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Deployment of Automated Hole Cleaning Advisor Increases Adoption of Drilling Automation Applications at a Global Scale

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Abstract

Modeling of cuttings transport has been profoundly enhanced to become the backbone of drilling automation applications dealing with well control. This paper presents the evolution and adoption of a world-leading physics-based drift flux cuttings transport model, its deployment as part of a drilling automation application validated across the globe in different environments, and the tangible benefits delivered to drilling operations.

The drift flux cuttings transport model is part of a digital twin of the wellbore and equipment deployed in real-time to continuously assess the well condition. The model has evolved over the years to become a world-leading cuttings transport model. This paper presents the continuous development of technology following agile processes to promptly create tangible deliverables for drilling operations.

The digital twin is part of a drilling automation application deploying a more holistic and automated hole cleaning advisor. The transient model is executed on demand to produce updated cuttings transport results and the associated context for it. Such results are converted into relevant information for drilling optimization engineers, hence simplifying the decision-making process. The adoption of the service is assessed globally and discussing the different regions.

The automation application containing the physics-based cuttings transport model was deployed in several locations across the globe. Some of the most sensitive deliverables of this model are the concentration of cuttings, its behavior as they are transported to surface, and the estimation of time and flow rate to transport the cuttings to surface. This kind of context information has enabled users to make informed decisions to maintain the health of the operation and avoid stuck-pipe events. Users can better decide where and for how long to circulate the wellbore after drilling a section to reduce cleaning time without endangering the formation and avoiding stuck-pipe events.

Furthermore, the hole cleaning application provides a central and concise visualization to highlight regions with high cuttings concentration and increasing risk of stuck-pipe events. The field deployments in Latin America, Asia Pacific, North Sea, Middle East, and North America Land are presented as example. Such deployments span across high-pressure, high-temperature environments, managed pressure drilling (MPD), long lateral sections, among others.

The automated hole cleaning advisor assess the wellbore condition in real-time and enhances the ability of drilling operations to react to potential drilling risks related to poor hole cleaning, thus avoiding costly corrective actions. The integration of transient modeling with drilling automation enables a safer optimization of procedures.

Introduction

The oil and gas (O&G) industry continues the quest to reduce operational costs. Since 2020, the cost of producing a barrel of hydrocarbon has increased steadily for all types of assets onshore and offshore. For instance, the cost of producing a barrel of oil in offshore deepwater fields is expected to increase from USD 8.6 in the year 2020 to USD 11.62 in 2025 (Rystad Energy 2024). Also, the investment forecast for well construction is more or less flat with a small decline of 2% from USD 313 billion in 2023 to USD 303 billion in 2030, as presented in Fig. 1 (Rystad Energy 2024). Under such circumstances, any technology that contributes to increase performance and operability of different assets, while maintain process and environmental safety is highly in demand. The ultimate goal is cost reduction without harming the operation and the personnel.

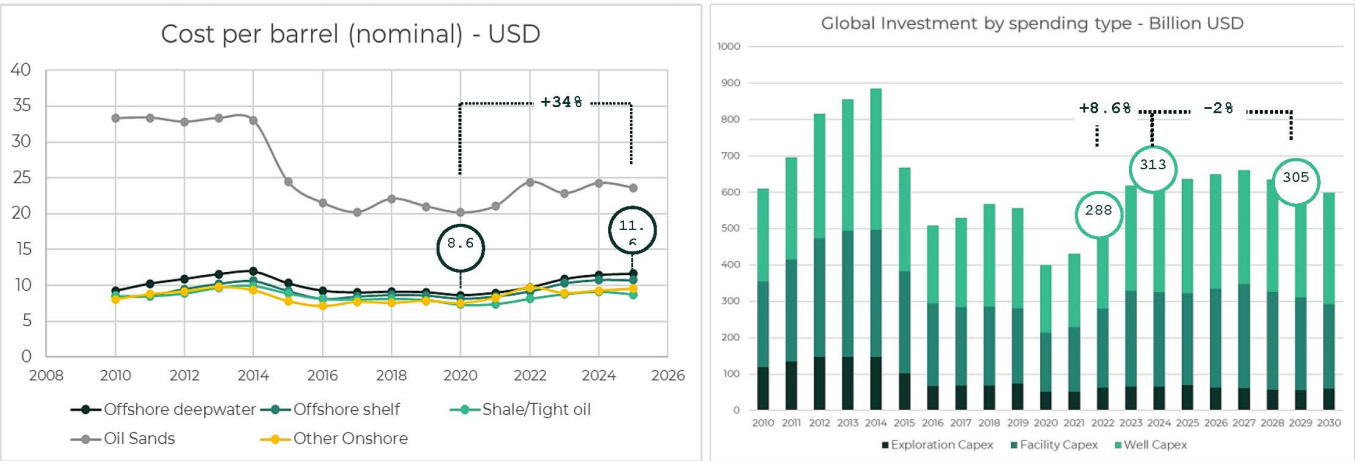


Figure 1—Overview of macro-economic environment for well construction. Left – Operational cost per barrel (nominal). Right – Global Investment. (Rystad Energy, E&P Macro Analysis, October 2023)

One of the main initiatives to improve the efficiency of existing processes while reducing costs is the digital transformation of operations, especially the migration from manual to automated processes, enablement of remote operations, de-man rig locations, and integrating digital assets across service companies and operators. Drilling automation and advisory services are some examples of dedicated technologies that aim to drastically reduce non-productive time (NPT), invisible lost time (ILT), while boosting performance. In this context, a holistic monitoring of hole cleaning state while drilling and circulating can greatly contribute to avoid costly events such as stuck-pipe. This paper presents the evolution of a hole cleaning monitoring application and its deployment at a global scale. The impressions of different users during the many years of deployment of the service have been instrumental in modifying the deliverables to facilitate the adoption of this and similar services. The hole cleaning monitoring application has become mainstream, and it catches attention of internal and external users. An example of the pre-job hole cleaning modeling is presented as starting point. Then, a case study from North America Land illustrates examples of hole cleaning monitoring. Afterwards, an assessment of global deployments is presented to discuss the adoption of the service. The paper concludes with a summary of the main take aways and a snapshot of the upcoming development in this arena.

The Inner Core of Hole Cleaning Monitoring: The Drift-Flux Cutting Transport Model

The current hole cleaning model deployed in real-time is the result of continuous evolution of the service under an agile software development umbrella. The physics-based drift-flux cuttings transport model considers the production of particles while drilling or reaming, the suspension of particles in the annular flow column, deposition of particles to form beds in the wellbore, and erosion of cuttings beds transforming stationary particles into suspended ones in the column of drilling fluid. A more detailed description of the model and its implications are presented in Starostin et al. 2022, Forshaw et al. 2022 and Aragall et al. 2022. Likewise, a detailed description of the deployment of such hole cleaning model is presented in Arévalo et al. 2022.

The same physics-based model is part of pre-job modeling and real-time modeling applications. In this fashion, application engineers can model the hole cleaning condition for a myriad of scenarios during pre-job, and then the same model will evolved when deployed in real-time, where the transient hole cleaning model is executed automatically and continuously using a feed of sensor data to provide more accurate predictions of concentration of stationary and suspended cuttings, as well as the associated density, and further advice derived from the hole condition, such as minimum flow rate to transport the array of cuttings in the wellbore. A simplified workflow for the execution of the model in real-time is presented in Fig. 2. A steady-state estimation of cuttings serves as initialization of the transient model, which is then executed periodically. Every iteration produces new results, which are stored, so that the next execution of the model can build on the previous results, as illustrated on the right side of the Fig. 2. The model is also equipped with recovery functions that prevent data loss in case of service interruption (i.e., connectivity issues or bad input data).

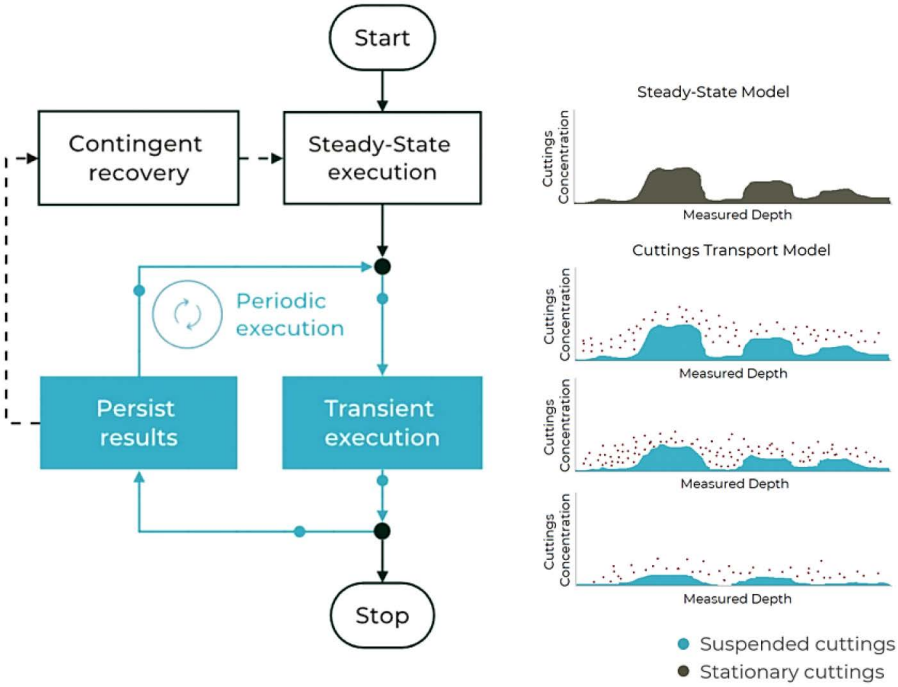


Figure 2—Simplified model execution workflow

The transient hole cleaning model has been deployed around the globe since its first introduction at the end of 2021. Since then, the model has evolved to increase its robustness and fidelity. Part of this evolution is a continuous validation of results. For instance, an in-depth analysis of the model was carried out in two separate regions: North Sea offshore and the Middle East onshore to corroborate the accuracy of the model.

The validation has been performed directly and indirectly. The direct validation compares the measured cuttings return with the modeled output volume, as presented in Fig. 3, where it can be observed that the modeled output volume has a good agreement with the measured cuttings return.

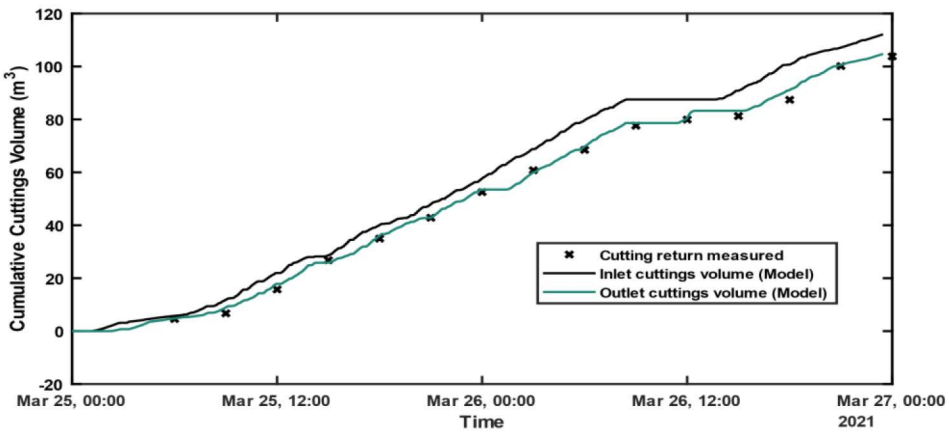


Figure 3—Direct validation: Comparison of measured and modeled cuttings return (Starostin et al. 2022)

In contrast to direct validations, where actual measurements are required, indirect validations can be performed by comparing variables that are easier to measure and that have a direct dependency on the output of the transient hole cleaning model, such as equivalent circulating density (ECD) while drilling. In this case, the modeled transient ECD is compared to actual density measurements from pressure while drilling (PWD) services deployed while drilling, as presented in Fig. 4.

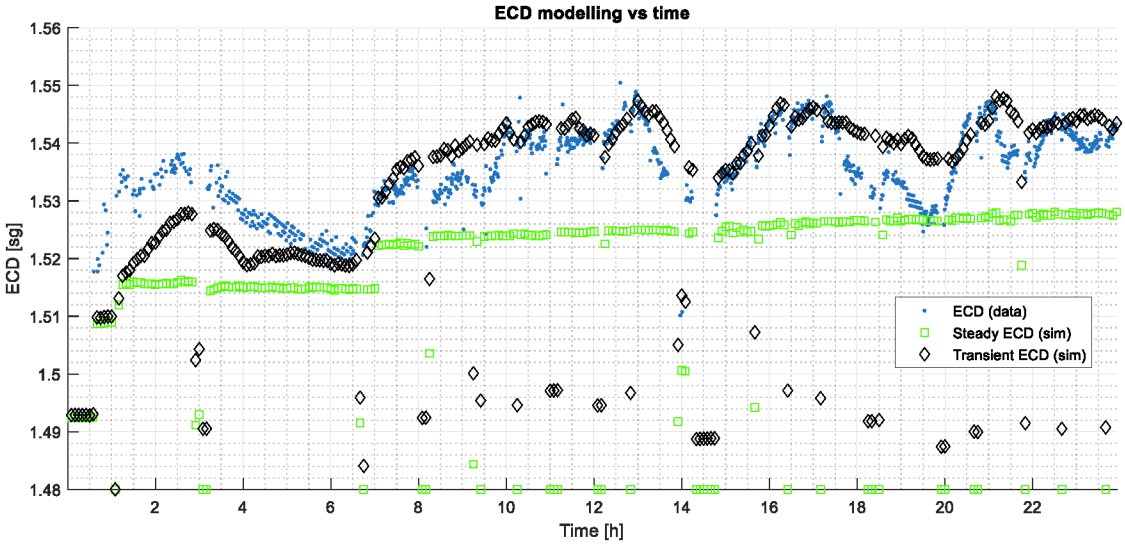


Figure 4—Indirect validation: Comparison of measured and modeled downhole ECD (Starostin et al. 2022)

The comparison includes steady state and transient hole cleaning models used as inputs for the calculation of ECD downhole. The modeled transient ECD has a good match with the downhole ECD. On the other hand, the modeled steady-state ECD follows the average trend of the density in the wellbore but it fails to depict the variations in real-time.

Overall, both forms of validations have been successful and consequently, a complete service has been built around the transient hole-cleaning model deployed in real-time. Currently, the advisory hole-cleaning service is deployed globally and its validation with a regional focus continues.

De-Risking Operations with Pre-Job Modeling

Pre-job modeling is of utmost importance to prepare an early verification of operational parameters, drillstring design, wellbore trajectory, among others before the actual drilling starts. The exercise of modeling downhole and surface response is a common practice in nowadays drilling operations. In the context of hole condition, simulating hole cleaning state and the response to changing surface parameters in a controlled environment allows application engineers and drilling engineers to de-risk upcoming operations by executing an early verification of the multiple pieces that compose a run plan (i.e., drillstring design, drilling fluid, surface parameters).

The hole cleaning model subject of this paper can be deployed in a pre-well environment as well as in real-time. Pre-well it has the benefit of extended computation capabilities that enables the model to run extended processes, such as sensitivity analysis, which is one of the most relevant analyses prepared during pre-job modeling or offset well analysis is the assessment of sensitivity of surface operational parameters on a defined outcome. In this case, the sensitivity analysis focuses on hole cleaning condition in terms of cuttings concentration along the wellbore, the annular velocity in the wellbore, and the required flow rate to transport cuttings to surface considering the main parameters used to circulate the hole clean: flow rate and rotation (RPM). The example below presents a hole cleaning sensitivity analysis for flow rate and RPM for a top-hole section in an offshore well in Asia Pacific. The analysis has been executed with a step size of 100 [gpm] of flow rate and 10 [rpm] for rotation. Fig. 5 illustrates the variation of flow rate and its impact on hole cleaning while drilling until the end of the section.

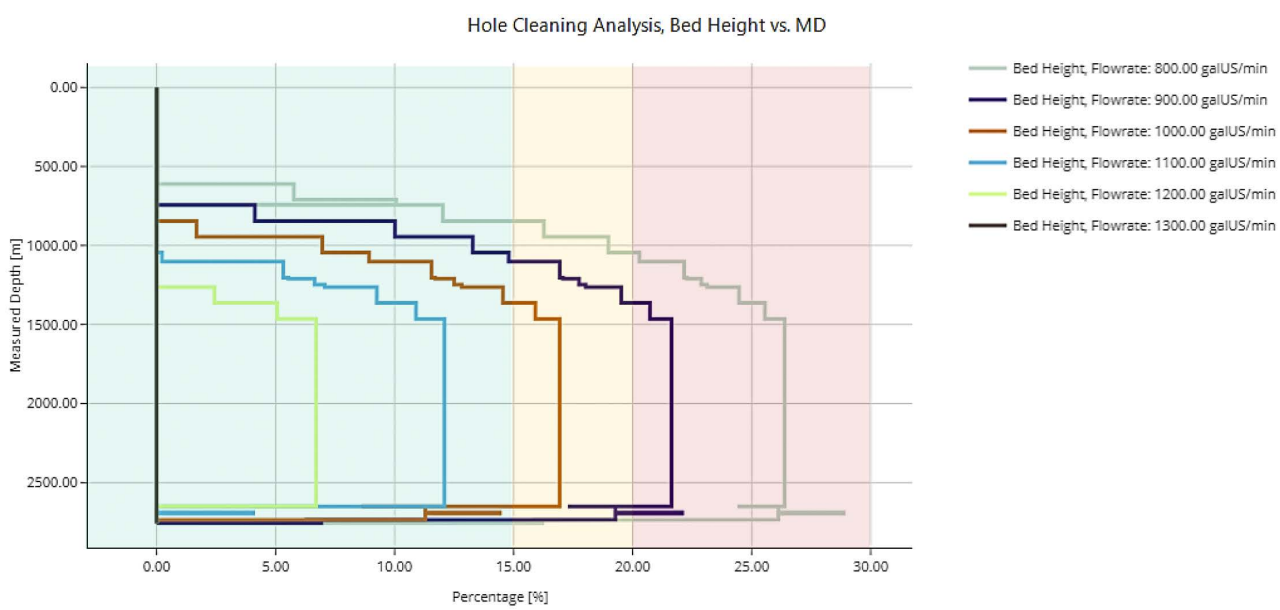


Figure 5—Hole Cleaning Analysis: Bed Height vs MD – Flow rate as varying parameter

In this particular example, operations tolerate up to 15% cuttings volume while drilling. Therefore, the viable options for flow rate are above 1100 [gpm]. In this case, the rig pumps were only able to provide a maximum flow rate of 1150 [gpm], therefore 1100 [gpm] was selected as the drilling flow rate, which would provide an estimate of 12% cuttings volume while drilling. Likewise, a similar analysis can be executed for rotation speed, as illustrated in Fig. 6 below.

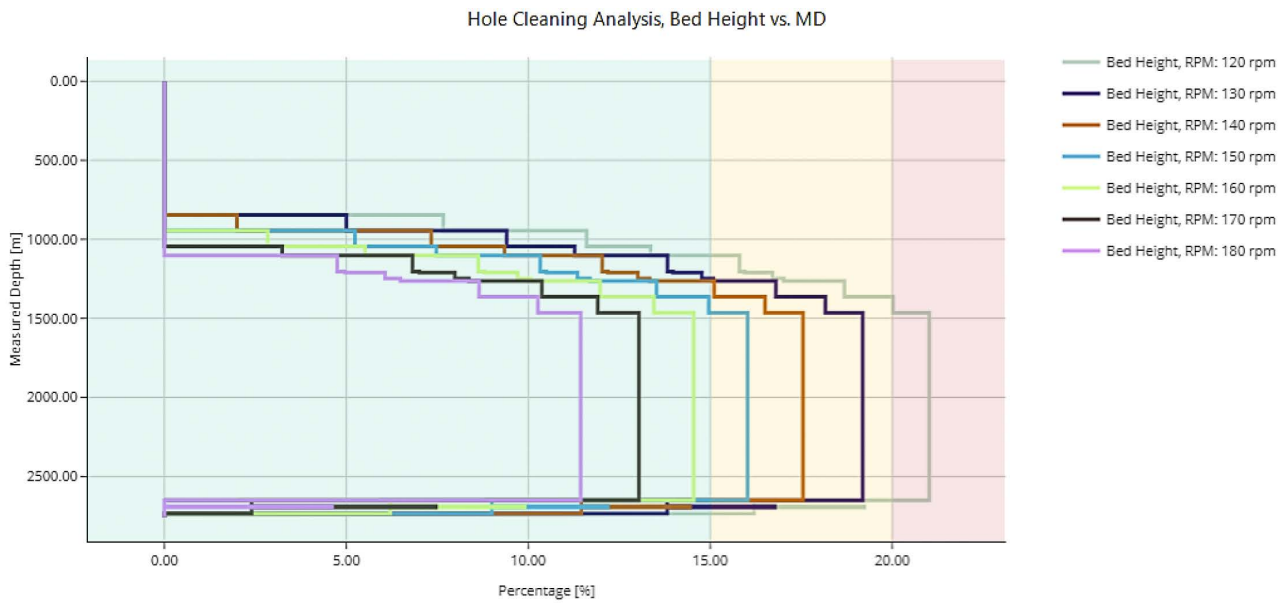


Figure 6—Hole Cleaning Analysis: Bed Height vs MD – RPM as varying parameter

Under the same conditions of operations accepting up to 15% cuttings volume while drilling, the only viable rotation speeds are above 160 [rpm]. The rig mechanical limit for rotation is well above this value, therefore, a value of 170 [rpm] was selected as the drilling rotation, which would create an estimate of 13% cuttings volume while drilling.

Once the parameters for flow rate and rotation are defined from the perspective of hole cleaning condition, they are verified against tool limitations, rig limitations, formation limitations by executing a single in-depth simulation of the well conditions using the selected parameters, as indicated in Fig. 7, where the expected cuttings beds and suspended cuttings are displayed. When using the selecting surface parameters, by the end of the section, the drilling activity would produce an estimated volume of cuttings of almost 11%.

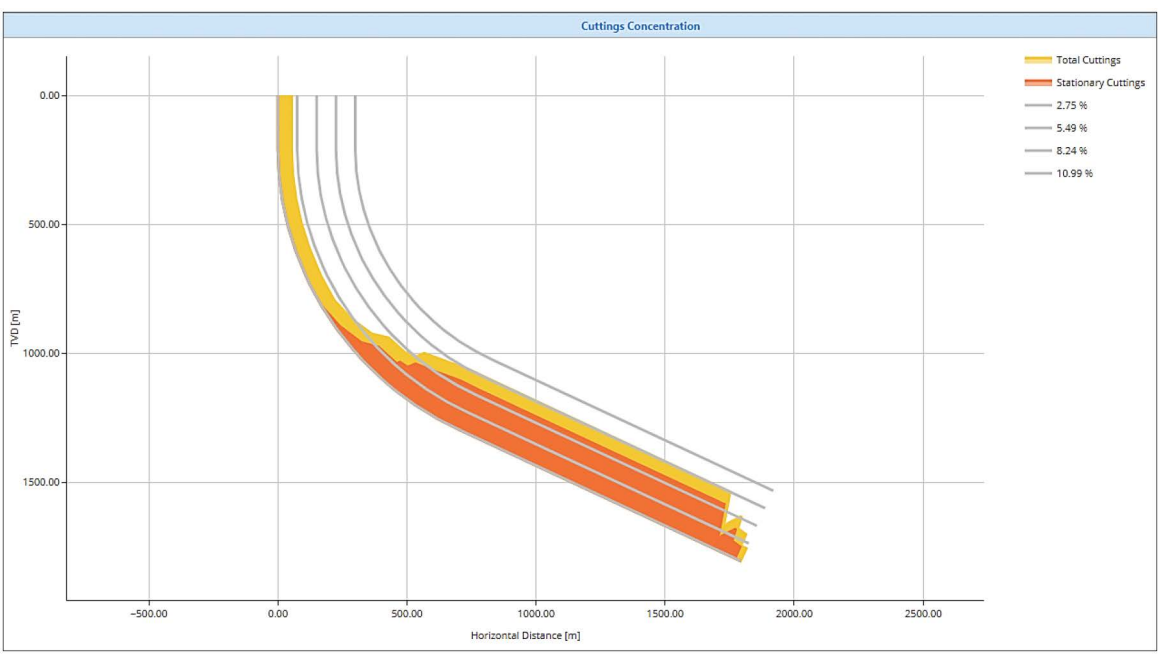


Figure 7—Pre-job verification of operational parameters in terms of hole cleaning

Similar analysis can be carried out for multiple wellbores in the same field to have a collective representation of hole cleaning condition in the pad, as indicated in Fig. 8, where two wellbores starting from the same position and drilled with similar parameters are compared.

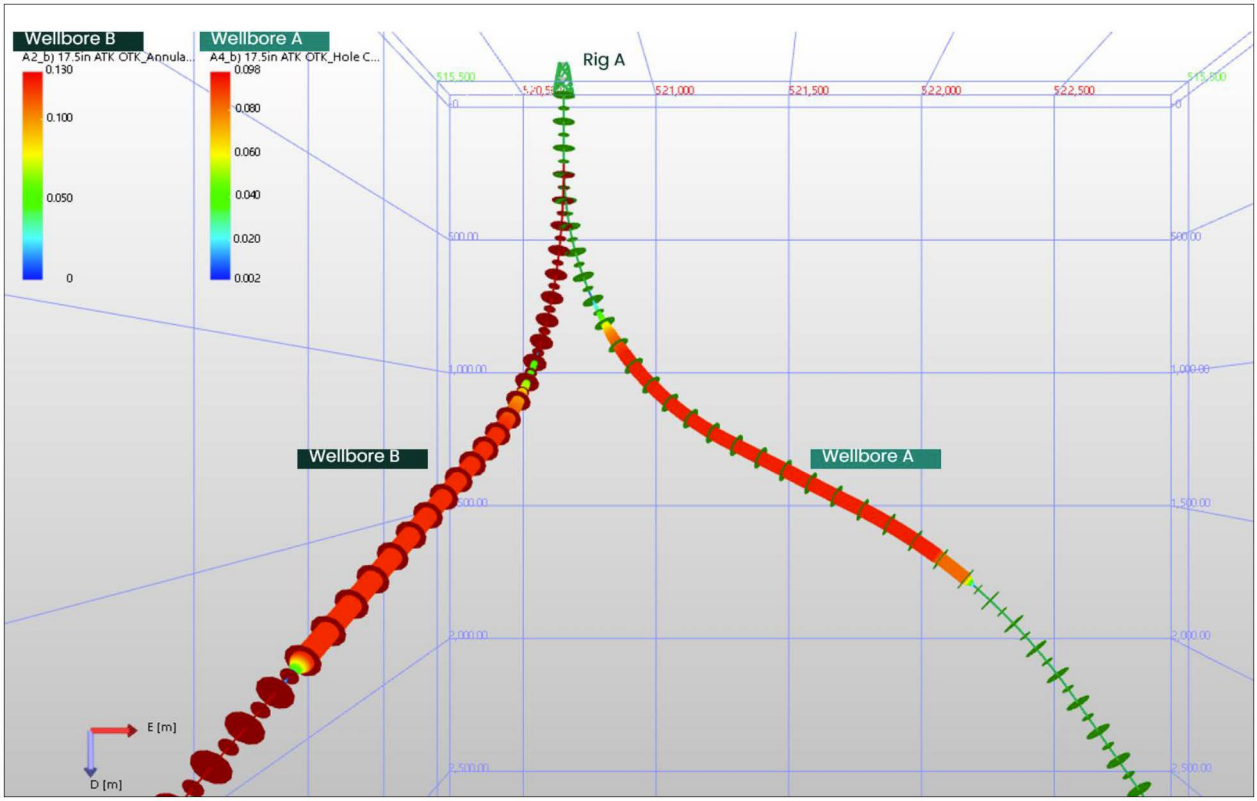


Figure 8—Representation of cuttings beds along multiple wellbores

Outer Layer of Hole Cleaning Monitoring: Automated Advisory Applications

While the hole cleaning model is a very important part of pre-job modeling applications and the inner core of real-time simulation services, a drilling automation application has been wrapped around the model to implement an automated monitoring system, which is denominated as automated advisory service. The advisory service deployed in real-time is the result of different building blocks that exchange information using a single aggregation layer based on the industrial protocol OPC UA, as presented in Fig. 9. A more detailed description of the system deployed in real-time is presented in Arévalo et al. 2021.

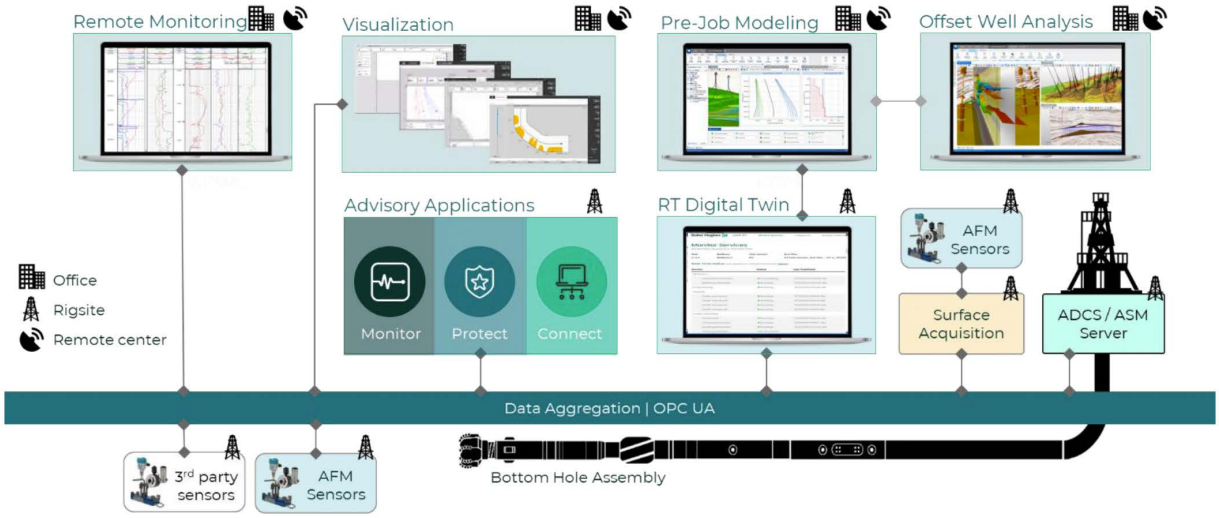


Figure 9—Overview of system components

The hole-cleaning service presents to the user the results of the continuous deployment of the drift-flux cuttings transport model and simplifies understanding of the influence of operational parameters in the creation, deposition, suspension, and further transport of particles to surface. The proposed approach to actively estimate and track the concentration of cuttings in the wellbore has been deployed around the world proving its validity. The results delivered by the model are greatly enhanced in deployments where automated fluid monitoring (AFM) units are present, since they produce measurements of the drilling fluid's properties in a matter of minutes. This frequent assessment of fluid properties helps to increase the accuracy of the physics-based hydraulics model in real-time. An example of the hole cleaning monitoring application is presented in Fig.10.

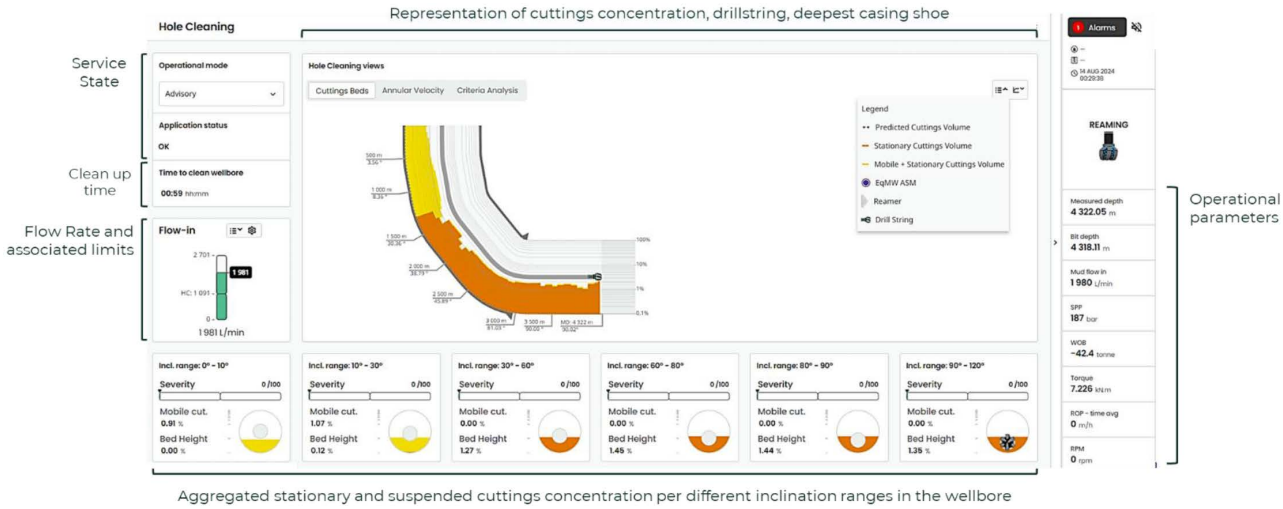


Figure 10—Hole cleaning monitoring application

The main deliverables of the hole cleaning advisor are the reduction of ILT by estimating the flow rate and time to circulate the well considering an accurate representation of cuttings in the wellbore, as well as NPT avoidance by monitoring ROP and warning users about excessive cuttings concentration that might lead to pack-off. Furthermore, since the hole cleaning advisor is deployed alongside a pressure regime module, it can estimate maximum flow rate limits to prevent damaging the formation or the rig pumps, and then notify users if such limits are exceeded.

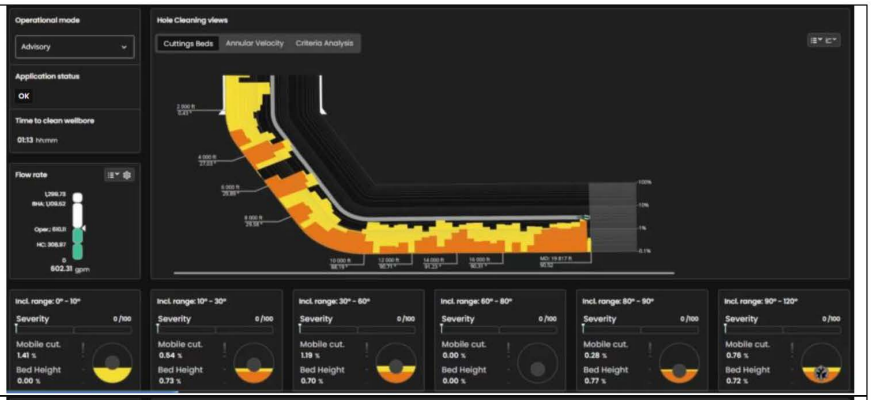
Deployment Example: Monitoring Long Laterals in North America Land

In North America Land, it is common to have wellbores with a long lateral section which is drilled in a single run for the curve, landing, and then the lateral until total depth (TD). Long lateral sections can pose a risk for stuck-pipe if hole cleaning is not adequate. The series of snapshots below summarize the deployment of the hole cleaning advisor to monitor the lateral portion of an 8.5 in section of over 12000 ft, with a reduced pressure window, which also imposed a top boundary for the flow rate to maintain formation integrity.

Table 1—Response of Transient Hole-Cleaning to Parameter Changes Over a Long Lateral Section

Scenario	Hole Cleaning Advisor
Drilling @ 10846 ft Flow rate: 602 gpm, ROP: 118 ft/h, RPM: 60 rpm - New suspended cuttings are created (yellow) as drilling continuous. - Drilling flow rate adequate for cuttings transport. **Monitoring:** - Minimum flow rate to transport cuttings: 309 gpm @ 60 rpm - Time to clean wellbore: 39 min - Beds in lateral: 0% - Beds in curve: 0%	
Connection @ 10948 ft Flow rate: 0 gpm, ROP: 0 ft/h, RPM: 0 rpm - Suspended cuttings settle and become stationary (brown) **Monitoring:** - Minimum flow rate to transport cuttings: 677 gpm w/o rotation - Time to clean wellbore: N/A - Beds in lateral (>80°): 5% - Beds in curve (30-80°): 2.5%	
Resume drilling @ 10954 ft Flow rate: 618 gpm, ROP: 236 ft/h, RPM: 60 rpm - Cuttings beds (brown) are eroded and lifted - Suspended cuttings (yellow) are produced while drilling. - Drilling flow rate adequate for cuttings transport. **Monitoring:** - Minimum flow rate to transport cuttings: 276 gpm @ 60 rpm - Time to clean wellbore: 42 min - Beds in lateral (>80°): 3% - Beds in curve (30-80°): 2%	

Continue drilling @ 10988 ft Flow rate: 618 gpm, ROP: 236 ft/h, RPM: 60 rpm - Cuttings beds (brown) are almost completely eroded and lifted - Suspended cuttings (yellow) are produced while drilling. - Drilling flow rate adequate for cuttings transport. **Monitoring:** - Minimum flow rate to transport cuttings: 330 gpm @ 60 rpm - Time to clean wellbore: 38 min - Beds in lateral (>80°): 0% Beds in curve (30-80°): 0%	
Continue drilling @ 12012 ft Flow rate: 618 gpm, ROP: 236 ft/h, RPM: 60 rpm - Cuttings beds (brown) undergoing erosion. - Suspended cuttings (yellow) are produced while drilling. - Drilling flow rate adequate for cuttings transport. **Monitoring:** - Minimum flow rate to transport cuttings: 309 gpm @ 60 rpm - Time to clean wellbore: 42 min - Beds in lateral (>80°): 0% Beds in curve (30-80°): 0%	
Continue drilling @ 17232 ft Flow rate: 602 gpm, ROP: 118 ft/h, RPM: 60 rpm - No cuttings beds. - Suspended cuttings (yellow) are produced while drilling. - Drilling flow rate adequate for cuttings transport. **Monitoring:** - Minimum flow rate to transport cuttings: 306 gpm @ 60 rpm - Time to clean wellbore: 1:02 hh:mm - Beds in lateral (>80°): 0% Beds in curve (30-80°): 0%	
Formation Integrity Alarm @ 18813 ft Flow rate: 618 gpm, ROP: 118 ft/h, RPM: 60 rpm - No cuttings beds. - Suspended cuttings (yellow) are produced while drilling. - Drilling flow rate adequate for cuttings transport. - Drilling flow rate higher than maximum to maintain formation integrity **Monitoring:** - Minimum flow rate to transport cuttings: 303 gpm @ 60 rpm - Maximum flow rate 616 gpm → action: pick-up off-bottom and circulate - Time to clean wellbore: 1:05 hh:mm - Beds in lateral (>80°): 0% Beds in curve (30-80°): 0%	

Continue drilling @ 19817 ft Flow rate: 602 gpm, ROP: 118 ft/h, RPM: 54 rpm - Cuttings beds (brown) undergoing erosion. - Suspended cuttings (yellow) are produced while drilling. - Drilling flow rate adequate for cuttings transport. **Monitoring:** - Minimum flow rate to transport cuttings: 309 gpm @ 54 rpm - Time to clean wellbore: 1:13 hh:mm - Beds in lateral (>80°): 1.5% Beds in curve (30-80°): 1.5%	
TD @ 20850 ft Flow rate: 602 gpm, ROP: 118 ft/h, RPM: 66 rpm - No cuttings beds. - Suspended cuttings (yellow) are produced while drilling. - Drilling flow rate adequate for cuttings transport. **Monitoring:** - Minimum flow rate to transport cuttings: 277 gpm @ 66 rpm - Time to clean wellbore: 1:18 hh:mm - Beds in lateral (>80°): 0% Beds in curve (30-80°): 0%	
Circulate off-bottom @ 20850 ft Flow rate: 634 gpm, ROP: 0 ft/h, RPM: 72 rpm - No cuttings beds. - Suspended cuttings transported to surface. **Monitoring:** - Minimum flow rate to transport cuttings: 277 gpm @ 66 rpm - Time to clean wellbore: 51 min - Beds in lateral (>80°): 0% Beds in curve (30-80°): 0%	

The example presented above illustrates how the hole cleaning monitoring service continuously advices users on parameters to circulate the hole clean, alarms about risk of damaging formation because of sudden increase of parameters, and also provides estimates of clean up time. The information delivered to the user via the visualization simplifies understanding of the drilling and circulation process and the effects of surface parameters in the overall hole cleaning condition. Furthermore, once the section reaches TD, the estimation of clean up time can significantly reduce ILT. When combined with torque and drag (T&D) advisor, the hole cleaning application provides a bigger picture of the wellbore condition in terms of material accumulating in the wellbore and excessive drag and torque caused by it.

The hole cleaning monitoring application can also be deployed with wired pipe sensors, or along-string measurements (ASM). Arévalo et al. 2022 describes this use case.

Adoption and Global Deployment

As described in Fig.11 adapted from Forshaw et al. 2023, adoption of drilling systems automation often faces resistance on initial introduction when the application is presented as a black-box system. Therefore, automation applications need to expose substantial amount of information to the end user to gain trust,

which positively affects acceptance. This technology development goes in the direction of grey or white box systems, where there is more transparency to users about the logic, settings, methods used to produce results.

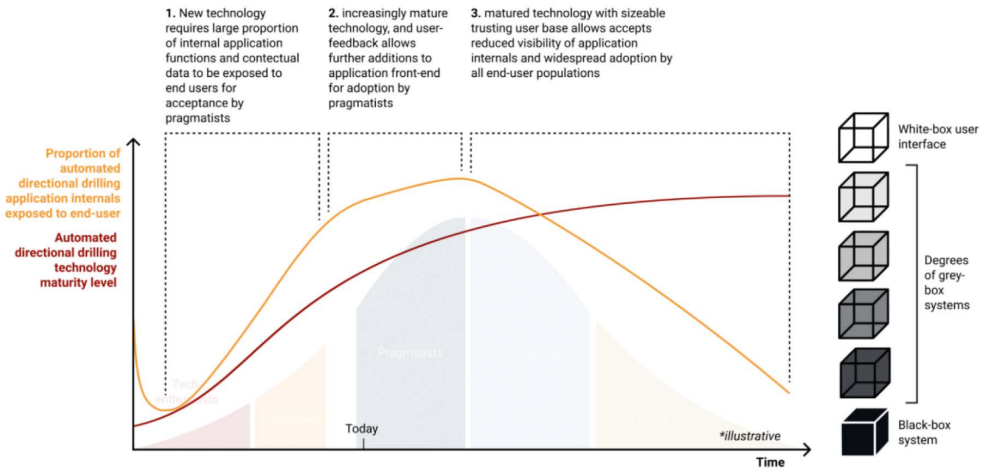


Figure 11—Automation technology maturity and proportion for application internals exposed to end-user (Forshaw et al. 2023)

As the technology becomes more mature and users are more familiar with it in the sense that they have learned to trust the application, then the amount of information put forth to the user can be reduced to be focused only on the content relevant for daily operations and to highlight any potential risk. In this case, the grey or white-box user interfaces trend back towards black-box approaches with an increased maturity of the system.

For the case of the hole cleaning monitoring application, global adoption has been achieved through continuous development in a close collaboration with operators and end users. The current version of the hole cleaning advisor deployed to the field has undergone a series of transformations in response to user feedback, market state, availability of technology, cost, among others. The most relevant stages in this transformation until the release of a stable transient hole cleaning advisor are listed in Fig. 12.

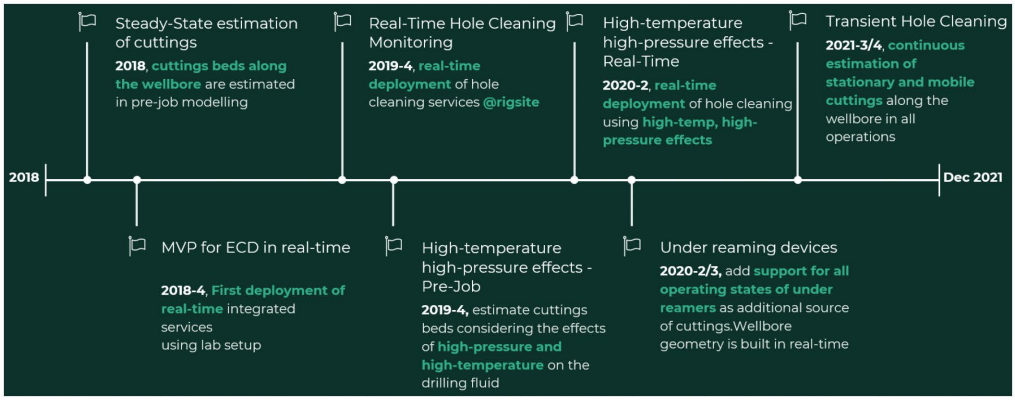


Figure 12—Evolution of modeling capabilities of hole cleaning physics-based model until reaching first holistic state.

Along this continuous transformation, the content presented to the user has been evolving over time until they feel comfortable using the hole cleaning and associated services. At this point, users can easily interact with the application and clearly recognize the value delivered by it. Furthermore, they get used to deploy such applications as a tool to simplify their daily job, which translates into trust, a very important precursor for adoption.

The first version of the hole cleaning advisor deployed in the field in Q4-2019 was built on previous steady-state models that had an additional layer to mimic transient behavior. Although this was a good

starting point, it was clear that accurate monitoring requires transient modeling enabled in a real-time environment. Following the first release of the application, parallel tracks of development started to cover three fronts: high-pressure and high-temperature effects on the drilling fluid, inclusion of cuttings produced by underreaming devices, drift-flux cuttings transport model. Out of those fronts of development the latter was by far the most representative and relevant: transient hole cleaning modeling. In Q3-2021, the first transient hole cleaning advisor was deployed in the North Sea with very positive feedback. Ever since, the model has been deployed globally with major usage in North Sea, Asia Pacific, Middle East, and Latin America (LATAM). Fig. 13 presents a snapshot of the distance drilled using drilling automation applications at a global scale highlighting the usage of the hole cleaning advisor as part of the deployments.

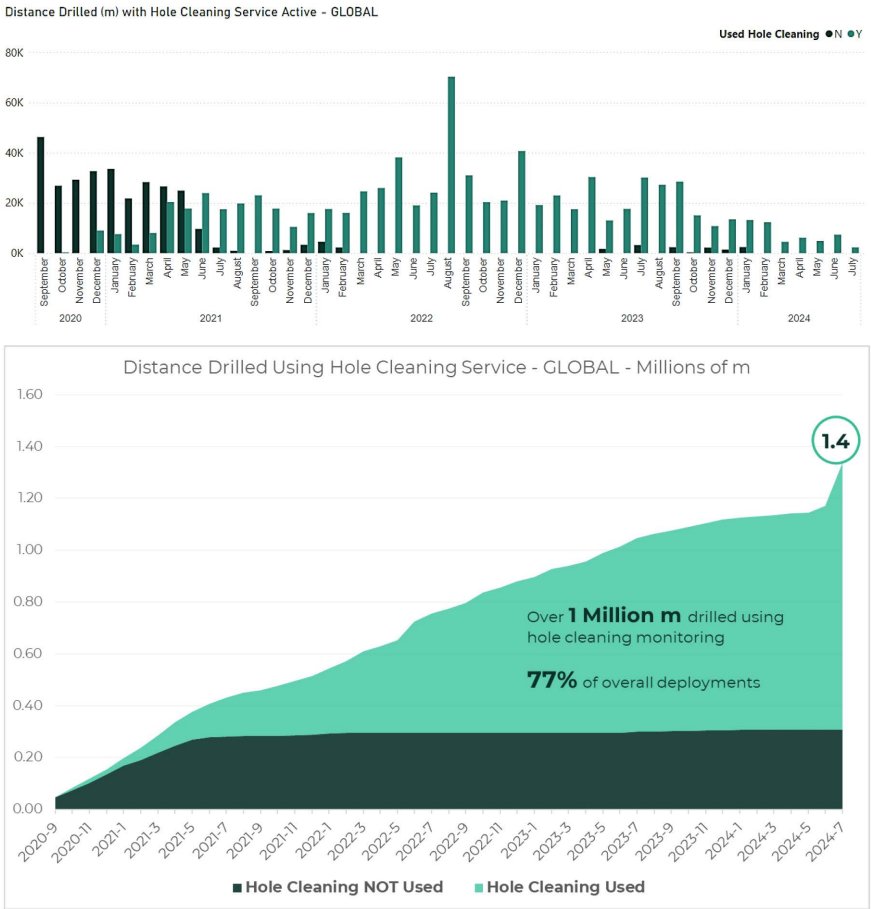


Figure 13—Distance drilled since introduction of the hole cleaning monitoring service. Top – Monthly, Bottom – Cumulative

Since the first commercial deployment of the service in Q3-2020, there have been over 1.4 Million meters drilled, out of which over 1 Million of meters were drilled using the hole cleaning monitoring application globally, which represents 77% of all deployments. Nowadays, the hole cleaning monitoring service is run in every single job.

At a regional level, the hole cleaning service was used first in the North Sea, which has proven to be an early adopter of drilling automation technologies. During the first deployments, the service was used in challenging well integrity scenarios involving high-pressure high-temperature influence on the drilling fluid, narrow density windows, multi-laterals. Afterwards, the next region picking up adoption was the Middle East, with a variety of deployments onshore. The next regions to follow were Asia Pacific, Africa, and Latin America (LATAM). In the last two years, many managed pressure drilling (MPD) deployments in Asia Pacific and LATAM have used the hole cleaning service as part of a more holistic advisory system

including T&D and density monitoring. Fig. 14, Fig. 15 and Fig. 16 present a snapshot of the usage of the hole cleaning service since its beginning to this date at a regional level.

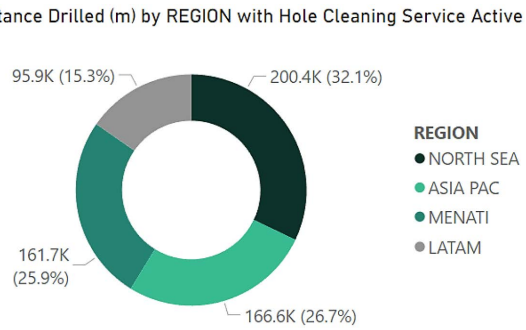


Figure 14—Distance drilled by region with hole cleaning service active

Figure 15—Distance drilled since introduction of the hole cleaning monitoring service per region. Top – North Sea, Middle-Top – Middle East, Middle-Bottom – LATAM, Bottom, Asia Pacific

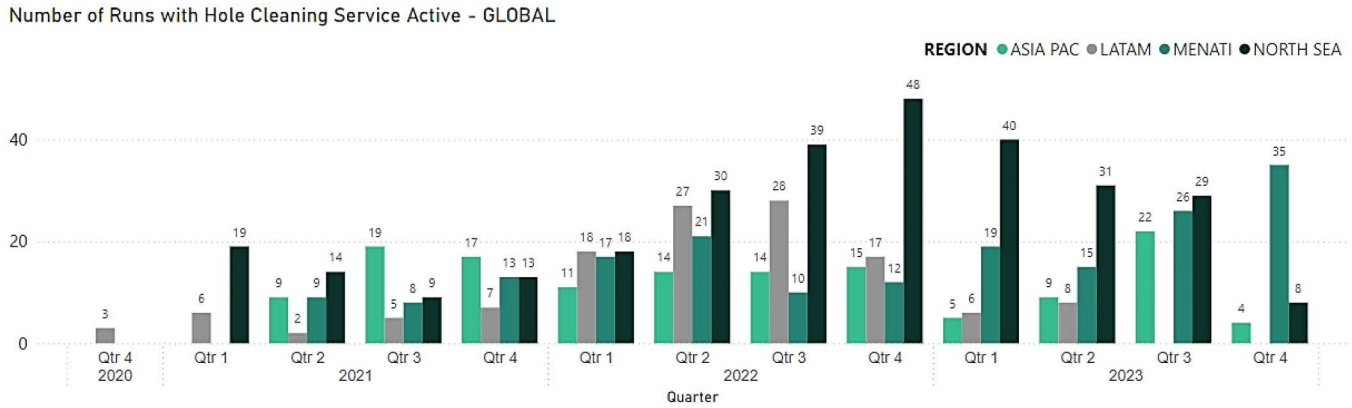


Figure 16—Historical number of runs drilled by region with hole cleaning service active

In the figures above, it can be observed that the hole cleaning service released in 2020 was not actively used in the regions. This version was built based on steady-state modeling. The next year, 2021, is when a transient cuttings transport model was introduced. This ability to dynamically represent the behavior of the cuttings transport operation was instrumental in crossing the chasm of acceptance in the regions. As a result, the hole cleaning service became mainstream as part of a more holistic advisory service combined with torque & drag (T&D), pressure regime and tripping optimization services. The fast inclusion of new technology into existing products was enabled by agile ways of working to shorten the time to market of new features.

Among the regions, the North Sea was an early adopter and operators invested in the development of drilling automation technology. This droves the adoption and usage in the region upwards having a peak of deployments in the 2022 and early 2023. The rest of the regions have been more cautious when adoption drilling automation technology. It's worth noting that, in the current year, 2024, Asia Pacific is showing a positive trend in the usage of drilling automation applications including hole cleaning monitoring.

Nowadays, the hole cleaning service is deployed in 100% of the runs, and its adoption is such, that the service is accepted as a daily tool to enhance the monitoring experience for Drilling Optimization Engineers (DOE).

Conclusions and Future Work

The O&G industry is heading towards a more efficient way of performing well construction operations by investing in digital technologies that can maximize the value of assets. One of the digital technologies contributing to unlock higher efficiency is drilling automation, which can greatly contribute to enhance performance while maintaining wellbore safety. The hole cleaning advisor subject of this paper is a relevant example of automated advisory deployments using physics-based models coupled with a layer of data-driven diagnostics to create a meaningful monitoring process. The deployment of such a monitoring system, increases the ability of monitoring applications to both predict and react to potential drilling risks related to poor hole-cleaning, thus avoiding costly corrective actions for operations. Mainly, the hole cleaning advisor can contribute to reduce ILT when circulating and identification of tight spots caused by excessive accumulation of cuttings in certain regions of the wellbore.

In terms of acceptance, advisory systems can cross the chasm once the user recognizes the value proposition of the application, learns how to use it and blends it into the daily operations. The hole cleaning monitoring application creates such user interaction by providing target visualization of cuttings concentration, annular velocity, required circulation parameters, and actionable alarms during the monitoring. Furthermore, when deployed along T&D and pressure-regime monitoring applications, a holistic monitoring and advisory service is achieved.

The upcoming development of technology will be focused on enabling application such as the hole cleaning monitor to be deployed in multiple setups (i.e., on premise, cloud-based, combination of edge-cloud), and to further integrate such applications with automated drilling control systems (ADCS) to configure its reaction to detected hazards, and to define automatically safe operating envelopes (SOE) for surface parameters.

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Nomenclature

ADCS	Automated drilling control system
AFM	Automated fluid monitoring
BHA	Bottom hole assembly
ECD	Equivalent circulating density
HPHT	High pressure, high temperature
ILT	Invisible lost time
MD	Measured Depth
ML	Machine Learning
MPD	Managed pressure drilling
MWD	Measurements while drilling
NPT	Non-productive time
OPC	Open platform communications
OPC UA	OPC unified architecture
PC	Personal computer
ROP	Rate of penetration
ROS	Remote Operations Systems
RPM	Revolution per minute
RT	Real-time
SOE	Safe Operating Envelope
SPP	Standpipe pressure
UI	User interface
WOB	Weight in bit

References

Arevalo, P., Forshaw, M., Starostin A., Aragall, R., Grymalyuk S. "Monitoring Hole-Cleaning during Drilling Operations: Case Studies with a Real-Time Transient Model". Presented at SPE Annual Technical Conference and Exhibition, Houston, Texas, October 2022. SPE-210244-MS. https://doi.org/10.2118/210244-M.

Forshaw, M., Hovda, S., Machpherson, J. "Introducing Automated Advisory and Control Applications to a North Sea Jack-Up, Technology, Human-Centric Challenges and Resulting Performance Improvements at Scale". Presented at SPE/IADC International Conference and Exhibition, Stavanger, Norway, March 2023. SPE-212463-MS. https://doi.org/10.2118/212463-M.

Arevalo, P., Hummes, O., Forshaw, M. "Integrated Real-Time Simulation in an Earth Model – Automating Drilling and Driving Efficiency". Presented at SPE/IADC International Conference and Exhibition (Virtual), Stavanger, Norway, March 2021. SPE/IADC-204069-MS. https://doi.org/10.2118/204069-M.

Aragall, R., Starostin, A., May, R. & Dahl, T. "Transient cuttings transport for real-time systems". Presented at Conference on Ocean, Offshore and Arctic Engineering OMAE, June 5-10, 2022, Hamburg, Germany.

Starostin A., Forshaw M., Aragall R., May R., Dahl T., Macpherson J. "Field Validation of a Full Transient Hydraulics Model Leveraging Digital Twin and Real-Time Rheology Technology, Case Studies from North Sea Continental Shelf". Presented at SPE Norway Subsurface Conference, April 2022. SPE-209568-MS. https://doi.org/10.2118/209568-M.

Forshaw M., Qahtani Y., Starostin A., Aragall R., May R., Dahl T. "Validation of Full Transient Hole Cleaning Model, with At-Scale Datasets, Implementation into an Automated Advisory System". Presented at Offshore Technology Conference, May 2022. OTC-32081-MS. https://doi.org/10.4043/32081-M.

Rystad Energy, E&P Macro-Analysis, August 2024. https://rystadenergy.co.

Drilling and Wells Interoperability Standards group (D-WIS). https://www.d-wis.or.