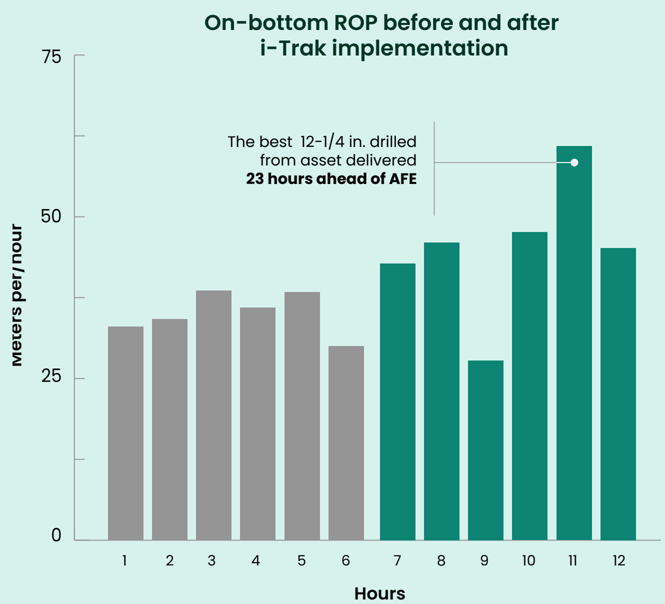


Accelerating drilling operations

Results from the field demonstrate the value of the automated system. While drilling a multiple-well program offshore, we put our automation applications—including the i-Trak directional drilling service and ROP optimization service—to the test. On wells where ROP averaged only 35 m/hr (115 ft/hr) with traditional technology, using i-Trak automation improved ROP to approximately 45 m/hr (148 ft/hr), a 25% gain.

Incredibly, one well in this drilling program was drilled 23 hr under AFE.

But efficiency gains are only part of the story.



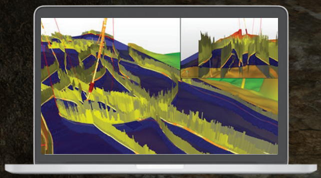
THE FOUR STAGES OF AUTOMATED RNS

The automated decision-making process for i-Trak automated RNS is not dissimilar to the process used by vehicles driving using automated control and steering. However, with i-Trak automation, the reservoir is the area we're driving through, and the desired wellpath is the road we have to follow.

1

PLANNING THE ROUTE

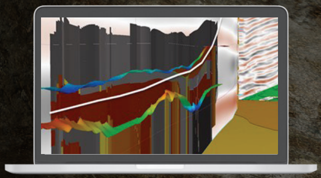
As with cars, the reservoir navigation process begins with route planning. Constructing a digital twin and building it into the process keeps the RNS team informed so drilling can proceed with confidence.



2

DETECTING DEVIATIONS

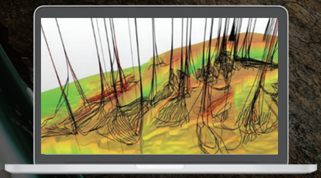
By identifying discrepancies between the referenced route and the real-time reservoir data, the system can suggest steering adjustments that keep the well path in the pay zone in much the same way that a self-driving car might incorporate unforeseen conditions like road closures.



3

SUGGESTING COURSE CORRECTIONS

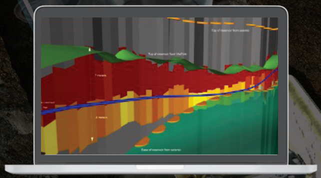
Just as a self-driving car might change its route based on traffic conditions, the i-Trak service uses navigation advice based on comparisons between the dynamic well path and the pre-well plan to make adjustments as the understanding of the reservoir environment changes.



4

ASSURING AN OPTIMAL PATH

Automatic downlinks verify the well plan has been received and generate an updated well plan that integrates suggested course corrections. Because changes are executed in real time, production is continuously optimized.

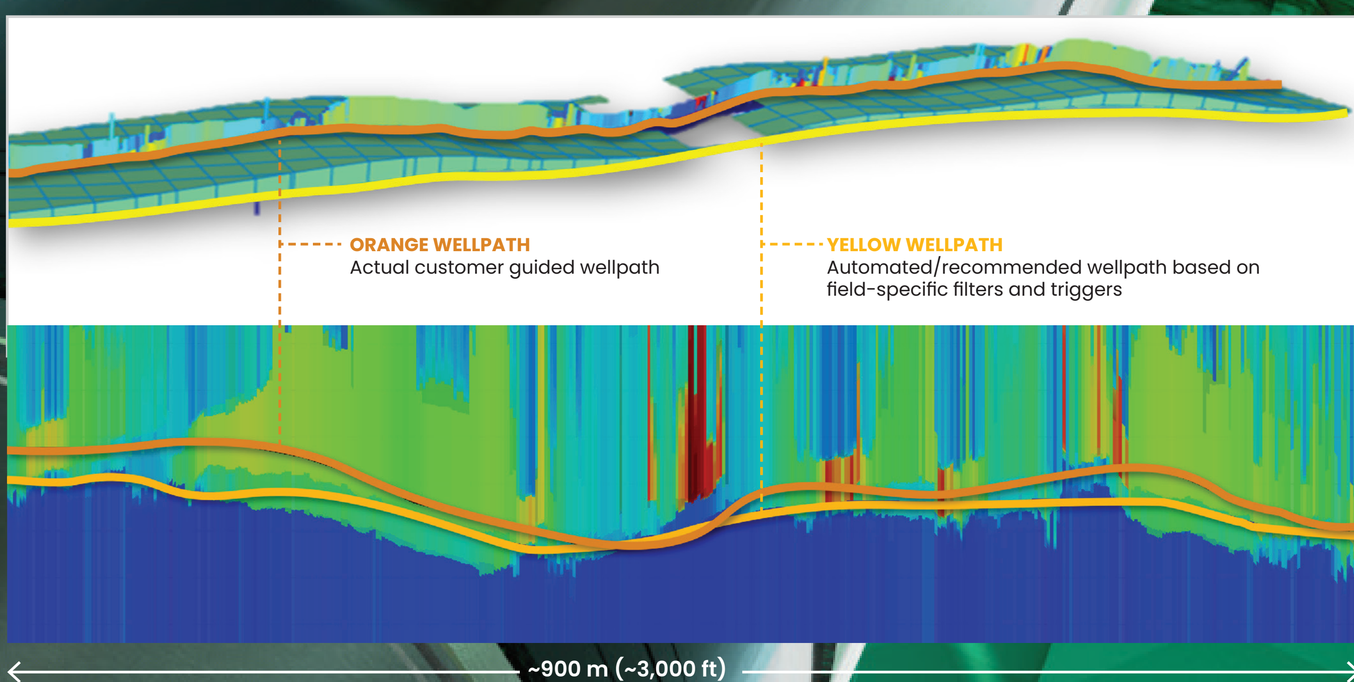


Navigating the reservoir: automation in action

In 2021, when running an initial North Sea deployment of the i-Trak automated RNS in shadow mode, the potential gains recognized by the well team were astounding.

A comparison actual well path (orange line in the figure below) with the path recommended by the i-Trak service (yellow line below) shows how much slower traditional geosteering was to respond to changes in formation dip. The shadow well path generated by the automated service, on the other hand, quickly responded to navigation changes and maintained a consistent standoff from the lower boundary.

The i-Trak system capitalizes on real-time data communicated directly from the reservoir to improve drilling performance in every well every time. Had this North Sea well been drilled using i-Trak automation, the operator's ultimate recovery would have increased by an estimated 100,000 bbl.



Leading the way

Baker Hughes has a track record for setting new standards of performance.

We have drilled more than 45 million meters (147+ million feet) using i-Trak and other drilling automation services, and we continue to push the limits of technology as we lead the industry in well construction automation.

We offer expertise across disciplines, bringing together the best minds and encouraging the creativity that leads to innovation in engineering, software, and applications.

We provide an ecosystem where the digital and physical worlds converge and AI and machine learning rapidly advance technology evolution.

And we deliver reliable execution by empowering expert teams to apply advanced tools that deliver exceptional value on the leading edge of operations.

The advances we have achieved in automated drilling technology prove the value of our approach and establish a path the industry can follow today to realize truly automated reservoir management.

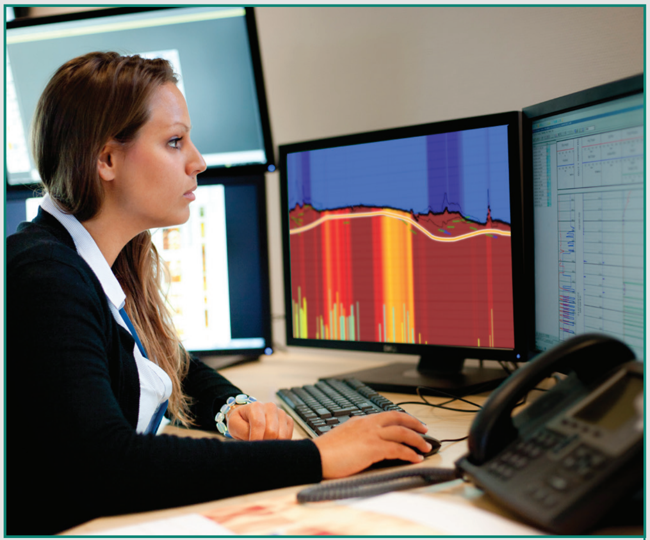
GREAT MOMENTS IN AUTOMATED STEERING HISTORY

2023

Working with Equinor on the Johan Sverdrup platform in the North Sea, Baker Hughes achieved the world's first autonomous reservoir placement from an offshore rig using the i-Trak drilling automation service.

Using data from deep-reading azimuthal resistivity tools, the system executed inversions to identify the reservoir roof or oil/water contact and used real-time trajectory planning to identify the optimal well path. Then, once the RNS team approved the recommendations, the i-Trak service took over the process and downlinked the required steering commands to place the well in the optimum position in the reservoir.

Previously, the human-based workflow averaged 13 minutes per geosteering decision, but automation decreased decision time to one minute. In this first-ever application, autonomous execution enabled Equinor to place a 1,339 m (4,393 ft) section an average of less than 1 m (3.3 ft) from the reservoir roof.



1979
Stanford cart navigates crowded room

1990
Baker Hughes introduces automated vertical control in drilling

2001
Nissan introduces automated warnings for lane departures

2014
Tesla motors introduces cars equipped with commercial autopilot system

ABOUT THE AUTHORS

Matthias Gatzen

Executive Director,
Digital and Automation
Drilling Services

Matthias Gatzen spent years in global engineering and research roles before joining Baker Hughes Drilling Services in Germany in 2010 as a research and development engineer for innovative downhole technologies.

He is accountable for the company's global downhole digital business, which is built on a suite of applications that includes Drilling Automation Services, Next-generation Well Engineering Applications, and Advanced Analytics offerings. His focus is leveraging digitalization to drive efficiency, predictability, and safety in the field.

Gatzen holds a PhD in Engineering from the Leibniz Universität, Hannover, Germany.

David Holbrough

Senior Global Advisor,
Reservoir Navigation
Reservoir Technical Services

David Holbrough has been with Baker Hughes for more than three decades and has spent the majority of his career in operational roles focusing on top-tier reservoir navigation across all major basins.

From 2015 to 2020, he led the company's real-time advisory business in Europe and today leads cross-functional teams, directing future curriculum, software, and technology development.

Holbrough holds a BSc in Geology from the University of Exeter in the UK.

Hamid Karimi

Digital Product Manager,
Reservoir Navigation Services
Drilling Services

Hamid Karimi has worked for nearly 10 years on the product development team at Baker Hughes, developing adaptive navigation automation capabilities, finding ways to integrate multidisciplinary data to mitigate hazards, capture mapping uncertainties and position wellbores for optimal recovery.

In his leadership role as the Global Digital Product Manager for Reservoir Navigation Services, he is focused on developing and rolling out solutions that maximize reservoir contact while drilling.

Karimi earned a PhD in Geophysics at Durham University, UK.

The authors would like to thank Judy Murray and Stephen Scheffer for their editorial support and assistance. They also wish to thank Phil Casillas and Peter Schreiber for their design of this white paper and its illustrations.

FURTHER READING

Introducing Automated Advisory and Control Applications to a North Sea Jack-Up, Technology, Human-Centric Challenges and Resulting Performance Improvements at Scale
Matthew Forshaw; Sigve Hovda; John Macpherson
Paper presented at the SPE/IADC International Drilling Conference and Exhibition, Stavanger, Norway, March 2023.
Paper Number: SPE-212463-MS

Executing the Digital Well Plan - Enhancing Process Automation
Olof Hummes; John D. Macpherson; Kimberley Bone; Gaurav Marwah; Pedro Arévalo; Matthew Forshaw
Paper presented at the Middle East Oil, Gas and Geosciences Show, Manama, Bahrain, February 2023.
Paper Number: SPE-213726-MS

Automated Trajectory Drilling for Rotary Steerable Systems
Christian Hansen; Matthew Stokes; Ralf Mieting; Francesco Quattrone; Vanja Klemme; Karthik Nageshwara Rao; Ingolf Wassermann; Ralf Zaeper
Paper presented at the IADC/SPE International Drilling Conference and Exhibition, Galveston, Texas, USA, March 2020.
Paper Number: SPE-199647-MS

Automating Log Interpretation for Optimal Well Placement and Increased Drilling Efficiency
Fredrik Jonsbråten, Baker Hughes; Marianne Iversen, Kåre Røsvik Jensen, Monica Vik Constable, and Hilde Haktorson, Equinor; David Holbrough and Stefan WesslingHaktorson, Equinor; David Holbrough and Stefan Wessling
Paper was prepared for presentation at the 2022 SPE Annual Technical Conference and Exhibition, Houston, Texas, USA, October 2022.
Paper Number: SPE-210361-MS

Quantitative Analysis of Drilling Progress with Real Time Modelling
Simon Austin, Hermanus Nieuwoudt, Richard Tilsley-Baker, and Fredrik Jonsbråten
Paper was prepared for presentation at the Offshore Technology Conference held in Houston, Texas, USA, 30 April–3 May 2018.
Paper Number: OTC-28967-MS

What Next After a Decade With Significant Advances in the Application of Deep Directional Measurements?
Frank Antonsen, Berit Ensted Danielsen, Kåre Røsvik Jensen, Marta Prymak-Moyle, Jon Kåre Lotsberg, Maria Emilia Teixeira De Oliveira, Monica Vik Constable, Equinor ASA
Paper was prepared for presentation at the SPWLA 63rd Annual Logging Symposium, Stavanger, Norway, June 10-15, 2022.

Quality Control of LWD Resistivity Data Inversion Results
Yuriy Antonov, Mikhail Sviridov, Sergey Martakov, Nikita Tropin, and Henrik Andersson
Paper was prepared for presentation at the SPE Annual Technical Conference and Exhibition, Calgary, Alberta, Canada, 30 Sep - 2 October 2019.
Paper Number: SPE-195817-MS

Integration of Geosteering into an Automated Wellbore Placement Systems, Possibilities and Challenges
David Holbrough, Matthew Forshaw, Stefan Wessling, Saskia Idzerda, Ralf Gelfort, and Simon Austin
Paper was prepared for presentation at the SPE Middle East Oil and Gas Show (MEOS) Manama, Bahrain, February 19-21, 2023.
Paper Number: SPE-213714

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