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MASTER'S THESIS

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Abstract

The industry down-time from the second half of 2013 and corona pandemic has effectively turned most companies into introduction of new technologies and digitalization. The industrial landscape is undergoing innovation, leading organizations to embrace fresh strategies in order to leverage emerging technologies.

Automation and automated work processes through the digital technologies are expanding through the life cycle of assets. The prevailing trend indicates that the competitive advantage of successful adapters is linked to automation, increase efficiency and safety, and add value to the asset. eDrilling is a global AI and digital twin software provider for the life cycle of drilling with mathematical- based model that represents the physical assets as the core technology. The suite of products comprises a transient hydraulic model, a mechanical torque and drag model, and a thermodynamic model. The models are embedded together which creates digital twin of a wellbore, in order to predict and optimize the drilling performance. The company is moving ahead with technology trend and recently developed a real-time parameter optimization software for drilling and tripping operations. This software leverages the concept of a digital twin, which is continuously calibrated in real-time, and perform lookahead simulations to optimize drilling parameters.

This thesis focuses on investigating the optimization of drilling parameters using the wellGuide software and its impact on work performance. The drilling process involves numerous variables that continuously and dynamically interact with each other. The study specifically examines the parameters optimized by the wellGuide software and their value-added impact on asset performance.

In order to evaluate the effectiveness of the software, field data obtained from real drilling operations is utilized. The lookahead simulations are subsequently analysed to assess their impact on value creation and work processes, as well as to gain insights into system design, human-machine interface, and the technical aspects of the wellGuide package. By examining relevant research papers and functional descriptions, a comprehensive exploration of the theoretical and practical considerations pertaining to the software and its functionalities is conducted. The findings and recommendations derived from this analysis are then discussed.

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Abbreviations and Acronyms	
AFM	automated fluid monitoring
AI	Artificial Intelligence
API	Application Programming Interface
BOD	Basic of Design
BHA	bottom hole assembly
BU	business unit
CAPEX	capital expenditure
DPM	Drilling performance module
DHT	Dynamic-temperatur-hydraulic
ECD	equivalent circulating density
ESD	Equivalent Static Density
FIT	Formation Integrity Test
FG	Fracture pressure
GUI	graphical user interface
HMI	Human Machine Interface
LOT	Leak-Off Test
MPD	managed pressure drilling
NPT	non-productive time
POOH	pull out of hole
PP	Pore pressure
ppg	pounds per gallon
RIH	run in hole
ROP	rate of penetration
RPM	revolutions per minute
SPP	stand pipe pressure
TD	Torque & drag
WOB	weight on bit

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1 Introduction

1.1 Background

With the advent of the digital age, the utilization of drilling digitalization and automation technologies has significantly increased. Initially, these technologies were applied to individual equipment pieces on the rig floor. However, in recent years, advanced solutions and applications have been developed to assist and guide drilling teams throughout the entire drilling process. The ultimate objective of digitalization and automation is to enhance safety, reduce costs, and improve overall performance.

The future vision entails achieving fully autonomous drilling operations, and digitalization plays a vital role in making this a reality. However, there are still several crucial steps that need to be taken before fully autonomous drilling can be implemented in a robust and reliable manner. These steps include addressing issues related to data sharing and quality, standardizing data formats, establishing trust in the system, handling unexpected situations, and ensuring the availability of experts to operate such systems. Furthermore, achieving fully autonomous drilling necessitates a close integration and seamless connection between surface machinery and downhole systems. Notably, older rigs often require substantial investments to be upgraded for automated drilling solutions, which can delay the automation or even semi-automation of drilling rigs.

To address these limitations and propel the digitalization and automation journey forward, eDrilling has taken the initiative to develop an automated real-time drilling optimization advisory system known as wellGuide. This solution serves as an automated advisory system that achieves the same objectives without the need for complete replacement or significant modifications. By leveraging wellGuide, potential savings can be achieved through reduced operational time, improved safety, and decreased reliance on experts (Lahlou et al., 2021).

1.1.1 Drilling efficiency considerations

As drilling activities continue to expand into more challenging environments, it becomes crucial to increase drilling efficiency in order to maintain lower operational costs. While the rate of penetration (ROP) is often discussed as a key factor in drilling efficiency, it should not be viewed as the sole indicator, but rather as as one among several drilling parameters, collectively influencing drilling efficiency (Mensa-Wilmot et al., 2010).

To improve drilling efficiency, it is essential to consider drilling parameters in a holistic manner, recognizing their interdependencies. Modifying any drilling parameter can have implications for other parameters, and in the worst-case scenario, can lead to operational issues and increased non-productive time (NPT) (Mensa-Wilmot et al., 2010).

To attain drilling efficiency, emphasis should be placed on achieving the lowest cost per section. Therefore, efforts to increase ROP and tripping velocities must be undertaken in conjunction with the optimization of other drilling parameters. These include flow rate, rotational speed, efficient hole cleaning, maintaining formation integrity, managing maximum equivalent circulating density (ECD) and surface pressure parameters, and adhering to tool limitations.

However, it is important to note that the conclusions may vary when dividing NPT and drilling efficiency by function and considering their related consequences. Excluding factors such as the rig, tools, and geological events, many drilling events and efficiency aspects can be linked to planned drilling parameter. Therefore, the utilization of real-time drilling software becomes critical in predicting drilling parameters, monitoring their values, and making adjustments accordingly to mitigate NPT events and improve drilling efficiency (Mensa-Wilmot et al., 2010).

1.2 The need of advanced and cost effective technology

In order to achieve economic benefits, drilling companies require advanced and cost-effective technologies to assist in lowering overall costs during the planning and execution of drilling operations. The time taken for planning and executing drilling processes is crucial for evaluating performance and budgeting. As the majority of drilling operation costs are time-dependent, reducing the time required directly correlates to cost reduction. Oil companies aim to measure and compare operational time while reducing incidents and the number of drilling operational days. Increasing the rate of penetration (ROP) and tripping velocity while ensuring well safety is a proactive approach to driving down operational costs.

Many operators of drilling projects have effectively controlled capital costs, specifically drilling expenditures, by prioritizing operational improvements. This includes reducing non-productive time (NPT) and enhancing drilling operational parameters through the application of past experiences and advanced technologies.

Drilling and completion projects typically represent 40% to 50% of the overall capital expenditure for each well, with approximately 70% to 80% of these expenses being time-dependent, particularly for offshore wells. Therefore, any reduction in well delivery time directly contributes to cost efficiency, as long as the well is delivered within its intended objectives (Brun et al., 2015)

	Well delivery process						
Improvement levers	Portfolio and rig strategy	Prospect maturation and high-grading	Wells engineering	Logistics and supply chain management	Drilling and completion execution	Hook-up and post-mortem learning	**Potentials,**[1] % of total well cost
Drive learning curves across the well delivery process	• Rigs to work on long series of similar jobs • Long range plans with strategic suppliers		• Planning teams to specialize on type of jobs		• Rig teams work on long series of similar jobs • Minimize rotation of crews		**20–25%**
Standardize and simplify specifications, designs, and processes		• "Perfect well" planning and estimation approach • Use of standardized wells as basis for 80% of portfolio	• Defined standardized well and options, based on drivers of costs				**10–15%**
Lean drilling execution					• Lean execution principles to drive down NPT • Drive actively operational efficiency	• Active planning and debottlenecking of hook-up toward asset	**5–10%**
Procurement and supply chain optimization	• Contracts incentivize real productivity improvements • Use down-turn to reduce unit costs			• Capitalize on standardized specs to drive down unit costs of procured services and equipment			**10–15%**
Rigorous performance management			• Active monitoring and target setting for engineering productivity		• Execution daily monitored against 'Perfect well'		**5–10%**
	10–15%	**5–10%**	**5–10%**	**10–15%**	**20–25%**	**3–5%**	**50%**

Figure 1.1: McKinsey drilling toolbox: Drilling spend improvement levers across the well delivery process, potentials and example improvements.

Figure 1.1 demonstrates that the primary driver for cost reduction is minimizing the reliance on human expertise, followed by standardizing and simplifying designs and processes. This can be accomplished through specialized personnel training or by utilizing advanced and automated technology to perform tasks. There are numerous advantages to using advanced and automated technology, including the ability to swiftly execute and analyse complex tasks, mitigating the risk of human error, and eliminating the need for experts to operate or interpret the results (Brun et al., 2015).

eDrilling is actively involved in the development and implementation of digitalization and digital twin solutions throughout the drilling life cycle. The focus of this thesis is to examine the current technology trends related to automated parameter optimization and automation in drilling operations, specifically by utilizing eDrilling' s latest product, wellGuide. Through conducting several case studies, the thesis aims to enhance the technology and its effectiveness.

The thesis has two primary objectives. Firstly, it aims to evaluate how wellGuide optimizes drilling parameters in real-time and provides added value to customers. Secondly, it investigates potential improvements to enhance the software by being more accurate. These improvements are crucial for adapting the product to different assets and ensuring its effectiveness across various operational contexts.

1.3 Scop and objective of the thesis

The objective of this thesis is to analyse the impact of advanced digitalization tools, with a specific emphasis on automation and automated drilling parameter optimization, within the oil and gas industry. The study is divided into two primary sections.

Firstly, case studies are conducted to utilize and test the wellGuide software, analysing its impact on value creation for the customer and the automation of work processes. These case studies serve as a basis for further investigating how eDrilling As can innovate and enhance the wellGuide software. This includes a comprehensive review of the software's technical aspects, as well as identifying areas for improvement and exploring potential possibilities.

The scope of the thesis encompasses highlighting important aspects of advanced digitalization tools in relation to automation and optimization. It aims to provide suggestions and potential solutions that delve into critical aspects and opportunities for further enhancements. By examining the impact and potential of digitalization tools, the thesis seeks to shed light on the significance of automation and optimization in the oil and gas industry and offer insights for future improvements.

1.4 Methodology

The methodology employed in this thesis consisted of an extensive literature review encompassing research papers, web articles, and reports pertaining to digital asset management and digitalization in the oil and gas industry. Special attention was given to real-time optimization and automation in drilling technology. Attendance and presentation at one SPE- automation conference also provided valuable insights into the industry's current technology and future prospects.

The study extensively examined eDrilling, including its history, vision, and core technology, through various sources such as published articles, discussions with employees, and hands-on experience with the products. The writer also had the opportunity to be part of the development team working with the utilized software. Then, the study continue on case studies by systematically utilizing the wellGuide on the collected data that can provide optimized operational parameters. The case studies was from operations from two major Oil and Gas operators, one in Norway and one in middle east. According to Liyanage, Jawad (2009), case study methods offer a robust approach to investigate real-life situations, allowing researchers to uncover meaningful insights and contribute to a deeper understanding of complex phenomena. The findings from these case studies served as a basis for proposing further improvements to the software.

By implementing this methodology, the thesis aimed to establish a holistic comprehension of the digitalization landscape within the oil and gas industry. It sought to evaluate the efficacy of eDrilling's software through practical implementation and offer recommendations for potential improvements based on the findings obtained.

1.5 Limitation of the study

It is acknowledged that no concept is universally applicable and comes without limitations, and the same holds true for this thesis. The scope of this thesis is confined to the eDrilling product, wellGuide within the context of using digital technologies for real-time automation and optimization of drilling parameters.

While considering drilling parameters, it is recognized that all surface equipment utilized during drilling and downhole parameters should be taken into account when developing digital and automated products. However, the scope of this thesis is limited in its ability to encompass all aspects, even though they are mentioned. Instead, the focus is placed on exploring the wellGuide software's capability to automate and optimize specific drilling parameters and how it contributes value to the business asset.

Furthermore, due to market sensitivity and limitations, no other similar software has been utilized or tested in conjunction with wellGuide. As a result, the study relies on analysing wellGuide results in conjunction with actual operational drilling parameters and pre-planned simulation results performed by third party software's.

By acknowledging these limitations and focusing on the specified scope, this thesis aims to provide valuable insights into the automation and optimization of drilling parameters using the wellGuide software and its impact on business assets.

1.6 Content of the thesis

Chapter 1: This chapter serves as the introduction to the thesis and outlines the challenges and objectives that will be addressed. Additionally, the methodology used in the thesis is explained, and any limitations are discussed.

Chapter 2: This chapter starting by describing shortly the relationship between Industrial asset management and digitalization and afterwards moving to the digitalization history in the oil and gas industry and use of digital twin during drilling operations in real-time. The chapter also takes us into the some of the most important drilling parameters that are necessary for wellGuide to perform automated real-time optimization simulations.

Chapter 3: This chapter provides an overview of eDrilling, including their background, technology, and current offerings to the industry. The evaluation of wellGuide is carried out in relation to its core technology.

Chapter 4: Case studies are presented in this chapter, analysing and discussing the added value brought by wellGuide for the business unit (BU) and its impact on work performance. The chapter also presents the findings and explores how eDrilling can enhance the DPM software.

Chapter 5: The key findings throughout the thesis, recommendations, and improvements regarding the software are discussed in this chapter.

Chapter 6: The section provides an overview of the thesis, highlights key learning points, addresses practical challenges encountered during the research process, and outlines potential avenues for future work.

Chapter 7: This final chapter concludes the thesis

2 Theory

2.1 Industrial asset and digitalization

Industrial asset management study includes digitalization and automation. Digitalization and automation are increasingly becoming important in industrial asset management as they offer opportunities to improve efficiency, reduce costs, increase reliability, and enhance safety.

Digitalization involves the use of digital technologies to collect, analyse, and utilize data to improve asset management decision-making. This includes the use of sensors and Internet of Things (IoT) devices to monitor asset performance, data analytics and machine learning to predict and prevent asset failures, and digital twins to perform lookahead simulations, and optimize asset operations.

Automation, on the other hand, involves the use of technologies to automate asset management processes, such as maintenance planning and scheduling, spare parts management, and inspection and testing. This includes the use of robotics and autonomous vehicles for asset inspection and maintenance, as well as the use of artificial intelligence and machine learning to automate decision-making processes.

Therefore, the integration of digitalization and automation into industrial asset management can help organizations to achieve better results in terms of cost-effectiveness, efficiency, increasing safety, and sustainability.

2.1.1 Intangible assets – software technology

Within organizations, there exist various types of assets that play a crucial role in their operations and value creation. These assets include financial assets, physical assets, human assets, information assets, and intangible assets (Hastings A.J., 2010).

Intangible assets, specifically, are a category of assets that lack a physical form but possess inherent value and contribute to the organization's success. These assets encompass a wide range of elements, ranging from customer relationships to software and technology. Despite their intangible nature, they hold significance for organizations as they confer a competitive advantage, facilitate revenue generation, and bolster market positioning. It is worth noting that despite their non-physical presence, intangible assets can exert substantial influence on a company's financial performance and overall valuation (Nicholas A.J. Hastings, 2010).

Effectively identifying, valuing, and managing intangible assets is vital for organizations seeking to safeguard their intellectual property, maintain a sustainable competitive edge, and foster long-term growth. By recognizing the value and potential of intangible assets, organizations can leverage them to enhance their market position, drive innovation, and create value for stakeholders.

Therefore, organizations must prioritize the strategic management of intangible assets alongside other asset categories to ensure they are adequately protected, utilized, and optimized to maximize their contribution to organizational success.

Liyanage et al. (2010) emphasize the significance of intangible assets and software technologies in their work titled "Smart Assets Through Digital Capabilities." They emphasize the role of real-time monitoring, 3D visualization, process automation, smart sensors, and online communication as integral components of smart assets. The integration of these advanced technologies into operations enhances the ability to collect, analyse, and communicate data, thereby improving the overall operational performance. This highlights the transformative potential of smart assets enabled by digital capabilities in optimizing asset utilization, decision-making, and operational efficiency.

2.1.2 The need for digitalization and automation

In today's highly competitive business environment, there is a strong emphasis on improving operational efficiencies, reducing costs, and optimizing processes. These initiatives are designed to enhance productivity, streamline operations, and maximize return on investment. However, it is crucial to acknowledge and prioritize the importance of maintaining a strong commitment to safety throughout these ventures (Asset management lectures by Liyanage, 2020).

Achieving a harmonious balance between operational efficiency and safety is paramount, especially in industries where safety-critical systems are involved. Major accidents in various industrial sectors, including the oil and gas industry, have demonstrated the significant role that human error can play (Asset management lectures by Liyanage, 2021).

For instance, the Piper Alpha disaster in July 1988 resulted in the loss of 167 lives when a major explosion and subsequent fire occurred on Occidental's platform in the North Sea.

According to Redmill (1997), human error can contribute to failures in several ways:

- Direct failures or indirect failures resulting from human actions or decisions.
- The response and decision-making process when individuals become aware of potential dangers.
- Actions taken during emergency situations.
- Latent failures, which can arise from management decisions that create work conditions conducive to failure.

Understanding the various dimensions of human error and its potential impact on safety is crucial for developing effective safety strategies and practices. Human being are considered as an unreliable components of the total system and at the extreme approaches proposed, to remove human failure is to remove the human factors entirely through automation, Redmill (2010). An alternative, more widespread and accepted, view is to improve human reliability through better ergonomic design of the workplace or the human machine interface (HMI), Redmill (2010).

Digitalization and digital twins playing a very important role in term of automation, operational efficiency and increased safety. The ongoing digitalization of equipment, instruments has brought about significant advancements in metering, measurement, automation, and control processes. These advancements have revolutionized daily operations by providing better information for decision-making, leading to improved recovery rates even in complex environments. Behind the scenes, artificial intelligence plays a crucial role in managing activities related to identifying model irregularities, addressing uncertainties, and enhancing forecasting and risk assessment capabilities, Cenk, et al (2019).

2.1.2.1 Automation

The concept of removing human involvement through automation is often regarded as a means to mitigate risk. However, it is important to note that automation may not entirely eliminate human error and can potentially introduce new sources of human unreliability. According to Redmill (1997) following are important when designing the new system

- The designer has more opportunity to introduce errors into the system during the design process
- The operator still has to do those tasks which the designer has not been able to automate
- The role of the operator is transformed into that of a supervisory monitor of an automated system, albeit with limited information about the system itself. ("Humans typically struggle with tasks that demand prolonged periods of vigilance, making continuous monitoring challenging")
- The operator may become de-skilled and yet be expected to intervene when the automated system fails.

2.1.2.2 HMI (Human machine interface)

According to Redmill (2010), human errors often occur due to a mismatch between the task requirements, the physical capabilities of individuals, and the characteristics of the interface provided to facilitate task execution.

User friendly HMI is necessary to improve the interaction between humans and machines, enhancing usability, efficiency, and safety. Intuitive interfaces, interactive displays, and alarm management systems should be considered in the design to minimize cognitive overload, facilitate effective communication, and reduce the likelihood of human errors (Chang and Wu, 2019).

2.2 Digital oil field

The history of digital oil field technology in drilling operations can be traced back to the 1990s when smart downhole sensors were developed to collect data [46]. In order to achieve safe, reliable, and efficient operations, many oil and gas industries have established real-time operation centres as a strategic tool. These centres, such as the Onshore Drilling Center (ODC) at ConocoPhillips, the Onshore Integrated Operations Centre (IOC) at Equinor, and Smart Fields at Shell, embody the concept of digitalization in the E&P industry. Digitalization is increasingly necessary to improve safety, add value, and reduce emissions.

The digitalization of the oil and gas industry is expected to follow the same trend as other industries and continue to grow in the coming years. The digital oilfield market is divided into hardware, software, and data storage, with hardware currently dominating the market as of 2021 [28]. The purpose of using software is to digitalize work processes, enhance efficiency, and automate tasks by reducing manual and repetitive work. Software is also utilized for remote control, analysis of complex data, and to support better decision-making. Furthermore, software solutions contribute to improved safety and security by enabling better decision-making, reducing risks, and adding value to assets.

Data storage plays a crucial role in accelerating digital transformation. It is essential for data to be easily accessible to all team members and partners involved in the project, facilitating seamless digital transformation and automation. Cloud storage solutions enable organizations to store, access, and maintain data that can be readily shared among all stakeholders in the projects.

2.2.1 Digital Twin

The automation of operations in the drilling industry is supported by various software categories, with one frequently utilized category being artificial intelligence (AI) and digital twins. The concept of the digital twin was first introduced by Dr. Michael Grieves during his Executive Course on Product Lifecycle Management at the University of Michigan in 2002. According to Dr. Grieves (2021), a digital twin is defined as the connection between a physical model and a digital model, where data collected from the physical space is utilized to populate the virtual space and enable informed decision-making. Presently, we are in the nascent stage of the digital twin era, where available data can be gathered and employed to generate virtual representations and simulate real-world environments. However, in order to advance further, it is crucial to automate the collection and integration of this information.

As per SINTEF (2022), a digital twin is a representation of a physical object or process that encompasses not only its static characteristics but also its dynamic behaviour over time. By recording and analysing the behaviour of the physical object over time, digital twins can anticipate future maintenance needs and improvements.

Nadhan (2018) describes digital twin technology as a virtual representation of an asset, serving as a digital copy of a physical system that connects the digital and physical worlds. Comparing actual data from the well with simulation outputs from digital twins enables the early detection of abnormalities before they become serious. Digital twins also provide automatic diagnostic alarms and suggestions on how to proceed in case of abnormalities, increasing safety, efficiency, and reducing potential downtime in operations.

2.3 The general concept and planning of drilling operations

Planning drilling operations can occur at both the concept and detailed engineering levels. In the concept level, a general drilling plan is developed to fulfil the project's objectives and goals. During this stage, various drilling methods, equipment, and materials are evaluated, and different technologies are tested and compared to determine their feasibility. The drilling technologies are also assessed in relation to completion, reservoir management, and production goals and constraints to achieve an optimal solution that meets all requirements. Once the selections are made and a Basic of Design (BOD) document is created, the engineering work can begin, Semwogerere (2021).

At the engineering level, planning for drilling involves considering detailed technical and operational factors to ensure the successful execution of the project. The results of the detailed engineering analysis are incorporated into a drilling plan framework that can be applied to most wells in the field and align with available equipment specifications. The goal is to standardize the well equipment and tools across the entire field, which simplifies planning, logistics, reduces lead times, requires less personnel training, and provides economic benefits.

2.4 Drilling parameters optimization in real-time

Drilling in the oil and gas industry involves creating a wellbore in the earth's subsurface to extract oil or natural gas. This process is typically carried out using a drilling rig, which can be located onshore or offshore, depending on the location of the reservoir. During drilling, various parameters are closely monitored and optimized to ensure safe and efficient operations. These parameters include rate of penetration (ROP), flow rate, revolutions per minute (RPM), weight on bit (WOB), tripping velocity, and drilling fluid properties.

The optimization of drilling parameters involves analysing the behaviour of the well, including data from downhole tools, equivalent circulating density (ECD), geothermal pressure, torque, WOB, hook load, and surface pump pressure (SPP). This analysis can be done manually by experts who examine available plots and data to make adjustments based on their experience or by running simulations. Alternatively, advanced real-time software technology can automatically optimize parameters throughout the entire operation, eliminating the need for constant expert supervision.

However, the digitalization of drilling operations requires a gradual implementation process that considers the specific requirements and operational needs of the rig. It's important to recognize that attempting to digitalize all processes at once, especially in complex and costly projects, can lead to failures. Underestimating the need for stepwise automation and the manual support required during these processes is a common mistake. Achieving fully digitalized operations often involves integrating new technologies like machine learning, artificial intelligence, and digital twins in a carefully planned and phased manner.

2.4.1 Transient hydraulic models – lookahead-simulations

A drilling and tripping advisor application is a software tool designed to provide guidance and recommendations during drilling and tripping operations. It utilizes real-time data from various sensors and drilling parameters to analyse the drilling process and offer optimization suggestions. The application can assist in well planning, monitoring drilling parameters, detecting anomalies or issues, and providing recommendations to improve drilling efficiency.

In the realm of real-time monitoring systems and parameter optimization solutions, numerous providers exist. However, the majority of these solutions rely on steady-state models, with only a few incorporating three closely interconnected real-time dynamic models (hydraulic, mechanical, and thermodynamic) that continually interact with one another. These models continuously evaluate drilling performance, borehole conditions, and associated risks by detecting real-time indicators and delivering automated notifications to users. Furthermore, the models can conduct forward-looking simulations to anticipate operational issues ahead of time and offer real-time optimized parameters (Ødegaard, S., et al., 2023).

These systems can be integrated either at the rig site or run in the cloud for easier accessibility and scalability, and lower deployment costs. Regardless of the chosen solution, the models require a set of hybrid input data comprising static, semi-static, and real-time parameters (Forshaw et al., 2019; Taugbøl et al., 2021). Static data typically remains unchanged from the pre-job phase to the real-time phase and can be directly loaded from there. Semi-static data changes in real-time but at a slow pace, such as wellbore trajectory and mud properties. Dynamic data changes rapidly with time, including flow rate, RPM, and WOB. The accuracy of these models depends on the input data, particularly the dynamic and semi-static input data. Real-time modelling applications receive dynamic data through WITSML, WITS, or other data transmission providers, while mud properties can be received through the same source or automated fluid monitoring systems (AFM). Important mud properties, such as mud density, rheology, gelling, and temperature, are among the data used in real-time applications (Arevalo, O., et al., 2023).

2.4.2 Importance of pressure gradient in drilling industry

The concept of the drilling margin or drilling window holds significant importance in drilling operations. It represents the range of fluid gradients situated between the pore pressure gradient and the fracture pressure gradient, and in some cases, may also incorporate the collapse gradient. This drilling margin is essential for both the planning and execution phases of drilling operations.

When the pressure in the wellbore drops below the pore pressure, there is a considerable risk of influx occurring, influenced by the permeability and porosity of the formation. Similarly, if the wellbore pressure falls below the collapse pressure, the size of the open hole decreases, and in severe cases, the hole may collapse, resulting in incidents like stuck pipe and non-productive time (NPT). In such scenarios, it may be necessary to re-drill the affected section. On the opposite side of the drilling margin lies the fracture gradient, surpassing which can lead to losses.

To ensure a safe and controlled drilling operation, it is crucial to maintain the downhole mud weight within the drilling window at all times. Exceeding the window in either direction can cause formation fracturing, losses, influx, kicks, and wellbore instability, all of which result in significant operational time loss (Kvam.Ø., 2005).

Drilling engineers and geoscientists employ various techniques, including well logs, rock mechanics data, and hydraulic fracturing tests, to estimate the pore gradient and fracture gradient of the formations being drilled. This information is used to design the drilling mud program using simulation software and set appropriate drilling parameters. By utilizing automated real-time parameter optimization software during drilling and tripping operations, even more accurate modelling can be achieved, as the software receives real-time data updates on mud properties and pressure gradient.

2.4.2.1 Pore pressure gradient

Pore pressure (PP) plays a pivotal role in various stages of oil and gas exploration, drilling, and production processes (Radwan et al., 2019a, 2020a; Zhang, 2011, 2017). It is typically measured in pounds per square inch per foot (psi/ft) in the British system of units. The pore pressure gradient denotes the ratio of pore pressure to the true vertical depth at a specific location.

The pore pressure gradient, also known as overburden pressure, signifies the pressure exerted by the weight of the rock formations above on the pore spaces within the rock matrix, accounting for the fluids contained within them. Pore pressure can be categorized into three types: normal, overpressure, and subnormal. The classification is determined by whether the pore pressure equals, is less than, or exceeds the hydrostatic pressure at the given depth, as elucidated by Radwan et al. (2020). Any deviation in pressure from the normal pressure is referred to as abnormal pressure.

2.4.2.2 Fracture pressure gradient

The fracture gradient represents the pressure at which a rock formation will fracture or break when subjected to external pressure, typically exerted by the drilling mud. It is influenced by the mechanical properties of the rock, such as compressive strength and tensile strength. The fracture gradient is calculated by dividing the fracture pressure by the true vertical depth.

The fracture gradient serves as an upper limit for mud weight and holds significance in mud weight design and subsequent calculations of Equivalent Circulation Density (ECD).

If the downhole mud weight, also known as Equivalent Static Density (ESD) or Equivalent Circulation Density (ECD), exceeds the formation's fracture gradient, the wellbore can experience tensile failures and fractures. This can result in lost circulation or even total loss of circulation, requiring remedial actions and a re-evaluation of mud density. In severe cases, the wellbore's hydrostatic pressure may drop below the pore pressure, leading to fluid influx. Additionally, there is a risk of pipe becoming stuck. These incidents contribute to non-productive time (NPT), increased operational costs, and higher operational risks.

To assess the formation's fracture pressure before drilling each section, practices such as Leak-Off Test (LOT) or Formation Integrity Test (FIT) are widely employed. These tests help evaluate the integrity of the formation and provide crucial information for proper mud weight management.

2.4.2.3 collapse pressure gradient

he drilling mud window is typically determined based on pore pressure and fracture pressure in order to prevent issues such as loss of drilling fluid, influx of formation fluids, and other non-productive time (NPT) and cost overruns. However, it is important to note that maintaining a stable wellbore cannot be guaranteed solely by controlling the downhole mud density or equivalent static density (ESD). Another critical parameter to consider when designing mud density for different sections is the collapse pressure gradient, also referred to as shear failure stress.

Wellbore stability is a significant concern that must be addressed during both drilling and tripping operations. Borehole collapse is an undesirable event that can result in the loss of the drilled section, requiring the costly and time-consuming process of side-tracking and re-drilling that particular section. Therefore, it is crucial to take into account factors such as the collapse pressure gradient when determining the appropriate mud density.

To ensure wellbore stability and minimize the risk of collapse, careful consideration of these parameters is necessary. Proper planning and implementation, incorporating data from reliable sources such as the study conducted by Baouche et al. in 2022, can help optimize mud density and mitigate the occurrence of borehole collapse.

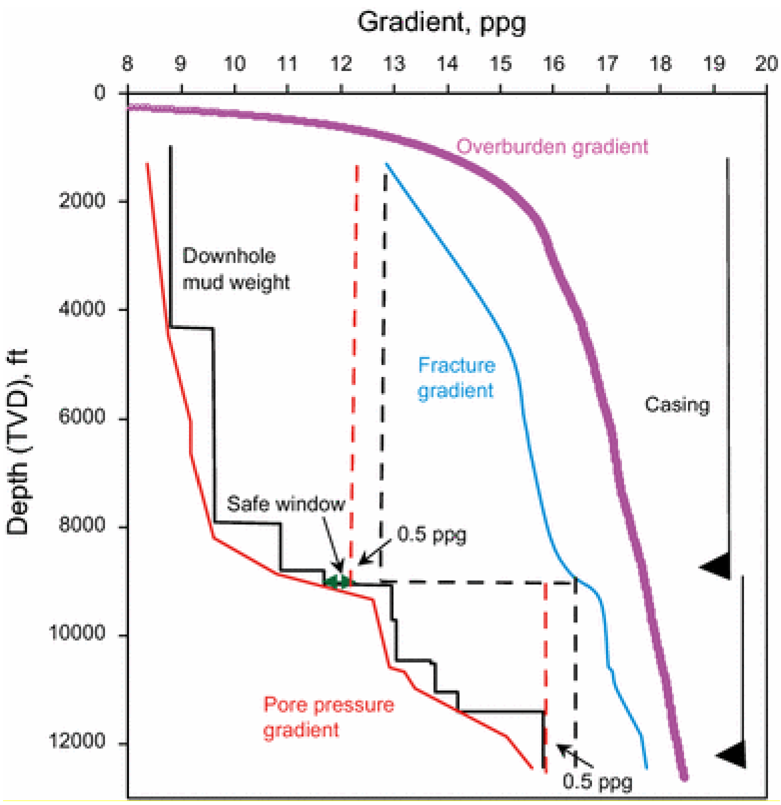


Figure 2.1: Pore pressure gradient, fracture gradient, overburden stress gradient, downhole mud weight, and casing shoes with depth. (Zhang,J, 2017)

2.4.3 Mud density and Equivalent Circulation Density (ECD)

Mud weight, also known as mud density or drilling fluid density, represents the density or weight of the drilling mud. Typically, it is measured in pounds per gallon (ppg) or kilograms per litre (kg/L).

Mud weight plays a crucial role in drilling operations as it helps in controlling the pressure within the wellbore and prevents blowouts. By appropriately setting the mud weight, drilling engineers can balance the pressure exerted by the formation and prevent the influx of formation fluids (such as oil, gas, or water) into the wellbore.

Equivalent Circulation Density (ECD) is another significant concept associated with drilling operations. It quantifies the effective density experienced by the wellbore during the circulation of drilling fluids. ECD takes into consideration both the static mud weight and the pressure losses resulting from friction between the drilling fluid and the wellbore.

The ECD is calculated by adding the hydrostatic pressure and the frictional pressure losses. The formula to calculate ECD is:

<u>ECD (psi) = Hydrostatic Pressure (psi) + Frictional Pressure Losses (psi)</u>

The hydrostatic pressure is determined by the mud weight and the vertical depth of the well. The formula to calculate hydrostatic pressure is:

<u>Hydrostatic Pressure (psi) = Mud Weight (ppg) × Vertical Depth (feet) × 0.052</u>

Frictional pressure losses are influenced by various factors including flow rate, the rheological properties of the mud, and the geometry of the wellbore. Calculating the exact value of frictional pressure losses is a complex task typically performed by specialized software.

Furthermore, accurately predicting the equivalent circulation density (ECD) requires considering the pressure and temperature-dependent rheology and density. The rheology's dependence on pressure and temperature can be determined through laboratory measurements of the specific mud system or by utilizing a model based on data from similar mud systems. It's important to note that predicting ECD reliably also necessitates knowledge of the temperature distribution along the annulus, as the rheology and density of drilling fluids are temperature-dependent. This information helps generate a density profile for the well and a viscosity profile, which in turn allows for calculating the total ECD at a given depth using the equation provided by Rommetveit et al. (1997):

$$\mathrm{ECD} = \frac{1}{\mathrm{TVD}}\left(\int_0^{\mathrm{MD}} \rho(z)dz + \frac{1}{g}\int_0^{\mathrm{MD}} \frac{dP_f}{dz}dz\right).$$

2.4.4 Temperature and pressure effect on wellbore pressure

In the oil and gas industry, there are various software packages available for calculating Equivalent Circulation Density (ECD) during drilling operations. These packages offer two levels of models: stationary models and transient models. Stationary models are more commonly used, although the use of transient models is increasing, especially in challenging drilling environments.

Stationary ECD models calculate the ECD based on hydrostatic pressure and frictional pressure loss. Input parameters include the static temperature profile along the wellbore, and mud properties depend on pressure and static temperature. The wellbore temperature is not significantly affected by circulation or heat exchange. It's important to note that stationary ECD models are more suitable for initial planning or basic assessments of ECD. They do not account for dynamic effects that occur during fluid circulation and drilling in the wellbore. However, these models provide fast calculations and can be repeated multiple times to study the impact of varying wellbore parameters such as geometry, bottom hole assembly (BHA), or fluid properties.

Transient or dynamic ECD modelling is becoming more important in high-pressure, high-temperature (HPHT) wells, especially in scenarios like resuming circulation after a stationary period in critical zones or within a narrow operational window. Several factors, in addition to hydrostatic pressure and friction pressure loss, affect ECD calculations in transient models. For instance, during longer static periods, the well temperature approaches the geothermal temperature. When circulation starts, the lower part of the annulus is cooled down by cold mud pumped down through the drill string, while the upper part is heated up by hot mud moving upward in the annulus. This phase leads to rapid changes in mud density, rheology, and subsequently, well pressure, as mud expands due to heat and compresses under pressure (Rommetveit et al., 1997).

“If the well is temperature-dominated, the density of the drilling fluid” (Skalle, 2013) decreases with depth, resulting in lower hydrostatic pressure compared to calculations and measurements performed at surface conditions. During pump shutdown, the lower part of the well experiences temperature increase over time, while the upper part cools down. In general, the effect of temperature increase outweighs the cooling effect, leading to lower hydrostatic pressure. Failure to consider these effects during mud design or hydraulic simulations can potentially result in a kick situation in the well (Skalle, 2013). Conversely, in a pressure-dominated well, the mud is compressed, leading to increased mud density in the wellbore, which can cause higher well pressure and fluid loss into formations. These effects work in the opposite direction to temperature effects. In some cases, pressure and temperature effects may neutralize each other, resulting in a zero net effect (McMordie, Bland, & Hauser, 1982).

Heat transfer and frictional heating are also crucial during drilling operations. Pumping mud down the drill string and up through the annulus not only disrupts the natural geothermal temperature distribution but also induces complex heat transfer between the circulating fluid and the surrounding rocks, casing, cement, riser, and seawater. Most drilling fluids exhibit non-Newtonian rheological properties and are thixotropic and shear-thinning. This means that mud rheology depends not only on temperature and pressure but also on shear history. Rapidly increasing mud pumps after static periods can result in ECD/pressure spikes in the well as gels break down, while mud viscosity decreases significantly over a time interval similar to one bottom-up circulation (Rommetveit et al., 1997).

2.4.5 Rate of penetration (ROP)

Drilling operations are known for being costly in the oil and gas industry, and the capital expenditure (CAPEX) associated with drilling increases significantly when non-productive time (NPT) occurs due to poor and inefficient drilling practices. NPT can account for as much as one-third of the total operational expenditure of a rig (Ramba et al., 2021). Additionally, inefficient and poor Rate of Penetration (ROP) is estimated to contribute to approximately 15% of the total drilling cost (Chandrasekaran et al., 2020). As a result, achieving optimal ROP has always been a priority for drilling teams and operating companies.

ROP serves as a primary measure of drilling efficiency and plays a crucial role in enhancing safety, reducing carbon footprint, and lowering overall capital expenditure (CAPEX) (Cao et al., 2022). However, ROP is dependent on various other parameters, and the relationship between these parameters is complex and nonlinear. Nonlinearity in ROP can be attributed to factors such as section type, well trajectory, mud type and viscosity, cuttings size and shape, and formation types. Therefore, optimizing ROP requires a robust model that can assess ROP in combination with other drilling parameters while maintaining operational safety (Zhou et al., 2023).

2.4.5.1 ROP optimization

The most significant parameters that influence the Rate of Penetration (ROP) in drilling operations are Weight on Bit (WOB), Rotations Per Minute (RPM), flow rate, drill string characteristics, and the type of drill bit used. To optimize ROP, the model must search for the optimal combination of drilling parameters, which can then be adjusted accordingly during actual drilling operations (Cao et al., 2022).

To enhance drilling efficiency, the relationship between ROP and corresponding drilling parameters has been analysed under certain assumptions. In the case of perfect hole cleaning, the relationship between ROP and WOB is assumed to be quadratic (Maurer, 1962). However, as drilling operations become more complex, involving longer and horizontal wells, achieving proper hole cleaning becomes a major challenge that must be considered alongside ROP optimization. Similarly, the relationship between ROP and RPM is assumed to be linear under ideal hole conditions (Maurer, 1962; Bourgoyne et al., 1986), but this relationship may deviate after reaching specific points due to reduced energy transfer to the drill bit (Cao et al., 2022). Nonetheless, a field study has shown that the relationship between ROP, RPM, and WOB is more complex, with softer formations being more sensitive to RPM variations, while harder formations tend to be more sensitive to WOB (Syaed et al., 2018). Flow rate impacts hole cleaning, bottom hole pressure, and bit wear, among other factors, but quantifying the direct relationship between flow rate and ROP is not straightforward.

Traditionally, drilling operators have relied on experience or duplicated best practices from previous wells to guide drilling parameters for current or future wells. This involves considering the drilling assembly, drill bit selection, and other relevant systems. In other words, operational parameters heavily rely on field experience, knowledge sharing, and knowledge transfer across different business units and organizations.

Given that these variables are continuously and dynamically changing, it is challenging to quantify the individual effects of different parameters at any given time. However, mathematical models based on physical properties can provide better predictions of the relationship between flow rate, RPM, and ROP, especially in terms of efficient hole cleaning.

2.4.6 Optimize axial Velocities during tripping

Non-productive time in well operations can arise due to various factors, leading to delays, problems, increased risk, and higher costs. Issues like lost circulation, formation influx, pack-offs, and stuck pipe events contribute to these challenges. In certain instances, these situations can escalate into critical events that necessitate costly and undesirable technical interventions. Tripping operations, although necessary for drilling operations, are considered non-productive time in terms of drilling progress. In extreme cases, tripping operations can consume a significant portion of overall well construction time, accounting for up to 30% of the total duration. This includes planned tripping as well as interruptions caused by operational problems like tool failures. Tripping operations can be divided into two main components: connection time and the time spent moving pipes up and down the wellbore. Both aspects are important Key Performance Indicators (KPIs) in well operations. The connection procedure can be optimized through process automation on the rig floor. However, optimizing the tripping process itself, involving the movement of pipes in and out of the wellbore, is more complex and requires considering numerous parameters. These parameters include drilling fluid properties, wellbore trajectory, wellbore geometry, and drill string design. Therefore, optimizing tripping velocity requires advanced systems that take all these factors into account during velocity optimization processes (Arevalo, O., et al., 2023).

The utilization of real-time digital twins of the wellbore has significantly increased in the past decade. Some digital twins now offer forward-looking simulations that can be used to optimize tripping velocity for the next pipe stand or within a specific depth interval. These digital twins are based on transient hydraulic models. During real-time operations, these models are fed with actual data from the rig, and the movement of the drill string is simulated to replicate the equivalent pressure wave generated by the motion. Most planning phase models, on the other hand, are steady-state models that rarely account for the velocity of the drill string during tripping operations. As a result, these models do not accurately capture the dynamic pressure waves created during acceleration and deceleration of the string movement (Arevalo, O., et al., 2023).

The illustration below depicts relatively smooth block position movement, while oscillations are observed in the bit velocity due to the acceleration when the bit starts moving. The same effect is visible in the equivalent mud weight (EMW) and the swab effect caused by the bit movement.

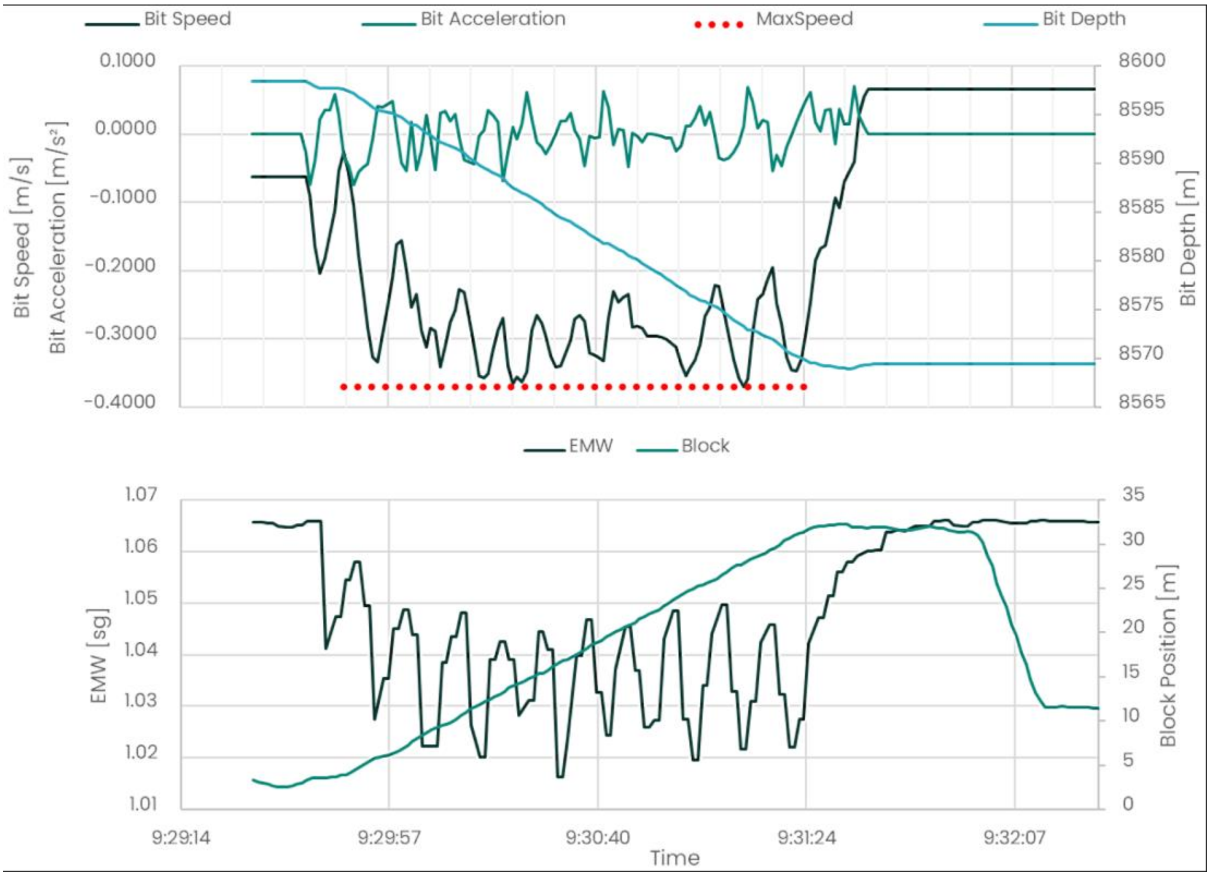


Figure 2.2: presents an excerpt of a POOH operation for one stand. The values at-bit have been estimated while the equivalent mud weight has been derived from pressure while drilling (PWD) service deployed in the run (Arevalo, O., et al., 2023)

The figure provided by Arevalo (Arevalo, O., et al., 2023) compares the outcomes of steady-state models versus transient hydraulic models when considering the drill string velocity. In the lift plot, it is evident that the steady-state model suggests a higher maximum allowable speed. However, the results in the right plot indicate that the equivalent mud weight (EMW) exceeds the fracture pressure. Relying on such models to simulate tripping velocity within a narrow downhole pressure window can result in losses during the process of running in hole (RIH) operations and can lead to a swabbed kick during pulling out of hole (POOH) operations.

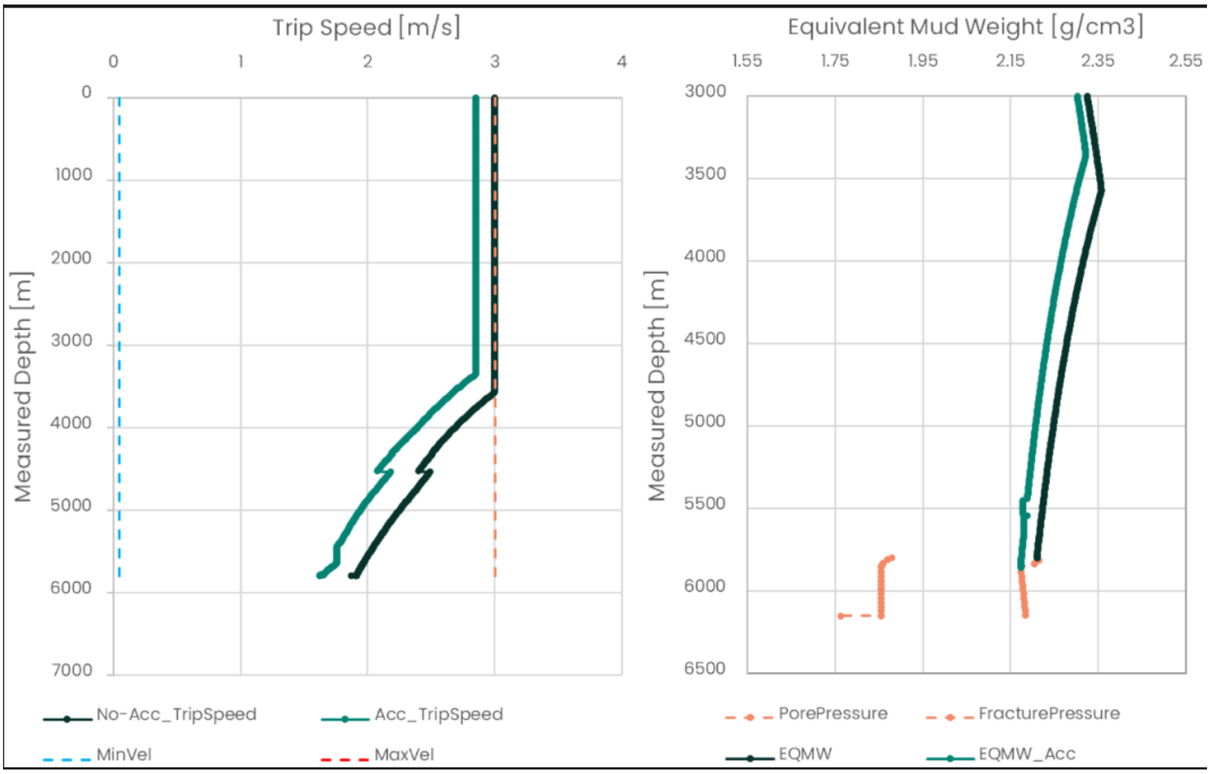


Figure 2.3: presents a comparison of the equivalent mud weight and tripping speed for a RIH scenario with and without acceleration effects (Arevalo, O., et al., 2023)

As described in section 2.3.3, the transient hydraulic models encompass the impact of temperature and pressure on fluid properties along the wellbore. This consideration is essential for enhancing the accuracy of the equivalent mud weight (EMW). Moreover, these models incorporate the acceleration of the drill string at the surface and its effects on the wellbore, particularly in relation to the bit. By incorporating these factors, the transient hydraulic models offer a more comprehensive and precise depiction of fluid dynamics during drilling operations (Arevalo, O., et al., 2023).

3 Introduction of wellGuide software/eDrilling AS

3.1 Intro

eDrilling AS is a globally recognized provider of digital twin technology, and predictive analytics for the energy industry. Their software solutions are primarily utilized in well construction operations to achieve cost savings, enhance safety, and improve overall operational efficiency and sustainability (eDrilling, 2022).

The company's vision originated in the late 1990s, with the goal of creating a "GPS" or "Google Maps" equivalent for drilling operations (eDrilling, 2021). This led to the development of the digital twin concept, which encompasses the entire life cycle of drilling operations. The digital twin serves as a virtual representation of the wellbore and integrates three key models: hydraulic, mechanical, and thermodynamic. These models are further augmented with 3D graphics and automated alarm systems that trigger in the event of abnormalities. Throughout the drilling value chain, these interconnected models work together, providing valuable insights (eDrilling, 2022).

The core technology behind eDrilling's software solutions is rooted in mathematical models developed by Sintef over the years. This has enabled eDrilling to offer high-quality and accurate modeling software, setting them apart in the drilling industry.

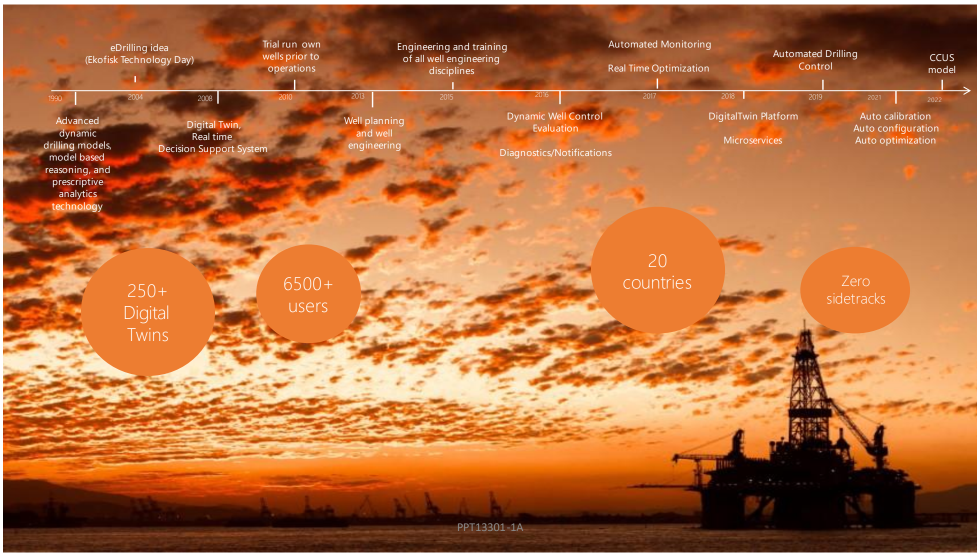


Figure 3.1: eDrilling journey on the digitalization and automation of drilling process

Source: (eDrilling, 2023)

3.2 Products - wellPlanner

The wellPlanner™ software is a planning tool that utilizes digital twin technology to integrate transient hydraulic, mechanical, and thermodynamic models. It comprises several modules, including hydraulic simulations, torque and drag analyses, well control simulations, and kick tolerance. The software can be installed on local computers or accessed as a cloud-based solution, making it adaptable to standalone or multi-user environments and scalable from individual users to enterprise-wide systems. Furthermore, the DHT and TD modules are offered as microservices with an Application Programming Interface (API), allowing for easy task automation and seamless integration with new and existing third-party software. As depicted below, module 1 is dedicated to hydraulic simulations, module 2 is utilized for torque and drag analyses, module 3 is employed for kick evaluation, and module 4 is specifically designed for kick tolerance assessments (eDrilling 2023).

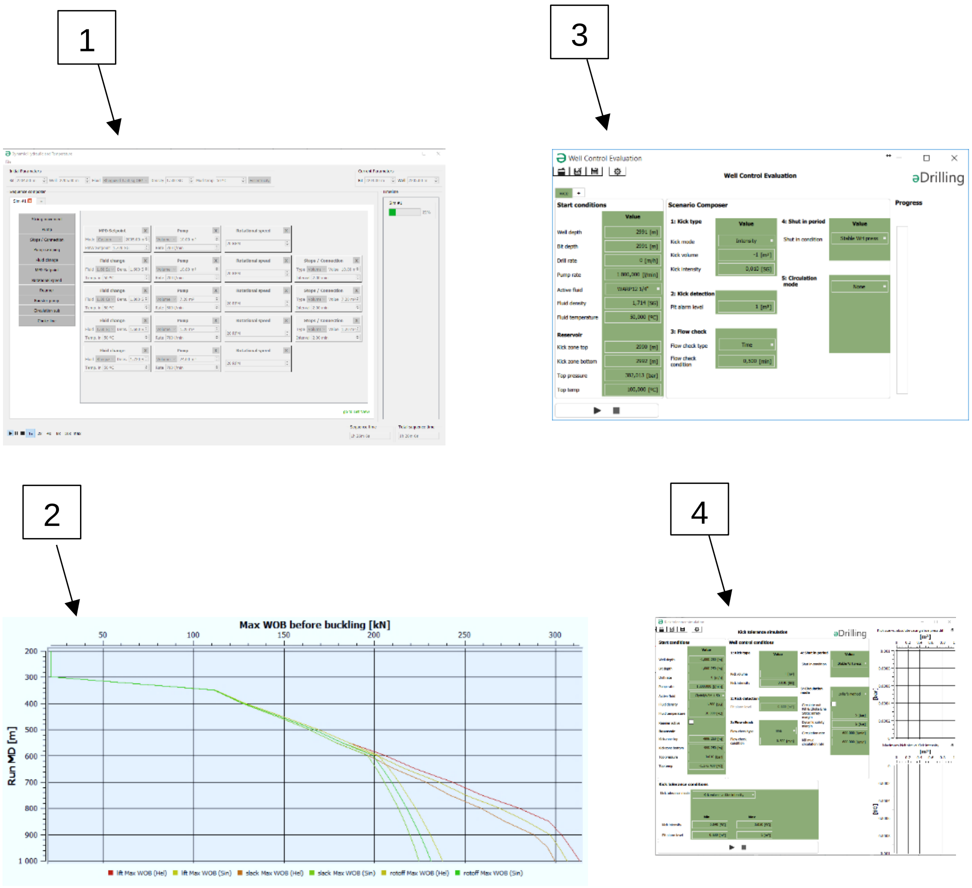


Figure 3.2: eDrilling wellPlanner™ modules

Source: (eDrilling, 2022)

3.3 Products - wellSim

The wellSim™ software serves as a comprehensive simulator suite for the engineering and training of various well engineering disciplines. It leverages advanced downhole simulation capabilities, incorporating models for rate of penetration (ROP), hydraulics, temperature, and dynamic torque and drag. The torque and drag model is integrated with the ROP model to enable calculations of ROP and weight on bit (WOB) based on formation properties. The wellSim, along with other eDrilling software applications, functions as a virtual replica of the well, accounting for dynamic changes such as temperature and pressure variations, acceleration/deceleration, and gel development over time. It incorporates a reservoir model within the two-phase hydraulic model to simulate influx behaviour, allowing for analysis of gas behaviour, gas migration, and the presence of dissolved and free gas during kill operations at different time intervals. The wellSim can be integrated with any third-party topside drilling simulator. Presently, the wellSim is bundled with a Virtual Reality (VR) topside simulator for collaborative training of rig floor teams (wellSim™ hidrill) and a simpler drilling control desktop interface (wellSim™ Interact) (Blikra. B., et al., 2014).

Furthermore, the software is utilized to test and verify third-party equipment in a safe and cost-effective environment, such as evaluating the performance of Managed Pressure Drilling (MPD) chokes, Dual Gradient Drilling (DGD) to name some (eDrilling 2023).

The figure presented below displays the graphical user interfaces (GUIs) and 3D visualizations integrated within the wellSim product.

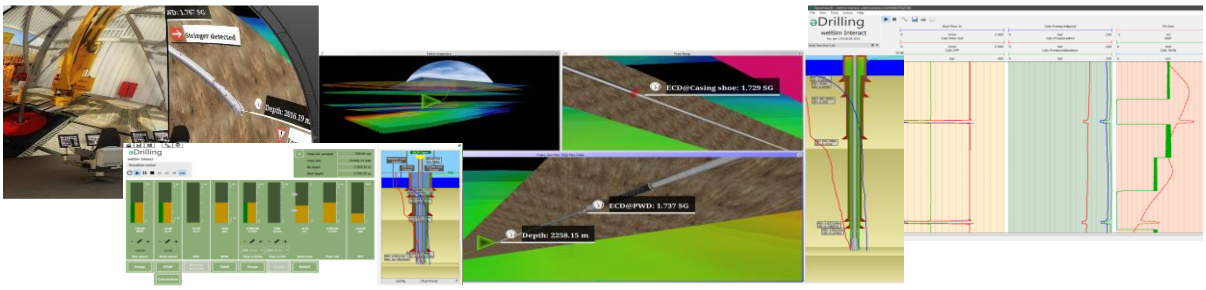


Figure 3.3: eDrilling wellSim™ modules

Source: (eDrilling, 2022)

3.4 Products - wellBalance

The software known as wəllBalance™ is specifically designed for use during managed pressure drilling (MPD) operations. It serves the purpose of enhancing the control system of MPD operations to maintain a constant well pressure at any chosen depth in real-time. The offline model of wəllBalance is utilized for planning, training, testing third-party MPD equipment, as well as conducting risk and sensitivity analyses (eDrilling 2023 & Petersen. J., et al., 2008).

By incorporating wəllBalance into MPD operations, operators can achieve improved control and accuracy in maintaining desired well pressures. The software's ability to account for dynamic changes in the well parameters enhances the understanding of well behaviour and enables more effective decision-making during MPD operations (Knut, S. et al., 2008)

3.5 Products - wellAhead

wəllAhead™ is an advanced software solution developed by eDrilling, designed to provide automated monitoring, real-time analyses, and live well support for drilling operations. The wellAhead as other eDrilling software's are based on digital twin technology and is a virtual representation of the well in real-time. The software is firstly configured with static well data such as casing, trajectory, pressure gradient, temperature gradient, fluid properties, and then supplied with real-time drilling data which in combination creates an accurate digital twin of the well. In general, wellAhead offers the potential for analyzing and optimizing drilling operations by providing automated forward-looking analysis, automated diagnostics and decision support, and real-time optimization of the drilling process (Mayani, M.G., Baybolov, T., et al., 2020).

The wellAhead is also connected to a downhole 3D model, which enables possible risks, diagnostics, pressure and acts like a "GPS" or "google Map" during operations (eDrilling 2023).

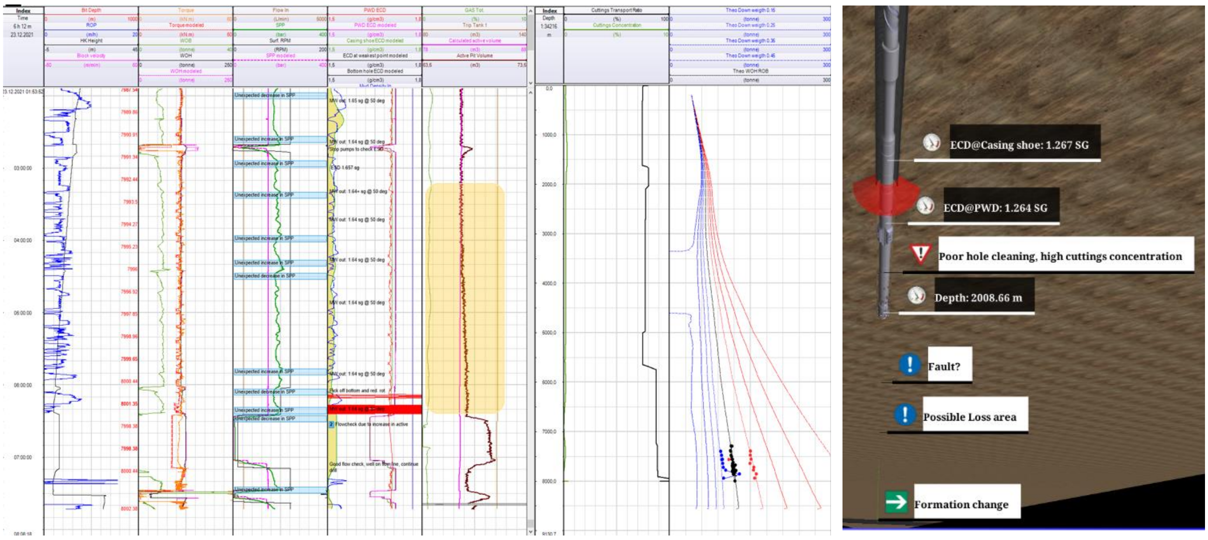


Figure 3.4: wellAhead & downhole 3D in RT operation

Source: (eDrilling, 2020)

3.5.1 Product -wellGuide

WellGuide is an extension of the functionality offered by wellAhead, specifically developed to further enhance the automation and optimization of drilling operations in real-time. Its primary focus lies in the auto calibration of drilling data, automated forward-looking analysis, automated diagnostics and decision support, and the automatic optimization of drilling parameters (Mayani, 2019). Notably, WellGuide places particular emphasis on optimizing drilling parameters associated with hole cleaning and well control, including flow rate, RPM, ROP, and axial velocity.

The system is comprised of two main components: auto calibration and advisory. The auto calibration component automates the calibration process of digital twin as there are always some differences between calculated values and physical worlds which needs to be calibrated (Ødegård, 2023), while the advisory component utilizes advanced models to provide recommendations and suggestions for optimal drilling parameter values. By continuously optimizing these parameters, wellGuide aims to improve drilling efficiency and overall performance. The integration of auto calibration and advisory components in wellGuide facilitates the automation of key work processes and decision-making in drilling operations (Lahlou, 2020)

To summarize, wellGuide expands on the features offered by wellAhead, with a specific focus on the auto calibration of the system (digital twin of the wellbore), analysis of drilling trends, decision support, and the automatic optimization of drilling parameters. Its objective is to improve drilling efficiency and overall operational performance by providing recommendations for optimal values of drilling parameters (Mal et al., 2023).

wellGuide is an edge and cloud-based software solution that offers users the convenience of accessing it from any location. The software provides a flexible and scalable platform, allowing for unlimited storage capacity and the ability to adapt to the varying requirements of customers. This scalability is achieved through vertical scaling, where the system can dynamically allocate additional computational resources as needed.

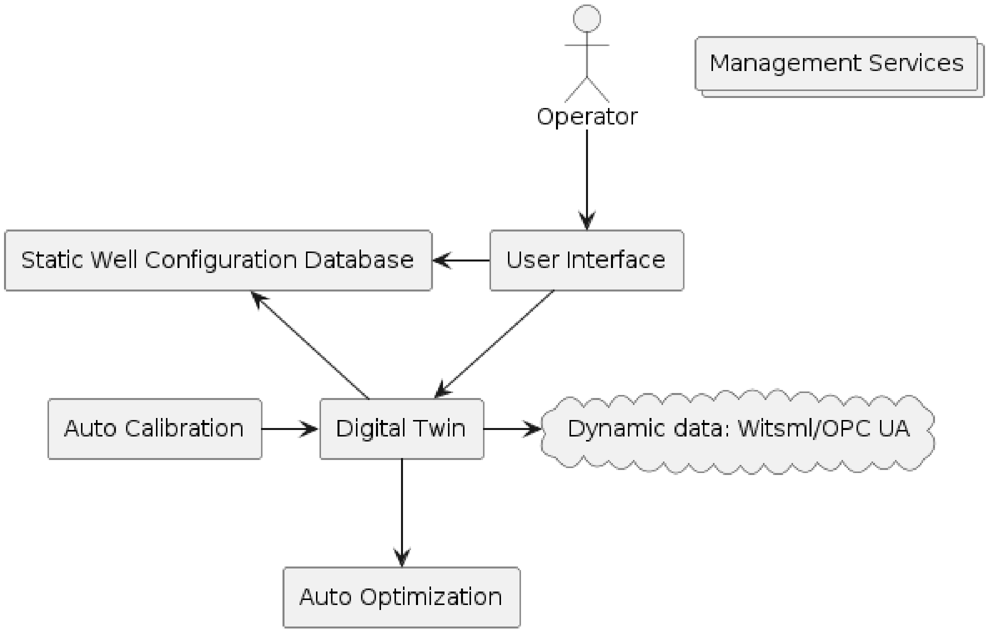


Figure 3.2: wellGuide set up

The integration of wellGuide into the operational workflow can be observed in Figure 3.2. The digital twin is connected to the witsml data, which in turn receives data from the rig site. Subsequently, the digital twin undergoes auto calibration through the auto calibration model. The calibrated well status is then saved and transmitted to wellGuide in real-time for each stand, enabling wellGuide to perform lookahead simulations by combining different flow rates, RPM, and ROP during drilling and different axial velocity during tripping. If the resulting values are deemed valid, the best option is selected and sent to the graphical user interface (GUI) (eDrilling 2022).

4 Case studies and database finding

This thesis provides an in-depth analysis of three case studies derived from actual operational scenarios, with two of them occurring in the past and the third one being monitored in real-time. The first case study revolves around the optimization of drilling parameters in real-time, while the second case study focuses on optimizing axial velocity during tripping and automatic friction mapping of the wellbore. Both cases are extensively examined in terms of their impact on drilling efficiency and subsequent value creation for the asset. Lastly, the third case study delves into the auto calibration of the hydraulic models in real-time, the impact on work process, and feedback from the customer.

4.1 Database finding

The investigation commenced firstly by applying the access to several databases such as planned drilling program, section plan, operational reports, fluid reports, pressure gradient data, and actual trajectory reports etc., to collect static and semi-static well data. The dynamic well data (real-time data) accessed through witsml.

4.1.1 Data processing and data analysing

The static and semi-static well data obtained from various documents serves as the foundation for creating the digital twin. Each component of the data, such as drill string information, wellbore geometry, fluid properties, and trajectory, undergoes a rigorous quality check process to ensure its accuracy and reliability. These data then will be stored in the database in order to be used in other section of the same well or similar wells from the same field.

In parallel, dynamic real-time data collected from the drilling rig is imported from the witsml store. The raw data is then subjected to further processing, including quality checks, missing values, data clean-up, and the removal of irrelevant information. When dealing with this specific dataset, the following steps are carried out:

- Importing the drilling data for well A, covering the entire well.
- Run the data set through the system, followed by a comprehensive quality check to ensure data integrity.

- Eliminating irrelevant data by utilizing the value of -999.25, as a criterion for identification and removal.

These steps and procedures are essential for handling acquired drilling data effectively and ensuring that only relevant and reliable information is utilized for subsequent analyses and simulations. The process employed in this study, as described by Liyanage (2010), was meticulously designed to encompass all operating conditions that could potentially impact the output of the model.

Note: The recorded "mud temperature in" for well A was determined to be invalid. To address this issue, manual adjustments were made based on the information provided in the daily mud reports. The adjusted data was then incorporated into the wellGuide software before running the simulations.

For the well B, the same procedure was used to import static and semi-static well data, while the dynamic well data was received in real-time without any further processing.

4.2 wellGuide installation

In order to run the wellGuide through the well A, the software has been installed in a dedicated internal cloud based system provided by eDrilling. For the well B, the software has been installed in the customers internal cloud based system as part of the pilot run. Following are the steps that need to be carried out to ensure correct and valid installation

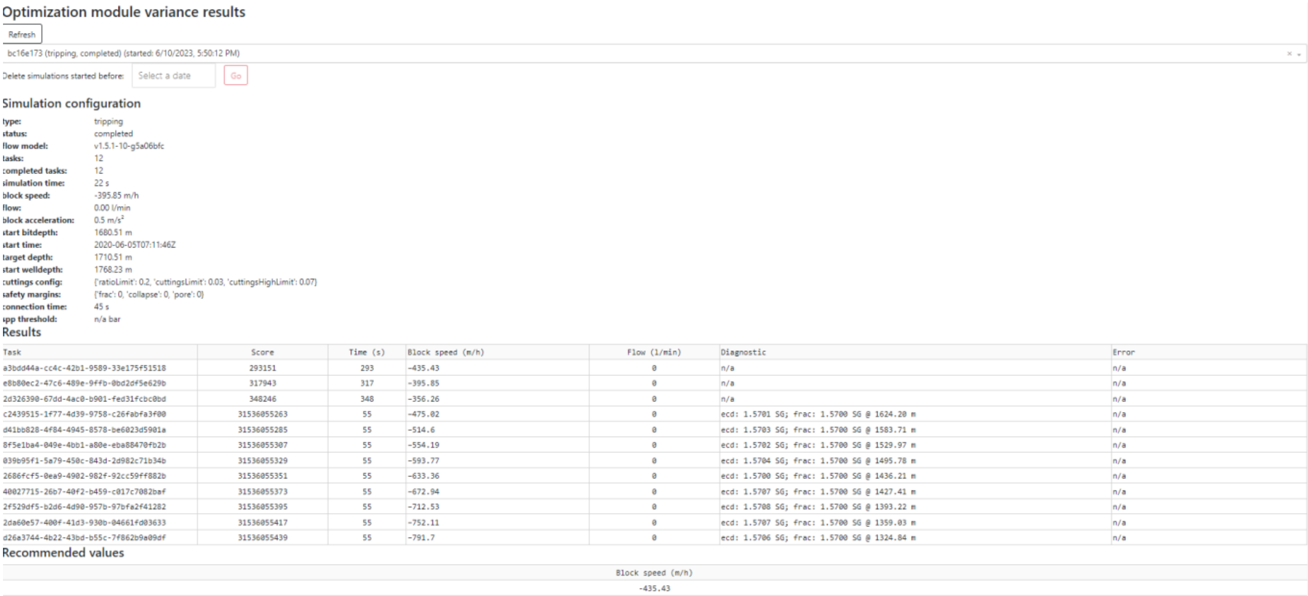
- Receive the latest version of wellGuide
- Get access to the cloud system and install the software
- Identify if all functionalities are in place and functions as expected
    - *Digital twin (core technology)*
    - *Auto calibration*
    - *Auto optimization*
    - *Hydraulic model*
    - *Thermo-dynamic model*
    - *T&D model*
    - *Diagnostic model*
    - *GUI*
- Dry run through several test well to make sure everything running as it should.

4.2.1 Plot optimization app

As previously mentioned, the Digital Twin captures the current state of the well during each connection and transmits it to wellGuide. In wellGuide, using the current well state, lookahead simulations are conducted. For drilling operations, the software performs 64 simulations, considering various combinations of flow rates, RPM, and ROP. Similarly, for tripping operations, 12 simulations are executed, evaluating different speed versus pressure gradient. The simulation that yields the most favourable outcome is selected and transmitted to the graphical user interface (GUI) for visualization. However, due to the intricate computational requirements and extensive data involved in such simulations, dedicated servers are employed to carry out the computational tasks. These servers are specifically designed to handle the high processing demands and vast data sets associated with the simulations. Consequently, the simulations are executed and managed within this server environment, rather than being directly presented on the eDrilling GUI. Therefore, to be able to ensure the quality of the simulations an application called "optimization plot app" has been developed and introduced to facilitate access to and analysis of these simulation results. The optimization plot app is divided into three main parts as per below:

1) Simulation Configuration: This section displays the current status of the operation, providing information on the drilling parameters and the state of the well. It serves as a reference point for understanding the context of the simulation and the subsequent results.
2) Results: In this section, the simulation values for the next stand are presented. It provides a comprehensive overview of the simulated parameters, such as flow rates, RPM, and ROP, enabling users to assess the predicted outcomes based on different parameter combinations. Moreover, the results of each simulation can be accessed by selecting the unique name of each simulation from the list provided below the task. By clicking on the respective name, users can download a file that contains the following data (Appendix 3):
    i. Static well data
    ii. Dynamic well data
    iii. Flow model results (For reference check Appendix 2)
    iv. Warnings if any parameters has been above the specified well limitations

3) <u>Recommended Values:</u> The optimized combination of drilling or tripping parameters, determined through the simulation process, is displayed in this section. These recommended values, representing the most efficient combination for the upcoming operation, are then sent to the GUI for implementation.



Optimization module variance results

Refresh

bc16e173 (tripping, completed) (started: 6/10/2023, 5:50:12 PM)

Delete simulations started before: Select a date Go

Simulation configuration

type:	tripping
status:	completed
flow model:	v1.5.1-10-g5a06bfc
tasks:	12
completed tasks:	12
simulation time:	22 s
block speed:	-395.85 m/h
flow:	0.00 l/min
block acceleration:	0.5 m/s²
start bitdepth:	1680.51 m
start time:	2020-06-05T07:11:46Z
target depth:	1710.51 m
start welldepth:	1768.23 m
cuttings config:	{'ratioLimit': 0.2, 'cuttingsLimit': 0.03, 'cuttingsHighLimit': 0.07}
safety margins:	{'frac': 0, 'collapse': 0, 'pore': 0}
connection time:	45 s
spp threshold:	n/a bar

Results

Task	Score	Time (s)	Block speed (m/h)	Flow (l/min)	Diagnostic	Error
a3bdd44a-cc4c-42b1-9589-33e175f51518	293151	293	-435.43	0	n/a	n/a
e8b80ec2-47c6-489e-9ffb-0bd2df5e629b	317943	317	-395.85	0	n/a	n/a
2d326390-67dd-4ac0-b901-fed31fcbc0bd	348246	348	-356.26	0	n/a	n/a
c2439515-1f77-4d39-9758-c26fabfa3f00	31536055263	55	-475.02	0	ecd: 1.5701 SG; frac: 1.5700 SG @ 1624.20 m	n/a
d41bb828-4f84-4945-8578-be6023d5901a	31536055285	55	-514.6	0	ecd: 1.5703 SG; frac: 1.5700 SG @ 1583.71 m	n/a
8f5e1ba4-049e-4bb1-a80e-eba88470fb2b	31536055307	55	-554.19	0	ecd: 1.5702 SG; frac: 1.5700 SG @ 1529.97 m	n/a
039b95f1-5a79-450c-843d-2d982c71b34b	31536055329	55	-593.77	0	ecd: 1.5704 SG; frac: 1.5700 SG @ 1495.78 m	n/a
2686fcf5-0ea9-4902-982f-92cc59ff882b	31536055351	55	-633.36	0	ecd: 1.5700 SG; frac: 1.5700 SG @ 1436.21 m	n/a
40027715-26b7-40f2-b459-c017c7082baf	31536055373	55	-672.94	0	ecd: 1.5707 SG; frac: 1.5700 SG @ 1427.41 m	n/a
2f529df5-b2d6-4d90-957b-97bfa2f41282	31536055395	55	-712.53	0	ecd: 1.5708 SG; frac: 1.5700 SG @ 1393.22 m	n/a
2da60e57-400f-41d3-930b-04661fd03633	31536055417	55	-752.11	0	ecd: 1.5707 SG; frac: 1.5700 SG @ 1359.03 m	n/a
d26a3744-4b22-43bd-b55c-7f862b9a09df	31536055439	55	-791.7	0	ecd: 1.5706 SG; frac: 1.5700 SG @ 1324.84 m	n/a

Recommended values

Block speed (m/h)
-435.43

Figure 4.1: optimization plot app – tripping

The example presented demonstrates 12 simulations conducted for a specific stand within the depth range of 1710m to 1768m MD. It shows that the axial velocity can be increased from 395 m/h to maximum 435m/h. Increasing the axial velocity further will fracture the formation. The appendix 4 contains the simulation results for the valid simulation for this stand. The valid simulation is highlighted as recommended value.

Moreover, an additional feature known as the scorecard has been integrated into the results, providing a comprehensive overview of the diverse combinations of simulation outcomes. Each data point on the scorecard corresponds to a specific combination of drilling parameters. It is important to note that the scorecard feature is exclusively applicable to drilling parameter optimization, as it involves multiple parameters being evaluated simultaneously. However, it is worth mentioning that the axial velocity during tripping is not included in the scorecard. This omission is attributed to the fact that the axial velocity during tripping is represented by a single numerical value, which does not align with the multi-dimensional nature of the scorecard. This scorecard serves as a visual representation of the simulation results, allowing to easily compare and analyse different combinations of drilling parameters. The green area on the scorecard provide the best combination of drilling parameters. If several simulations scores equal in the scorecard, the simulation with shighest ROP will be selected.

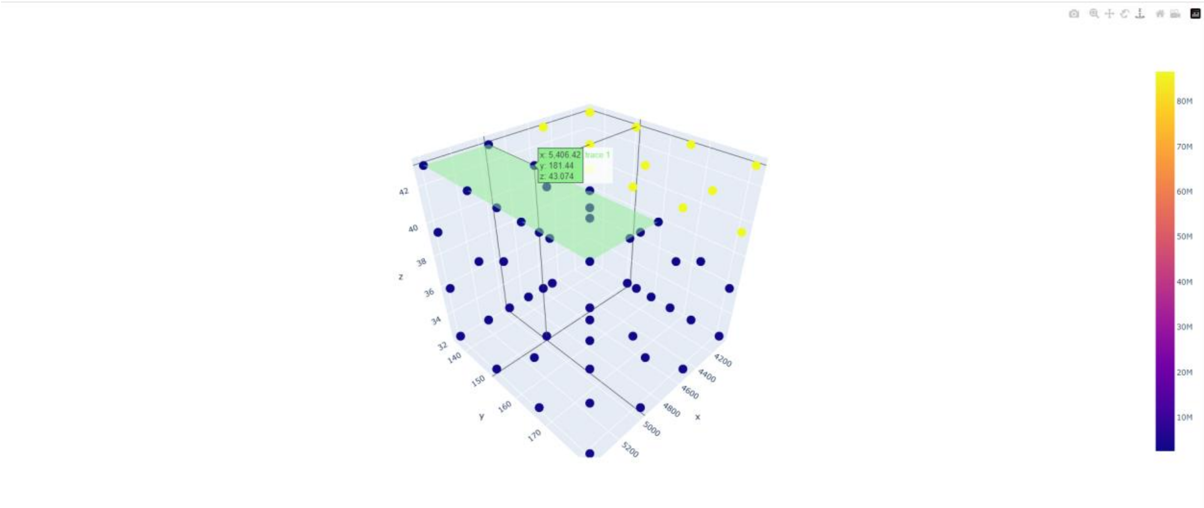


Figure 4.2: optimization results scorecard – drilling

4.3 Case study – well information

The case study conducted in this thesis involves the analysis of two wells, referred to as Well A and Well B. Well A represents a past drilling operation, while Well B is monitored in real-time during its drilling operation. The primary objective of these case studies is to investigate the autocalibration of the models and optimization of drilling parameters in real-time and assess its impact on value creation and work processes.

The impact of real-time drilling parameter optimization on value creation is assessed by analysing various performance indicators, such as drilling efficiency, cost reduction and overall productivity. Additionally, the case studies examine the effect of real-time parameter optimization software on work processes, including operational procedures, task performance, decision-making, and collaboration among stakeholders.

By analysing both Well A and Well B, this research provides insights into the importance of using digital twin for drilling parameter optimization in real-time and its potential to improve drilling performance, reduce costs, and enhance overall value creation.

4.3.1 Case study A – drilling

The well A, drilled in the NCS in 2020, holds the distinction of being the longest well ever drilled in the field, reaching an approximate total vertical depth (TVD) of 4183m and measured depth (MD) of 8552m. The well features an S-shape trajectory, with a 17 ½" section designated as the build-up section.

The build-up section of the well A starts at a depth of around 1170m with an inclination of 15° and gradually increases to approximately 53° at a depth of 1769m. This section is critical in terms of potential risks associated with hole cleaning and losses. Most research shows that the well inclination in these interval is the most challenging area for hole cleaning (most of the research paper referenced in this study highlight this). Therefore, during the drilling process, ensuring effective hole cleaning becomes crucial to maintain wellbore integrity and prevent any losses or obstructions.

Additional information related to rig pump limitations, planned operational parameters, and pre-liminary input to wellGuide are added below:

The dynamic well data needed for wellGuide to run in real-time are as follow:

Bit depth	Well depth	Block position	Flow rate	RPM	WOB	Hookload	Torque	Mud density in	Mud temperature in

Rig pump capacity

Max SPP limit
300 [bar]

Following has been introduced into wellGuide prior running the simulation.

Default Cuttings percentage for efficient hole cleaning	Cuttings percentage used for this section	Safety margin
7 %	2.3 %	0.1 sg

Planned drilling parameters based on third party simulations.

ROP	Flow rate	RPM	Max ECD @ casing shoe (1150m MD)	Max pore pressure at section TD @ 1768m MD
35 [m/h]	4800 [lpm]	150 [rpm]	FIT = 1.57 [sg]	Max PP: 1.48 [sg]

4.3.2 Optimization results

The graph presented illustrates the optimization results for the drilling of the 17 ½" section within the depth range of 1210 to 1768 meters measured depth (MD). It demonstrates that the advised Rate of Penetration (ROP) consistently surpasses the actual ROP throughout the entire section, while maintaining the flow rate and revolutions per minute (RPM) at values equal to the actual flow rate and RPM for the majority of the time. Additionally, the advisory system recommends increasing both ROP and the flow rate at several depths in response to the cuttings load in the wellbore exceeding the predefined threshold. This indicates that the advisory system actively responds to the fluctuating conditions and provides guidance accordingly in order to enhance drilling performance.

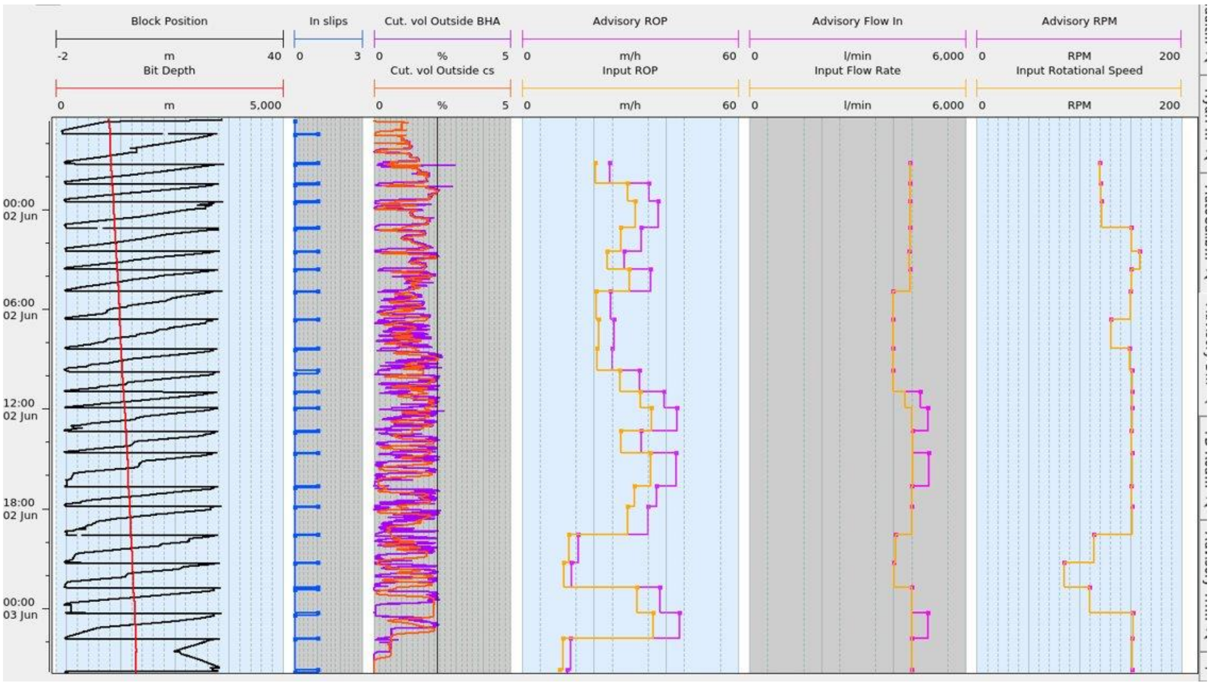


Figure 4.3: optimization results well A – drilling – a snapshot from wellGuide software showing Advisory ROP, Flow In and RPM (pink) and actual ROP, Flow In and RPM (yellow) from Well A.

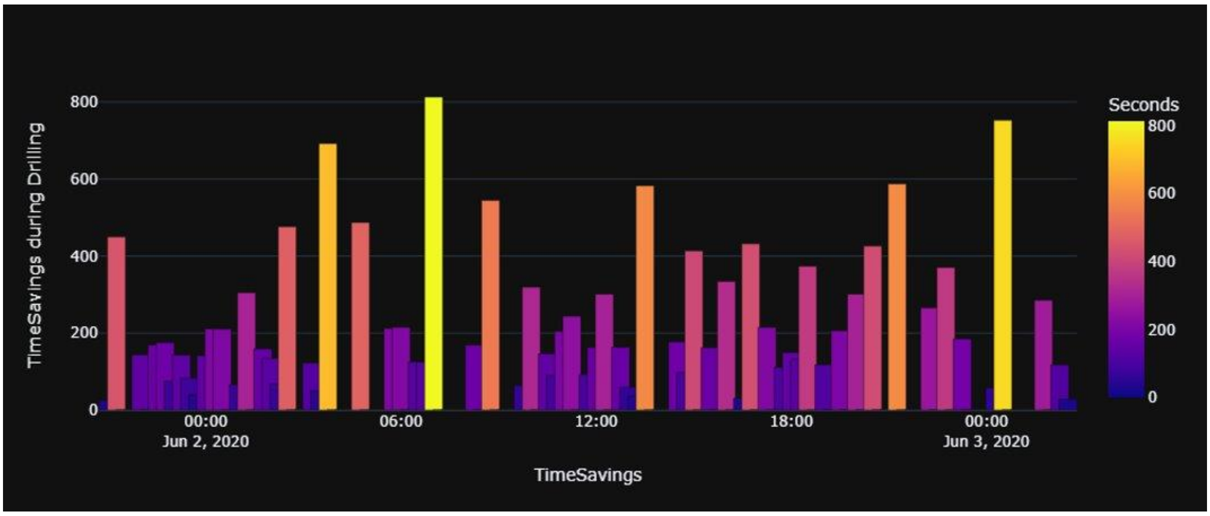


Figure 4.4: time savings well A – drilling

The time savings associated with each detected drilling sequence are represented in the graph 4.4. The colour scheme utilized provides visual differentiation for the magnitude of time savings. Specifically, blue colour indicates the least amount of savings, pink represents a moderate level of savings, and yellow signifies the maximum level of saving. It is important to note that the advisory system's recommendations for increasing the Rate of

Penetration (ROP) are limited to 20% higher than the current ROP. Consequently, the time savings achieved for lower ROP values will be comparatively lower. This implies that the impact of the advisory system's recommendations on reducing drilling time will be more significant for drilling sequences with higher initial ROP values, as the potential for improvement is greater in those cases.

The analysis reveals that the total time savings achieved for drilling this section amount to approximately <u>**260**</u> minutes. It is important to note that the total operation time, which includes connection periods, is estimated to be around 30 hours.

To calculate the potential drilling efficiency time, a formula is employed as follows and coded in phyton to collect total savings.

$$Time\ saving = Current\ Opeation\ Duration - \frac{Current\ Operation\ Duration * Actual\ ROP}{Advisory\ ROP}$$

$$TotalSavings = \sum_{starttime}^{endtime} savingsperStand$$

In this formula, the time savings are determined by subtracting the connection period from the total active drilling time. This approach ensures that only the time directly associated with the active drilling phase of the operation is taken into account when calculating the overall time savings.

By excluding the connection time, a more accurate representation of the drilling efficiency time can be obtained. The total time savings are then calculated by summing the individual savings for each stand drilled within the defined start and end time.

In this particular instance, the calculated connection time amounted to approximately 2 hours, thereby yielding approximately 28 hours of active drilling time. Through the utilization of optimized drilling parameters, it was possible to achieve a reduction of approximately 4.3 hours in active operation time, which equates to a 15% decrease in overall operation duration.

4.4 Case study – Tripping well A

After completing the drilling of the 17 ½" section in well A and subsequently pulling out of hole (POOH) the 17 ½" bottom hole assembly (BHA), the next step in the workflow involved running in hole (RIH) with 13 5/8" casing. FIT was conducted to 1.57sg at 20” casing shoe (1170m MD) during drilling. This value represents the maximum allowable pressure during both drilling and RIH with 13 5/8” casing.

The wellGuide use the FIT (1.57sg) and running 12 different simulations. Based on the scorecard, the best option will be chosen and send to GUI.

Surge limitation to optimize axial velocity

Max ECD @ casing shoe (1150m MD)
FIT = 1.57 [sg]

4.4.1 Optimization results

In the context of the tripping workflow, the wellGuide application provides various simulation capabilities, including the estimation of tripping speed and acceleration limits, as well as the verification of planned tripping profiles against these limits. Figure 4.5 showcases the wellGuide results from RIH operation of 13 5/8” casing in well A, where the drilling contractor adheres to a predetermined tripping speed profile, which is simulated against the maximum surge limitation (1.57 sg). The tripping speed profile in then evaluated against the tripping speed provided by wellGuide.

The figure 4.4 contains following data.

- 1 : Casing depth - well depth – block position
- 2 – Connections
- 3 – Actual tripping speed vs simulated tripping speed from wellGuide
- 4 - Calculated ESD at 20” casing shoe and bottom hole of the section
- 5 – Calculated ESD at 13 5/8” casing shoe while tripping
- 6 – compares measured active volume vs. modelled active volume
- 7 – Compares measured and modelled hookload during tripping

As seen in the graph, in section number 3, the defined tripping profile used for the RIH 13 5/8” casing is very conservative until 1150m (yellow line), and wellGuide suggest higher speed while keeping the formation integrity in consideration. Section 4 in the plots shows the surge pressure created during RIH with 13 5/8" casing and the maximum allowed surge pressure as a reference line. This is a common scenario during pre-job modelling, where the planning software's suggest constant tripping speed for longer intervals and not dynamically according to well conditions. The wellGuide application operates in real-time and incorporates a hybrid combination of input data comprising static, semi-static, and real-time parameters (Arvelo et al., 2023).

Side note: The axial velocity for RIH is represented as a negative number, while it will positive number during POOH.

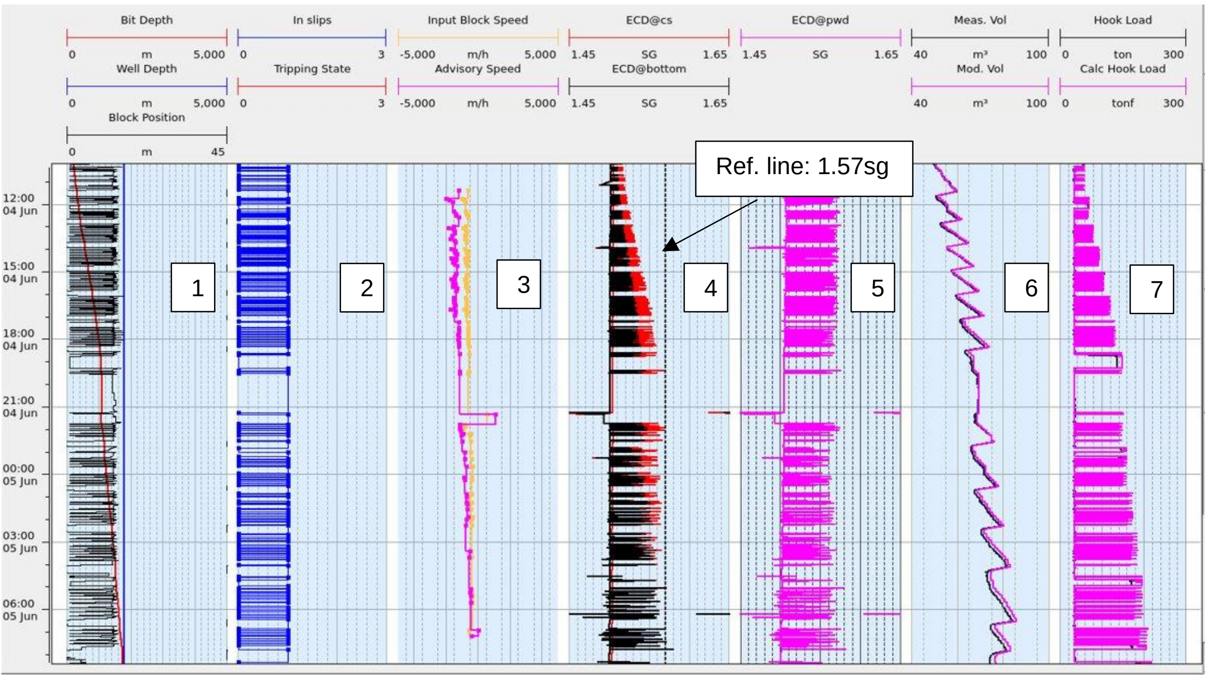


Figure 4.5: optimization results -tripping

Figure 4.5 illustrates the potential opportunities for savings during the run in Hole (RIH) operation with 13 5/8" casing on each stand. The graph indicates that the maximum potential time savings per stand amount to approximately 30 seconds particularly from 0 depth to around 1150m. This time saving is particularly significant when considering that each stand typically requires only around 60 to 90 seconds according to the planned tripping speed profile. The total saving for this operation is around 40 minutes and the total operation time is approximately 18 hours including connections.

Below formula is coded in phyton and used to collect time savings for each stand and the total time savings for each operation. the time savings are calculated by subtracting the connection period and the time taken for accelerations and decelerations from the total active running time. This approach ensures that only the time directly related to the active running of the operation is considered when determining the total time savings.

$$AccelarationDecceleration = 25\% * TotalTripTime$$

$$CurrentTripTime = TotalTripTime - AccelarationDecceleration$$

$$SavingsperStand = CurrentTripTime - \frac{CurrentTripTime * InputBlockSpeed}{AdvisoryTripSpeed}$$

$$TotalSavings = \sum_{starttime}^{endtime} SavingsperStand$$

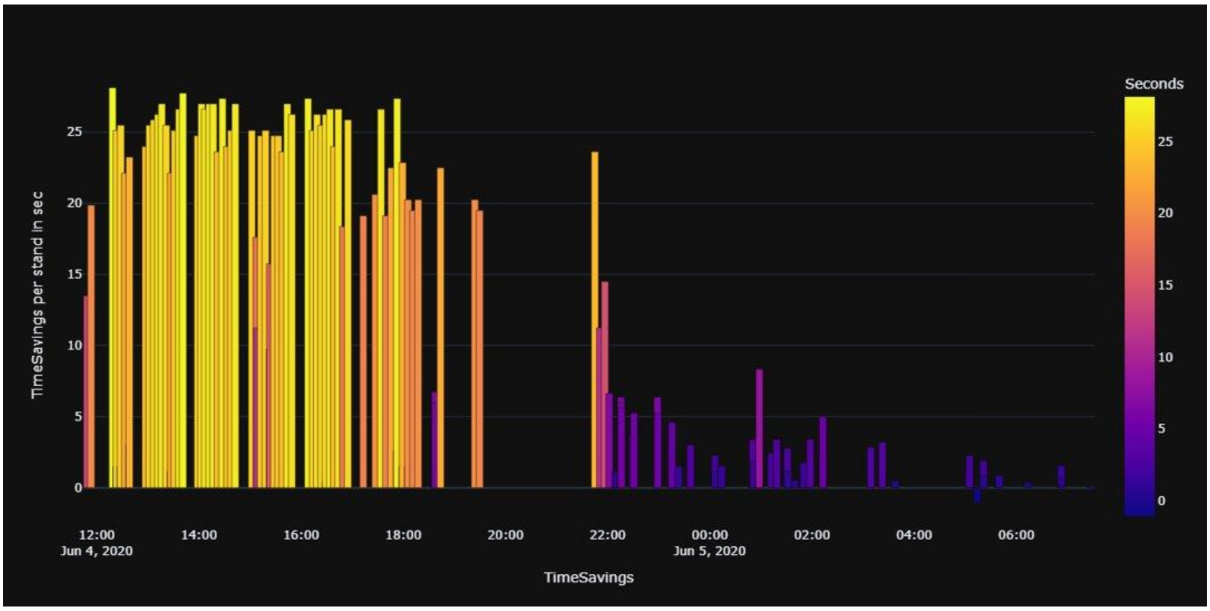


Figure 4.6: Potential saving for each stand – RIH 13 5/8" casing

The time savings associated with each detected drilling sequence are represented in the graph 4.5. The colour scheme utilized provides visual differentiation for the magnitude of time savings. Specifically, blue colour indicates the least amount of savings, pink represents a moderate level of savings, and yellow signifies the maximum level of saving. As described above, there is a huge potential for increasing the efficiency of the RIH operation from 0m – 1150m MD as highlighted by yellow colour which represents the most saving potential.

In this particular instance, the calculated connection time and passive operational time amounted to approximately 6 hours, thereby yielding approximately 12 hours of active tripping time. Through the utilization of optimized drilling parameters, it was possible to achieve a reduction of approximately 0.66 hours in active operation time, which equates to a 5.5% decrease in overall operation duration.

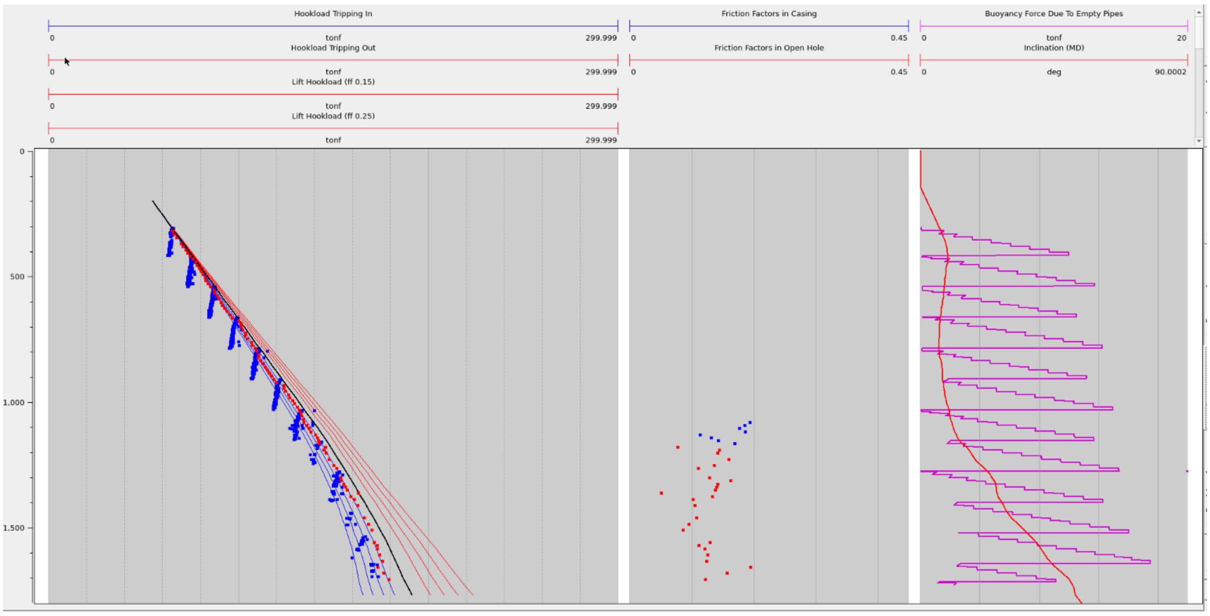


Figure 4.7: Auto calibration of torque and drag model during RIH with 13 5/8” casing

The blue dots represented on the roadmap correspond to the actual hookload detected by the system, while the red dots indicate the buoyancy-compensated values, revealing the genuine friction experienced within the well. The torque and drag model automatically calibrate itself and detect empty pipe sections during tripping operations. Additionally, it is equipped to dynamically map the friction encountered in the well in real-time, ensuring accurate and up-to-date information.

4.5 Case study – well B – Auto calibration

Well B, situated in the Middle East, is a vertical well with a designated total depth of 6107 meters. The specific section of interest in this study is the 14 ¾" x 16" section, planned to be drilled between 2750 and 4437 meters measured depth (MD). This section holds significance due to the presence of uncertain pressure gradients and the potential for fluid losses and gains.

In order to facilitate the drilling operation, the customer implemented wellAhead, an additional eDrilling product. The wellGuide system encompasses two distinct systems simultaneously: wellAhead, which serves as the digital twin of the wellbore in real-time, and the advisory module, which enables lookahead simulations.

To ensure precise modelling, the digital twin (wellAhead) undergoes automatic calibration to accurately represent the current state of the wellbore. This calibrated well state is then transmitted to the advisory module. Leveraging the calibrated well state, the advisory module conducts lookahead simulations and forecast optimized drilling parameters.

4.5.1 Auto calibration results

The image 4.8 shows a visual representation of the autocalibration transient hydraulic and thermos-dynamic model, providing clarity on how autocalibration operates. The red box highlights the initial triggering of autocalibration.

Upon observation, it is evident that prior to autocalibration being triggered, there is a lack of convergence between the modelled and measured values of the SPP (2) and ECD (3). This indicates a discrepancy between the predicted values generated by the model and the actual measurements recorded. This inconsistency may be attributed to changes in fluid specifications and other alterations in the wellbore conditions that were not accounted for by the digital twin

The purpose of autocalibration is to rectify this discrepancy by adjusting the model parameters to better align with the measured data. By triggering autocalibration, the model can be calibrated in real-time, ensuring improved accuracy both in real-time simulations and lookahead simulations performed by wellGuide.

When the result has been presented to the customer, the main contact person in the company asked “is it possible to have auto calibration in the wellAhead product as well”. It was mentioned that autocalibration give them the below benefits:

- The system can run by itself with out any manual calibration
- Manual calibration can lead to calibrate operational problems by unexperienced users. It will increase the trust ability of the software.
- Save them time as they don’t need to auto calibrate manually and they need to analyse the plots before each calibration.
- It is more consistent with auto calibration and easy to be tracked back when the system has been calibrated.

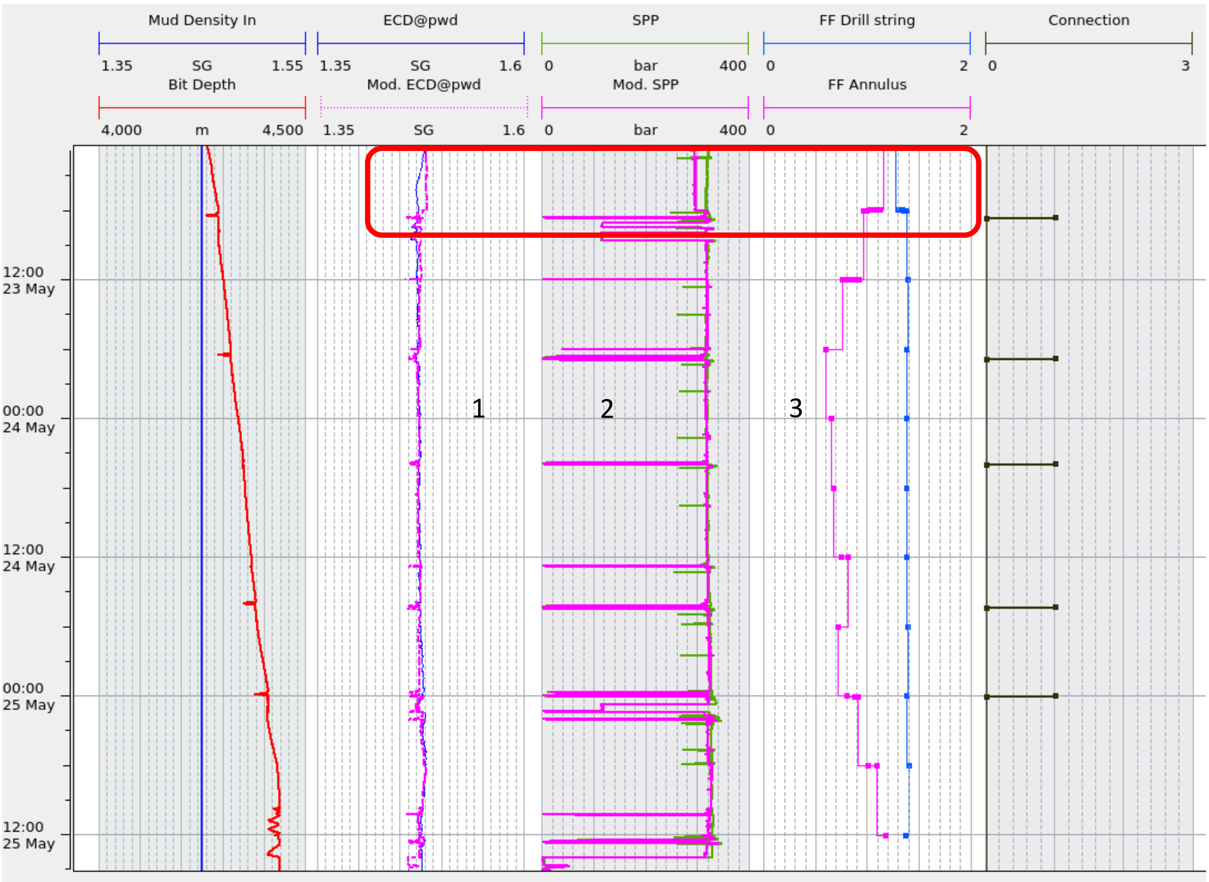


Figure 4.8: Auto calibration results flow model

5 Findings and recommendations

This master thesis concentrated on examining the implementation and effects of automatic real-time parameter optimization in drilling operations by conducting multiple case studies within the oil and gas industry. The objective was to analyze the advantages, obstacles, and overall efficacy of these approaches in enhancing drilling operations. The research involved integrating the wellGuide software, collecting and processing data, performing data analytics, and optimizing drilling parameters to enhance drilling efficiency. The purpose of this chapter is to address the thesis objective, which is partly answered through the case studies: assessing the impact of digitalization tools on value creation and work processes during drilling operations.

5.1 Drilling efficiency and value creation

The first category of findings, which is discussed in Chapter 5.1.1, centres around the drilling efficiency and value creation for the asset. This value creation is substantiated through the examination of case studies that utilize actual operational data, as well as through the exploration of relevant theories supported by research.

5.1.1 Improved Drilling Efficiency

As demonstrated in the case study of well A, utilizing optimized drilling parameters for the 17 ½" section leads to a reduction of approximately 15% in drilling time and 5.5% in tripping time. This results in overall time savings, increased rate of penetration (ROP), improved axial velocity during tripping while ensuring well integrity, and enhanced operational efficiency. Moreover, real-time parameter optimization contributes to enhanced safety and risk mitigation. By employing digital twin technology for real-time monitoring, equipment anomalies can be detected early, preventing accidents and mitigating potential operational risks and non-productive time (NPTs) (Mayani, 2018).

The implementation of automatic parameters optimization holds the potential for cost reduction in drilling operations. By optimizing drilling parameters, minimizing non-productive time, and improving operational parameters, companies can achieve significant cost savings. Furthermore, the automation of parameter optimization eliminates the need for manual intervention from drilling or planning engineers, thereby optimizing resource allocation and reducing overall operational expenses (Ambrus et al., 2017; Ashena et al., 2021).

Automatic parameters optimization enables the selection of optimal drilling parameters based on real-time data and advanced algorithms. This approach enhances drilling performance by taking into account actual fluid properties, drilling parameters, and equipment capabilities. The dynamic optimization of drilling parameters leads to improved drilling efficiency and reduced operational risks (Said, 2022).

Additionally, customer feedback highlights the potential of the auto-calibration feature to decrease human involvement in software deployment, leading to cost reductions and improved software accuracy:

[…] is it possible to implement the auto calibration functionality in wellAhead? (a product used by the customer today). This feature has the potential to minimize human intervention in the software deployment processes, thereby facilitating reduction in personnel costs and enhancing the software accuracy.

5.1.2 Automated work process

The second category discussed in Chapter 5 explores the potential of digital twins in automated work processes. The concept of automated work processes, coupled with automation through digital twin technology, has gained significant traction across various industries. This approach involves leveraging advanced technology and software to streamline and optimize routine tasks, ultimately reducing the reliance on manual intervention and enhancing overall operational efficiency. By implementing digital twin technology, organizations can create virtual replicas of physical systems or processes, enabling real-time monitoring, analysis, and control. The integration of digital twin technology with automated work processes holds immense promise for improving productivity, reducing errors, and enhancing decision-making capabilities.

5.1.2.1 Automated work process

The wellGuide system enables the optimization and automation of work processes through two primary mechanisms. Firstly, it conducts automated analysis of drilling parameter trends and calculates optimized parameters based on the available data. Secondly, it incorporates auto-calibration functionality, eliminating the need for manual calibration by operational personnel. These features of the wellGuide system contribute to reducing workloads, improving efficiency, and enhancing safety within drilling operations.

By integrating auto-calibration and real-time advisory modules, the wellGuide allows for automated real-time analyses and real-time optimization without the involvement of domain experts. The implementation of digitalization tools not only leads to cost and time savings but also facilitates continuous performance improvement. However, it is crucial to acknowledge that discrepancies may exist between the digital model and the physical system due to the inherent complexity and real-time nature of the drilling process. Thus, calibration becomes necessary to align the system with the actual operational conditions.

During a drilling operation, the calibration factors need to be continuously updated as the conditions change. However, it is crucial to use representative data for calibration and avoid masking significant events such as kicks, losses, or poor hole cleaning that should be identified as anomalies. Achieving fully automatic calibration without user or expert intervention requires the development of algorithms that consider these factors while maintaining speed and robustness (Mal et al., 2023).

As highlighted in Chapter 2, Section 2.1.2.1, minimizing human involvement in operational tasks has the potential to enhance safety and reduce the likelihood of human errors. Automation and advanced technologies can mitigate risks associated with human factors such as fatigue, distraction, and cognitive limitations. By reducing reliance on manual intervention, the likelihood of errors, accidents, and safety incidents can be significantly reduced. This aspect aligns with the goal of improving operational safety and underscores the importance of incorporating automation in various industries (Redmill 2010).

Additionally, customer feedback highlights the potential of the auto-calibration feature to decrease human involvement in software deployment, leading to cost reductions and improved software accuracy:

A customer informant describes how they would see the future of wellGuide within there operations:

[…] wellGuide, currently functioning as an advisory module, operates in real-time without directly controlling or modifying operational parameters. However, as part of their continuous automation efforts, there is a desire to develop a product that can actively

assume control over operations and autonomously adjust the parameters. This transition aims to further enhance operational efficiency and optimize drilling processes by reducing human intervention and leveraging advanced automation capabilities.

5.1.3 The need of verification of the case study results

To validate and study the results of the simulations performed by wellGuide, it was essential to analyse both the input and output data. This analysis was crucial for ensuring the functionality and effectiveness of wellGuide in accordance with its design. By examining the input data, such as drilling parameters, well characteristics, and operational conditions, it was possible to assess the accuracy and relevance of the simulations. Furthermore, analysing the output data, which includes the auto calibration results, hole cleaning index, wellbore integrity versus simulated, and any deviations from expected outcomes, helped to verify the value creation and optimized work processes achieved by wellGuide. This validation process ensures that wellGuide is operating as intended and provides reliable insights for decision-making in drilling operations.

During the validation process, the following input and output data were analysed to ensure the accuracy and reliability of the simulations performed by wellGuide:

Input data:

- Static well data: This includes information about the well trajectory, drill string configuration, wellbore geometry, pressure gradient, and temperature profile. These static parameters are essential for modelling the well and its characteristics accurately.
- Semi-static well data: This involves fluid specifications, such as rheology (flow behaviour), gelling properties, and density. These parameters are crucial for understanding the behaviour of the drilling fluid and its impact on the drilling process.
- Dynamic well data: To ensure consistency and reliability, dynamic well data, such as real-time measurements of flow rates, pressures, and temperatures, were considered. These dynamic parameters help validate the simulations against actual operating conditions.

Output data:

- *Drilling simulation results:* The distribution of cuttings along the wellbore, equivalent circulating density (EMW), and surface pump pressure (SPP) were carefully analysed. These results were compared against wellbore integrity and equipment capacities to verify the feasibility and adherence to operational constraints.
- *Tripping simulation results:* The axial velocity, and EMW during tripping operations were examined. These results were compared against wellbore integrity requirements and evaluated to ensure their consistency and logical interpretation.

By scrutinizing both the input and output data, the validation process aims to confirm the accuracy, reliability, and functionality of wellGuide's simulations. It ensures that the model outputs align with the limitations, capacities, and expected behaviour of the well and equipment, thus providing valuable insights for optimizing drilling operations

5.1.3.1 Verification process and validation

The validation process of the results obtained from wellGuide simulations was conducted based on three key assumptions:

1) Deployment of core technology: The core technology and models used in wellGuide have been deployed in both training simulators and real-time operations since 2012. This extensive deployment on numerous wells worldwide over several years provides a solid foundation for validating the results. The accumulated experience and track record of successful implementation contribute to the reliability and credibility of the simulation outcomes (eDrilling 2023).
2) Qualitative comparison with actual operational data: Where available, the simulation results were qualitatively compared with the actual operational data. This involves trends, and patterns observed during real-time drilling operations. By comparing the simulated results to the actual data, the accuracy and consistency of wellGuide's predictions and recommendations can be assessed.
3) Qualitative comparison with third-party simulations: In addition to comparing the results with real-time operational data, a qualitative comparison was made with third-party simulations performed during the well planning phase. These simulations,

conducted by a third party software, provide an additional reference point for evaluating the validity of the wellGuide results.

In the table, the drilling parameters for 17 ½” drilling is presented and were planned using a third-party software. The actual operational parameters were kept within or lower than these planned values. However, wellGuide suggests higher rates of penetration (ROP) and, at several depths, higher flow rates to ensure good hole cleaning. It is important to note that these suggested values are still within the well boundaries and equipment capacities. The full results of this simulation is added in appendix 2.

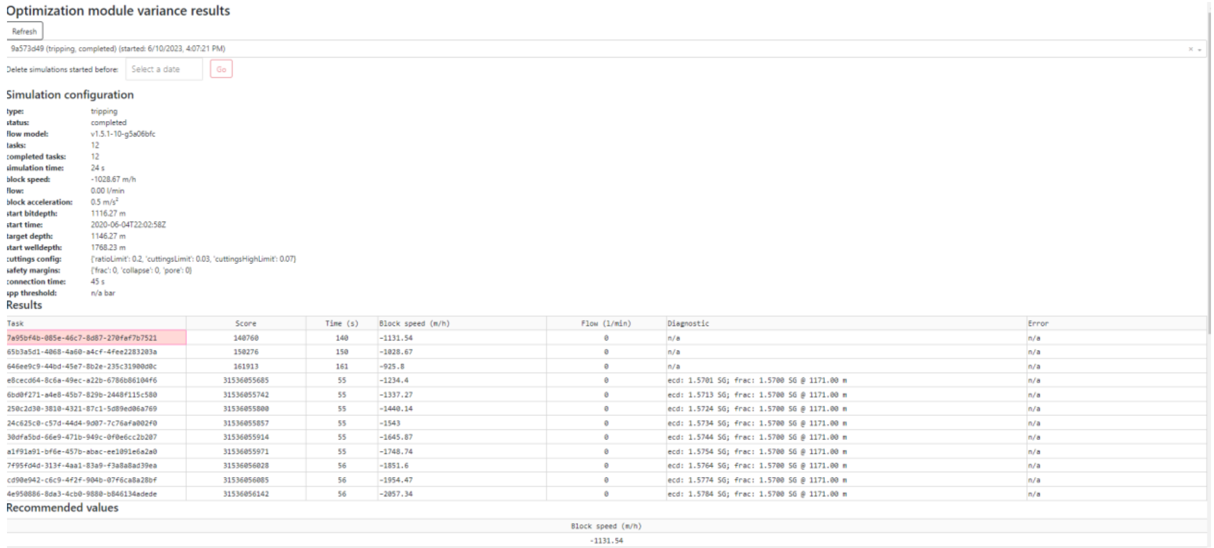
Planned drilling parameters for 17 ½” section

ROP	Flow rate	RPM	Max ECD @ casing shoe (1150m MD)	Max pore pressure at section TD @ 1768m MD	Max SPP
35 [m/h]	4800 [lpm]	150 [rpm]	FIT = 1.57 [sg]	Max PP: 1.48 [sg]	300 [bar]

Drilling parameters suggested by wellGuide in the interval of 1517 – 1547m MD

Advisory ROP	Advisory Flow rate	Advisory RPM	Calculated ECD @ casing shoe (1150m MD)	Max calculated SPP	Max cuttings load
43 [m/h]	4955 [lpm]	150 [rpm]	1.41sg	205 [bar]	2.02 %

In the tripping case study, the figure presented below displays a section extracted from the plot optimization app, specifically focusing on the simulation results of Running in Hole (RIH) for a 13 5/8" casing within a single stand ranging from 1116m to 1146m measured depth (MD). The figure provides a visual representation of the various speeds utilized in the simulations, the number of simulations resulting in fracture formation, and the valid speed values considered for analysis. The model output of the highlighted simulation (red colour) is added in appendix 4.



RIH with 13 5/8” casing simulation results – 1116 – 1146m MD

5.2 Recommendation and improvements

Based on the case studies and research findings and analysis conducted in this master's thesis, the following recommendations are proposed for the implementation of wellGuide during drilling operations.

5.2.1 User centred product

According to Eason (1996), advanced technology alone does not yield benefits for organizations. Instead, it requires people to effectively utilize its capabilities in order to generate organizational advantages. Employees must feel motivated and engaged in the tasks they are assigned, considering them as meaningful contributions to the organization. Additionally, they need to recognize the technology as a valuable asset that can aid them in carrying out their responsibilities effectively, otherwise they will reject the system.

Eason (1988) argues that the success of advanced technology systems depends on considering both social and technical aspects. This includes understanding the needs, values, and preferences of users, as well as considering the social and organizational context in which the technology will be implemented. By taking a socio-technical perspective, designers can ensure that technology aligns with the social and organizational requirements, enhances user satisfaction, and contributes to organizational effectiveness.

The socio-technical design approach recognizes that technology implementation is not solely a technical process but also involves addressing human factors, organizational culture, communication, and other social aspects. It promotes a holistic understanding of technology and its impact on individuals, groups, and organizations. By integrating social and technical considerations, organizations can create advanced technology systems that are better aligned with user needs, promote user acceptance, and facilitate positive outcomes in the organizational context.

In accordance with Redmill's (2010) perspective, the incorporation of a user-friendly graphical user interface (GUI) is deemed necessary to enhance the interaction between human operators and technological systems. The objective is to improve overall safety levels and mitigate the occurrence of human errors.

Several enhancements to the wellGuide graphical user interface (GUI) have been proposed and designed, with the active involvement of the eDrilling development team. These improvements are currently in the development phase. The design process involved thorough analysis, deliberation, and feedback from both internal users within the organization and a select group of external users. By engaging various stakeholders and incorporating their perspectives, the aim is to ensure that the redesigned GUI meets the needs and preferences of the end users, resulting in a more intuitive and user-friendly interface. The significance of enhancing human reliability through ergonomic design of the graphical user interface (GUI), as emphasized by Redmill (2010), played a crucial role in shaping the design process of wellGuide. By considering the principles of ergonomic design, the aim was to create a user interface that promotes user comfort, efficiency, and effectiveness in interacting with the software. Also, Eason's (1988) research on work flow and design resources played an important role in shaping the design process and facilitating its implementation. By understanding the workflow and considering the available design resources, the design of the system can be aligned with users' needs, preferences, and cognitive capabilities. This, in turn, enables the development of an interface that supports efficient task performance and reduces cognitive load, ultimately leading to enhanced usability and user satisfaction.

5.2.2 Introducing safety margins

The inclusion of safety margins in real-time parameter optimization software plays a vital role in ensuring the accuracy and reliability of the optimization process. By acknowledging the inherent limitations and uncertainties in drilling operations, safety margins serve as a protective measure to prevent the optimized parameters from surpassing critical thresholds or jeopardizing the integrity and safety of the well (Baouche et al., 2022; Radwan et al., 2019a, 2020a; Zhang, 2011, 2017).

To ensure a secure and controlled drilling operation, it is imperative to keep the downhole mud weight within the specified drilling window at all times. Deviating from this window, either above or below, can lead to adverse consequences such as formation fracturing, losses, influx, kicks, and wellbore instability, resulting in significant time loss during operations (Kvam.Ø., 2005).

To address the uncertainties inherent in the optimization process and promote conservative decision-making, safety margins for wellbore pressure gradient have been incorporated into wellGuide for both drilling and tripping operations. These safety margins act as a safety net, allowing for slight deviations from the optimized values while ensuring the maintenance of safe operating conditions.

The analysis of case studies in wellGuide has resulted in the identification of specific safety margins for parameters such as Collapse Pressure, Pore Pressure, and Fracture Pressure. It is important to note that these safety margins are derived from a limited number of data sets and cannot be universally applied to all drilling operations. As a result, the wellGuide software allows for the dynamic adjustment of safety margins during real-time operations.

AdvisoryModule.Collapse Pressure	AdvisoryModule.Pore Pressure	AdvisoryModule.Fracture Pressure
5 [kg/m3]	5 [kg/m3]	-5 [kg/m3]

5.2.3 Consider rig equipment capacities

When conducting real-time automated parameter optimization in drilling operations, it is essential to take into account the capacities and limitations of rig equipment. By considering the capabilities of the drilling equipment, the optimized parameters can be aligned to ensure safe and efficient operations. Various rig equipment components, such as pump pressure limits and weight-on-bit (WOB) limits, play a critical role in the interaction with drilling parameters.

The importance of incorporating rig equipment capacities in real-time parameter optimization has been recognized in the literature. For instance, Radwan et al. (2019a) and Radwan et al. (2020a) highlight the significance of considering pump pressure limits as a constraint in the optimization process. By ensuring that the optimized parameters fall within the acceptable range of pump pressure, the drilling operation can be carried out safely and effectively.

Additionally, Zhang (2011, 2017) emphasizes the importance of considering WOB limits during parameter optimization. By taking into account the maximum allowable weight that can be applied to the drill bit, the optimized parameters can be adjusted to prevent excessive load on the drilling equipment and avoid potential failures or inefficiencies.

As wellGuide performing lookahead simulation and WOB calculations is dependent on many factors related to formation properties it is a long term research work which is recommended as a future research.

To enhance the safety and reliability of the optimized parameters generated by wellGuide and advance towards increased automation, a pump pressure limitation has been integrated into the software. The purpose of this limitation is to mitigate the risks associated with high pump pressures during drilling parameter optimization. The implementation of the pump pressure limitation involves comparing the calculated pump pressure obtained from different simulations that employ varying flow rates. By comparing the pump pressure output from the simulations, the software can identify instances where the pressure approaches or surpasses the predefined pump pop-off limitation. When the pump pressure exceeds the specified limitation, the simulation results are deemed invalid and are not recommended to the user, even if other drilling parameters indicate favourable conditions.

Lookahead simulation for WOB is influenced by numerous factors associated with formation properties. Given the complexity and significance of these factors, further research in this area is suggested as a future research direction.

5.2.4 Hole cleaning index

Hole cleaning is a critical aspect of drilling operations as it involves the essential task of removing drilled cuttings and debris from the wellbore. Effective hole cleaning is essential for ensuring optimal drilling performance and maintaining well integrity.

The efficiency of hole cleaning is influenced by various factors, including formation lithology, fluid properties, wellbore inclination, flow rate, revolutions per minute (RPM), rate of penetration (ROP), and cuttings size, among others. Over the years, several indexes have been developed to evaluate hole cleaning performance, such as the cuttings transport ratio (CTR), hole cleaning ratio, cuttings concentration in the annulus (CCA), and carrying capacity index (CCI) (Alawami et al., 2019).

In the wellGuide system, the cuttings concentration in the annulus and the cuttings transport ratio serve as indicators for evaluating hole cleaning efficiency. Research conducted by Alawami et al. (2019) suggests that the cuttings percentage in the annulus should not exceed 8%, and the CTR should not decrease below 50% for efficient hole cleaning. In the wellGuide model, a default value of a maximum of 7% cuttings in the annulus has been implemented for efficient hole cleaning. This default value was determined by the Sintef research team during the development of the model.

During the analysis of cuttings percentage in the annulus and the calculated cuttings transport ratio during case studies using wellGuide, certain unanswered questions have arisen. To address these questions and ensure the consistency and accuracy of hole cleaning evaluations, a verification process is necessary. This process involves comparing the results obtained from wellGuide with relevant research papers and conducting real-time operational verification. These questions are related to the behaviour of hole cleaning efficiency in deviated wellbore sections and the accuracy of wellGuide's predictions in such scenarios.

By conducting such evaluations, wellGuide aims to enhance its hole cleaning assessment capabilities and ensure that the system aligns with established research findings and best practices. This continuous improvement process contributes to the reliability and effectiveness of wellGuide in optimizing drilling parameters and maintaining efficient hole cleaning throughout drilling operations.

6 Discussions

6.1 Overview of the project

The objective of this master's thesis was to examine the influence of advanced digital technology on value creation and work processes in drilling operations. To achieve this objective, a series of case studies were conducted using a real-time parameter optimization software called wellGuide. The purpose was to investigate how this software can optimize drilling parameters in real-time and assess its impact on the work process and value creation within the drilling operations context.

In order to address the research questions and achieve the objective of the thesis, a comprehensive review of the wellGuide software was conducted, focusing on its design and technical aspects. Additionally, a thorough understanding of drilling operations, including terminology and technical considerations, was acquired. The history of digitalization in the oil and gas industry was also explored to provide a broader context for the study.

By combining relevant theories, conducting case studies, and analysing the findings, the impact of wellGuide on drilling operations and its ability to enhance value creation were illuminated. The research questions were systematically addressed, and the findings were presented to demonstrate the influence of wellGuide on the work process and its potential for value creation.

Based on the research findings, recommendations were provided for further enhancing the wellGuide software and utilization of wellGuide in drilling operations. These recommendations encompassed aspects such as improving GUI design, and continuous improvement of the software's capabilities. Moreover, suggestions for future research were outlined, including areas such as inclusion of WOB as part of the lookahead simulations.

In conclusion, this master's thesis successfully examined the impact of advanced digital technology, specifically the wellGuide software, on value creation and work processes in drilling operations. The research provided insights into the optimization potential of wellGuide and its implications for enhancing efficiency, safety, and operational performance. The recommendations and future research directions outlined in this thesis contribute to the ongoing efforts to further leverage digital technology and its applications in the oil and gas industry.

6.2 Learning points

Working on this thesis has provided invaluable insights into a rapidly evolving industry environment characterized by complexity in systems, technology, and human interaction. The oil and gas industry operates in a dynamic landscape where advancements in technology, emerging trends, and evolving industry practices continuously shape the operational dynamics. Understanding the complex interplay between various factors such as systems, technology, and human interactions has shed light on the many-sided nature of the industry and the challenges it faces. By dig in to these challenges, this thesis has contributed to a deeper understanding of the industry's complexities, and the need for innovative solutions to navigate the ever-changing landscape.

By talking to customer decision makers and engineers, this study also contributed on better understanding of the companies vision behind digitalization and digital twin software. A better understanding on the move ahead and how they are thinking about wellGuide on their future plan if deployed. The thesis work has yielded valuable insights into innovative approaches to product development, with a specific focus on the design and implementation of valuable functionalities and user interfaces that enhance the interaction between users and the product. In today's highly competitive market, organizations are increasingly recognizing the importance of delivering products that not only meet functional requirements but also provide a seamless and engaging user experience. Through the exploration of novel approaches and methodologies, this thesis has shed light on how to design and develop products that effectively meet user needs and expectations.

6.3 Practical challenges

One of the primary challenges encountered during the thesis was defining the scope of the work. Initially, the plan was to explore the parameter optimization software (DPM), which comprised modules for both the planning phase and real-time operation phase. However, as the thesis progressed, it became necessary to narrow down the scope to focus solely on the real-time parameter optimization aspect provided by wellGuide. This decision was crucial for bringing the research to a meaningful conclusion. Furthermore, another significant challenge was deciding whether to focus on a specific part of the drilling operations, such as drilling or tripping, and delve deeper into analysing the results, or to explore the full potential of wellGuide in both drilling and tripping operations and assess its impact on value creation and work processes. This decision required careful consideration and weighing the potential benefits and limitations of each approach

Another major hurdle faced during the study was obtaining access to operator companies willing to share their data to deploy wellGuide in real-time operations. This challenge persisted throughout the research, and although some progress was made towards the end, it was at a relatively late stage. Securing the necessary data and cooperation from operator companies is essential to validate the effectiveness and practical application of wellGuide in real-time scenarios.

Overcoming these challenges required adaptability, perseverance, and the ability to make informed decisions based on the available resources and constraints. By addressing these challenges and making strategic choices, the thesis was able to progress and provide valuable insights into the real-time parameter optimization capabilities of wellGuide.

6.4 Future work

Continuous improvement is essential for automated real-time parameter optimization software (wellGuide) to remain competitive in the rapidly advancing landscape of technology, digitalization, and automation. It is important that the software is explored more and the benefits it provides is well known and shared. Additionally, integrating the software with rigsite systems and enabling automated operations is an important progression, as the industry is moving towards full or semi automation of the operations. To accomplish this objective, it is crucial to establish interoperability among drilling contractors, service companies, and operators. This entails creating a digital ecosystem where the wellGuide software is installed and can seamlessly collaborate with other third-party systems. Achieving interoperability requires collaboration at all levels within the oil and gas value chain. This collaborative effort will enable the exchange of data, integration of systems, and effective communication among different stakeholders, thereby facilitating a holistic approach to digitalization and automation in the industry.

The thesis highlights the advantages of utilizing transient hydraulic models, specifically in providing lookahead simulations in real-time for drilling parameters such as rate of penetration (ROP), revolutions per minute (RPM), and flow rate. Future work should also include weight on bit (WOB) in the optimization processes, which is another very important parameters during drilling operations.

Introducing new functionalities to the software should be approached incrementally, ensuring that each step is completed before moving to the next. Completion entails the development, testing, and verification of the new functionality in actual real-time operations. This approach offers two benefits: minimizing the upfront investment and resource requirements and allowing the software to mature before progressing to the next phase.

7 Conclusions

Digitalization and automation are crucial elements of the ongoing fourth industrial revolution, and their importance is expected to grow even further. To remain competitive, companies in the oil and gas sector must embrace the digital revolution and leverage the value it creates, particularly in the realm of real-time well operations. This thesis focuses on evaluating the performance of a real-time drilling parameter optimization software, comprising autocalibration and automated optimization modules. The aim is to investigate how the utilization of such software can reduce drilling operational time and streamline tasks conventionally performed by engineers. The following points underscore the relevance of automatically optimizing drilling parameters in real-time.

- Automated parameter optimization and auto-calibrated systems (wellGuide) substantially decrease operational time by dynamically optimizing drilling parameters to prevent non-productive time (NPT), while enhancing drilling efficiency and performance. Furthermore, they eliminate the need for engineers and other operational personnel to manually analyse operational parameters and assess drilling efficiency and performance.
- The implementation of wellGuide software does not necessarily require significant investments or modifications at the rig site. These solutions can be deployed on the cloud or edge, necessitating minimal in-person support and training. Being implemented in Cloud or edge offerings the flexibility of scalable computing resources and storage capacity and cloud environment also offering centralized data storage, facilitating data sharing and collaboration among multiple stakeholders.
- Users engaging with automated drilling parameter optimization software do not necessarily need to be drilling or digital tools experts to reap its benefits. They function as end-users with the ability to verify the quality of input data and perform basic output analysis.
- It is crucial to highlight that the quality of output depends on the quality of user input. Despite the advantages of digital experience in reducing well operational time and automating specific tasks, it cannot entirely replace the human sources.
- A collaborative cloud ecosystem among different stakeholders would be relevant in the present work environment, enabling communication and data exchange between different systems and organizations.

In conclusion, the benefits of automated real-time drilling parameter optimization outweigh the initial investment, as it significantly enhances operational efficiency, reduces time-consuming tasks, and reducing NPT.

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9 Appendix

9.1 Appendix 1 .

The following output is generated from the plot optimization app, a tool developed to examine simulation results obtained from wellGuide. These simulations were conducted for a specific interval ranging from 1515m to 1545m measured depth (MD). It is evident that there are 64 different variations of the simulations.

Optimization module variance results

Refresh

8d1372dc (drilling, completed) (started: 6/5/2023, 12:02:17 PM)

Delete simulations started before: Select a date Go

Simulation configuration

type: drilling
status: completed
flow model: v1.5.0-160-g36a8aa95
tasks: 64
completed tasks: 64
simulation time: 99 s
rpm: 151.20 rpm
rop: 35.90 m/h
flow: 4505.35 l/min
start time: 2020-06-02T11:56:04Z
target depth: 1545.56 m
start welldepth: 1515.56 m
cuttings config: {'ratioLimit': 0.2, 'cuttingsLimit': 0.03, 'cuttingsHighLimit': 0.023}
safety margins: {'frac': 0, 'collapse': 0, 'pore': 0}
connection time: 45 s

Results

Task	Score	Time (s)	RPM	ROP (m/h)	Flow (l/min)	Diagnostic	Error
18fe31f5-42f6-4bcd-9598-bac4189e067d	2552313	2552	136.08	43.07	4955.89	n/a	n/a
35dc9ec5-d9bd-4b00-942b-1d261492d9a7	2552313	2552	181.44	43.07	5406.42	n/a	n/a
47181efa-28da-44db-8d03-feacb00a5c56	2552313	2552	166.32	43.07	4955.89	n/a	n/a
5fdeed1e-e12e-4d80-93db-aa7ee1c97098	2552313	2552	166.32	43.07	5406.42	n/a	n/a
ae205616-96a4-4746-a428-47b68e80b131	2552313	2552	151.2	43.07	4955.89	n/a	n/a
b37c0160-8fbe-4ffa-bc50-ddb0fd35e6c8	2552313	2552	181.44	43.07	4955.89	n/a	n/a
d2aacfd7-cf04-49dd-b093-d260d16d8459	2552313	2552	151.2	43.07	5406.42	n/a	n/a
e0dfa013-8ba3-42da-9741-6fd4646e6cc5	2552313	2552	136.08	43.07	5406.42	n/a	n/a
0e0b12dd-e8e1-4d51-bc0d-ef33dd9debd6	2780251	2780	136.08	39.48	4505.35	n/a	n/a
30f05138-8517-43b6-a901-a63b1b759847	2780251	2780	166.32	39.48	5406.42	n/a	n/a
3fbda29f-f591-473b-ad0b-7f6ff1d4233e	2780251	2780	151.2	39.48	5406.42	n/a	n/a
5bf3964f-912a-49ff-a70a-3a20b02b2fae	2780251	2780	181.44	39.48	4505.35	n/a	n/a
624200de-a5ac-4bde-861c-4c02692328b3	2780251	2780	151.2	39.48	4505.35	n/a	n/a
62ff1322-ab46-490a-a3ce-1965ad9cec81	2780251	2780	136.08	39.48	4955.89	n/a	n/a
6df34a21-bf1e-4eac-a463-3a337ab035a1	2780251	2780	181.44	39.48	4955.89	n/a	n/a
83d8954c-5815-4eff-a0a6-9aa0ea788ee0	2780251	2780	151.2	39.48	4955.89	n/a	n/a

Task	Score	Time (s)	RPM	ROP (m/h)	Flow (l/min)	Diagnostic	Error
88ded4d2-1aeb-48ac-8e22-135f6e6b4951	2780251	2780	181.44	39.48	5406.42	n/a	n/a
bbbca4aa-891b-4cd7-a2d8-7dd6d1c11e92	2780251	2780	166.32	39.48	4505.35	n/a	n/a
d5a62ab3-b48f-44ff-b5a9-aa5d1659260d	2780251	2780	166.32	39.48	4955.89	n/a	n/a
e4a81697-0ec8-4428-aa96-51e2a8d422fc	2780251	2780	136.08	39.48	5406.42	n/a	n/a
0204793c-70e5-4799-9348-ead22810acbc	3053776	3053	151.2	35.9	5406.42	n/a	n/a
03774e1f-64fc-4d02-9184-ffb47ef72f74	3053776	3053	166.32	35.9	4505.35	n/a	n/a
2376241b-4676-442f-a373-6e036e8f91a5	3053776	3053	166.32	35.9	5406.42	n/a	n/a
28d62a62-bd77-4942-b52e-61598767e7d3	3053776	3053	181.44	35.9	4054.82	n/a	n/a
2f17d409-157c-4ea3-9a2b-f00f5eaaf60c	3053776	3053	151.2	35.9	4955.89	n/a	n/a
4203e079-c2a9-4495-868f-e0ca7cf43bf4	3053776	3053	136.08	35.9	4054.82	n/a	n/a
4de3907b-842b-4f66-8bb4-0f625f606fbe	3053776	3053	136.08	35.9	5406.42	n/a	n/a
6284d557-b41e-4e0b-b355-6e0306c285f4	3053776	3053	151.2	35.9	4054.82	n/a	n/a
78e9d2fc-9a36-4f4b-bc01-d1a71bab1486	3053776	3053	136.08	35.9	4955.89	n/a	n/a
88a53b57-b1cc-4512-be5c-3005bba008f3	3053776	3053	181.44	35.9	4505.35	n/a	n/a
8fdfd49e-2241-483e-b61e-d51a9b566759	3053776	3053	136.08	35.9	4505.35	n/a	n/a
9a0e9609-6b89-433a-898e-444c42608026	3053776	3053	181.44	35.9	4955.89	n/a	n/a

Task	Score	Time (s)	RPM	ROP (m/h)	Flow (l/min)	Diagnostic	Error
d4ded5c5-4916-4b14-8477-e90d1b7d7cbd	3053776	3053	166.32	35.9	4955.89	n/a	n/a
d562263f-cd1a-41c8-9801-468ee6584b4c	3053776	3053	166.32	35.9	4054.82	n/a	n/a
d724fd6e-5d83-436b-a61e-a1403d5b4fd7	3053776	3053	151.2	35.9	4505.35	n/a	n/a
e0bc512e-b198-4def-974e-52b92c796f82	3053776	3053	181.44	35.9	5406.42	n/a	n/a
1e0695fa-ef7b-4685-accc-7d9c96dbfa67	3388084	3388	181.44	32.31	4955.89	n/a	n/a
22f961e3-c1ce-4e96-b401-73ed693cfc5c	3388084	3388	151.2	32.31	4054.82	n/a	n/a
2584ebd4-8e04-4bb6-b8f4-ea72bfad979d	3388084	3388	166.32	32.31	4054.82	n/a	n/a
44dc4bd6-98a1-4c53-99c6-9c9ba6b16f7c	3388084	3388	136.08	32.31	4955.89	n/a	n/a
49fc3d68-bd05-491c-8aa1-bd520d80de64	3388084	3388	181.44	32.31	4054.82	n/a	n/a
4ab1070e-3b05-4248-a602-d3777cc7259b	3388084	3388	136.08	32.31	4054.82	n/a	n/a
5a1412c7-bf87-4a65-b358-c2cae15bcbcd	3388084	3388	166.32	32.31	4955.89	n/a	n/a
6c84abe4-96bf-469f-943b-bfaf8ec89194	3388084	3388	151.2	32.31	4505.35	n/a	n/a
6c9bf11a-9a8c-4505-af31-26ef7afe5d99	3388084	3388	166.32	32.31	4505.35	n/a	n/a
831cdc42-5ee9-4367-9707-653f9a87436e	3388084	3388	166.32	32.31	5406.42	n/a	n/a
90e6a210-1c4c-4773-8285-b83bac15b525	3388084	3388	151.2	32.31	4955.89	n/a	n/a
9a463ded-55e2-45c0-a062-e7abc51f96d1	3388084	3388	136.08	32.31	5406.42	n/a	n/a

Task	Score	Time (s)	RPM	ROP (m/h)	Flow (l/min)	Diagnostic	Error
9e32a507-f15f-4098-8522-ea1ebd750467	3388084	3388	136.08	32.31	4505.35	n/a	n/a
a2eca88c-6f54-49c0-9469-da82c889da1c	3388084	3388	181.44	32.31	4505.35	n/a	n/a
a6b21b2e-ceaa-42e1-b232-25b7ecfcaf58	3388084	3388	181.44	32.31	5406.42	n/a	n/a
e62d8e9c-ae9f-42dd-b12b-98e22409717b	3388084	3388	151.2	32.31	5406.42	n/a	n/a
09995ed2-9d29-4988-a383-e05c5b2323a9	86545000	145	181.44	43.07	4054.82	Cuttings conc.: 2.31% @ 1516.76 m	n/a
3f28eb0c-ac72-4f99-babd-bebea90eae27	86545000	145	166.32	43.07	4054.82	Cuttings conc.: 2.31% @ 1516.76 m	n/a
74ee4699-f811-4092-b676-74036a6f5c26	86545000	145	136.08	43.07	4054.82	Cuttings conc.: 2.31% @ 1516.76 m	n/a
ca1ae044-3408-4594-8338-1cc51e45da9a	86545000	145	151.2	43.07	4054.82	Cuttings conc.: 2.31% @ 1516.76 m	n/a
2c16ee8d-818a-489b-87cc-f0a989c5e965	86595000	195	166.32	39.48	4054.82	Cuttings conc.: 2.31% @ 1517.21 m	n/a
37884eb8-43ce-4e8f-953a-9e8c97043bcf	86595000	195	136.08	43.07	4505.35	Cuttings conc.: 2.32% @ 1517.35 m	n/a
77c7d7ad-4e92-42a0-9da0-db7d5e04601c	86595000	195	136.08	39.48	4054.82	Cuttings conc.: 2.31% @ 1517.21 m	n/a
90930436-f62b-4fe4-bec2-a8d073630ccf	86595000	195	151.2	39.48	4054.82	Cuttings conc.: 2.31% @ 1517.21 m	n/a
9cd2ff85-5f0e-40ff-9cd0-d10dfa33daa1	86595000	195	166.32	43.07	4505.35	Cuttings conc.: 2.32% @ 1517.35 m	n/a
a53a93b2-8b08-480c-87d0-0004d23dd427	86595000	195	181.44	43.07	4505.35	Cuttings conc.: 2.32% @ 1517.35 m	n/a
d2cb8d95-1907-4a21-9c28-37cdc4aa52d5	86595000	195	151.2	43.07	4505.35	Cuttings conc.: 2.32% @ 1517.35 m	n/a
d9d743e6-52cd-4d80-95e2-1a5152851489	86595000	195	181.44	39.48	4054.82	Cuttings conc.: 2.31% @ 1517.21 m	n/a

9.2 Appendix 2

The model outputs presented below represent the data generated from a single simulation out of the 64 simulations outlined in Appendix 1. This dataset encompasses a substantial volume of information that required analysis and verification processes.

1	Input parameters						Calculated parameters by wellGuide														
2	DateTime	BitPositior	DepthHole	MudFlowIn	RotarySpeed	MudDensityIn	sppCalc	csEcdCalc	pwdEcdCa	pwdEsdCa	bhEcdCal	MudTemp	csTempCalc	pwdTemp	bhTempCalc	tempOutCalc	csPresCalc	pwdPresCalc	bhPresCalc	ropCalc	cuttingsBHA
3		M	m	m3/s	rad/s	kg/m3	Pas	kg/m3	kg/m3	kg/m3	kg/m3	k	k	k	k	k	Pas	Pas	Pas	m/s	ratio
4	2020-06-02T12:00:09	1517.95	1517.95	0.09	19.00	1380.00	20269900.00	1408.26	1409.95	1395.51	1410.50	303.15	319.96	315.84	315.13	308.30	15862100.00	20174600.00	20483800.00	0.0120	0.0201
5	2020-06-02T12:00:19	1518.07	1518.07	0.09	19.00	1380.00	20283600.00	1408.18	1409.88	1395.56	1410.43	303.15	319.92	315.19	314.38	308.42	15861200.00	20174900.00	20484200.00	0.0120	0.0201
6	2020-06-02T12:00:29	1518.19	1518.19	0.09	19.00	1380.00	20296900.00	1408.12	1409.84	1395.62	1410.40	303.15	319.88	314.49	313.56	308.54	15860500.00	20175600.00	20485000.00	0.0120	0.0201
7	2020-06-02T12:00:39	1518.31	1518.31	0.09	19.00	1380.00	20309500.00	1408.07	1409.79	1395.66	1410.36	303.15	319.83	313.73	312.68	308.66	15859900.00	20176300.00	20485800.00	0.0120	0.0201
8	2020-06-02T12:00:49	1518.43	1518.43	0.09	19.00	1380.00	20321500.00	1408.03	1409.77	1395.73	1410.35	303.15	319.77	312.94	311.77	308.78	15859600.00	20177400.00	20486900.00	0.0120	0.0201
9	2020-06-02T12:00:59	1518.55	1518.55	0.09	19.00	1380.00	20332500.00	1407.99	1409.75	1395.78	1410.33	303.15	319.71	312.12	310.84	308.90	15859100.00	20178400.00	20488100.00	0.0120	0.0202
10	2020-06-02T12:01:09	1518.67	1518.67	0.09	19.00	1380.00	20342700.00	1407.96	1409.75	1395.86	1410.34	303.15	319.64	311.29	309.91	309.01	15858800.00	20179800.00	20489500.00	0.0120	0.0202
11	2020-06-02T12:01:19	1518.79	1518.79	0.09	19.00	1380.00	20352000.00	1407.94	1409.75	1395.92	1410.35	303.15	319.57	310.46	308.98	309.12	15858500.00	20181100.00	20490900.00	0.0120	0.0202
12	2020-06-02T12:01:29	1518.91	1518.91	0.09	19.00	1380.00	20360500.00	1407.93	1409.77	1396.00	1410.37	303.15	319.48	309.64	308.07	309.23	15858300.00	20182800.00	20492700.00	0.0120	0.0202
13	2020-06-02T12:01:39	1519.03	1519.03	0.09	19.00	1380.00	20368000.00	1407.92	1409.78	1396.06	1410.40	303.15	319.39	308.84	307.19	309.34	15858200.00	20184300.00	20494300.00	0.0120	0.0202
14	2020-06-02T12:01:49	1519.15	1519.15	0.09	19.00	1380.00	20375000.00	1407.91	1409.82	1396.14	1410.44	303.15	319.29	308.05	306.35	309.45	15858200.00	20186200.00	20496200.00	0.0120	0.0202
15	2020-06-02T12:01:59	1519.27	1519.27	0.09	19.00	1380.00	20381300.00	1407.91	1409.84	1396.21	1410.47	303.15	319.17	307.29	305.54	309.55	15858100.00	20187900.00	20498000.00	0.0120	0.0202
16	2020-06-02T12:02:09	1519.39	1519.39	0.09	19.00	1380.00	20387000.00	1407.91	1409.89	1396.30	1410.52	303.15	319.05	306.57	304.77	309.66	15858200.00	20189900.00	20500100.00	0.0120	0.0202
17	2020-06-02T12:02:19	1519.50	1519.50	0.09	19.00	1380.00	20392200.00	1407.91	1409.93	1396.37	1410.56	303.15	318.92	305.87	304.05	309.76	15858200.00	20191800.00	20502000.00	0.0120	0.0202
18	2020-06-02T12:02:29	1519.62	1519.62	0.09	19.00	1380.00	20397000.00	1407.92	1409.98	1396.46	1410.62	303.15	318.77	305.21	303.37	309.86	15858300.00	20194000.00	20504200.00	0.0120	0.0202
19	2020-06-02T12:02:39	1519.74	1519.74	0.09	19.00	1380.00	20401300.00	1407.93	1410.03	1396.54	1410.67	303.15	318.62	304.58	302.74	309.96	15858400.00	20196000.00	20506300.00	0.0120	0.0202
20	2020-06-02T12:02:49	1519.86	1519.86	0.09	19.00	1380.00	20405300.00	1407.94	1410.09	1396.62	1410.74	303.15	318.46	303.99	302.15	310.05	15858500.00	20198200.00	20508600.00	0.0120	0.0202
21	2020-06-02T12:02:59	1519.98	1519.98	0.09	19.00	1380.00	20409100.00	1407.95	1410.15	1396.70	1410.80	303.15	318.28	303.43	301.60	310.14	15858600.00	20200400.00	20510800.00	0.0120	0.0202
22	2020-06-02T12:03:09	1520.10	1520.10	0.09	19.00	1380.00	20412600.00	1407.96	1410.21	1396.79	1410.86	303.15	318.10	302.90	301.10	310.24	15858700.00	20202600.00	20513100.00	0.0120	0.0202
23	2020-06-02T12:03:19	1520.22	1520.22	0.09	19.00	1380.00	20415800.00	1407.97	1410.27	1396.87	1410.93	303.15	317.90	302.40	300.63	310.32	15858900.00	20204900.00	20515400.00	0.0120	0.0202
24	2020-06-02T12:03:29	1520.34	1520.34	0.09	19.00	1380.00	20418900.00	1407.99	1410.34	1396.95	1411.00	303.15	317.70	301.94	300.19	310.41	15859000.00	20207200.00	20517700.00	0.0120	0.0202
25	2020-06-02T12:03:39	1520.46	1520.46	0.09	19.00	1380.00	20421800.00	1408.00	1410.41	1397.04	1411.07	303.15	317.49	301.50	299.79	310.50	15859200.00	20209600.00	20520100.00	0.0120	0.0202
26	2020-06-02T12:03:49	1520.58	1520.58	0.09	19.00	1380.00	20424600.00	1408.02	1410.48	1397.12	1411.14	303.15	317.26	301.09	299.42	310.58	15859300.00	20211900.00	20522500.00	0.0120	0.0202
27	2020-06-02T12:03:59	1520.70	1520.70	0.09	19.00	1380.00	20427200.00	1408.03	1410.55	1397.21	1411.22	303.15	317.03	300.71	299.08	310.66	15859500.00	20214300.00	20524900.00	0.0120	0.0202
28	2020-06-02T12:04:09	1520.82	1520.82	0.09	19.00	1380.00	20429800.00	1408.05	1410.62	1397.29	1411.29	303.15	316.79	300.35	298.76	310.74	15859700.00	20216700.00	20527300.00	0.0120	0.0202
29	2020-06-02T12:04:19	1520.94	1520.94	0.09	19.00	1380.00	20432200.00	1408.06	1410.70	1397.37	1411.37	303.15	316.55	300.01	298.48	310.81	15859900.00	20219100.00	20529700.00	0.0120	0.0202
30	2020-06-02T12:04:29	1521.06	1521.06	0.09	19.00	1380.00	20434500.00	1408.08	1410.77	1397.46	1411.44	303.15	316.29	299.70	298.21	310.89	15860000.00	20221500.00	20532100.00	0.0120	0.0202
31	2020-06-02T12:04:39	1521.18	1521.18	0.09	19.00	1380.00	20436700.00	1408.10	1410.85	1397.54	1411.52	303.15	316.03	299.40	297.96	310.96	15860200.00	20223900.00	20534500.00	0.0120	0.0202
32	2020-06-02T12:04:49	1521.30	1521.30	0.09	19.00	1380.00	20438900.00	1408.11	1410.92	1397.62	1411.59	303.15	315.76	299.13	297.73	311.03	15860400.00	20226400.00	20537000.00	0.0120	0.0202
33	2020-06-02T12:04:59	1521.42	1521.42	0.09	19.00	1380.00	20441000.00	1408.13	1411.00	1397.71	1411.67	303.15	315.49	298.87	297.53	311.10	15860700.00	20228800.00	20539400.00	0.0120	0.0202
34	2020-06-02T12:05:09	1521.54	1521.54	0.09	19.00	1380.00	20443100.00	1408.15	1411.07	1397.79	1411.75	303.15	315.21	298.63	297.33	311.17	15860900.00	20231200.00	20541900.00	0.0120	0.0202
35	2020-06-02T12:05:19	1521.66	1521.66	0.09	19.00	1380.00	20445000.00	1408.18	1411.15	1397.87	1411.82	303.15	314.92	298.40	297.15	311.23	15861100.00	20233700.00	20544300.00	0.0120	0.0202
36	2020-06-02T12:05:29	1521.78	1521.78	0.09	19.00	1380.00	20447000.00	1408.20	1411.22	1397.95	1411.90	303.15	314.63	298.19	296.99	311.30	15861400.00	20236100.00	20546700.00	0.0120	0.0202
37	2020-06-02T12:05:39	1521.90	1521.90	0.09	19.00	1380.00	20448900.00	1408.22	1411.30	1398.03	1411.97	303.15	314.34	297.99	296.83	311.36	15861700.00	20238500.00	20549200.00	0.0120	0.0202
38	2020-06-02T12:05:49	1522.01	1522.01	0.09	19.00	1380.00	20450700.00	1408.25	1411.37	1398.11	1412.05	303.15	314.05	297.80	296.69	311.42	15862000.00	20241000.00	20551600.00	0.0120	0.0202
39	2020-06-02T12:05:59	1522.13	1522.13	0.09	19.00	1380.00	20452500.00	1408.28	1411.45	1398.19	1412.12	303.15	313.75	297.62	296.56	311.47	15862300.00	20243400.00	20554000.00	0.0120	0.0202
40	2020-06-02T12:06:09	1522.25	1522.25	0.09	19.00	1380.00	20454300.00	1408.30	1411.52	1398.27	1412.20	303.15	313.45	297.46	296.44	311.53	15862600.00	20245800.00	20556400.00	0.0120	0.0202
41	2020-06-02T12:06:19	1522.37	1522.37	0.09	19.00	1380.00	20456000.00	1408.34	1411.60	1398.34	1412.27	303.15	313.14	297.30	296.33	311.58	15862900.00	20248200.00	20558800.00	0.0120	0.0202
42	2020-06-02T12:06:29	1522.49	1522.49	0.09	19.00	1380.00	20457700.00	1408.37	1411.67	1398.42	1412.35	303.15	312.84	297.15	296.22	311.64	15863300.00	20250600.00	20561200.00	0.0120	0.0202
43	2020-06-02T12:06:39	1522.61	1522.61	0.09	19.00	1380.00	20459300.00	1408.40	1411.74	1398.49	1412.42	303.15	312.53	297.02	296.12	311.69	15863600.00	20253000.00	20563600.00	0.0120	0.0202
44	2020-06-02T12:06:49	1522.73	1522.73	0.09	19.00	1380.00	20461000.00	1408.43	1411.82	1398.57	1412.49	303.15	312.22	296.89	296.03	311.74	15864000.00	20255400.00	20566000.00	0.0120	0.0202
45	2020-06-02T12:06:59	1522.85	1522.85	0.09	19.00	1380.00	20462600.00	1408.47	1411.89	1398.64	1412.56	303.15	311.92	296.76	295.94	311.78	15864400.00	20257800.00	20568400.00	0.0120	0.0202
46	2020-06-02T12:07:09	1522.97	1522.97	0.09	19.00	1380.00	20464200.00	1408.51	1411.96	1398.72	1412.63	303.15	311.61	296.65	295.86	311.83	15864900.00	20260200.00	20570700.00	0.0120	0.0202
47	2020-06-02T12:07:19	1523.09	1523.09	0.09	19.00	1380.00	20465700.00	1408.55	1412.03	1398.79	1412.70	303.15	311.30	296.54	295.79	311.87	15865300.00	20262500.00	20573100.00	0.0120	0.0202
48	2020-06-02T12:07:29	1523.21	1523.21	0.09	19.00	1380.00	20467300.00	1408.59	1412.10	1398.86	1412.77	303.15	311.00	296.44	295.72	311.92	15865700.00	20264900.00	20575400.00	0.0120	0.0202
49	2020-06-02T12:07:39	1523.33	1523.33	0.09	19.00	1380.00	20468800.00	1408.63	1412.17	1398.93	1412.84	303.15	310.69	296.34	295.65	311.96	15866200.00	20267200.00	20577800.00	0.0120	0.0202
50	2020-06-02T12:07:49	1523.45	1523.45	0.09	19.00	1380.00	20470300.00	1408.67	1412.24	1399.00	1412.91	303.15	310.39	296.25	295.59	312.00	15866700.00	20269600.00	20580100.00	0.0120	0.0202
51	2020-06-02T12:07:59	1523.57	1523.57	0.09	19.00	1380.00	20471700.00	1408.71	1412.31	1399.07	1412.98	303.15	310.09	296.16	295.53	312.04	15867200.00	20271900.00	20582400.00	0.0120	0.0202
52	2020-06-02T12:08:09	1523.69	1523.69	0.09	19.00	1380.00	20473200.00	1408.76	1412.37	1399.14	1413.04	303.15	309.79	296.08	295.47	312.08	15867600.00	20274200.00	20584700.00	0.0120	0.0202
53	2020-06-02T12:08:19	1523.81	1523.81	0.09	19.00	1380.00	20474600.00	1408.80	1412.44	1399.20	1413.11	303.15	309.49	296.00	295.42	312.11	15868100.00	20276500.00	20587000.00	0.0120	0.0202
54	2020-06-02T12:08:29	1523.93	1523.93	0.09	19.00	1380.00	20476000.00	1408.85	1412.51	1399.27	1413.18	303.15	309.20	295.92	295.37	312.15	15868700.00	20278800.00	20589300.00	0.0120	0.0202
55	2020-06-02T12:08:39	1524.05	1524.05	0.09	19.00	1380.00	20477400.00	1408.89	1412.57	1399.34	1413.24	303.15	308.90	295.85	295.32	312.18	15869200.00	20281100.00	20591600.00	0.0120	0.0202
56	2020-06-02T12:08:49	1524.17	1524.17	0.09	19.00	1380.00	20478800.00	1408.94	1412.64	1399.40	1413.31	303.15	308.61	295.78	295.27	312.21	15869700.00	20283400.00	20593800.00	0.0120	0.0202
57	2020-06-02T12:08:59	1524.29	1524.29	0.09	19.00	1380.00	20480200.00	1408.99	1412.70	1399.47	1413.37	303.15	308.33	295.72	295.23	312.25	15870200.00	20285700.00	20596000.00	0.0120	0.0202
58	2020-06-02T12:09:09	1524.41	1524.41	0.09	19.00	1380.00	20481600.00	1409.04	1412.76	1399.53	1413.43	303.15	308.04	295.66	295.19	312.28	15870800.00	20287900.00	20598200.00	0.0120	0.0202
59	2020-06-02T12:09:19	1524.52	1524.52	0.09	19.00	1380.00	20482900.00	1409.08	1412.83	1399.59	1413.50	303.15	307.76	295.60	295.15	312.30	15871300.00	20290200.00	20600400.00	0.0120	0.0202
60	2020-06-02T12:09:29	1524.64	1524.64	0.09	19.00	1380.00	20484300.00	1409.13	1412.89	1399.65	1413.56	303.15	307.49	295.54	295.11	312.33	15871800.00	20292400.00	20602600.00	0.0120	0.0202
61	2020-06-02T12:09:39	1524.76	1524.76	0.09	19.00	1380.00	20485600.00	1409.18	1412.95	1399.72	1413.62	303.15	307.21	295.49	295.07	312.36	15872400.00	20294600.00	20604800.00	0.0120	0.0202
62	2020-06-02T12:09:49	1524.88	1524.88	0.09	19.00	1380.00	20486900.00	1409.23	1413.01	1399.78	1413.68	303.15	306.94	295.44	295.04	312.39	15872900.00	20296900.00	20607000.00	0.0120	0.0202
63	2020-06-02T12:09:59	1525.00	1525.00	0.09	19.00	1380.00	20488300.00	1409.28	1413.07	1399.84	1413.74	303.15	306.68	295.39	295.00	312.41	15873500.00	20299100.00	20609200.00	0.0120	0.0202
64	2020-06-02T12:10:09	1525.12	1525.12	0.09	19.00	1380.00	20489600.00	1409.33	1413.14	1399.90	1413.80	303.15	306.42	295.34	294.97	312.43	15874000.00	20301300.00	20611400.00	0.0120	0.0202
65	2020-06-02T12:10:19	1525.24	1525.24	0.09	19.00	1380.00	20490900.00	1409.38	1413.20	1399.96	1413.86	303.15	306.16	295.30	294.94	312.46	15874600.00	20303500.00	20613500.00	0.0120	0.0202
66	2020-06-02T12:10:29	1525.36	1525.36	0.09	19.00	1380.00	20492100.00	1409.43	1413.25	1400.02	1413.92	303.15	305.91	295.25	294.91	312.48	15875200.00	20305700.00	20615700.00	0.0120	0.0202
67	2020-06-02T12:10:39	1525.48	1525.48	0.09	19.00	1380.00	20493400.00	1409.48	1413.31	1400.08	1413.98	303.15	305.66	295.21	294.88	312.50	15875700.00	20307900.00	20617800.00	0.0120	0.0202
68	2020-06-02T12:10:49	1525.60	1525.60	0.09	19.00	1380.00	20494700.00	1409.53	1413.37	1400.14	1414.03	303.15	305.41	295.17	294.85	312.52	15876300.00	20310100.00	20620000.00	0.0120	0.0202
69	2020-06-02T12:10:59	1525.72	1525.72	0.09	19.00	1380.00	20496000.00	1409.58	1413.43	1400.19	1414.09	303.15	305.17	295.13	294.82	312.54	15876900.00	20312300.00	20622100.00	0.0120	0.0202
70	2020-06-02T12:11:09	1525.84	1525.84	0.09	19.00	1380.00	20497200.00	1409.63	1413.49	1400.25	1414.15	303.15	304.93	295.09	294.80	312.56	15877400.00	20314400.00	20624200.00	0.0120	0.0202
71	2020-06-02T12:11:19	1525.96	1525.96	0.09	19.00	1380.00	20498500.00	1409.68	1413.55	1400.31	1414.21	303.15	304.70	295.06	294.77	312.57	15878000.00	20316600.00	20626400.00	0.0120	0.0202
72	2020-06-02T12:11:29	1526.08	1526.08	0.09	19.00	1380.00	20499700.00	1409.73	1413.60	1400.37	1414.26	303.15	304.47	295.02	294.74	312.59	15878600.00	20318800.00	20628500.00	0.0120	0.0202
72	2020-06-02T12:11:29	1526.08	1526.08	0.09	19.00	1380.00	20499700.00	1409.73	1413.60	1400.37	1414.26	303.15	304.47	295.02	294.74	312.59	15878600.00	20318800.00	20628500.00	0.0120	0.0202
73	2020-06-02T12:11:39	1526.20	1526.20	0.09	19.00	1380.00	20500900.00	1409.78	1413.66	1400.42	1414.32	303.15	304.25	294.99	294.72	312.61	15879100.00	20320900.00	20630600.00	0.0120	0.0202
74	2020-06-02T12:11:49	1526.32	1526.32	0.09	19.00	1380.00	20502200.00	1409.83	1413.72	1400.48	1414.37	303.15	304.03	294.96	294.69	312.62	15879700.00	20323100.00	20632700.00	0.0120	0.0202
75	2020-06-02T12:11:59	1526.44	1526.44	0.09	19.00	1380.00	20503400.00	1409.89	1413.77	1400.53	1414.43	303.15	303.81	294.93	294.67	312.63	15880300.00	20325200.00	20634800.00	0.0120	0.0202
76	2020-06-02T12:12:09	1526.56	1526.56	0.09	19.00	1380.00	20504600.00	1409.94	1413.83	1400.59	1414.48	303.15	303.60	294.89	294.65	312.65	15880800.00	20327400.00	20636900.00	0.0120	0.0202
77	2020-06-02T12:12:19	1526.68	1526.68	0.09	19.00	1380.00	20505900.00	1409.99	1413.88	1400.64	1414.54	303.15	303.39	294.87	294.62	312.66	15881400.00	20329500.00	20639000.00	0.0120	0.0202
78	2020-06-02T12:12:29	1526.80	1526.80	0.09	19.00	1380.00	20507100.00	1410.04	1413.94	1400.70	1414.59	303.15	303.19	294.84	294.60	312.67	15882000.00	20331600.00	20641100.00	0.0120	0.0202
79	2020-06-02T12:12:39	1526.92	1526.92	0.09	19.00	1380.00	20508300.00	1410.09	1413.99	1400.75	1414.65	303.15	302.99	294.81	294.58	312.68	15882600.00	20333800.00	20643200.00	0.0120	0.0202
80	2020-06-02T12:12:49	1527.04	1527.04	0.09	19.00	1380.00	20509500.00	1410.14	1414.05	1400.81	1414.70	303.15	302.79	294.78	294.56	312.69	15883100.00	20335900.00	20645300.00	0.0120	0.0202
81	2020-06-02T12:12:59	1527.15	1527.15	0.09	19.00	1380.00	20510700.00	1410.19	1414.10	1400.86	1414.76	303.15	302.60	294.75	294.54	312.70	15883700.00	20338000.00	20647400.00	0.0120	0.0202
82	2020-06-02T12:13:09	1527.27	1527.27	0.09	19.00	1380.00	20511900.00	1410.25	1414.16	1400.92	1414.81	303.15	302.41	294.73	294.52	312.71	15884300.00	20340100.00	20649400.00	0.0120	0.0202
83	2020-06-02T12:13:19	1527.39	1527.39	0.09	19.00	1380.00	20513100.00	1410.30	1414.21	1400.97	1414.86	303.15	302.23	294.70	294.50	312.72	15884900.00	20342300.00	20651500.00	0.0120	0.0202
84	2020-06-02T12:13:29	1527.51	1527.51	0.09	19.00	1380.00	20514300.00	1410.35	1414.26	1401.02	1414.92	303.15	302.05	294.68	294.48	312.73	15885500.00	20344400.00	20653600.00	0.0120	0.0202
85	2020-06-02T12:13:39	1527.63	1527.63	0.09	19.00	1380.00	20515500.00	1410.40	1414.32	1401.08	1414.97	303.15	301.87	294.65	294.46	312.74	15886000.00	20346500.00	20655600.00	0.0120	0.0202
86	2020-06-02T12:13:49	1527.75	1527.75	0.09	19.00	1380.00	20516700.00	1410.45	1414.37	1401.13	1415.02	303.15	301.70	294.63	294.44	312.74	15886600.00	20348600.00	20657700.00	0.0120	0.0202
87	2020-06-02T12:13:59	1527.87	1527.87	0.09	19.00	1380.00	20517900.00	1410.51	1414.42	1401.18	1415.07	303.15	301.53	294.61	294.42	312.75	15887200.00	20350700.00	20659800.00	0.0120	0.0202
88	2020-06-02T12:14:09	1527.99	1527.99	0.09	19.00	1380.00	20519000.00	1410.56	1414.48	1401.23	1415.12	303.15	301.37	294.58	294.40	312.75	15887800.00	20352800.00	20661800.00	0.0120	0.0202
89	2020-06-02T12:14:19	1528.11	1528.11	0.09	19.00	1380.00	20520200.00	1410.61	1414.53	1401.29	1415.18	303.15	301.21	294.56	294.38	312.76	15888400.00	20354900.00	20663900.00	0.0120	0.0202
90	2020-06-02T12:14:29	1528.23	1528.23	0.09	19.00	1380.00	20521400.00	1410.66	1414.58	1401.34	1415.23	303.15	301.05	294.54	294.36	312.76	15889000.00	20357000.00	20665900.00	0.0120	0.0202
91	2020-06-02T12:14:39	1528.35	1528.35	0.09	19.00	1380.00	20522600.00	1410.72	1414.63	1401.39	1415.28	303.15	300.90	294.52	294.35	312.76	15889600.00	20359100.00	20668000.00	0.0120	0.0202
92	2020-06-02T12:14:49	1528.47	1528.47	0.09	19.00	1380.00	20523700.00	1410.77	1414.69	1401.44	1415.33	303.15	300.75	294.50	294.33	312.77	15890100.00	20361200.00	20670000.00	0.0120	0.0202
93	2020-06-02T12:14:59	1528.59	1528.59	0.09	19.00	1380.00	20524900.00	1410.82	1414.74	1401.49	1415.38	303.15	300.60	294.48	294.31	312.77	15890700.00	20363300.00	20672100.00	0.0120	0.0202
94	2020-06-02T12:15:09	1528.71	1528.71	0.09	19.00	1380.00	20526100.00	1410.87	1414.79	1401.54	1415.43	303.15	300.46	294.46	294.29	312.77	15891300.00	20365400.00	20674100.00	0.0120	0.0202
95	2020-06-02T12:15:19	1528.83	1528.83	0.09	19.00	1380.00	20527200.00	1410.93	1414.84	1401.60	1415.48	303.15	300.32	294.44	294.28	312.77	15891900.00	20367500.00	20676200.00	0.0120	0.0202
96	2020-06-02T12:15:29	1528.95	1528.95	0.09	19.00	1380.00	20528400.00	1410.98	1414.89	1401.65	1415.54	303.15	300.18	294.42	294.26	312.77	15892500.00	20369600.00	20678200.00	0.0120	0.0202
97	2020-06-02T12:15:39	1529.07	1529.07	0.09	19.00	1380.00	20529600.00	1411.03	1414.94	1401.70	1415.59	303.15	300.04	294.40	294.24	312.77	15893100.00	20371600.00	20680200.00	0.0120	0.0202
98	2020-06-02T12:15:49	1529.19	1529.19	0.09	19.00	1380.00	20530700.00	1411.09	1414.99	1401.75	1415.64	303.15	299.91	294.38	294.22	312.77	15893700.00	20373700.00	20682300.00	0.0120	0.0202
99	2020-06-02T12:15:59	1529.31	1529.31	0.09	19.00	1380.00	20531900.00	1411.14	1415.04	1401.80	1415.69	303.15	299.79	294.36	294.21	312.76	15894300.00	20375800.00	20684300.00	0.0120	0.0202
100	2020-06-02T12:16:09	1529.43	1529.43	0.09	19.00	1380.00	20533000.00	1411.19	1415.10	1401.85	1415.74	303.15	299.66	294.34	294.19	312.76	15894900.00	20377900.00	20686300.00	0.0120	0.0202
101	2020-06-02T12:16:19	1529.55	1529.55	0.09	19.00	1380.00	20534200.00	1411.25	1415.15	1401.90	1415.79	303.15	299.54	294.32	294.18	312.76	15895500.00	20379900.00	20688400.00	0.0120	0.0202
102	2020-06-02T12:16:29	1529.66	1529.66	0.09	19.00	1380.00	20535300.00	1411.30	1415.20	1401.95	1415.84	303.15	299.42	294.31	294.16	312.75	15896100.00	20382000.00	20690400.00	0.0120	0.0202
103	2020-06-02T12:16:39	1529.78	1529.78	0.09	19.00	1380.00	20536500.00	1411.35	1415.25	1402.00	1415.89	303.15	299.30	294.29	294.14	312.75	15896700.00	20384100.00	20692400.00	0.0120	0.0202
104	2020-06-02T12:16:49	1529.90	1529.90	0.09	19.00	1380.00	20537600.00	1411.41	1415.30	1402.05	1415.94	303.15	299.19	294.27	294.13	312.74	15897300.00	20386100.00	20694400.00	0.0120	0.0202
105	2020-06-02T12:16:59	1530.02	1530.02	0.09	19.00	1380.00	20538700.00	1411.46	1415.35	1402.10	1415.98	303.15	299.08	294.25	294.11	312.74	15897900.00	20388200.00	20696500.00	0.0120	0.0202
106	2020-06-02T12:17:09	1530.14	1530.14	0.09	19.00	1380.00	20539900.00	1411.51	1415.40	1402.15	1416.03	303.15	298.97	294.24	294.10	312.73	15898500.00	20390300.00	20698500.00	0.0120	0.0202
107	2020-06-02T12:17:19	1530.26	1530.26	0.09	19.00	1380.00	20541000.00	1411.57	1415.45	1402.20	1416.08	303.15	298.86	294.22	294.08	312.72	15899100.00	20392300.00	20700500.00	0.0120	0.0202

108	2020-06-02T12:17:29	1530.38	1530.38	0.09	19.00	1380.00	20542200.00	1411.62	1415.49	1402.25	1416.13	303.15	298.76	294.20	294.07	312.72	15899700.00	20394400.00	20702500.00	0.0120	0.0202
109	2020-06-02T12:17:39	1530.50	1530.50	0.09	19.00	1380.00	20543300.00	1411.67	1415.54	1402.29	1416.18	303.15	298.66	294.19	294.05	312.71	15900300.00	20396400.00	20704500.00	0.0120	0.0202
110	2020-06-02T12:17:49	1530.62	1530.62	0.09	19.00	1380.00	20544400.00	1411.72	1415.59	1402.34	1416.23	303.15	298.56	294.17	294.04	312.70	15900900.00	20398500.00	20706500.00	0.0120	0.0202
111	2020-06-02T12:17:59	1530.74	1530.74	0.09	19.00	1380.00	20545500.00	1411.78	1415.64	1402.39	1416.28	303.15	298.46	294.15	294.02	312.69	15901400.00	20400500.00	20708500.00	0.0120	0.0202
112	2020-06-02T12:18:09	1530.86	1530.86	0.09	19.00	1380.00	20546700.00	1411.83	1415.69	1402.44	1416.32	303.15	298.37	294.14	294.01	312.68	15902000.00	20402600.00	20710500.00	0.0120	0.0202
113	2020-06-02T12:18:19	1530.98	1530.98	0.09	19.00	1380.00	20547800.00	1411.88	1415.74	1402.49	1416.37	303.15	298.28	294.12	293.99	312.67	15902600.00	20404600.00	20712500.00	0.0120	0.0202
114	2020-06-02T12:18:29	1531.10	1531.10	0.09	19.00	1380.00	20548900.00	1411.94	1415.79	1402.53	1416.42	303.15	298.19	294.11	293.98	312.65	15903200.00	20406700.00	20714500.00	0.0120	0.0202
115	2020-06-02T12:18:39	1531.22	1531.22	0.09	19.00	1380.00	20550000.00	1411.99	1415.83	1402.58	1416.47	303.15	298.10	294.09	293.96	312.64	15903800.00	20408700.00	20716500.00	0.0120	0.0202
116	2020-06-02T12:18:49	1531.34	1531.34	0.09	19.00	1380.00	20551100.00	1412.04	1415.88	1402.63	1416.51	303.15	298.02	294.07	293.95	312.63	15904400.00	20410700.00	20718500.00	0.0120	0.0202
117	2020-06-02T12:18:59	1531.46	1531.46	0.09	19.00	1380.00	20552200.00	1412.09	1415.93	1402.68	1416.56	303.15	297.93	294.06	293.93	312.61	15905000.00	20412800.00	20720500.00	0.0120	0.0202
118	2020-06-02T12:19:09	1531.58	1531.58	0.09	19.00	1380.00	20553300.00	1412.15	1415.98	1402.72	1416.61	303.15	297.85	294.04	293.92	312.60	15905600.00	20414800.00	20722400.00	0.0120	0.0202
119	2020-06-02T12:19:19	1531.70	1531.70	0.09	19.00	1380.00	20554400.00	1412.20	1416.02	1402.77	1416.65	303.15	297.77	294.03	293.90	312.58	15906200.00	20416800.00	20724400.00	0.0120	0.0202
120	2020-06-02T12:19:29	1531.82	1531.82	0.09	19.00	1380.00	20555500.00	1412.25	1416.07	1402.82	1416.70	303.15	297.69	294.01	293.89	312.57	15906700.00	20418800.00	20726400.00	0.0120	0.0202
121	2020-06-02T12:19:39	1531.94	1531.94	0.09	19.00	1380.00	20556600.00	1412.30	1416.12	1402.86	1416.74	303.15	297.62	294.00	293.88	312.55	15907300.00	20420800.00	20728400.00	0.0120	0.0202
122	2020-06-02T12:19:49	1532.06	1532.06	0.09	19.00	1380.00	20557700.00	1412.35	1416.16	1402.91	1416.79	303.15	297.54	293.98	293.86	312.53	15907900.00	20422900.00	20730300.00	0.0120	0.0202
123	2020-06-02T12:19:59	1532.18	1532.18	0.09	19.00	1380.00	20558800.00	1412.41	1416.21	1402.95	1416.84	303.15	297.47	293.97	293.85	312.51	15908500.00	20424900.00	20732300.00	0.0120	0.0202
124	2020-06-02T12:20:09	1532.29	1532.29	0.09	19.00	1380.00	20559900.00	1412.46	1416.26	1403.00	1416.88	303.15	297.40	293.96	293.84	312.49	15909100.00	20426900.00	20734300.00	0.0120	0.0202
125	2020-06-02T12:20:19	1532.41	1532.41	0.09	19.00	1380.00	20561000.00	1412.51	1416.30	1403.05	1416.93	303.15	297.33	293.94	293.82	312.47	15909600.00	20428900.00	20736200.00	0.0120	0.0202
126	2020-06-02T12:20:29	1532.53	1532.53	0.09	19.00	1380.00	20562100.00	1412.56	1416.35	1403.09	1416.97	303.15	297.26	293.93	293.81	312.45	15910200.00	20430900.00	20738200.00	0.0120	0.0202
127	2020-06-02T12:20:39	1532.65	1532.65	0.09	19.00	1380.00	20563200.00	1412.61	1416.39	1403.14	1417.02	303.15	297.20	293.91	293.79	312.43	15910800.00	20432900.00	20740100.00	0.0120	0.0202
128	2020-06-02T12:20:49	1532.77	1532.77	0.09	19.00	1380.00	20564200.00	1412.66	1416.44	1403.18	1417.06	303.15	297.13	293.90	293.78	312.40	15911300.00	20434900.00	20742100.00	0.0120	0.0202
129	2020-06-02T12:20:59	1532.89	1532.89	0.09	19.00	1380.00	20565300.00	1412.71	1416.48	1403.22	1417.11	303.15	297.07	293.88	293.77	312.38	15911900.00	20436900.00	20744000.00	0.0120	0.0202
130	2020-06-02T12:21:09	1533.01	1533.01	0.09	19.00	1380.00	20566400.00	1412.76	1416.53	1403.27	1417.15	303.15	297.01	293.87	293.75	312.36	15912500.00	20438900.00	20746000.00	0.0120	0.0202
131	2020-06-02T12:21:19	1533.13	1533.13	0.09	19.00	1380.00	20567400.00	1412.81	1416.57	1403.31	1417.19	303.15	296.95	293.86	293.74	312.33	15913000.00	20440900.00	20747900.00	0.0120	0.0202
132	2020-06-02T12:21:29	1533.25	1533.25	0.09	19.00	1380.00	20568500.00	1412.86	1416.62	1403.36	1417.24	303.15	296.89	293.84	293.73	312.30	15913600.00	20442800.00	20749900.00	0.0120	0.0202
133	2020-06-02T12:21:39	1533.37	1533.37	0.09	19.00	1380.00	20569600.00	1412.92	1416.66	1403.40	1417.28	303.15	296.83	293.83	293.71	312.28	15914200.00	20444800.00	20751800.00	0.0120	0.0202
134	2020-06-02T12:21:49	1533.49	1533.49	0.09	19.00	1380.00	20570600.00	1412.97	1416.70	1403.44	1417.32	303.15	296.77	293.82	293.70	312.25	15914700.00	20446800.00	20753800.00	0.0120	0.0202
135	2020-06-02T12:21:59	1533.61	1533.61	0.09	19.00	1380.00	20571700.00	1413.02	1416.75	1403.49	1417.37	303.15	296.72	293.80	293.69	312.22	15915300.00	20448800.00	20755700.00	0.0120	0.0202
136	2020-06-02T12:22:09	1533.73	1533.73	0.09	19.00	1380.00	20572700.00	1413.06	1416.79	1403.53	1417.41	303.15	296.66	293.79	293.68	312.19	15915900.00	20450800.00	20757600.00	0.0120	0.0202
137	2020-06-02T12:22:19	1533.85	1533.85	0.09	19.00	1380.00	20573800.00	1413.11	1416.83	1403.57	1417.45	303.15	296.61	293.78	293.66	312.16	15916400.00	20452700.00	20759500.00	0.0120	0.0202
138	2020-06-02T12:22:29	1533.97	1533.97	0.09	19.00	1380.00	20574900.00	1413.16	1416.88	1403.62	1417.50	303.15	296.56	293.76	293.65	312.13	15917000.00	20454700.00	20761500.00	0.0120	0.0202
139	2020-06-02T12:22:39	1534.09	1534.09	0.09	19.00	1380.00	20575900.00	1413.21	1416.92	1403.66	1417.54	303.15	296.51	293.75	293.64	312.09	15917500.00	20456700.00	20763400.00	0.0120	0.0202
140	2020-06-02T12:22:49	1534.21	1534.21	0.09	19.00	1380.00	20577000.00	1413.26	1416.96	1403.70	1417.58	303.15	296.46	293.74	293.63	312.06	15918100.00	20458700.00	20765300.00	0.0120	0.0202
141	2020-06-02T12:22:59	1534.33	1534.33	0.09	19.00	1380.00	20578000.00	1413.31	1417.01	1403.75	1417.62	303.15	296.41	293.72	293.61	312.03	15918600.00	20460600.00	20767200.00	0.0120	0.0202
142	2020-06-02T12:23:09	1534.45	1534.45	0.09	19.00	1380.00	20579000.00	1413.36	1417.05	1403.79	1417.67	303.15	296.36	293.71	293.60	311.99	15919200.00	20462600.00	20769200.00	0.0120	0.0202
143	2020-06-02T12:23:19	1534.57	1534.57	0.09	19.00	1380.00	20580100.00	1413.41	1417.09	1403.83	1417.71	303.15	296.32	293.70	293.59	311.95	15919700.00	20464500.00	20771100.00	0.0120	0.0202

143	2020-06-02T12:23:19	1534.57	1534.57	0.09	19.00	1380.00	20580100.00	1413.41	1417.09	1403.83	1417.71	303.15	296.32	293.70	293.59	311.95	15919700.00	20464500.00	20771100.00	0.0120	0.0202
144	2020-06-02T12:23:29	1534.69	1534.69	0.09	19.00	1380.00	20581100.00	1413.46	1417.13	1403.87	1417.75	303.15	296.27	293.68	293.58	311.92	15920300.00	20466500.00	20773000.00	0.0120	0.0202
145	2020-06-02T12:23:39	1534.80	1534.80	0.09	19.00	1380.00	20582200.00	1413.51	1417.18	1403.91	1417.79	303.15	296.23	293.67	293.56	311.88	15920800.00	20468400.00	20774900.00	0.0120	0.0202
146	2020-06-02T12:23:49	1534.92	1534.92	0.09	19.00	1380.00	20583200.00	1413.56	1417.22	1403.96	1417.83	303.15	296.18	293.66	293.55	311.84	15921400.00	20470400.00	20776800.00	0.0120	0.0202
147	2020-06-02T12:23:59	1535.04	1535.04	0.09	19.00	1380.00	20584200.00	1413.61	1417.26	1404.00	1417.87	303.15	296.14	293.65	293.54	311.80	15921900.00	20472300.00	20778700.00	0.0120	0.0202
148	2020-06-02T12:24:09	1535.16	1535.16	0.09	19.00	1380.00	20585300.00	1413.66	1417.30	1404.04	1417.92	303.15	296.10	293.63	293.53	311.76	15922500.00	20474200.00	20780600.00	0.0120	0.0202
149	2020-06-02T12:24:19	1535.28	1535.28	0.09	19.00	1380.00	20586300.00	1413.70	1417.35	1404.08	1417.96	303.15	296.06	293.62	293.51	311.71	15923000.00	20476200.00	20782500.00	0.0120	0.0202
150	2020-06-02T12:24:29	1535.40	1535.40	0.09	19.00	1380.00	20587400.00	1413.75	1417.39	1404.12	1418.00	303.15	296.02	293.61	293.50	311.67	15923500.00	20478100.00	20784500.00	0.0120	0.0202
151	2020-06-02T12:24:39	1535.52	1535.52	0.09	19.00	1380.00	20588400.00	1413.80	1417.43	1404.16	1418.04	303.15	295.98	293.60	293.49	311.63	15924100.00	20480000.00	20786400.00	0.0120	0.0202
152	2020-06-02T12:24:49	1535.64	1535.64	0.09	19.00	1380.00	20589400.00	1413.85	1417.47	1404.21	1418.08	303.15	295.94	293.58	293.48	311.58	15924600.00	20481900.00	20788300.00	0.0120	0.0202
153	2020-06-02T12:24:59	1535.76	1535.76	0.09	19.00	1380.00	20590500.00	1413.90	1417.51	1404.25	1418.12	303.15	295.90	293.57	293.47	311.54	15925200.00	20483900.00	20790200.00	0.0120	0.0202
154	2020-06-02T12:25:09	1535.88	1535.88	0.09	19.00	1380.00	20591500.00	1413.95	1417.55	1404.29	1418.16	303.15	295.87	293.56	293.46	311.49	15925700.00	20485800.00	20792100.00	0.0120	0.0202
155	2020-06-02T12:25:19	1536.00	1536.00	0.09	19.00	1380.00	20592500.00	1414.00	1417.60	1404.33	1418.20	303.15	295.83	293.55	293.44	311.44	15926300.00	20487700.00	20794000.00	0.0120	0.0202
156	2020-06-02T12:25:29	1536.12	1536.12	0.09	19.00	1380.00	20593500.00	1414.04	1417.64	1404.37	1418.25	303.15	295.79	293.54	293.43	311.39	15926800.00	20489600.00	20795900.00	0.0120	0.0202
157	2020-06-02T12:25:39	1536.24	1536.24	0.09	19.00	1380.00	20594600.00	1414.09	1417.68	1404.41	1418.29	303.15	295.76	293.52	293.42	311.34	15927400.00	20491600.00	20797800.00	0.0120	0.0202
158	2020-06-02T12:25:49	1536.36	1536.36	0.09	19.00	1380.00	20595600.00	1414.14	1417.72	1404.45	1418.33	303.15	295.72	293.51	293.41	311.29	15927900.00	20493500.00	20799700.00	0.0120	0.0202
159	2020-06-02T12:25:59	1536.48	1536.48	0.09	19.00	1380.00	20596600.00	1414.19	1417.76	1404.49	1418.37	303.15	295.69	293.50	293.40	311.24	15928500.00	20495400.00	20801600.00	0.0120	0.0202
160	2020-06-02T12:26:09	1536.60	1536.60	0.09	19.00	1380.00	20597700.00	1414.24	1417.80	1404.54	1418.41	303.15	295.66	293.49	293.39	311.19	15929000.00	20497300.00	20803500.00	0.0120	0.0202
161	2020-06-02T12:26:19	1536.72	1536.72	0.09	19.00	1380.00	20598700.00	1414.29	1417.85	1404.58	1418.45	303.15	295.63	293.48	293.37	311.13	15929500.00	20499300.00	20805400.00	0.0120	0.0202
162	2020-06-02T12:26:29	1536.84	1536.84	0.09	19.00	1380.00	20599700.00	1414.34	1417.89	1404.62	1418.49	303.15	295.59	293.46	293.36	311.08	15930100.00	20501200.00	20807300.00	0.0120	0.0202
163	2020-06-02T12:26:39	1536.96	1536.96	0.09	19.00	1380.00	20600800.00	1414.39	1417.93	1404.66	1418.53	303.15	295.56	293.45	293.35	311.02	15930600.00	20503100.00	20809200.00	0.0120	0.0202
164	2020-06-02T12:26:49	1537.08	1537.08	0.09	19.00	1380.00	20601800.00	1414.43	1417.97	1404.70	1418.57	303.15	295.53	293.44	293.34	310.96	15931200.00	20505000.00	20811100.00	0.0120	0.0202
165	2020-06-02T12:26:59	1537.20	1537.20	0.09	19.00	1380.00	20602800.00	1414.48	1418.01	1404.74	1418.61	303.15	295.50	293.43	293.33	310.91	15931700.00	20507000.00	20813000.00	0.0120	0.0202
166	2020-06-02T12:27:09	1537.32	1537.32	0.09	19.00	1380.00	20603900.00	1414.53	1418.05	1404.78	1418.65	303.15	295.47	293.42	293.32	310.85	15932300.00	20508900.00	20814900.00	0.0120	0.0202
167	2020-06-02T12:27:19	1537.43	1537.43	0.09	19.00	1380.00	20604900.00	1414.58	1418.09	1404.82	1418.69	303.15	295.44	293.41	293.31	310.79	15932800.00	20510800.00	20816800.00	0.0120	0.0202
168	2020-06-02T12:27:29	1537.55	1537.55	0.09	19.00	1380.00	20605900.00	1414.63	1418.13	1404.86	1418.74	303.15	295.41	293.40	293.30	310.73	15933400.00	20512700.00	20818700.00	0.0120	0.0202
169	2020-06-02T12:27:39	1537.67	1537.67	0.09	19.00	1380.00	20607000.00	1414.68	1418.18	1404.90	1418.78	303.15	295.39	293.38	293.28	310.67	15933900.00	20514700.00	20820600.00	0.0120	0.0202
170	2020-06-02T12:27:49	1537.79	1537.79	0.09	19.00	1380.00	20608000.00	1414.73	1418.22	1404.94	1418.82	303.15	295.36	293.37	293.27	310.60	15934500.00	20516600.00	20822500.00	0.0120	0.0202
171	2020-06-02T12:27:59	1537.91	1537.91	0.09	19.00	1380.00	20609000.00	1414.78	1418.26	1404.99	1418.86	303.15	295.33	293.36	293.26	310.54	15935000.00	20518500.00	20824400.00	0.0120	0.0202
172	2020-06-02T12:28:09	1538.03	1538.03	0.09	19.00	1380.00	20610100.00	1414.82	1418.30	1405.03	1418.90	303.15	295.30	293.35	293.25	310.48	15935500.00	20520400.00	20826300.00	0.0120	0.0202
173	2020-06-02T12:28:19	1538.15	1538.15	0.09	19.00	1380.00	20611200.00	1414.87	1418.34	1405.07	1418.94	303.15	295.28	293.34	293.24	310.41	15936100.00	20522400.00	20828200.00	0.0120	0.0202
174	2020-06-02T12:28:29	1538.27	1538.27	0.09	19.00	1380.00	20612100.00	1414.92	1418.38	1405.11	1418.98	303.15	295.25	293.33	293.23	310.35	15936600.00	20524200.00	20830100.00	0.0120	0.0202
175	2020-06-02T12:28:39	1538.39	1538.39	0.09	19.00	1380.00	20613200.00	1414.97	1418.43	1405.15	1419.02	303.15	295.23	293.32	293.22	310.28	15937200.00	20526200.00	20832000.00	0.0120	0.0202
176	2020-06-02T12:28:49	1538.51	1538.51	0.09	19.00	1380.00	20614200.00	1415.02	1418.46	1405.19	1419.06	303.15	295.20	293.31	293.21	310.21	15937700.00	20528100.00	20833800.00	0.0120	0.0202
177	2020-06-02T12:28:59	1538.63	1538.63	0.09	19.00	1380.00	20615300.00	1415.07	1418.51	1405.23	1419.10	303.15	295.18	293.30	293.20	310.14	15938300.00	20530100.00	20835800.00	0.0120	0.0202
178	2020-06-02T12:29:09	1538.75	1538.75	0.09	19.00	1380.00	20616300.00	1415.12	1418.54	1405.27	1419.14	303.15	295.15	293.29	293.19	310.07	15938800.00	20531900.00	20837600.00	0.0120	0.0202

143	2020-06-02T12:23:19	1534.57	1534.57	0.09	19.00	1380.00	20580100.00	1413.41	1417.09	1403.83	1417.71	303.15	296.32	293.70	293.59	311.95	15919700.00	20464500.00	20771100.00	0.0120	0.0202
144	2020-06-02T12:23:29	1534.69	1534.69	0.09	19.00	1380.00	20581100.00	1413.46	1417.13	1403.87	1417.75	303.15	296.27	293.68	293.58	311.92	15920300.00	20466500.00	20773000.00	0.0120	0.0202
145	2020-06-02T12:23:39	1534.80	1534.80	0.09	19.00	1380.00	20582200.00	1413.51	1417.18	1403.91	1417.79	303.15	296.23	293.67	293.56	311.88	15920800.00	20468400.00	20774900.00	0.0120	0.0202
146	2020-06-02T12:23:49	1534.92	1534.92	0.09	19.00	1380.00	20583200.00	1413.56	1417.22	1403.96	1417.83	303.15	296.18	293.66	293.55	311.84	15921400.00	20470400.00	20776800.00	0.0120	0.0202
147	2020-06-02T12:23:59	1535.04	1535.04	0.09	19.00	1380.00	20584200.00	1413.61	1417.26	1404.00	1417.87	303.15	296.14	293.65	293.54	311.80	15921900.00	20472300.00	20778700.00	0.0120	0.0202
148	2020-06-02T12:24:09	1535.16	1535.16	0.09	19.00	1380.00	20585300.00	1413.66	1417.30	1404.04	1417.92	303.15	296.10	293.63	293.53	311.76	15922500.00	20474200.00	20780600.00	0.0120	0.0202
149	2020-06-02T12:24:19	1535.28	1535.28	0.09	19.00	1380.00	20586300.00	1413.70	1417.35	1404.08	1417.96	303.15	296.06	293.62	293.51	311.71	15923000.00	20476200.00	20782500.00	0.0120	0.0202
150	2020-06-02T12:24:29	1535.40	1535.40	0.09	19.00	1380.00	20587400.00	1413.75	1417.39	1404.12	1418.00	303.15	296.02	293.61	293.50	311.67	15923500.00	20478100.00	20784500.00	0.0120	0.0202
151	2020-06-02T12:24:39	1535.52	1535.52	0.09	19.00	1380.00	20588400.00	1413.80	1417.43	1404.16	1418.04	303.15	295.98	293.60	293.49	311.63	15924100.00	20480000.00	20786400.00	0.0120	0.0202
152	2020-06-02T12:24:49	1535.64	1535.64	0.09	19.00	1380.00	20589400.00	1413.85	1417.47	1404.21	1418.08	303.15	295.94	293.58	293.48	311.58	15924600.00	20481900.00	20788300.00	0.0120	0.0202
153	2020-06-02T12:24:59	1535.76	1535.76	0.09	19.00	1380.00	20590500.00	1413.90	1417.51	1404.25	1418.12	303.15	295.90	293.57	293.47	311.54	15925200.00	20483900.00	20790200.00	0.0120	0.0202
154	2020-06-02T12:25:09	1535.88	1535.88	0.09	19.00	1380.00	20591500.00	1413.95	1417.55	1404.29	1418.16	303.15	295.87	293.56	293.46	311.49	15925700.00	20485800.00	20792100.00	0.0120	0.0202
155	2020-06-02T12:25:19	1536.00	1536.00	0.09	19.00	1380.00	20592500.00	1414.00	1417.60	1404.33	1418.20	303.15	295.83	293.55	293.44	311.44	15926300.00	20487700.00	20794000.00	0.0120	0.0202
156	2020-06-02T12:25:29	1536.12	1536.12	0.09	19.00	1380.00	20593500.00	1414.04	1417.64	1404.37	1418.25	303.15	295.79	293.54	293.43	311.39	15926800.00	20489600.00	20795900.00	0.0120	0.0202
157	2020-06-02T12:25:39	1536.24	1536.24	0.09	19.00	1380.00	20594600.00	1414.09	1417.68	1404.41	1418.29	303.15	295.76	293.52	293.42	311.34	15927400.00	20491600.00	20797800.00	0.0120	0.0202
158	2020-06-02T12:25:49	1536.36	1536.36	0.09	19.00	1380.00	20595600.00	1414.14	1417.72	1404.45	1418.33	303.15	295.72	293.51	293.41	311.29	15927900.00	20493500.00	20799700.00	0.0120	0.0202
159	2020-06-02T12:25:59	1536.48	1536.48	0.09	19.00	1380.00	20596600.00	1414.19	1417.76	1404.49	1418.37	303.15	295.69	293.50	293.40	311.24	15928500.00	20495400.00	20801600.00	0.0120	0.0202
160	2020-06-02T12:26:09	1536.60	1536.60	0.09	19.00	1380.00	20597700.00	1414.24	1417.80	1404.54	1418.41	303.15	295.66	293.49	293.39	311.19	15929000.00	20497300.00	20803500.00	0.0120	0.0202
161	2020-06-02T12:26:19	1536.72	1536.72	0.09	19.00	1380.00	20598700.00	1414.29	1417.85	1404.58	1418.45	303.15	295.63	293.48	293.37	311.13	15929500.00	20499300.00	20805400.00	0.0120	0.0202
162	2020-06-02T12:26:29	1536.84	1536.84	0.09	19.00	1380.00	20599700.00	1414.34	1417.89	1404.62	1418.49	303.15	295.59	293.46	293.36	311.08	15930100.00	20501200.00	20807300.00	0.0120	0.0202
163	2020-06-02T12:26:39	1536.96	1536.96	0.09	19.00	1380.00	20600800.00	1414.39	1417.93	1404.66	1418.53	303.15	295.56	293.45	293.35	311.02	15930600.00	20503100.00	20809200.00	0.0120	0.0202
164	2020-06-02T12:26:49	1537.08	1537.08	0.09	19.00	1380.00	20601800.00	1414.43	1417.97	1404.70	1418.57	303.15	295.53	293.44	293.34	310.96	15931200.00	20505000.00	20811100.00	0.0120	0.0202
165	2020-06-02T12:26:59	1537.20	1537.20	0.09	19.00	1380.00	20602800.00	1414.48	1418.01	1404.74	1418.61	303.15	295.50	293.43	293.33	310.91	15931700.00	20507000.00	20813000.00	0.0120	0.0202
166	2020-06-02T12:27:09	1537.32	1537.32	0.09	19.00	1380.00	20603900.00	1414.53	1418.05	1404.78	1418.65	303.15	295.47	293.42	293.32	310.85	15932300.00	20508900.00	20814900.00	0.0120	0.0202
167	2020-06-02T12:27:19	1537.43	1537.43	0.09	19.00	1380.00	20604900.00	1414.58	1418.09	1404.82	1418.69	303.15	295.44	293.41	293.31	310.79	15932800.00	20510800.00	20816800.00	0.0120	0.0202
168	2020-06-02T12:27:29	1537.55	1537.55	0.09	19.00	1380.00	20605900.00	1414.63	1418.13	1404.86	1418.74	303.15	295.41	293.40	293.30	310.73	15933400.00	20512700.00	20818700.00	0.0120	0.0202
169	2020-06-02T12:27:39	1537.67	1537.67	0.09	19.00	1380.00	20607000.00	1414.68	1418.18	1404.90	1418.78	303.15	295.39	293.38	293.28	310.67	15933900.00	20514700.00	20820600.00	0.0120	0.0202
170	2020-06-02T12:27:49	1537.79	1537.79	0.09	19.00	1380.00	20608000.00	1414.73	1418.22	1404.94	1418.82	303.15	295.36	293.37	293.27	310.60	15934500.00	20516600.00	20822500.00	0.0120	0.0202
171	2020-06-02T12:27:59	1537.91	1537.91	0.09	19.00	1380.00	20609000.00	1414.78	1418.26	1404.99	1418.86	303.15	295.33	293.36	293.26	310.54	15935000.00	20518500.00	20824400.00	0.0120	0.0202
172	2020-06-02T12:28:09	1538.03	1538.03	0.09	19.00	1380.00	20610100.00	1414.82	1418.30	1405.03	1418.90	303.15	295.30	293.35	293.25	310.48	15935500.00	20520400.00	20826300.00	0.0120	0.0202
173	2020-06-02T12:28:19	1538.15	1538.15	0.09	19.00	1380.00	20611200.00	1414.87	1418.34	1405.07	1418.94	303.15	295.28	293.34	293.24	310.41	15936100.00	20522400.00	20828200.00	0.0120	0.0202
174	2020-06-02T12:28:29	1538.27	1538.27	0.09	19.00	1380.00	20612100.00	1414.92	1418.38	1405.11	1418.98	303.15	295.25	293.33	293.23	310.35	15936600.00	20524200.00	20830100.00	0.0120	0.0202
175	2020-06-02T12:28:39	1538.39	1538.39	0.09	19.00	1380.00	20613200.00	1414.97	1418.43	1405.15	1419.02	303.15	295.23	293.32	293.22	310.28	15937200.00	20526200.00	20832000.00	0.0120	0.0202
176	2020-06-02T12:28:49	1538.51	1538.51	0.09	19.00	1380.00	20614200.00	1415.02	1418.46	1405.19	1419.06	303.15	295.20	293.31	293.21	310.21	15937700.00	20528100.00	20833800.00	0.0120	0.0202
177	2020-06-02T12:28:59	1538.63	1538.63	0.09	19.00	1380.00	20615300.00	1415.07	1418.51	1405.23	1419.10	303.15	295.18	293.30	293.20	310.14	15938300.00	20530100.00	20835800.00	0.0120	0.0202
178	2020-06-02T12:29:09	1538.75	1538.75	0.09	19.00	1380.00	20616300.00	1415.12	1418.54	1405.27	1419.14	303.15	295.15	293.29	293.19	310.07	15938800.00	20531900.00	20837600.00	0.0120	0.0202

179	2020-06-02T12:29:19	1538.87	1538.87	0.09	19.00	1380.00	20617300.00	1415.16	1418.59	1405.31	1419.18	303.15	295.13	293.28	293.18	310.00	15939300.00	20533900.00	20839600.00	0.0120	0.0202
180	2020-06-02T12:29:29	1538.99	1538.99	0.09	19.00	1380.00	20618300.00	1415.21	1418.62	1405.35	1419.22	303.15	295.11	293.26	293.17	309.93	15939900.00	20535700.00	20841400.00	0.0120	0.0202
181	2020-06-02T12:29:39	1539.11	1539.11	0.09	19.00	1380.00	20619400.00	1415.26	1418.67	1405.39	1419.26	303.15	295.08	293.25	293.16	309.86	15940400.00	20537700.00	20843400.00	0.0120	0.0202
182	2020-06-02T12:29:49	1539.23	1539.23	0.09	19.00	1380.00	20620400.00	1415.31	1418.70	1405.43	1419.30	303.15	295.06	293.24	293.15	309.79	15941000.00	20539500.00	20845200.00	0.0120	0.0202
183	2020-06-02T12:29:59	1539.35	1539.35	0.09	19.00	1380.00	20621400.00	1415.36	1418.75	1405.47	1419.34	303.15	295.04	293.23	293.14	309.71	15941500.00	20541500.00	20847100.00	0.0120	0.0202
184	2020-06-02T12:30:09	1539.47	1539.47	0.09	19.00	1380.00	20622400.00	1415.40	1418.78	1405.50	1419.37	303.15	295.02	293.22	293.13	309.64	15942000.00	20543300.00	20848900.00	0.0120	0.0202
185	2020-06-02T12:30:19	1539.59	1539.59	0.09	19.00	1380.00	20623500.00	1415.45	1418.83	1405.55	1419.42	303.15	294.99	293.21	293.12	309.56	15942600.00	20545300.00	20850900.00	0.0120	0.0202
186	2020-06-02T12:30:29	1539.71	1539.71	0.09	19.00	1380.00	20624400.00	1415.50	1418.86	1405.58	1419.45	303.15	294.97	293.20	293.11	309.49	15943100.00	20547100.00	20852700.00	0.0120	0.0202
187	2020-06-02T12:30:39	1539.83	1539.83	0.09	19.00	1380.00	20625500.00	1415.55	1418.91	1405.63	1419.50	303.15	294.95	293.19	293.10	309.41	15943600.00	20549100.00	20854600.00	0.0120	0.0202
188	2020-06-02T12:30:49	1539.94	1539.94	0.09	19.00	1380.00	20626500.00	1415.59	1418.94	1405.66	1419.53	303.15	294.93	293.18	293.09	309.33	15944100.00	20550900.00	20856400.00	0.0120	0.0202
189	2020-06-02T12:30:59	1540.06	1540.06	0.09	19.00	1380.00	20627600.00	1415.64	1418.99	1405.71	1419.57	303.15	294.91	293.17	293.08	309.25	15944700.00	20552900.00	20858400.00	0.0120	0.0202
190	2020-06-02T12:31:09	1540.18	1540.18	0.09	19.00	1380.00	20628500.00	1415.69	1419.02	1405.74	1419.61	303.15	294.89	293.16	293.07	309.18	15945200.00	20554700.00	20860100.00	0.0120	0.0202
191	2020-06-02T12:31:19	1540.30	1540.30	0.09	19.00	1380.00	20629600.00	1415.73	1419.06	1405.78	1419.65	303.15	294.87	293.15	293.06	309.10	15945700.00	20556700.00	20862100.00	0.0120	0.0202
192	2020-06-02T12:31:29	1540.42	1540.42	0.09	19.00	1380.00	20630500.00	1415.78	1419.10	1405.81	1419.68	303.15	294.85	293.14	293.05	309.02	15946200.00	20558500.00	20863900.00	0.0120	0.0202
193	2020-06-02T12:31:39	1540.54	1540.54	0.09	19.00	1380.00	20631600.00	1415.83	1419.14	1405.86	1419.73	303.15	294.83	293.13	293.04	308.94	15946800.00	20560400.00	20865800.00	0.0120	0.0202
194	2020-06-02T12:31:49	1540.66	1540.66	0.09	19.00	1380.00	20632600.00	1415.87	1419.17	1405.89	1419.76	303.15	294.81	293.12	293.03	308.85	15947300.00	20562200.00	20867600.00	0.0120	0.0202
195	2020-06-02T12:31:59	1540.78	1540.78	0.09	19.00	1380.00	20633600.00	1415.92	1419.22	1405.94	1419.80	303.15	294.79	293.11	293.02	308.77	15947800.00	20564200.00	20869600.00	0.0120	0.0202
196	2020-06-02T12:32:09	1540.90	1540.90	0.09	19.00	1380.00	20634600.00	1415.96	1419.25	1405.97	1419.83	303.15	294.77	293.10	293.01	308.69	15948300.00	20566000.00	20871300.00	0.0120	0.0202
197	2020-06-02T12:32:19	1541.02	1541.02	0.09	19.00	1380.00	20635600.00	1416.01	1419.29	1406.01	1419.88	303.15	294.76	293.09	293.00	308.61	15948800.00	20568000.00	20873300.00	0.0120	0.0202
198	2020-06-02T12:32:29	1541.14	1541.14	0.09	19.00	1380.00	20636600.00	1416.06	1419.33	1406.04	1419.91	303.15	294.74	293.08	292.99	308.52	15949300.00	20569800.00	20875000.00	0.0120	0.0202
199	2020-06-02T12:32:39	1541.26	1541.26	0.09	19.00	1380.00	20637600.00	1416.10	1419.37	1406.08	1419.95	303.15	294.72	293.07	292.98	308.44	15949800.00	20571700.00	20876900.00	0.0120	0.0202
200	2020-06-02T12:32:49	1541.38	1541.38	0.09	19.00	1380.00	20638600.00	1416.15	1419.40	1406.12	1419.99	303.15	294.70	293.07	292.97	308.35	15950300.00	20573500.00	20878800.00	0.0120	0.0202
201	2020-06-02T12:32:59	1541.50	1541.50	0.09	19.00	1380.00	20639600.00	1416.19	1419.44	1406.16	1420.03	303.15	294.68	293.06	292.96	308.27	15950800.00	20575400.00	20880600.00	0.0120	0.0202
202	2020-06-02T12:33:09	1541.62	1541.62	0.09	19.00	1380.00	20640600.00	1416.24	1419.48	1406.19	1420.06	303.15	294.67	293.05	292.96	308.18	15951300.00	20577300.00	20882500.00	0.0120	0.0202
203	2020-06-02T12:33:19	1541.74	1541.74	0.09	19.00	1380.00	20641600.00	1416.28	1419.52	1406.23	1420.10	303.15	294.65	293.04	292.95	308.09	15951800.00	20579100.00	20884300.00	0.0120	0.0202
204	2020-06-02T12:33:29	1541.86	1541.86	0.09	19.00	1380.00	20642600.00	1416.32	1419.55	1406.27	1420.13	303.15	294.63	293.03	292.94	308.01	15952300.00	20581000.00	20886100.00	0.0120	0.0202
205	2020-06-02T12:33:39	1541.98	1541.98	0.09	19.00	1380.00	20643600.00	1416.37	1419.59	1406.30	1420.17	303.15	294.62	293.02	292.93	307.92	15952800.00	20582900.00	20888000.00	0.0120	0.0202
206	2020-06-02T12:33:49	1542.10	1542.10	0.09	19.00	1380.00	20644600.00	1416.41	1419.63	1406.34	1420.21	303.15	294.60	293.01	292.92	307.83	15953300.00	20584700.00	20889800.00	0.0120	0.0202
207	2020-06-02T12:33:59	1542.22	1542.22	0.09	19.00	1380.00	20645600.00	1416.46	1419.66	1406.38	1420.24	303.15	294.58	293.00	292.91	307.74	15953800.00	20586600.00	20891700.00	0.0120	0.0202
208	2020-06-02T12:34:09	1542.34	1542.34	0.09	19.00	1380.00	20646600.00	1416.50	1419.70	1406.41	1420.28	303.15	294.57	292.99	292.90	307.65	15954300.00	20588500.00	20893500.00	0.0120	0.0202
209	2020-06-02T12:34:19	1542.45	1542.45	0.09	19.00	1380.00	20647600.00	1416.55	1419.74	1406.45	1420.32	303.15	294.55	292.98	292.89	307.56	15954800.00	20590300.00	20895300.00	0.0120	0.0202
210	2020-06-02T12:34:29	1542.57	1542.57	0.09	19.00	1380.00	20648600.00	1416.59	1419.77	1406.49	1420.35	303.15	294.54	292.98	292.89	307.47	15955300.00	20592200.00	20897200.00	0.0120	0.0202
211	2020-06-02T12:34:39	1542.69	1542.69	0.09	19.00	1380.00	20649600.00	1416.63	1419.81	1406.52	1420.39	303.15	294.52	292.97	292.88	307.38	15955800.00	20594000.00	20899000.00	0.0120	0.0202
212	2020-06-02T12:34:49	1542.81	1542.81	0.09	19.00	1380.00	20650600.00	1416.68	1419.85	1406.56	1420.42	303.15	294.51	292.96	292.87	307.29	15956300.00	20595900.00	20900900.00	0.0120	0.0202
213	2020-06-02T12:34:59	1542.93	1542.93	0.09	19.00	1380.00	20651600.00	1416.72	1419.88	1406.60	1420.46	303.15	294.49	292.95	292.86	307.20	15956700.00	20597700.00	20902700.00	0.0120	0.0202
214	2020-06-02T12:35:09	1543.05	1543.05	0.09	19.00	1380.00	20652600.00	1416.76	1419.92	1406.63	1420.50	303.15	294.48	292.94	292.85	307.11	15957200.00	20599600.00	20904500.00	0.0120	0.0202
215	2020-06-02T12:35:19	1543.17	1543.17	0.09	19.00	1380.00	20653600.00	1416.80	1419.96	1406.67	1420.53	303.15	294.46	292.93	292.85	307.02	15957700.00	20601500.00	20906300.00	0.0120	0.0202
216	2020-06-02T12:35:29	1543.29	1543.29	0.09	19.00	1380.00	20654600.00	1416.85	1419.99	1406.70	1420.57	303.15	294.45	292.93	292.84	306.93	15958200.00	20603300.00	20908200.00	0.0120	0.0202
217	2020-06-02T12:35:39	1543.41	1543.41	0.09	19.00	1380.00	20655600.00	1416.89	1420.03	1406.74	1420.60	303.15	294.43	292.92	292.83	306.84	15958700.00	20605200.00	20910000.00	0.0120	0.0202
218	2020-06-02T12:35:49	1543.53	1543.53	0.09	19.00	1380.00	20656600.00	1416.93	1420.06	1406.77	1420.64	303.15	294.42	292.91	292.82	306.75	15959100.00	20607000.00	20911800.00	0.0120	0.0202
219	2020-06-02T12:35:59	1543.65	1543.65	0.09	19.00	1380.00	20657600.00	1416.97	1420.10	1406.81	1420.67	303.15	294.40	292.90	292.81	306.65	15959600.00	20608900.00	20913700.00	0.0120	0.0202
220	2020-06-02T12:36:09	1543.77	1543.77	0.09	19.00	1380.00	20658600.00	1417.02	1420.14	1406.85	1420.71	303.15	294.39	292.89	292.81	306.56	15960100.00	20610700.00	20915500.00	0.0120	0.0202
221	2020-06-02T12:36:19	1543.89	1543.89	0.09	19.00	1380.00	20659600.00	1417.06	1420.17	1406.88	1420.75	303.15	294.37	292.89	292.80	306.47	15960500.00	20612500.00	20917300.00	0.0120	0.0202
222	2020-06-02T12:36:29	1544.01	1544.01	0.09	19.00	1380.00	20660600.00	1417.10	1420.21	1406.92	1420.78	303.15	294.36	292.88	292.79	306.38	15961000.00	20614400.00	20919100.00	0.0120	0.0202
223	2020-06-02T12:36:39	1544.13	1544.13	0.09	19.00	1380.00	20661600.00	1417.14	1420.24	1406.95	1420.82	303.15	294.35	292.87	292.78	306.28	15961500.00	20616200.00	20920900.00	0.0120	0.0202
224	2020-06-02T12:36:49	1544.25	1544.25	0.09	19.00	1380.00	20662600.00	1417.19	1420.28	1406.99	1420.85	303.15	294.33	292.86	292.78	306.19	15962000.00	20618100.00	20922800.00	0.0120	0.0202
225	2020-06-02T12:36:59	1544.37	1544.37	0.09	19.00	1380.00	20663600.00	1417.23	1420.31	1407.02	1420.89	303.15	294.32	292.85	292.77	306.10	15962400.00	20619900.00	20924600.00	0.0120	0.0202
226	2020-06-02T12:37:09	1544.49	1544.49	0.09	19.00	1380.00	20664600.00	1417.27	1420.35	1407.06	1420.92	303.15	294.31	292.85	292.76	306.00	15962900.00	20621800.00	20926400.00	0.0120	0.0202
227	2020-06-02T12:37:19	1544.61	1544.61	0.09	19.00	1380.00	20665600.00	1417.31	1420.38	1407.09	1420.95	303.15	294.29	292.84	292.75	305.91	15963400.00	20623600.00	20928200.00	0.0120	0.0202
228	2020-06-02T12:37:29	1544.73	1544.73	0.09	19.00	1380.00	20666500.00	1417.35	1420.42	1407.13	1420.99	303.15	294.28	292.83	292.75	305.82	15963900.00	20625400.00	20930000.00	0.0120	0.0202
229	2020-06-02T12:37:39	1544.85	1544.85	0.09	19.00	1380.00	20667500.00	1417.40	1420.45	1407.16	1421.02	303.15	294.27	292.83	292.74	305.72	15964300.00	20627300.00	20931800.00	0.0120	0.0202
230	2020-06-02T12:37:49	1544.97	1544.97	0.09	19.00	1380.00	20668500.00	1417.44	1420.49	1407.19	1421.06	303.15	294.26	292.82	292.73	305.63	15964800.00	20629100.00	20933600.00	0.0120	0.0202
231	2020-06-02T12:37:59	1545.08	1545.08	0.09	19.00	1380.00	20669500.00	1417.48	1420.52	1407.23	1421.09	303.15	294.24	292.81	292.73	305.53	15965300.00	20630900.00	20935500.00	0.0120	0.0202
232	2020-06-02T12:38:09	1545.20	1545.20	0.09	19.00	1380.00	20670500.00	1417.52	1420.56	1407.26	1421.13	303.15	294.23	292.80	292.72	305.44	15965700.00	20632700.00	20937300.00	0.0120	0.0202
233	2020-06-02T12:38:19	1545.32	1545.32	0.09	19.00	1380.00	20671500.00	1417.56	1420.59	1407.30	1421.16	303.15	294.22	292.80	292.71	305.35	15966200.00	20634600.00	20939100.00	0.0120	0.0202
234	2020-06-02T12:38:29	1545.44	1545.44	0.09	19.00	1380.00	20672500.00	1417.60	1420.62	1407.33	1421.19	303.15	294.21	292.79	292.71	305.25	15966700.00	20636400.00	20940900.00	0.0120	0.0202
235	2020-06-02T12:38:39	1545.56	1545.56	0.09	19.00	1380.00	20673400.00	1417.64	1420.66	1407.36	1421.22	303.15	294.19	292.79	292.70	305.16	15967100.00	20638200.00	20942600.00	0.0120	0.0202

9.3 Appendix 3

Data generated by wellGuide during simulations. These data sets are generated for each simulation.

bit	10/06/2023 15:36	JSON File	1 KB
diag_input_20230610_133649	10/06/2023 15:36	Text Document	47 KB
diag_output_20230610_133649	10/06/2023 15:36	Text Document	1 KB
edh	10/06/2023 15:36	Text Document	4 KB
FlowModelResults_2020-06-04_18.38	10/06/2023 15:36	Text Document	13 KB
fluid	10/06/2023 15:36	JSON File	2 KB
formations	10/06/2023 15:36	JSON File	81 KB
input	10/06/2023 15:36	JSON File	1 KB
log_DDS_Interface_20230610_133649.out	10/06/2023 15:36	OUT File	8 KB
modules	10/06/2023 15:36	JSON File	1 KB
pressureprofile	10/06/2023 15:36	JSON File	5 KB
result	10/06/2023 15:36	JSON File	1 KB
sequence	10/06/2023 15:36	JSON File	1 KB
signals	10/06/2023 15:36	JSON File	1 KB
temp_restartPCWM.fmrstr	10/06/2023 15:36	FMRSTR File	18,102 KB
temperatureprofile	10/06/2023 15:36	JSON File	2 KB
trajectory	10/06/2023 15:36	JSON File	53 KB
tubular	10/06/2023 15:36	JSON File	49 KB
tuning	10/06/2023 15:36	JSON File	1 KB
wbgeometry	10/06/2023 15:36	JSON File	2 KB

9.4 Appendix 4

The model outputs presented below represent the data generated from a single simulation out of the 12 simulations. This dataset encompasses a substantial volume of information that required analysis and verification processes

	Input parameters						Calculated parameters by wellGuide				
DateTime	BitPosition	DepthHole	MudDensityIn	MudTempIn	MudFlowIn	RotarySpeed	DesiredEMW	Axial velocity	csEcdCalc	pwdEcdCalc	bhEcdCalc
	m	m	kg/m3	k	m3/s	rad/s	kg/m3	m/s	kg/m3	kg/m3	kg/m3
2020-06-04T22:02:58	1116.27	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.00000	1510.32	1510.87	1505.12
2020-06-04T22:03:08	1116.27	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.00875	1505.14	1505.43	1501.47
2020-06-04T22:03:18	1116.27	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.00000	1504.72	1504.99	1501.17
2020-06-04T22:03:28	1116.27	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.00000	1504.72	1504.99	1501.17
2020-06-04T22:03:38	1116.27	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.00000	1504.72	1504.99	1501.17
2020-06-04T22:03:43	1116.27	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.00000	1504.72	1504.99	1501.17
2020-06-04T22:03:44	1116.37	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.09860	1518.98	1519.93	1511.22
2020-06-04T22:03:54	1119.51	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.32646	1568.84	1572.02	1546.38
2020-06-04T22:04:04	1122.65	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.31432	1567.21	1570.11	1545.24
2020-06-04T22:04:14	1125.80	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.31432	1565.27	1567.90	1543.88
2020-06-04T22:04:24	1128.94	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.31432	1563.53	1565.91	1542.65
2020-06-04T22:04:34	1132.08	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.31432	1561.83	1563.96	1541.45
2020-06-04T22:04:44	1135.23	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.31432	1560.33	1562.24	1540.41
2020-06-04T22:04:54	1138.37	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.31432	1558.99	1560.68	1539.46
2020-06-04T22:05:04	1141.51	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.31432	1557.77	1559.27	1538.61
2020-06-04T22:05:14	1144.66	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.31432	1556.67	1557.98	1537.84
2020-06-04T22:05:19	1146.27	1768.23	1500.00	303.15	0.00	0.00	1570.00	0.31431	1556.13	1557.34	1537.46

DateTime	csPresCalc	bhPresCalc	pwdPresCalc	csTempCalc	bhTempCalc	pwdTempCalc	tempOutCalc	pitGainCalc	flowOutCalc	surgeVolCalc	sppCalc	pwdEsdCalc	cuttingsBHA
	pascal	pascal	pascal	k	k	k	k	m3	m3/s	m3/s	pascal	kg/m3	ratio
2020-06-04T22:02:58	17309700.00	24492000.00	16494600.00	312.56	336.36	311.43	289.958	72.1096	0.0042	0.0042	101325	1505.01	0
2020-06-04T22:03:08	17250600.00	24432800.00	16436900.00	312.56	336.36	311.43	289.957	72.1216	0.0012	0.0012	101325	1504.99	0
2020-06-04T22:03:18	17245800.00	24427900.00	16432000.00	312.56	336.36	311.44	289.956	72.1218	0.0000	0.0000	101325	1504.99	0
2020-06-04T22:03:28	17245800.00	24427900.00	16432000.00	312.56	336.36	311.44	289.955	72.1218	0.0000	0.0000	101325	1504.99	0
2020-06-04T22:03:38	17245800.00	24427900.00	16432000.00	312.56	336.36	311.44	289.954	72.1218	0.0000	0.0000	101325	1504.99	0
2020-06-04T22:03:43	17245800.00	24427900.00	16432000.00	312.56	336.36	311.44	289.953	72.1218	0.0000	0.0000	101325	1504.99	0
2020-06-04T22:03:44	17408300.00	24590900.00	16595700.00	312.56	336.36	311.44	289.953	72.122	0.0002	0.0002	101325	1505.02	0
2020-06-04T22:03:54	17976500.00	25160600.00	17208500.00	312.56	336.36	311.45	289.952	72.3841	0.0272	0.0272	101325	1505.19	0
2020-06-04T22:04:04	17957900.00	25142000.00	17235100.00	312.45	336.36	311.61	289.951	72.681	0.0297	0.0297	101325	1505.16	0
2020-06-04T22:04:14	17935800.00	25120000.00	17258300.00	312.35	336.36	311.77	289.949	72.9781	0.0297	0.0297	101325	1505.14	0
2020-06-04T22:04:24	17915900.00	25100100.00	17283700.00	312.24	336.36	311.93	289.948	73.2767	0.0299	0.0299	101325	1505.11	0
2020-06-04T22:04:34	17896500.00	25080700.00	17309500.00	312.13	336.36	312.09	289.947	73.5737	0.0297	0.0297	101325	1505.09	0
2020-06-04T22:04:44	17879500.00	25063700.00	17337700.00	312.02	336.36	312.25	289.946	73.8705	0.0297	0.0297	101325	1505.07	0
2020-06-04T22:04:54	17864200.00	25048400.00	17367600.00	311.91	336.36	312.41	289.945	74.1672	0.0297	0.0297	101325	1505.05	0
2020-06-04T22:05:04	17850300.00	25034600.00	17398900.00	311.80	336.36	312.57	289.944	74.4638	0.0297	0.0297	101325	1505.02	0
2020-06-04T22:05:14	17837800.00	25022100.00	17431500.00	311.68	336.36	312.73	289.943	74.7603	0.0297	0.0297	101325	1505.00	0
2020-06-04T22:05:19	17831600.00	25016000.00	17448400.00	311.56	336.36	312.89	289.942	74.9121	0.0296	0.0296	101325	1504.99	0