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Advanced Drilling Optimization through Predictive Data Analytics and Machine Learning Pipeline

Gaurav Kumar Sinha

Amazon Web Services Inc, USA

ABSTRACT

The paper provides a pattern and methodology to optimize drilling in the oil and gas industry through integration of data analytics and machine learning. Drilling operations have unpredictable subsurface conditions, which leads to operational inefficiencies. My methodology ingests historical drilling data, real-time sensor data, and geological data to train machine learning models. I discuss the implementation and analysis of a data analytics framework that collects and preprocesses data streams, and send the data for machine learning. The paper offers keywords aimed at enhancing discoverability, indexing, clarity, and visibility. The introduction section details context, relevance, objectives, scope and structure of the paper. The Problem Statement section details business problem. The solution section provides methodology to address the identified problem. The architecture diagram section illustrates the system architecture and design. The architecture review details the selected architecture. The implementation section provides steps to implement solution, detailing the specific tools, technologies, and methodologies utilized in its development. The implementation for Proof of Concept (PoC) section provides a strategy as how to plan for the implementation of the solution at the organization level. The use cases section provides details about what a business can derive information to make decision. The impact section details the business value. The extended use case section so how the proposed solution can be implemented across diverse industries and domains, highlighting the potential for widespread applicability.

***Corresponding author**

Gaurav Kumar Sinha, Amazon Web Services Inc, USA.

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Keywords: Drilling Optimization, Predictive Data Analytics, Machine Learning Pipelines, Oil and Gas Industry, Real-time Sensor Data, Geological Information, Drilling Risks Prediction, Operational Efficiencies, Data Streams Preprocessing, Advanced Machine Learning Algorithms, Drilling Hazards Identification, Drilling Speed Optimization, Regression Models, Decision Trees, Neural Networks, Data Quality, Model Interpretability, Operational Workflows, Data-driven Decision-making, Drilling Efficiency Improvement

Introduction

The oil and gas industry provide energy for industry and people all over the world. Drilling activity for oil and gas industry is difficult and resource consuming.

The paper provides a new analytics method that uses data analytics and machine learning to make drilling operations efficient and safer. The Process starts with ingesting data set from previous drilling projects, real-time sensor data and geology data. I then use this data to train machine learning models to predict risks and give recommendations on how to adjust the drilling process.

The goal is to create a smart technical framework using latest technology to analyze all the data and give business informed recommendation and analysis on how to avoid problems and optimize their operations. The objective is to save time, save money, and make the drilling process safer for workers.

The paper will provide how i designed this system using latest aws cloud technology and how it can provide informative decision to improve drilling process.

The paper aims to show how using cutting-edge data analysis and machine learning technology can revolutionize the way we drill for oil and gas.

Problem Statement

In the realm of the oil and gas sector, the act of drilling is essential but comes with its set of difficulties due to the unpredictable nature of what lies below the earth's surface, which often leads to considerable inefficiencies in operation and a spike in expenses. The traditional methods utilized in drilling operations are predominantly based on past experiences and broad geological models, which tend to not forecast the complexities found underground with high accuracy. These inefficiencies don't just lead to economic losses but also heighten the environmental hazards linked to drilling processes. The failure of the sector to effectively combine and examine an extensive collection of historical data from drilling, real- time information from sensors, and comprehensive geological details in a unified way further complicates the situation. This prevents those in charge from making knowledgeable decisions that could lessen risks and enhance the effectiveness of operations. This paper aims to tackle the urgent necessity for an all-encompassing, data-centric method that employs the most recent developments in data analytics and machine learning to streamline drilling operations, minimize uncertainties, and bolster the safety and financial gains of oil and gas extraction activities.

Solution

Here's a structured approach to developing the solution using AWS Services

Data Collection and Storage
- **AWS IoT Core:** Use to collect real-time sensor data from the equipment.
- **Amazon S3:** Use store large volumes of structured and unstructured data

Data Integration and Processing
- **AWS Glue:** To prepare and transform data for analysis
- **Amazon Kinesis:** For real-time data streaming and processing,

Data Analytics and Visualization
- **Amazon Athena:** For analyzing data directly in Amazon S3 using standard SQL queries.
- **Amazon QuickSight:** For business intelligence and data visualization.

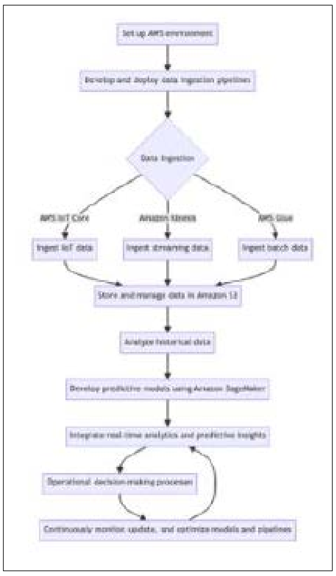
Machine Learning and Predictive Analytics
- **Amazon SageMaker:** To build, train, and deploy machine learning models
- **AWS Lambda:** To run code in response to triggers from S3 and Amazon Kinesis

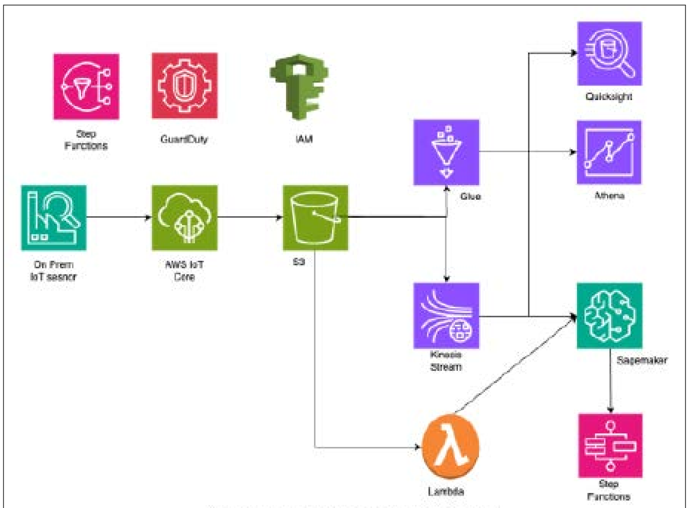
Workflow Automation and Integration
- **AWS Step Functions:** To automate the data pipeline and integrate machine learning model
- **Amazon SNS and Amazon SQS:** For messaging and inter-service communication

Security and Compliance
- **AWS Identity and Access Management (IAM):** To control access and permissions.
- **Amazon GuardDuty:** For threat detection and monitoring of AWS environment.

Scalability and Reliability
- **AWS Auto Scaling:** To scale response to application demand.
- **Amazon EC2:** To run applications and support the data processing workload.

Architecture Diagram





Analytic System for Advanced Drilling Optimization

Architecture Overview
The framework has been crafted to enhance data processing and analysis by an effortless merging of AWS solutions, thereby supporting analytics both in batch and in real-time scenarios. Here's the operational flow:

Data Collection
In the first stage, data is gathered from sources located on-premises and smoothly transferred to the AWS cloud via AWS IoT Core, guaranteeing data capture that's both secure and efficient.

Storage Solution
Following collection, this data is then held in an Amazon S3 bucket, offering a storage solution that's both secure and capable of scaling.

Data Organization and Cataloging
To organize the data for easy accessibility and analysis, AWS Glue, which is a managed service for extract, transform, and load (ETL) tasks, is used to systematize the data into a unified catalog.

Instant Data Processing
For insights without delay, the streaming of raw data is also managed through Amazon Kinesis, which allows for the data's real-time processing and analysis.

Insight Generation and Representation
The organized data within AWS Glue is further primed for exploration with Amazon Athena and illustrated through Amazon QuickSight, making it simpler to delve into data and uncover insights.

Creation of Machine Learning Models
With the aid of Amazon SageMaker, the treated data is taken up for the crafting, educating, and deploying of machine learning models that are custom-fitted for particular analytic requirements.

Workflow Management Automation and Integration
The integration of AWS Step Functions automates the data workflow, meshing perfectly with the machine learning model to ensure a seamless management across the architecture.

Trigger-Based Automation
In response to specific events in S3 and Amazon Kinesis, AWS Lambda functions are set off to automate the processing and reacting to changes in the data.

Alerts and Updates
For timely communication of alerts and notifications, Amazon Simple Notification Service (SNS) is put to use.

Safety Monitoring
To protect against potential threats, Amazon GuardDuty is on continuous duty, monitoring for security issues and detecting threats.

Managed Access
Finally, AWS Identity and Access Management (IAM) plays a critical role in resource access control, confirming that only those authorized can reach the data and infrastructure resources.

This designed framework not only guarantees the proficient management of vast data volumes but also capitalizes on sophisticated AWS offerings. This enables refined data analysis, the building of machine learning models, and immediate data processing - all while upholding stringent security measures and ensuring easy access.

Implementation
Here's a step-by-step implementation plan

Phase 1: Planning and Architecture Design
Assessment
- Start with evaluation of the current state of drilling operations, focusing on the existing data collection practices and infrastructure.
- Identify specific goals and objectives for optimization, include aspects like reducing non- productive time, enhancing operational safety, or improving overall drilling efficiency.

Phase 2: Data Collection and Storage Setup
Data Collection
- Integrate AWS IoT Core to with drilling equipment and sensors to enable the real-time collection of operational data.
- Implement best practices for data encryption and transmission security to securely and reliable transmission of data from filed operations

Data Storage
- Use S3 buckets for the storage of various types of data, including historical drilling records, real- time sensor readings, and geological datasets.
- Implement appropriate data lifecycle management policies to automate the transition of data to cost-effective storage classes.
- Apply encryption mechanisms for the security of data at rest

Phase 3: Data Integration and Processing
Data Integration
- Use AWS Glue to create a centralized catalog of data sources using ETL job
- Prepare the data for analysis by performing data cleaning, normalization, and transformation.

Data Processing
- Use Amazon Kinesis for the real-time streaming and processing of sensor data
- Set up data processing workflows to allow for the detection of patterns, anomalies, and critical conditions

Phase 4: Analytics, Visualization, and Machine Learning
Data Analytics
- Use Amazon Athena to enable SQL querying capabilities directly on stored data
- Use Amazon QuickSight for creating interactive dashboards and visualizations.

Machine Learning
- Use Amazon SageMaker to develop, train, and deploy machine learning models
- Create predictive models that can forecast drilling risks and suggest optimal drilling parameters

Phase 5: Model Deployment and Real-Time Analytics
Model Deployment
- Deploy the trained machine learning models into production environments using Amazon SageMaker endpoints

Real-time Analytics
- Use AWS Lambda functions to automatically apply the deployed machine learning models to incoming real-time data streams.
- Configure the system to provide insights and predictions based on the real-time data

Phase 6: Workflow Automation and Decision Integration
Automation
- Use AWS Step Functions to design and implement automated workflows that are triggered by machine learning insights.

Integration
- Implement seamless integration of the new system with existing operational workflows and decision-making processes.

Phase 7: Security, Monitoring and Compliance
Security
- Use IAM to control access to AWS services and resources securely.
- Use Amazon GuardDuty for monitoring and detection of malicious activity and unauthorized behavior across AWS accounts and workloads.

Monitoring
- Use Amazon CloudWatch to monitor the performance and operational health of AWS resources involved in the drilling optimization system.
- Configure alarms and notifications to alert on events or metrics that indicate system issues.

Compliance
- Review and ensure that system adhere to relevant industry regulations and standards
- Implement procedures and checks to maintain ongoing compliance,
- Implement regular audits and updates in response to changing regulations and standards.

Phase 8: Evaluation and Continuous Improvement
Evaluation
- Conduct regular assessments of the system's performance against predetermined goals.
- Collect and analyze feedback from end-users to understand any issues.

- Analyze system data to identify underperforming areas and opportunities for enhancement.
- Implement monitoring tools to track performance and user engagement in real-time.

Optimization

- Continuously update and refine machine learning models to improve accuracy and efficiency.
- Revise data processing workflows to enhance speed, reliability, and relevance.
- Improve user interfaces based on user feedback to enhance usability and satisfaction.
- Incorporate new data sources and features to keep the system relevant and effective.
- Conduct A/B testing to compare different improvements and implement the most effective ones.
- Establish a cycle of feedback, analysis, and updates to ensure continuous improvement.

Phase 9: Training and Change Management

Training

- Develop and conduct comprehensive training programs
- Include interpreting insights generated by the system to effectively utilizing predictive analytics.
- Provide hands-on training sessions, demonstrations, and access to training materials
- Establish a continuous learning environment.

Change Management

- Develop a change management strategy to support the integration of the new system into existing workflows.
- Identify and address any resistance from staff
- Engage with all stakeholders early in the process to gather input
- Provide clear, consistent communication about the changes and expected outcomes
- Assign change agents within different teams to facilitate the transition

Successful Implementation

- Ensure careful planning and coordination across different teams and disciplines
- Foster collaboration and open communication among personnel
- Maintain ongoing management and support to resolve any emerging challenges
- Regularly review and assess the system's performance and the overall implementation process

Implementing the PoC

Here's is step by step approach for implementing above as PoC

Step 1: Define Objectives and Success Criteria

- Clearly define the primary objectives of the PoC, such as reducing non-productive time, improving drilling efficiency, or enhancing safety measures.
- Establish clear, measurable success criteria to evaluate the performance of the PoC.

Step 2: Scope the PoC

- Determine the scope of the PoC, the datasets to be used, the drilling operations to be optimized, and the specific AWS services involved.
- Select a particular drilling site as the starting point for the PoC

Step 3: Assemble the Team

- Form a cross-functional team comprising data scientists, drilling engineers, IT specialists, and operational staff
- Define roles and responsibilities for all team members involved in the PoC.

Step 4: Set Up the Infrastructure

- Utilize AWS services for the PoC infrastructure.
- Ensure infrastructure is secure, compliant with industry standards, and capable of handling the data and processing needs of the PoC.

Step 5: Data Collection and Preparation

- Begin collecting real-time and historical drilling data.
- Clean, preprocess, and normalize the data.

Step 6: Develop and Train Machine Learning Models

- Use Amazon SageMaker to develop and train predictive
- Focus on models that can predict key performance indicators
- Potential operational issues relevant to the PoC objectives.

Step 7: Implement Real-time Data Processing and Analytics

- Set up real-time data processing using Amazon Kinesis and apply the trained machine learning models to this data stream for real-time analytics.
- Develop dashboards using Amazon QuickSight to visualize the analytics and insights generated from the data.

Step 8: Conduct the PoC

- Run the PoC over a designated period
- Ensure continuous communication among team members and stakeholders

Step 9: Evaluate Results and Gather Feedback

- Evaluate the results against the predefined success criteria.
- Collect feedback from all stakeholders, including drilling engineers, data scientists, and operational staff

Step 10: Document and Review Findings

- Document the results, lessons learned, challenges encountered, and the feedback received during the PoC.
- Review the findings with all stakeholders to decide on the next steps

Step 11: Plan for Full-scale Implementation

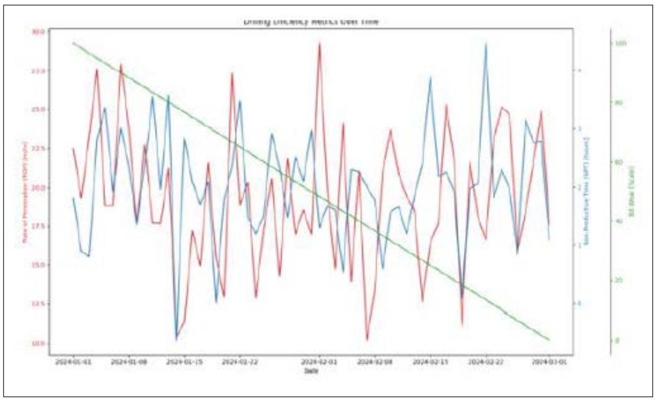
- If the PoC is successful, develop a detailed plan for full-scale implementation
- Consider creating a roadmap that outlines phased deployment, additional features or capabilities, and ongoing support and maintenance.

Uses

Drilling Efficiency Metrics

Rate of Penetration (ROP)

- Analyzing trends and factors affecting ROP
- Help identify the most efficient drilling practices and equipment settings.

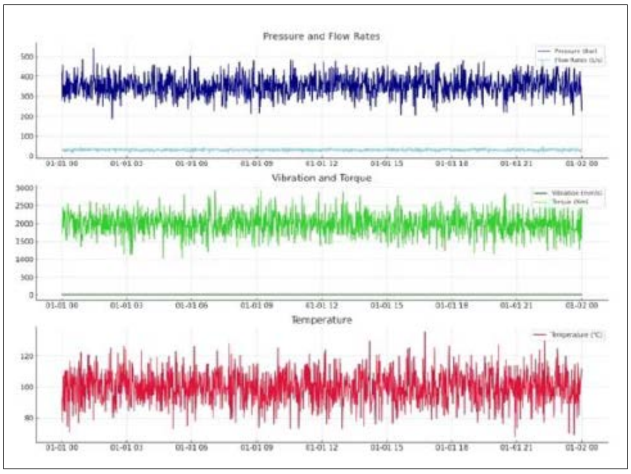


Real-time Sensor Data

Pressure and Flow Rates: Variations in pressure and flow rates indicates potential well control issues.

Vibration and Torque: signal equipment problems or suboptimal drilling conditions.

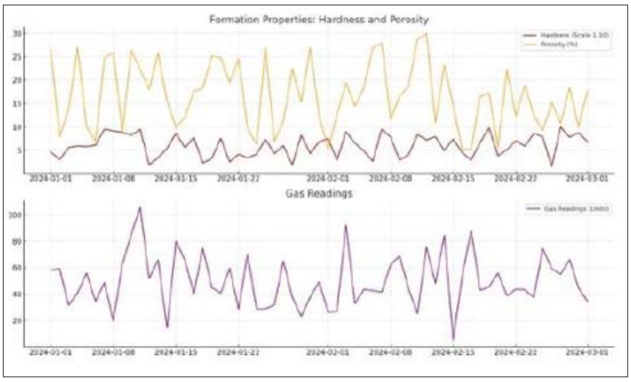
Temperature: indicate equipment malfunction or critical conditions affecting well integrity.



Geological and Formation Data

Formation Properties: Guides the selection of appropriate drilling parameters and equipment.

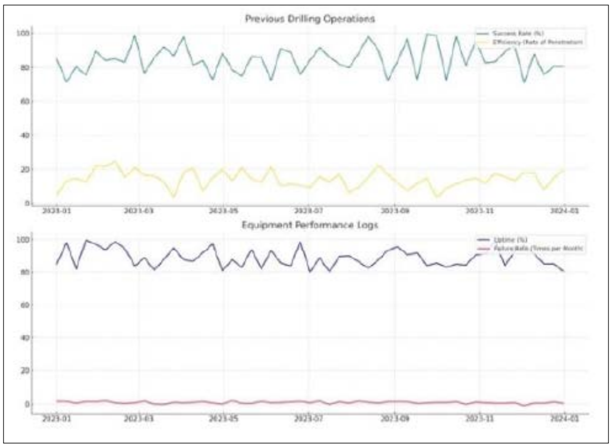
Gas Readings: Helps in assessing formation pressures and identifying potential hydrocarbon zones.



Historical Performance Data

Previous Drilling Operations: Helps identify best practices and areas for improvement.

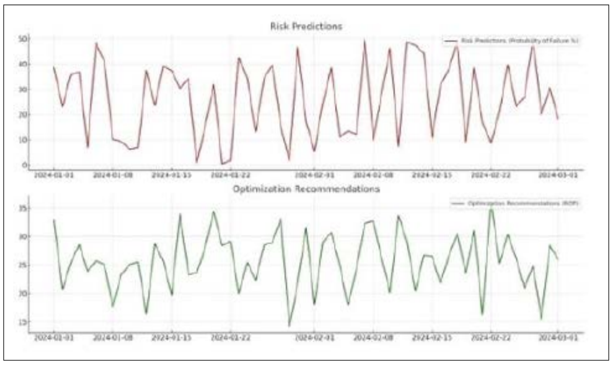
Equipment Performance Logs: Helps predicting future failures and optimizing maintenance schedules.



Predictive Model Outputs

Risk Predictions: Predict potential risks, such as equipment failure or hazardous conditions, allowing for preemptive action.

Optimization Recommendations: Help optimize drilling efficiency and safety based on current and historical data.



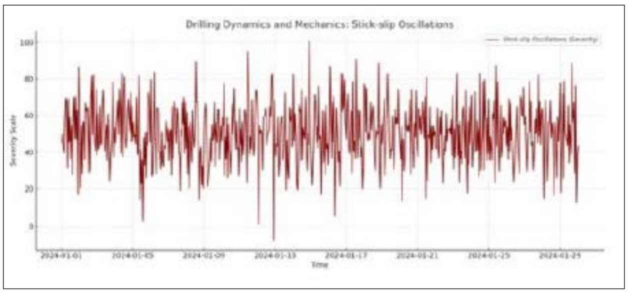
Economic and Operational Factors

Cost Analysis: Help in optimizing for both efficiency and budget.

Resource Allocation: Help in effective allocation of human and material resources.

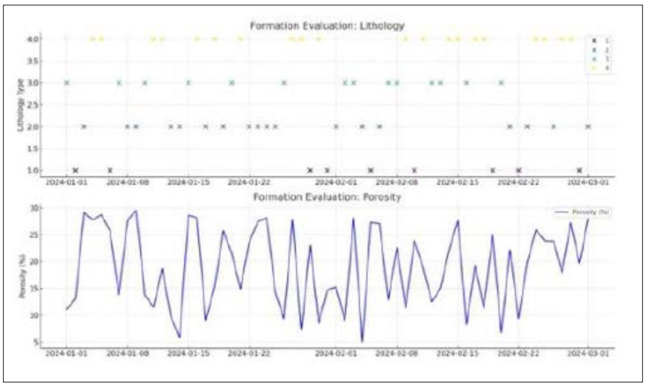
Drilling Dynamics and Mechanics

Stick-slip Oscillations: Help adjust drilling parameters to avoid bit stalling and reduce equipment wear.



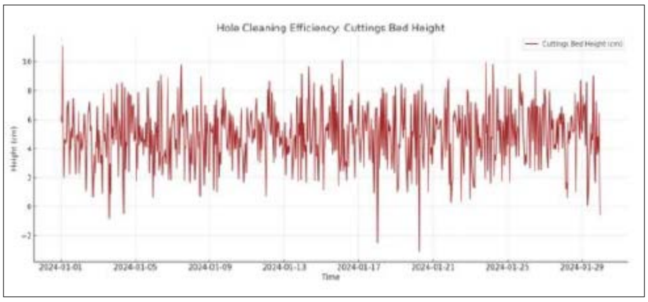
Formation Evaluation

Lithology and Porosity: helps in identifying lithology changes and porosity



Hole Cleaning Efficiency

Cuttings Bed Height: Informs decisions on mud properties and flow rates to improve hole cleaning.

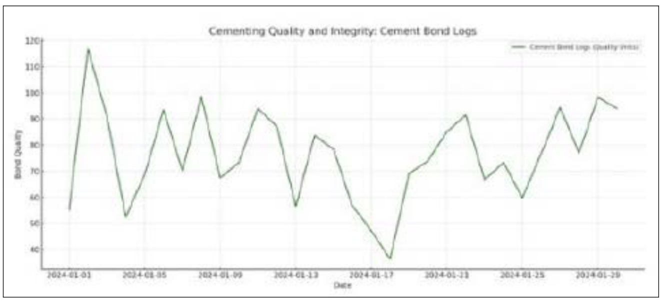


Bit Performance and Selection

Bit Dullness and Wear Patterns: Guides the selection of more suitable bit types and cutting structures for different formations.

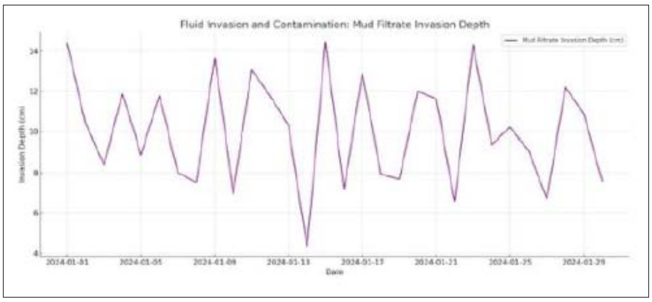
Cementing Quality and Integrity

Cement Bond Logs: Helps in assessing the quality of cement jobs and identifying zones with poor bonding for remedial actions.



Fluid Invasion and Contamination

Mud Filtrate Invasion Depth: Helps adjusting mud properties to minimize formation damage and improve sample quality.



Pressure Management and Well Control: Pore Pressure and Fracture Gradients: Helps in maintaining well control and preventing blowouts.

Hydraulic Optimization

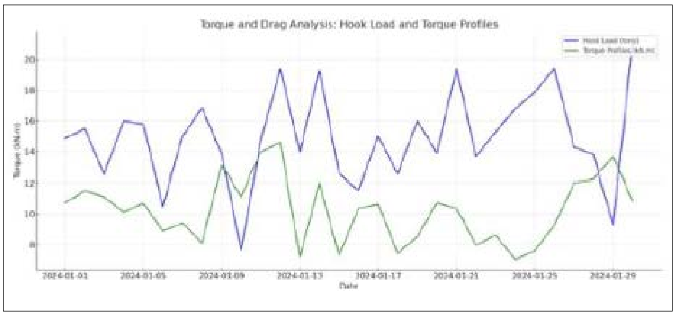
Hydraulic Horsepower and Impact Force: Helps in optimizing drilling hydraulics for better rate of penetration and bit life.

Drilling Vibration Management

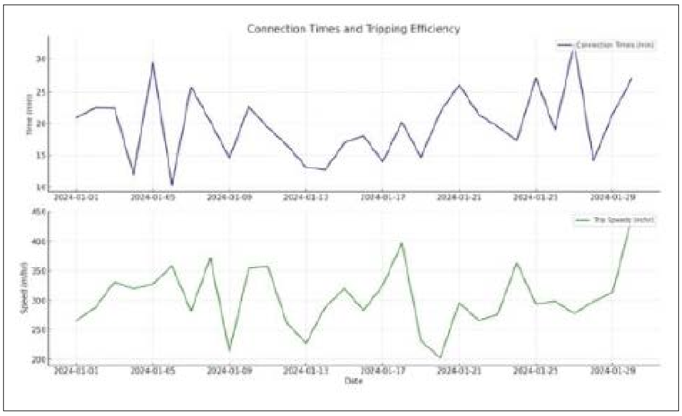
Axial, Lateral, and Torsional Vibrations: Guides adjustments in drilling parameters to mitigate harmful vibrations and reduce equipment fatigue.

Torque and Drag Analysis

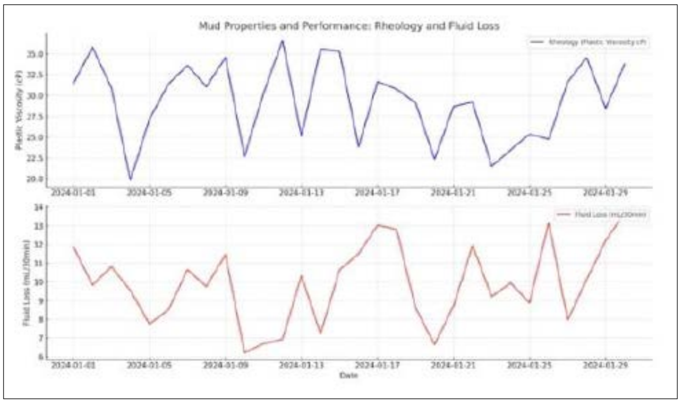
Hook load and Torque Profiles: Helps in identifying problematic zones and adjusting drilling practices to reduce friction and prevent stuck pipe incidents.



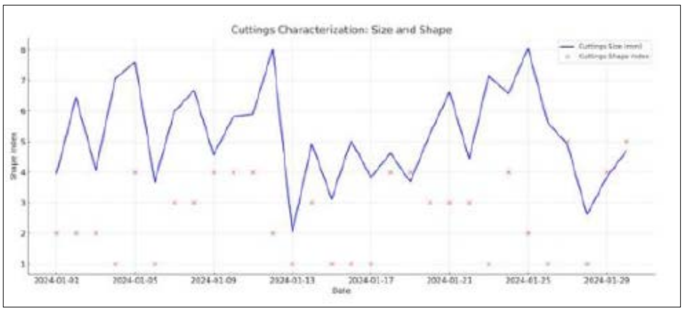
Connection Times and Tripping Efficiency
Connection Times and Trip Speeds: Helps in identifying inefficiencies and guide improvements in drilling practices.



Mud Properties and Performance
Rheology and Fluid Loss: Helps in maintaining optimal mud properties for effective drilling and wellbore stability.

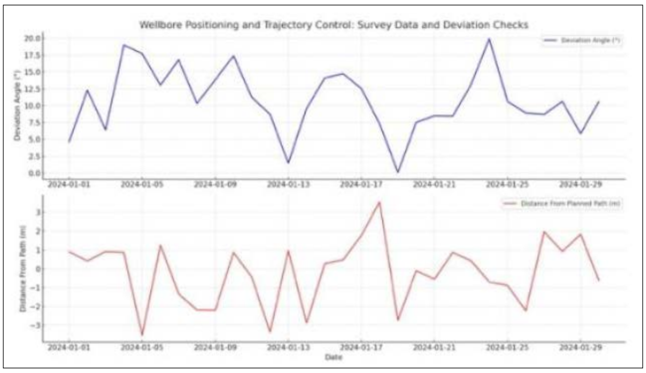


Cuttings Characterization
Cuttings Size and Shape: Provides insights into the drilling process and formation characteristics, aiding in bit selection and drilling optimization.



Underbalanced Drilling Operations
Gas in Mud and Flow Rates: Helps in ensuring safety and optimizing production from reservoirs.

Wellbore Positioning and Trajectory Control
Survey Data and Deviation Checks: Helps in maintaining the correct wellbore trajectory and avoiding collision with existing wells.



Impact
Improved Drilling Efficiency
- Faster drilling times.
- Lower operational costs.

Enhanced Safety Measures
- Identification of risks for proactive prevention.
- Monitoring ensures detection of potential hazards.

Cost Reduction
- Drilling performance enhancement
- Reduces the need for frequent mud replacement.
- Regular monitoring of bit wear patterns.
- Allows for timely replacement or reconditioning.

Increased Production Rates
- Ensures proper control of drilling conditions.
- Maintains optimal underbalanced conditions.
- Maintains reservoir pressure during drilling.
- Prevents damage to the formation.
- Maximizes recovery efficiency.
- Facilitates higher extraction rates.
- Optimizes production output.

Well Integrity and Stability
- Assess the quality of cement job.
- Ensures proper zonal isolation.
- Monitoring properties density, viscosity, and pH.
- Helps in early detection of potential issues.
- Reduced likelihood of costly well control issues.
- Integrity throughout the drilling process.

Reduced Non-Productive Time (NPT)
- Help identify areas of high friction.
- Proactive measures to prevent pipe sticking.
- Adjusting drilling parameters to reduce friction.
- Implementing proper lubrication techniques.
- Prevents costly downtime
- Minimizes the need for expensive interventions

Operational Decision Making
- Provides information on the location of drill bit.
- Adjustments to drilling direction and depth.
- Allows for detection of potential collision paths.
- Facilitates timely corrective actions
- Helps alignment with the intended target zone.
- Minimizes the risk of deviation
- Optimizes drilling resource utilization.

Resource Optimization
- Team performance during operations.
- Areas for improvement and training needs.
- Proper staffing levels and task assignments.
- Maximizing productivity by assigning tasks
- Streamlining between drilling activities.
- Minimizing downtime and delays
- Utilizing human and material resources
- Reducing unnecessary costs and wastage.

Preventative Maintenance
- Forecasts potential equipment failures.
- Identifying patterns and trends
- Scheduling maintenance activities
- Conducting preventive measures
- Reducing unexpected downtime:
- Minimizes disruptions to operations.
- Maximizes productivity and efficiency.
- Prolonging equipment life:
- Prevents premature wear and tear.
- Optimizes asset utilization

Compliance and Environmental Protection
- Regular assessment of drilling fluids
- Measures to contain and mitigate fluid spills.
- Ensuring proper cement bonding to prevent leaks
- Adherence to environmental regulations
- Avoidance of penalties and legal consequences.
- Protecting ecosystems and natural resources.
- Preserving biodiversity and habitat integrity.

Investment Decisions
- Optimize drilling processes and efficiency.
- Geological data for hydrocarbon reserves.
- Identifying areas for exploration
- Directing investment towards drilling prospects.

Technological Advancements
- AIdentify trends and patterns for enhancement.
- To extract actionable insights.
- Inspiring development of drilling techniques
- Experimentation with cutting-edge tools
- To optimize drilling

Market Competitiveness
- Increase productivity and reduce timelines.
- Adherence to regulations mitigates risks
- A safety record builds trust with stakeholders
- Efficient utilization and cost management
- Cost-effectiveness enhances competitiveness

Data-Driven Culture
- Incorporating data analytics tools and techniques
- analyze relevant data to make decision
- learning and adaptation based on data insights.
- Employees identify areas for improvement
- Empowering decision-makers
- Reliance on data when making decisions.
- Collaboration and knowledge-sharing

Customer Satisfaction
- less disruptions and downtime during operations.
- Efficient drilling processes
- Efficient operations help control costs for clients
- Providing cost-effective solutions
- Building relationships based on reliability

Extended Use Cases

Here are ten extended use cases across different sectors:

Healthcare

Predictive Patient Care
- Identifying patterns for of deteriorating health.
- Analyze patient data and predict diseases Drug Discovery and Development:
- Screening large databases for drug candidates.
- Identification of compounds for investigation. Medical Imaging Analysis:
- To identify subtle abnormalities
- Improves accuracy in detecting signs of diseases

Finance

Fraud Detection
- Detects fraudulent activities in real-time. Algorithmic Trading:
- To respond to market changes faster Credit Scoring:
- Enabling more accurate and fair lending decisions. Customer Service Automation:
- Provide customers personalized financial advice.

Retail

Customer Segmentation and Personalization
- Market strategies to improve engagement and sales. Inventory Management:
- To reduce overstock and out-of-stock situations
- To improve supply chain efficiency. Price Optimization:
- Adjust prices based on demand and competition Augmented Reality Shopping:
- Offers AR experiences to customers to try products

Manufacturing

Predictive Maintenance
- Predict failures to reduce downtime Supply Chain Optimization:
- Improve supply chain visibility and forecast demand, Quality Control
- Inspect and detect defects in products Smart Factory
- Create connected and flexible manufacturing

Agriculture

Precision Farming
- Monitor crop health and optimize water usage Livestock Monitoring:
- To track the health and behavior of animals Supply Chain

Traceability:
- To ensure the traceability of agricultural products from farm to table, enhancing food safety and consumer trust.

Energy

Smart Grid Management
- To optimize the generation, distribution, and consumption of electricity.

Renewable Energy Forecasting
- To facilitate the integration of renewable sources into the energy mix.

Demand Response
- To manage peak load and encourage energy savings

Asset Optimization
- To optimize the performance and lifespan of energy assets.

Transportation

Traffic Management
- To optimize traffic flow, reduce congestion, and improve urban mobility.

Predictive Maintenance for Fleets
- To predict maintenance needs

Route Optimization
- To determine the most efficient routes for delivery and transportation.

Education

Adaptive Learning Platforms
- Creating personalized learning experiences

Automated Grading and Feedback
- To grade assignments and provide instant feedback.

Student Success Prediction
- To identify students at risk of underperforming

Virtual Reality Training
- VR experiences for interactive learning

Real Estate

Property Valuation Models
- To predict property prices based on location

Virtual Property Tours
- Offering 3D virtual tours of properties.

Predictive Maintenance for Buildings
- To predict maintenance issues in buildings.

Market Demand Forecasting
- To forecast real estate trends

Entertainment

Content Recommendation Engines
- To recommend movies, shows, and music.

Audience Analysis
- To understand preferences and trends.

Virtual Reality Experiences
- Creating VR environments for gaming, concerts, and virtual travel.

Automated Content Creation
- To generate music, art, and scripts

Conclusion

In summary, the implementation of an advanced drilling optimization framework utilizing predictive data analytics and machine learning harnesses vast datasets, including real-time sensor data, historical drilling records, and geological information, to unlock levels of efficiency, safety, and cost-effectiveness in drilling operations.

By employing machine learning models, companies can predict drilling risks, optimize drilling parameters, and enhance decision-making processes. The predictive analytics enables real-time adjustments and foresight, minimizing costly errors and equipment failures.

The economic and improvements in safety and environmental protection, highlight the value of investing in advanced data analytics and machine learning technologies.

The continuous learning aspect of machine learning models ensures that drilling operations become more efficient and safer over time, as the system becomes adept at identifying and responding to subsurface conditions and operational nuances.

The integration of predictive data analytics and machine learning into drilling operations signifies a significant shift towards data-driven decision-making in the oil and gas sector offers a pathway to optimize resource extraction while upholding safety and environmental standards [1-25].

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