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DRILLING OPTIMIZATION IN ROMANIAN GAS FIELDS USING ADVANCED DIGITAL TOOLS

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ABSTRACT

The continuous evolution of the energy industry, driven by decarbonization goals and digital transformation imperatives, has led to significant advancements in drilling operations. This article explores the integration of advanced digital tools, real-time monitoring systems, predictive analytics, and automated drilling rigs as key enablers of operational excellence in upstream activities. A comprehensive overview is provided on how closed-loop digital workflows, adaptive control systems, and automation technologies have improved drilling efficiency, reduced non-productive time (NPT), enhanced safety, and supported environmental sustainability efforts.

The paper presents an in-depth case study conducted in a Romanian gas field, where targeted drilling optimization initiatives were implemented across multiple well sections. In addition to digital enhancements, the use of Non-Aqueous Drilling Fluids (NADF) was a decisive factor in overcoming geological challenges associated with reactive shales and unstable formations. Compared to conventional Water-Based Muds (WBM), NADF systems delivered superior wellbore stability, reduced filtrate invasion, higher rate of penetration (ROP), and improved compatibility with directional drilling.

Through real-time parameter adjustments, connection efficiency improvements, surveying strategy optimization, and dynamic management of critical-path activities, cumulative time savings exceeding five rig days per well were achieved. The study also highlights the benefits of predictive maintenance, adaptive drilling practices, and digital twin simulations as future avenues for further optimization.

The findings demonstrate that a strategic approach combining advanced technology, high-performance drilling fluids, real-time operational intelligence, and continuous improvement frameworks can substantially enhance drilling performance, reduce costs, and support sustainable field development. The article concludes by identifying future focus areas such as adaptive drilling systems, machine learning-driven predictive analytics, expanded use of digital twins, and organizational standardization, offering a roadmap for achieving resilient and competitive drilling operations in the context of the global energy transition.

Keywords: Drilling Optimization, Digital Transformation, Automated Drilling Rigs, Real-Time Monitoring, Rate of Penetration (ROP), Invisible Lost Time (ILT), Non-Productive Time (NPT), Casing while Drilling (CwD), Drilling Performance Benchmarking, Upstream Digitalization, Drilling Safety Enhancements, Non-Aqueous Drilling Fluids (NADF).

INTRODUCTION

The global energy industry is experiencing a paradigm shift, driven by the urgent need to decarbonize operations, increase operational efficiency, and accelerate digital transformation. In response to these challenges, upstream operators have increasingly focused on reimagining drilling operations through the strategic integration of advanced digital technologies, automated systems, and data-centric methodologies. These efforts aim not only to enhance drilling performance but also to improve safety, reduce environmental impact, and ensure the long-term sustainability of operations.

This paper examines the comprehensive application of digital workflows and automation in modern drilling activities, highlighting the transformative impact of innovations such as real-time data acquisition, predictive analytics, closed-loop optimization systems, and next-generation automated rigs. A significant emphasis is placed on the operational advantages gained through these technologies, including reduced non-productive time, improved rate of penetration (ROP), optimized resource utilization, and enhanced decision-making capabilities.

In parallel with digital advancements, the selection of appropriate drilling fluids has emerged as a critical factor in maximizing the benefits of automation and high-performance drilling. In geologically challenging environments, such as those characterized by reactive shales, variable pore pressures, and low formation stability, the use of Non-Aqueous Drilling Fluids (NADF) has proven essential. Compared to traditional Water-Based Muds (WBM), NADF systems offer superior inhibition properties, lower filtrate invasion, improved borehole stability, and compatibility with the high-efficiency demands of digital and automated drilling operations.

In addition to presenting an overview of the industry-wide adoption of digital drilling practices, the paper features an in-depth case study from a Romanian gas field, offering empirical insights into how detailed performance benchmarking, real-time monitoring, and systematic process optimizations combined with the use of NADF have led to substantial operational improvements. By analyzing drilling data across multiple well sections and operational domains, the case study provides a clear illustration of how targeted interventions, informed by advanced analytics, fluid engineering, and automation, can drive measurable enhancements in drilling efficiency and project outcomes.

Ultimately, the discussion sets the foundation for exploring future opportunities in drilling optimization, emphasizing the role of adaptive systems, machine learning algorithms, digital twin simulations, and enterprise-wide best practice institutionalization as key enablers of next-generation drilling excellence.

OPTIMIZING DRILLING OPERATIONS WITH ADVANCED DIGITAL TOOLS AND AUTOMATED RIGS

As the energy industry evolves under the imperatives of decarbonization and digital transformation, upstream operators have proactively redefined drilling operations through comprehensive digital transformation programs. These initiatives have enabled the integration of advanced digital technologies, automated systems, and data-driven methodologies, positioning drilling operations at the forefront of innovation within gas field developments.

A cornerstone of this transformation is the adoption of a closed-loop digital workflow, encompassing well planning, execution, and post-well analysis. Key components include integrated drilling management systems, collaborative planning platforms, real-time monitoring infrastructures, optimization tools, and automated drilling rigs. These elements enable real-time data acquisition, predictive analytics, dynamic operational adjustments, and continuous performance evaluation, ensuring optimized drilling performance and enhanced decision-making. Figure 1 presents an overview of drilling optimization opportunities, highlighting the impact caused by invisible lost time (ILT).

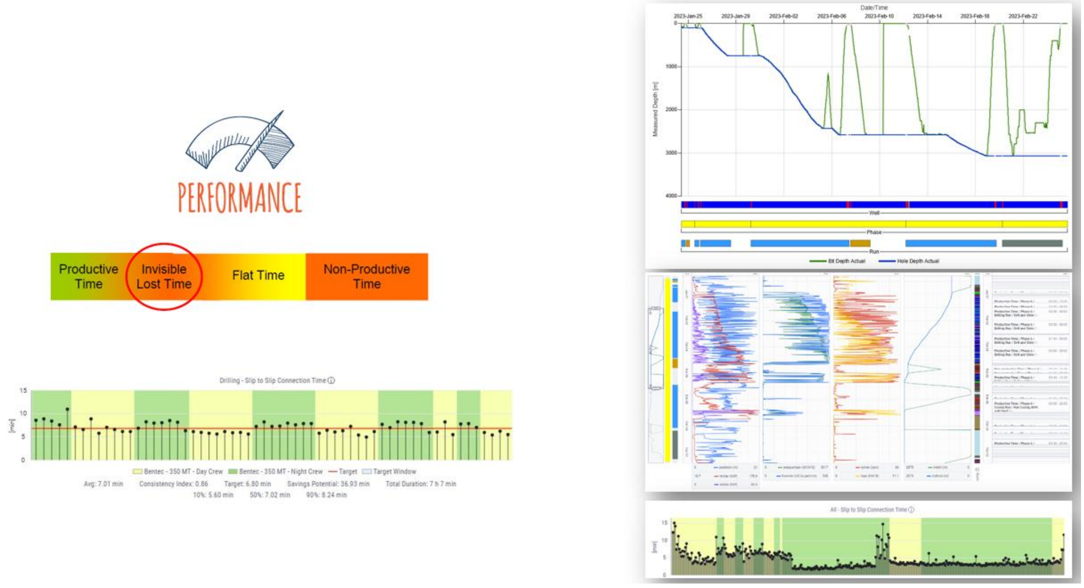

***Figure 1**. Optimization opportunities* [1]

The digitalization of daily drilling reports (DDRs) through integrated platforms has eliminated manual data entry, significantly improving data accuracy, consistency, and accelerating decision cycles [2]. Automated data ingestion processes allow operational teams to monitor deviations in real-time and implement corrective actions without delays. Advanced planning environments facilitate collaborative well construction planning by consolidating offset well data, geomechanical models, casing designs, BHA configurations, and drilling fluid programs, thus reducing planning times and inconsistencies across multidisciplinary teams.

Meanwhile, real-time monitoring platforms support continuous supervision, anomaly detection, and instantaneous performance corrections. They enable central operations teams to visualize rig activity, monitor critical events, detect early signs of dysfunction (e.g., stuck pipe, formation influx), and provide real-time support to field crews. This real-time supervision contributes to improved operational predictability, enhanced safety, and faster execution cycles.

A major breakthrough was achieved with the deployment of next-generation fully automated drilling rigs. These electric-powered, crane-less trailer rigs incorporate automated pipe handling, automated tripping sequences, dynamic drilling parameter adjustments, and high-frequency sensor data acquisition through dense instrumentation and fiber-optic communication infrastructures. The systems' automation and integration with cloud infrastructures have significantly reduced human intervention, minimized non-productive time (NPT), optimized connection practices, and improved overall safety standards. Real-time optimization of parameters such as Weight on Bit (WOB), Rotary Speed (RPM), Mud Flow Rate, and Standpipe Pressure based on live downhole feedback has yielded significant increases in rate of penetration (ROP) compared to conventional rigs, as evidenced by field benchmarking campaigns. Figure 2 shows the HM 150 automated rig installed at the wellsite.

***Figure 2**. Automatic Rig HM 150* [3]

Automated systems leverage pre-programmed drilling instructions based on offset well data and simulation outputs. These instructions are dynamically adjusted based on formation response, enabling automated transitions between drilling modes (rotary drilling, sliding, or geosteering) without manual intervention. Machine learning algorithms continuously process surface and downhole data [4] to predict optimal drilling windows, reduce stick-slip, mitigate vibrations, and prevent downhole tool failures.

The introduction of predictive maintenance algorithms based on real-time sensor feedback has enabled early identification of equipment degradation, allowing preventive interventions that minimize downtime and equipment failures. Field data highlighted substantial drilling time savings for the first batches of wells drilled using automated rigs, translating into major cost reductions. Continuous field upgrades, such as enhanced

TopDrive alignment, gripper modifications, and mud system optimizations, have further reinforced safety, operational reliability, and procedural consistency. Figure 3 presents an analysis of wells drilled with the automatic rig, highlighting the lithology and well profiles.

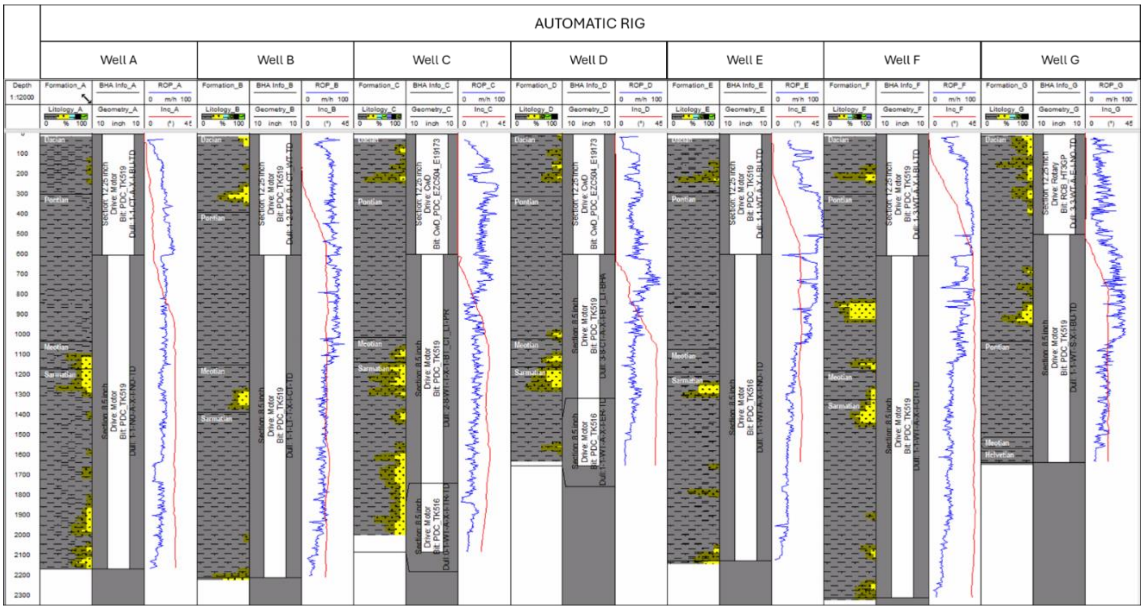

***Figure 3**. Performance analysis – Automatic Rig* [1]

Optimization efforts extend beyond equipment automation. Operators employ rigorous Key Performance Indicator (KPI) frameworks to monitor and benchmark ROP, flat time, tripping time, NPT, mechanical specific energy (MSE), and overall well delivery times [5,6]. Systematic analysis of mechanical and hydraulic parameters, supported by real-time dashboards and advanced analytics, enables proactive identification of optimization opportunities aimed at maintaining low MSE values and maximizing drilling rates [7,8,9].

Connection practices, traditionally a significant source of flat time, have been standardized across fleets, leading to more consistent and predictable operational outcomes. Automated slips-to-weight procedures, remote-controlled handling tools, and ergonomic improvements have collectively enhanced connection efficiency and safety [10,11].

Drill bit selection has been enhanced through real-time monitoring and historical data analytics, ensuring optimal compatibility with varying lithological profiles. Bit performance is further optimized through dynamic mechanical parameter adjustments during drilling operations [12]. Pre-spud engineering workflows include the use of simulation-based roadmaps that recommend specific operating windows for Weight on Bit (WOB), rotary speeds, and mud properties based on offset well benchmarking and expected lithology sequences.

Engineering workflows now integrate iterative feedback loops, digital twin simulations [13], dynamic lookbacks, and continuous improvement frameworks. Lessons learned from each well are systematically captured and institutionalized into best practice repositories, ensuring cross-team knowledge retention and operational standardization.

The results of these initiatives are multifaceted and significant:

- **Efficiency gains**: Well delivery times have decreased by several days per well through real-time performance tracking, dynamic drilling adjustments, and optimized operational sequences.
- **Safety improvements**: Automated systems have reduced personnel exposure to hazardous manual operations, leading to a measurable decrease in incidents, near misses, and ergonomics-related injuries.
- **Environmental benefits**: The electrification of drilling rigs has substantially reduced CO_2 emissions compared to diesel-powered rigs, supporting decarbonization strategies. Optimization of drilling performance has curtailed unnecessary fuel consumption, mud losses, and waste generation.

Overall, the experience demonstrates that the strategic integration of digital technologies and automated systems is critical for achieving operational excellence, organizational agility, and sustainability. By embracing scalable, data-centric operational models, upstream operators have set new benchmarks for drilling optimization in gas fields, showcasing a successful pathway for legacy energy companies transitioning to future-ready enterprises.

CASE STUDY ON DRILLING OPTIMIZATION IN A ROMANIAN GAS FIELD

A comprehensive case study was conducted to evaluate drilling optimization initiatives in a Romanian gas field, focusing on detailed performance benchmarking and operational practices across multiple well sections. Through depth-matched comparisons of the rate of penetration (ROP), significant operational insights were uncovered, providing a foundation for targeted performance improvements across the field.

The analyzed wells were constructed with a standard casing program. A 16" section was drilled for the surface casing, providing initial well integrity and isolation. The intermediate casing was run through a 12-1/4" section and with an 8-1/2" section. The production interval consisted of a 6" section, which was frequently under-reamed to 7" to facilitate the installation of a production liner.

In the 12-1/4" section, ROP exhibited considerable variation between wells, primarily driven by differences in operational techniques and practices. A notable enhancement was observed when transitioning from manual to automated Weight on Bit (WOB) application, which resulted in an increase of ROP from 26.9 m/h to 32.6 m/h. This improvement translated into an average of approximately 5 hours saved per well, demonstrating the tangible benefits of automation. Further analysis indicated that aligning drilling practices with formation-specific target ROPs was critical for maximizing efficiency. For instance, maintaining ROPs above 35 m/h in Dacian formations and exceeding 38 m/h in Pontian layers consistently delivered the best drilling performances (Figure 4).

Extending the analysis to the 8-1/2" section revealed even greater opportunities for optimization. In this section, average ROPs improved dramatically, from 19.3 m/h to 36.2 m/h, leading to cumulative time savings exceeding 30 hours per well. It became increasingly evident that inconsistencies in operational practices, such as varying wiping and reaming routines and non-standardized parameter staging, had a substantial impact on drilling performance. Targeted improvements in formations such as the Meotian and Sarmatian 7 layers, where optimal practices achieved ROPs exceeding 48 m/h and 51 m/h respectively, further underscored the criticality of operational consistency and formation-specific optimization (figure 5).

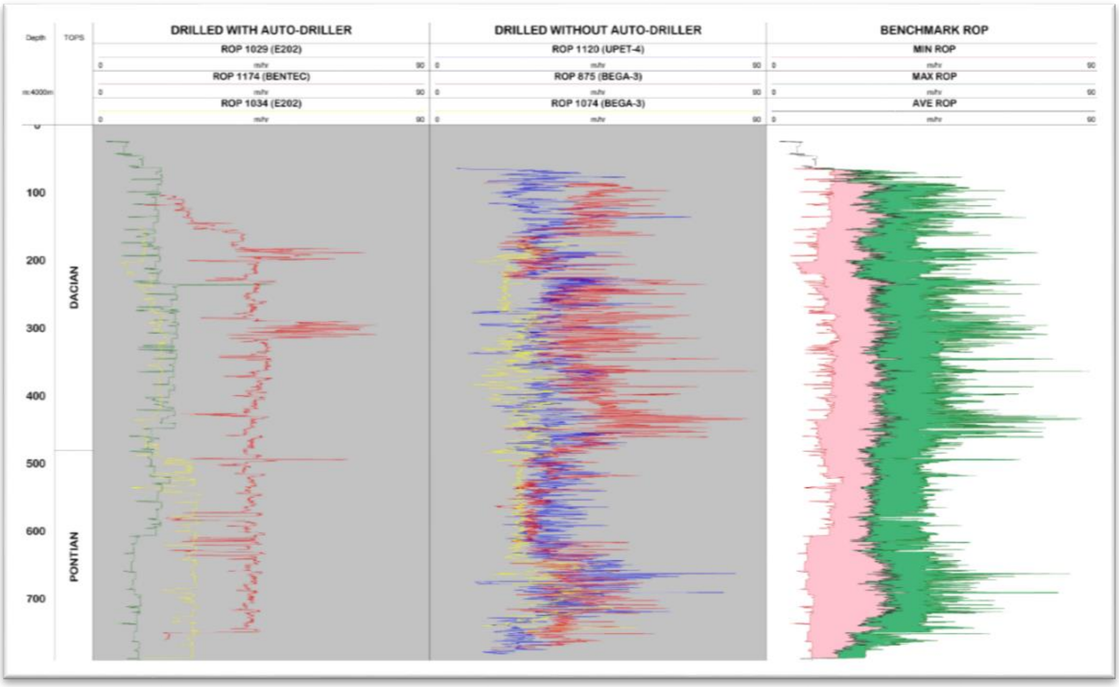

***Figure 4**. 12-1/4" Section – depth-matched best of best ROP*

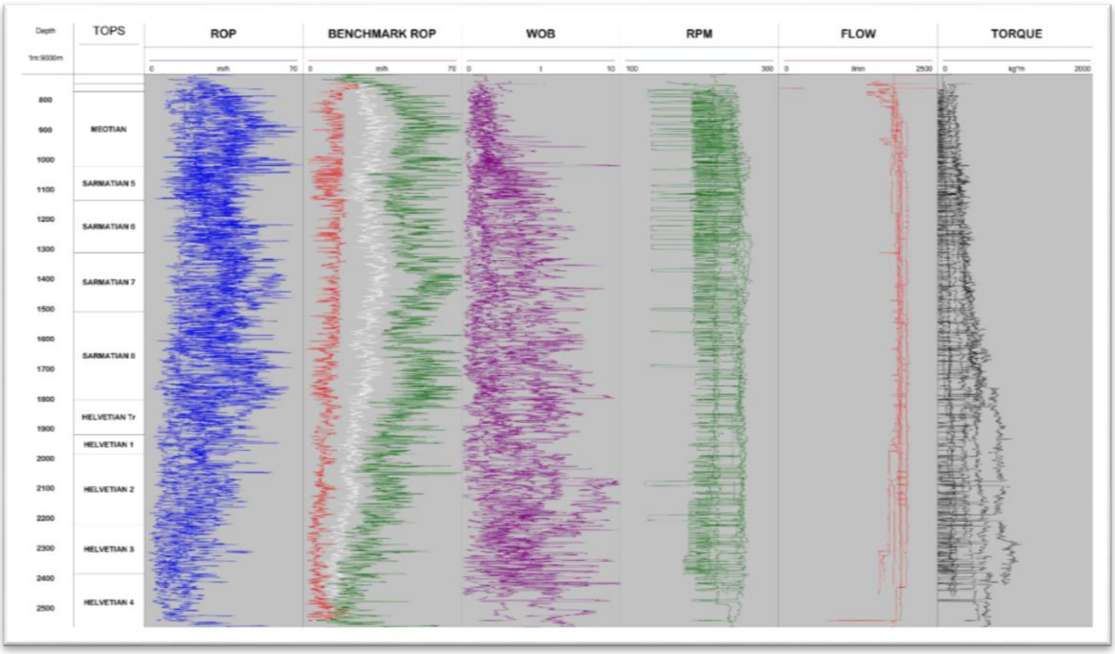

***Figure 5**. 8-1/2" Section – depth-matched best of best ROP*

The evaluation of the 6" sections (figure 6) focused on the comparison between different drilling methodologies, namely dedicated under-reaming versus simultaneous drilling and under-reaming operations.

The combined operations demonstrated superior outcomes, notably by reducing the number of trips and minimizing cumulative reaming time. Subsequent caliper log evaluations confirmed the effectiveness of this approach, indicating high borehole quality, minimal breakout occurrences, and an overall improvement in operational efficiency.

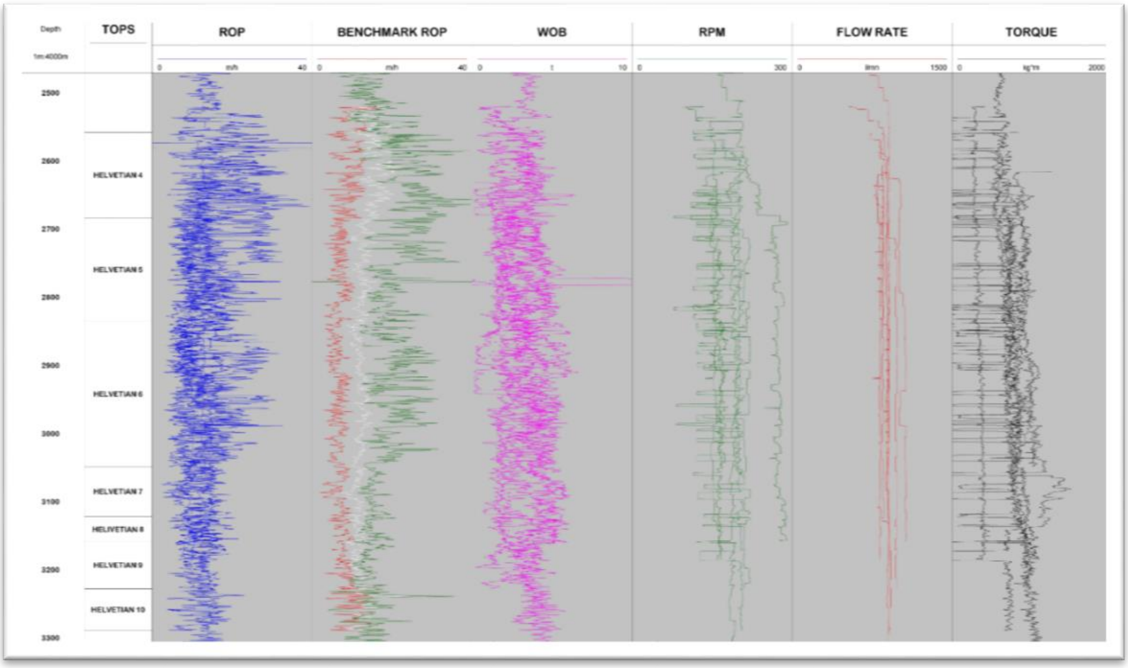

Figure 6. *6" Section – depth-matched best of best ROP*

Connection practices also emerged as a significant area for optimization. Detailed analysis revealed that up to 50% of the total connection time was consumed by the weight-to-slip phase, largely driven by unnecessary wiping and reaming activities.

By optimizing wiping speeds to 10 m/min and eliminating redundant reaming passes, substantial reductions in connection time were achieved. Additionally, enhancements in stand-down practices – specifically initiating immediate pick-up after drilling off 50% of the WOB – offered further time savings, estimated between 5 and 8 hours per well. Figure 7 shows the operations performed during drill pipe connections throughout the drilling process.

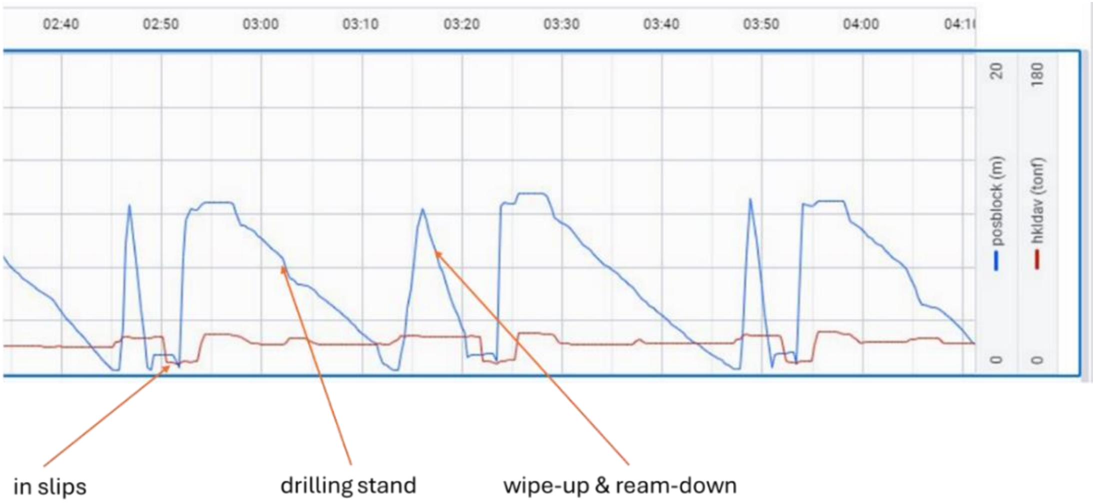

***Figure 7**. Optimization opportunities for connection practices*

Surveying practices underwent similarly rigorous evaluation. Routine surveys conducted every 20 meters were found to contribute significantly to non-productive time (NPT). Transitioning to selective surveying strategies, particularly in vertical and tangent sections, combined with the elimination of waiting times for signal reception, introduced potential time savings of up to 10.9 hours per well. These findings highlighted the value of a risk-based surveying approach tailored to wellbore trajectory characteristics.

Moreover, critical path interruptions due to downlinking operations were identified as a major source of invisible lost time. By strategically repositioning these downlinking activities to coincide with connection times, approximately 7 hours of non-productive time per well were effectively recovered, thus enhancing drilling continuity and operational flow. Figure 8 illustrates the invisible lost time associated with downlinking operations.

Comparative assessments of casing-while-drilling (CwD) operations further emphasized the importance of precise parameter management [14]. Wells that utilized optimized WOB and torque settings consistently achieved lower Mechanical Specific Energy (MSE) values, higher ROPs, and reduced bit wear, while simultaneously minimizing invisible lost time. These results underscored the benefits of real-time parameter adjustments based on formation responses and drilling dynamics.

Collectively, the findings from this case study demonstrate that an integrated management approach – encompassing ROP optimization, connection efficiency improvements, strategic surveying practices, and enhanced real-time operational monitoring – can deliver cumulative time savings exceeding 5.3 rig days per well. Such efficiency gains not only contribute to reduced drilling costs but also to improved overall field development timelines, offering a substantial competitive advantage in high-stakes drilling operations.

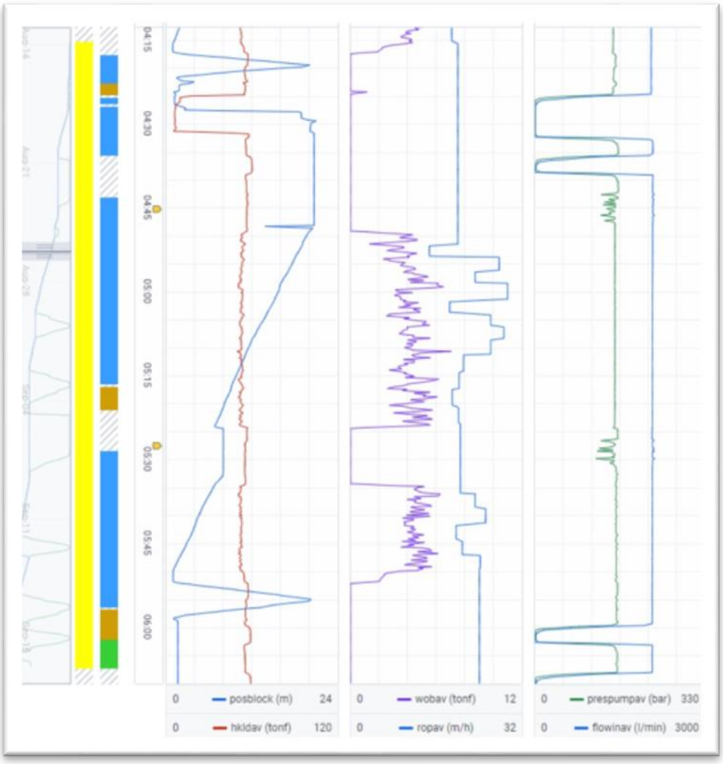

Figure 8. *Rotary Steerable System (RSS) critical-path downlinking time*

OPTIMIZING DRILLING FLUID SYSTEM

The development wells drilled in this gas field traverse geologically complex and mechanically unstable formations, specifically within the Upper and Lower Helvetian. These intervals are characterized by reactive clays interbedded with weakly consolidated sandstones and siltstones, leading to significant drilling challenges such as wellbore instability, stuck pipe events, circulation losses, and operational delays. In this context, selecting an optimal drilling fluid is critical to maintaining borehole integrity and achieving technical and economic success.

Non-Aqueous Drilling Fluid (NADF) systems, based on invert emulsions with a typical oil-to-water ratio of 75/25, offer superior performance in such formations. The continuous oil phase isolates water-sensitive shales from hydration, effectively preventing clay swelling, disintegration, and wall collapse. Additionally, NADF systems produce a thin, low-permeability filter cake composed primarily of oil, reducing differential sticking risks and minimizing filtrate invasion into the reservoir.

In the 8.5” sections, NADF demonstrates clear advantages over Water-Based Mud (WBM), which has shown poor performance in nearby offset wells due to limited inhibition capacity and high filtrate volumes. NADF maintains structural integrity during tripping, logging, and cementing operations. In the deeper 6x7” sections, where pore pressures vary and temperatures increase, NADF provides enhanced thermal stability and controlled fluid density (up to 1.30 SG) without inducing excessive Equivalent Circulating Density (ECD).

Operational benefits include increased rate of penetration (ROP) (figure 9), reduced tool wear, effective cuttings transport, and compatibility with rotary steerable systems (RSS) and reamer tools. Field data confirms the stability of rheological parameters, low high-temperature high-pressure (HTHP) filtrate values (<5 ml), and high emulsion stability (>500 V), ensuring wellbore cleanliness and reduced formation damage.

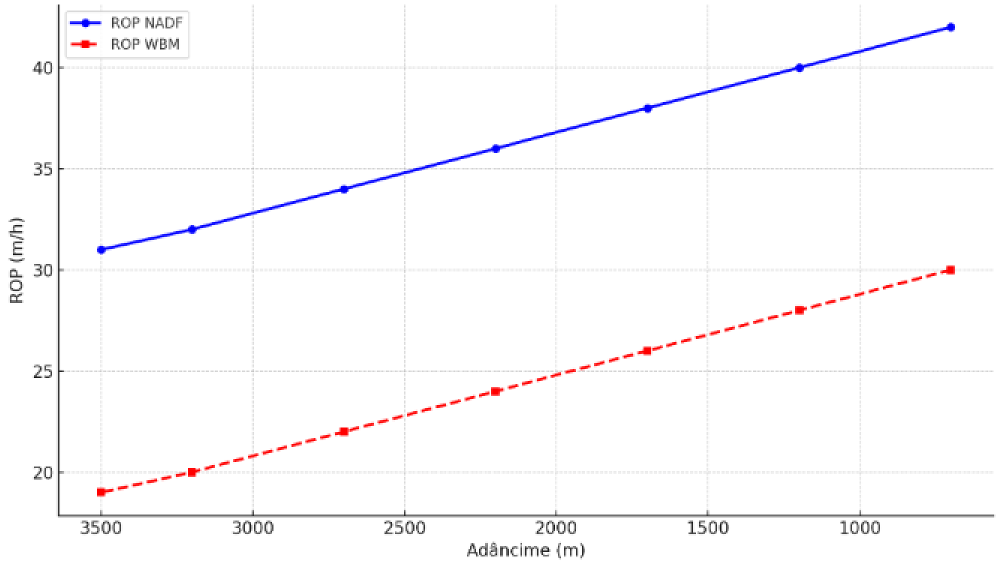

Figure 9. *ROP comparison NADF vs. WBM*

While WBM systems may offer lower initial material costs, their limitations in reactive and pressure-sensitive formations often lead to extended non-productive time (NPT), wellbore failures, and costly remedial operations. In contrast, NADF reduces drilling time, improves borehole quality, and can be efficiently recycled in a liquid mud plant (LMP), lowering the overall cost per drilled meter and per operational day.

Considering the geological risks and drilling objectives in this gas field, the use of NADF in the 8.5” and 6x7” sections is not only technically justified but essential for delivering safe, efficient, and high-performance drilling operations.

OPTIMIZATION RESULTS AND FUTURE OPPORTUNITIES

Enhancing the rate of penetration (ROP) through dynamic Weight on Bit (WOB) adjustments, revolutions per minute (RPM) optimization, and real-time parameter tuning proved to be a critical factor in achieving significant time reductions across all well sections.

Specifically, the application of these optimization techniques resulted in time savings of approximately 9 hours in the 12-1/4" section, 30 hours in the 8-1/2" section, and 17 hours in the 6" section. These outcomes highlight the importance of continuously monitoring and adjusting drilling parameters to align with evolving downhole conditions.

Connection efficiency also contributed notably to the overall time savings. By implementing optimized wiping and reaming practices, between 5 and 8 hours were saved per well. Rationalization of survey intervals, combined with streamlined data acquisition and processing, further yielded time savings of approximately 10.9 hours per well, underscoring the benefits of a risk-based surveying strategy tailored to specific wellbore profiles.

In terms of improvements to the drilling workflow, relocating Rotary Steerable System (RSS) and Measurement While Drilling (MWD) downlinking activities outside of the critical drilling path provided an additional estimated savings of 7 hours per well. This adjustment minimized interruptions to drilling continuity and enhanced overall operational efficiency. Furthermore, the elimination of unnecessary wiper trips – where formation stability data supported the decision – resulted in a reduction of drilling time by an additional 12 to 18 hours per well, particularly within the 8-1/2" section.

Another significant area of improvement was observed in Casing while Drilling (CwD) operations. Optimization of drill-out parameters, alongside efforts to minimize bit damage, contributed to a reduction in invisible lost time and an increase in the overall mechanical efficiency of the system [15]. This approach not only improved drilling speed but also prolonged bit life and enhanced overall well delivery performance. A summary of the key optimization results is presented in Table 1.

Table 1. *Key optimization results*

Optimization Area	***Estimated Time Saved per Well (hours)***
ROP Improvement (12-1/4" section)	9
ROP Improvement (8-1/2" section)	30
ROP Improvement (6" section)	17
Survey Optimization	11
Connection Efficiency Improvements	5–8
Downlinking Critical Path Removal	7
Wiper Trip Elimination (8-1/2" section)	12–18

The cumulative implementation of these initiatives provides a robust and scalable framework for reducing well delivery times and controlling operational expenditures. These efficiency gains not only translate to lower drilling costs but also improve project scheduling predictability, offering strategic advantages in competitive resource development environments.

Looking ahead, several strategic opportunities have been identified to further advance drilling optimization efforts. Future developments should prioritize the deployment of adaptive drilling systems capable of real-time parameter control, based on continuous live downhole feedback. Such systems would allow for immediate, data-driven adjustments to optimize performance and mitigate operational risks. Additionally, predictive analytics leveraging machine learning algorithms will play a pivotal role in future optimization strategies. These models will enhance proactive decision-making by forecasting ROP trends, optimizing trip schedules, and predicting bit wear patterns, thus further improving drilling efficiency and asset utilization.

The expanded use of digital twin simulations represents another transformative opportunity. Digital twins will enable dynamic pre-well planning, support real-time trajectory adjustments during drilling, and provide comprehensive post-well analysis, ultimately leading to improved wellbore quality and drilling performance.

Finally, operational standardization across teams and rigs, through the institutionalization of best practices, will be critical to ensuring consistency, scalability, and sustainability in drilling operations. Embedding these practices enterprise-wide will promote a culture of continuous improvement and operational excellence. A summary of the future optimization focus areas is outlined in the Table 2.

Table 2. *Future optimization focus areas*

Future Focus Area	***Objective***
Adaptive Drilling Systems	Real-time optimization of drilling parameters
Predictive Analytics	Proactive decision-making
Digital Twin Simulations	Enhanced pre-well planning and real-time support
Operational Standardization	Embedding best practices across the enterprise

The consistent application of these continuous improvement initiatives is expected to reinforce operational competitiveness, maintain high safety and quality standards, and contribute substantially to the long-term sustainability goals within the drilling sector. By embracing innovation and leveraging advanced digital technologies, the drilling industry can achieve more resilient, efficient, and environmentally responsible operations.

CONCLUSIONS

The systematic adoption of advanced digital tools and automation technologies has fundamentally redefined the operational framework for drilling activities, establishing new standards for efficiency, safety, and sustainability. Through the implementation of closed-loop digital workflows, integrated real-time monitoring systems, and predictive optimization platforms, operators have successfully transitioned from reactive to proactive drilling management models, enabling dynamic adaptation to downhole conditions and operational challenges.

The case study conducted in a Romanian gas field serves as a compelling demonstration of the value created by digitalization and automation. By optimizing rate of penetration (ROP), enhancing connection practices, streamlining surveying strategies, and relocating critical-path activities outside of the active drilling cycle, the operators achieved cumulative time savings exceeding five rig days per well. These efficiency gains not only translated into lower drilling costs but also improved overall project delivery timelines, safety records, and environmental performance metrics.

Moreover, the integration of real-time parameter tuning, predictive maintenance algorithms, and automated rig functionalities has significantly reduced invisible lost time (ILT) and non-productive time (NPT), while also mitigating risks associated with manual interventions. The electrification of automated rigs further contributed to the industry's decarbonization goals, demonstrating that performance optimization and environmental responsibility can be successfully aligned.

A key enabler of these performance improvements was the use of Non-Aqueous Drilling Fluids (NADF), which provided superior wellbore stability, low filtrate invasion, and enhanced drilling efficiency in geologically complex intervals. Compared to conventional Water-Based Muds (WBM), NADF systems offered greater inhibition of reactive shales, reduced differential sticking, minimized formation damage, and facilitated higher ROP with fewer incidents of stuck pipe or borehole collapse. Despite their higher daily cost, NADF systems proved to be more cost-effective over the entire drilling cycle, by reducing remedial operations, sidetracks, and downtime. Their compatibility with automated drilling systems and ability to maintain stable rheological properties under high pressure and temperature conditions further underscores their value in modern digital drilling environments.

Looking ahead, several strategic avenues for continued drilling optimization have been identified. The development and deployment of adaptive drilling systems, capable of adjusting operational parameters in real time based on continuous downhole feedback, will be critical to maintaining high-performance drilling trajectories. Predictive analytics, powered by machine learning algorithms, will further enhance the ability to forecast performance trends, optimize trip schedules, and extend bit life, contributing to even greater operational predictability [16].

The expanded application of digital twin simulations will revolutionize pre-well planning, real-time trajectory adjustments, and post-well performance analysis, facilitating a more integrated and resilient drilling approach. Equally important, the standardization of best practices across teams and drilling fleets will ensure that continuous improvement initiatives are systematically embedded within organizational cultures, promoting long-term operational excellence and agility.

In conclusion, the consistent and strategic application of digital technologies, automation, and data-driven methodologies – complemented by the selection of high-performance drilling fluids such as NADF – has proven to be a decisive factor in achieving superior drilling performance. By fostering a culture of innovation, leveraging advanced analytics, and prioritizing real-time operational adaptability, the drilling industry can confidently meet the evolving demands of the global energy transition, ensuring resilience, competitiveness, and sustainability in an increasingly complex and dynamic operating environment.

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