Engineering Heritage Journal (GWK)

DOI: http://doi.org/10.26480/gwk.02.2023.157.166

ISSN: 2521-0904 (Print)
ISSN: 2521-0440 (Online)
CODEN: EHJNA9

RESEARCH ARTICLE

BALANCING EFFICIENCY AND RESILIENCE: A CRITICAL REVIEW OF MAINTENANCE STRATEGIES IN CONVENTIONAL AND UNCONVENTIONAL OIL AND GAS PRODUCTION

Joachim Osheyor Gidiagba[a], Joel Leonard[b], Oluwaseun Ayo Ogunjobi[c], Kelechi Anthony Ofonagoro[d], Chibuike Daraojimba[e]*

[a] *University of Johannesburg, South Africa*
[b] *University of Pretoria, South Africa*
[c] *S A & G Beeline Consulting, Nigeria*
[d] *Kelanth Energy Solutions Limited, Nigeria*
[e] *University of Pretoria, South Africa*
**Corresponding Author Email: chibuike.daraojimba@tuks.co.za*

ARTICLE DETAILS

Article History:

Received 06 July 2023
Revised 09 August 2023
Accepted 12 September 2023
Published 06 October 2023

ABSTRACT

Efficiency and resilience are critical aspects of maintenance strategies in the dynamic oil and gas industry. This paper provides a comprehensive review of maintenance approaches in conventional and unconventional production, highlighting the delicate balance required between efficient operations and the ability to withstand disruptions. Through case studies, emerging technologies, and future trends, the paper explores strategies to optimize production processes while ensuring robustness against challenges. By offering insights into integrated maintenance solutions, this review contributes to informed decision-making and the advancement of sustainable practices in oil and gas production.

KEYWORDS

Production, Maintenance, Resilience, Oil and Gas, Efficiency.

1. Introduction

1.1 Background and Significance of Maintenance Strategies in The Oil and Gas Industry

Maintenance strategies play a crucial role in the oil and gas industry due to its critical role in global energy supply and the complex operational environment (Dženopoljac et al., 2019a). The industry's infrastructure consists of various equipment, including drilling rigs, pipelines, and refining facilities, all of which require consistent and effective maintenance to ensure safe and efficient operations (Dženopoljac et al., 2019b). There are several factors that highlight the significance of maintenance strategies in the industry. Firstly, the high capital investment in oil and gas assets necessitates optimal performance and longevity (Dženopoljac et al., 2019b). Any disruption or failure can lead to substantial financial losses and production downtime. Secondly, the industry operates in harsh and challenging conditions, such as extreme temperatures, corrosive environments, and high-pressure conditions, which place additional stress on equipment and demand rigorous maintenance practices (Dženopoljac et al., 2019b).

Moreover, the oil and gas industry operate within a regulatory framework that prioritizes safety, environmental protection, and compliance (Dženopoljac et al., 2019b) .Maintenance strategies play a crucial role in meeting these regulations by preventing accidents, leaks, and environmental hazards. Additionally, the industry's strategic role in global energy security relies on dependable and resilient production systems, which are heavily influenced by effective maintenance strategies (Dženopoljac et al., 2019b). Considering these challenges and imperatives, maintenance strategies offer a pathway to ensure reliability, minimize downtime, extend equipment life, and enhance safety and environmental performance. It is essential for the sustainable growth of the oil and gas sector to have a thorough understanding of maintenance approaches, their benefits, and their alignment with operational goals (Dženopoljac et al., 2019b).

1.2 Importance of Balancing Efficiency and Resilience

Maintenance strategies in the oil and gas industry are crucial for achieving a delicate equilibrium between efficiency and resilience. Balancing these two factors is paramount due to several key reasons. Efficiency is vital to optimize resource utilization, reduce costs, and maximize production output (Kalisch et al., 2015). Efficient processes enhance competitiveness and contribute to achieving operational goals. However, overemphasizing efficiency can make systems vulnerable to unexpected disruptions, potentially leading to severe financial and reputational consequences (Kalisch et al., 2015).

On the other hand, resilience ensures that operations can withstand and recover from disturbances, maintaining continuity and mitigating losses (Kalisch et al., 2015). Resilient systems are better equipped to respond to uncertainties, be they market fluctuations, geopolitical events, or natural disasters. Yet, an excessive focus on resilience may hinder cost-effectiveness and responsiveness to market demands (Kalisch et al., 2015). The synergy between efficiency and resilience lies in finding the optimal trade-off that aligns with an organization's strategic objectives. Striking this balance safeguards against both short-term setbacks and long-term vulnerabilities (Kalisch et al., 2015). It involves leveraging efficiency gains without compromising the ability to adapt and recover from unforeseen challenges.

In conclusion, the importance of balancing efficiency and resilience in the oil and gas industry cannot be overstated. The ability to simultaneously optimize operational performance and navigate uncertainties enhances an

Quick Response Code	Access this article online	
	Website: www.enggheritage.com	**DOI:** 10.26480/gwk.02.2023.157.166

Cite The Article: Joachim Osheyor Gidiagba, Joel Leonard, Oluwaseun Ayo Ogunjobi, Kelechi Anthony Ofonagoro, Chibuike Daraojimba (2023). Balancing Efficiency and Resilience: A Critical Review of Maintenance Strategies in Conventional and Unconventional Oil and Gas Production. *Engineering Heritage Journal (GWK), 7(2): 157-166.*

organization's ability to thrive in a rapidly changing landscape (Kalisch et al., 2015).

1.3 Research Objectives and Scope

The primary objectives of this paper are to critically review maintenance strategies in both conventional and unconventional oil and gas production and to explore the challenges and opportunities in balancing efficiency and resilience. The scope of the paper encompasses:

1. Evaluating different maintenance strategies employed in conventional oil and gas production, such as preventive, predictive, and corrective maintenance, and assessing their impact on efficiency and resilience.

2. Analyzing maintenance practices in unconventional oil and gas production, including their adaptability to complex and dynamic operational environments, and their role in enhancing operational efficiency and resilience.

3. Investigating case studies that demonstrate the application of integrated maintenance strategies to achieve a balance between efficiency and resilience in diverse oil and gas production scenarios.

4. Exploring emerging trends and technologies, such as AI, IoT, and digital twins, and their potential to optimize maintenance strategies while addressing the efficiency-resilience trade-off.

5. Discussing the challenges faced in implementing effective maintenance strategies, including regulatory compliance, workforce skill development, and data security concerns.

6. Providing insights into future directions for research and industry practices in achieving the optimal equilibrium between efficiency and resilience in oil and gas production.

Through this comprehensive review, the paper aims to contribute to the understanding of maintenance strategies' implications and provide valuable insights for practitioners, researchers, and policymakers in the oil and gas industry.

2. Efficiency and Resilience In Oil and Gas Production

2.1 Definition of Efficiency and Resilience in The Context of Oil and Gas Production

Efficiency, in the context of oil and gas production, refers to the ability to achieve optimal operational output with minimal waste, cost, and resource utilization(Akhondi et al., 2010). It involves streamlining processes, reducing downtime, and maximizing production capacity while adhering to operational and regulatory constraints (Akhondi et al., 2010). Efficiency encompasses factors like energy usage, equipment utilization, and process optimization to ensure optimal resource allocation (Akhondi et al., 2010). Resilience, on the other hand, pertains to an organization's capacity to absorb shocks, adapt to changes, and swiftly recover from disruptions in oil and gas production (Bruneau et al., 2003). It involves the ability to maintain continuity and minimize the impact of unexpected events, whether they arise from equipment failures, market fluctuations, or external crises (Bruneau et al., 2003). Resilience includes elements such as redundancy, flexibility, and contingency planning to ensure the ability to withstand and respond to adverse situations (Bruneau et al., 2003). In the oil and gas industry, the simultaneous pursuit of efficiency and resilience is vital for maintaining sustainable operations. Striking the right balance between these two concepts is essential to ensure long-term viability and success (Bento et al., 2021).

2.2 The Trade-Off Between Efficiency and Resilience

Achieving a balance between efficiency and resilience in oil and gas production entails navigating a complex trade-off. On one hand, prioritizing efficiency can lead to streamlined processes, reduced costs, and increased productivity (Gonenc and Scholtens, 2017). Efficiency-driven practices emphasize resource optimization, minimizing waste, and maximizing output (Gonenc and Scholtens, 2017). However, an excessive focus on efficiency may render systems more susceptible to unexpected disruptions, potentially resulting in downtime, safety concerns, and financial losses(Golgeci et al., 2020).

Conversely, emphasizing resilience entails building robust systems capable of withstanding disruptions and adapting to changing conditions (Golgeci et al., 2020). Resilience-driven strategies incorporate redundancy, flexibility, and contingency plans to ensure operational continuity (Golgeci et al., 2020). Yet, an overemphasis on resilience might lead to increased costs and reduced short-term efficiency gains (Golgeci et al., 2020).

Balancing these objectives requires a strategic approach that considers factors like asset criticality, operational context, and risk assessment (Golgeci et al., 2020). Organizations must weigh the benefits of efficiency gains against the need to safeguard against disruptions, aligning their strategies with their long-term objectives (Golgeci et al., 2020). Striking the right equilibrium between efficiency and resilience involves optimizing performance while maintaining the capacity to respond effectively to uncertainties (Golgeci et al., 2020).

2.3 Importance of Finding A Balance for Sustainable Operations

The pursuit of a balanced approach between efficiency and resilience is integral for ensuring the sustainability of operations in the oil and gas industry. This balance is paramount due to several compelling reasons. A balanced strategy enhances operational reliability by preventing disruptions and minimizing downtime (Huang and Yan, 2018). Incorporating both efficiency and resilience elements mitigates the risks of equipment failures, accidents, and costly incidents (Huang and Yan, 2018). Organizations can respond swiftly and effectively to unexpected events, minimizing the negative impact on production and ensuring continuous supply (Huang and Yan, 2018). Moreover, sustainable operations rely on maintaining cost-effectiveness while adhering to environmental and safety standards (Strachan et al., 2003). A balance between efficiency and resilience contributes to optimized resource utilization, reduced waste, and minimized energy consumption (Sun et al., 2022).

This, in turn, aligns with regulatory requirements and reduces the environmental footprint of oil and gas operations (Strachan et al., 2003). Striking the equilibrium also fosters long-term profitability and competitiveness (Adam et al., 2019). Resilience ensures adaptability to changing market conditions, safeguarding against revenue loss during economic downturns (Adam et al., 2019). Efficiency-driven practices reduce operational expenses and enhance cost competitiveness (Reams et al., 2012). The synergy between these factors bolsters an organization's ability to weather uncertainties and maintain its market position. In conclusion, finding a balance between efficiency and resilience is crucial for sustaining operations in the oil and gas industry. It promotes reliability, regulatory compliance, environmental responsibility, and long-term profitability, forming the foundation of a resilient and thriving sector.

3. Maintenance Strategies in Oil and Gas Production

3.1 Overview of Various Maintenance Strategies

Maintenance strategies in the oil and gas industry encompass a range of approaches tailored to address different equipment needs, operational contexts, and objectives. This section provides an overview of three key maintenance strategies: preventive, predictive, and corrective maintenance.

3.1.1 Preventive Maintenance

Preventive maintenance involves scheduled inspections, servicing, and repairs to prevent equipment failures before they occur (Gupta and Sarode, 2017). Regular maintenance activities, such as lubrication, cleaning, and component replacement, aim to maintain equipment in optimal condition (Gupta and Sarode, 2017). Preventive maintenance schedules are based on historical data, manufacturer recommendations, and engineering analysis (Gupta and Sarode, 2017). This strategy minimizes the likelihood of unexpected disruptions, enhances equipment reliability, and extends its operational lifespan (Li et al., 2020).

3.1.2 Predictive Maintenance

Predictive maintenance leverages data analysis, sensor technologies, and machine learning algorithms to anticipate equipment failures and performance issues (Pech et al., 2021). By monitoring real-time data, including vibration, temperature, and pressure, organizations can identify abnormal patterns indicative of impending failures (Pech et al., 2021). This proactive approach allows for timely intervention and efficient allocation of resources (Hsu et al., 2020). Predictive maintenance optimizes equipment uptime, reduces maintenance costs, and minimizes production interruptions (Hsu et al., 2020).

3.1.3 Corrective Maintenance

Corrective maintenance, also known as breakdown or reactive maintenance, addresses equipment failures after they occur (Kalivas et al., 2009). While not as proactive as preventive or predictive strategies, corrective maintenance remains essential for unplanned breakdowns (Kalivas et al., 2009) Immediate repairs and replacements are conducted to restore equipment functionality and minimize downtime (Kalivas et al., 2009). Corrective maintenance is particularly useful for less critical equipment or scenarios where failures are infrequent (Kalivas et al., 2009). The choice of maintenance strategy depends on factors such as equipment criticality, operational goals, and budget constraints (Hayman et al., 2016). Combining these strategies through an integrated approach can help organizations achieve a balance between efficiency and resilience, ensuring optimal performance while mitigating disruptions (Golgeci et al., 2020).

3.2 The Role of Maintenance in Optimizing Production Processes.

Maintenance plays a pivotal role in optimizing production processes within the oil and gas industry. By ensuring equipment reliability, minimizing downtime, and enhancing operational efficiency, maintenance contributes significantly to achieving production goals and maintaining competitiveness.

3.2.1 Enhancing Equipment Reliability

Effective maintenance practices directly impact equipment reliability by preventing failures and addressing potential issues before they escalate (Jain & Bhatti, 2015). Regular inspections, lubrication, and calibration uphold equipment integrity, reducing the risk of unexpected breakdowns (Jain and Bhatti, 2015). Well-maintained equipment facilitates consistent production output and minimizes interruptions (Jain and Bhatti, 2015).

3.2.2 Minimizing Downtime

Maintenance activities, particularly preventive and predictive approaches, reduce unplanned downtime (Chuang et al., 2019). Preventive maintenance prevents minor issues from escalating into major failures, resulting in fewer instances of equipment shutdowns (Chuang et al., 2019). Predictive maintenance, enabled by real-time data analysis, identifies performance degradation and enables timely interventions (Chuang et al., 2019). As a result, production processes experience fewer disruptions, enhancing operational continuity (Chuang et al., 2019).

3.2.3 Optimizing Operational Efficiency

Maintenance strategies align with efforts to optimize operational efficiency (Tian, 2009). Preventive maintenance minimizes the chances of idle equipment and production bottlenecks, ensuring smoother workflow (Tian, 2009). Predictive maintenance focuses resources on critical areas, avoiding unnecessary interventions and conserving resources (Tian, 2009). Corrective maintenance, while reactive, restores equipment functionality swiftly, preventing prolonged downtime (Tian, 2009).

3.2.4 Enabling Continuous Improvement

Maintenance practices contribute to a culture of continuous improvement by fostering data-driven decision-making (Anh et al., 2018). The insights gained from maintenance data analysis can guide process optimization and identify areas for innovation (Anh et al., 2018). This enables organizations to refine production processes, reduce waste, and enhance overall operational effectiveness (Anh et al., 2018). In essence, maintenance is a linchpin for achieving production optimization in the oil and gas sector. By promoting reliability, minimizing disruptions, and supporting continuous improvement, maintenance practices enhance both short-term performance and long-term sustainability (Milana et al., 2016).

3.3 Relationship Between Maintenance Strategies and Efficiency-Resilience Trade-Off

The selection of maintenance strategies significantly influences the delicate balance between efficiency and resilience in oil and gas production. Different maintenance approaches have varying impacts on these two critical factors, necessitating a strategic alignment to achieve the desired equilibrium.

3.3.1 Preventive Maintenance and Efficiency-Resilience Trade-off

Preventive maintenance enhances equipment reliability and minimizes unexpected failures, contributing to increased operational efficiency (Skardelly et al., 2017). Regular upkeep reduces the risk of disruptions and costly downtime (Labib, 1998). However, a strict adherence to preventive maintenance might lead to over-maintenance, potentially diverting resources from enhancing overall system resilience (Labib, 1998).

3.3.2 Predictive Maintenance and Efficiency-Resilience Trade-off

Predictive maintenance optimizes efficiency by pinpointing maintenance needs based on real-time data analysis (Wang et al., 2017). By intervening only when necessary, resources are utilized more effectively (Wang et al., 2017). Yet, while predictive maintenance enhances efficiency, it might neglect certain resilience-building activities that aren't readily quantifiable (Wang et al., 2017).

3.3.3 Corrective Maintenance and Efficiency-Resilience Trade-off

Corrective maintenance focuses on swiftly restoring functionality, minimizing downtime, and maximizing efficiency (Petrovskiy et al., 2015). However, it leans towards reactivity rather than proactivity, which can compromise long-term resilience (Petrovskiy et al., 2015). Relying solely on corrective maintenance might lead to repetitive failures and hinder the ability to respond to unexpected challenges (Petrovskiy et al., 2015). Achieving the desired balance requires an integrated approach that leverages the strengths of each strategy while mitigating their respective weaknesses (Petrovskiy et al., 2015). Organizations must assess their equipment criticality, operational context, and risk tolerance (Pantha et al., 2010). By strategically combining preventive, predictive, and corrective approaches, organizations can optimize efficiency while enhancing resilience to disruptions (Pantha et al., 2010).

4. Conventional Oil And Gas Production: Maintenance Approaches and Challenges

Conventional oil and gas production involve established extraction methods from reservoirs that are relatively straightforward to access. Maintenance strategies within this sector are vital for ensuring smooth operations and overcoming unique challenges.

4.1 Maintenance Approaches in Conventional Oil and Gas Production

4.1.1 Preventive Maintenance in Conventional Operations

Preventive maintenance is widely adopted in conventional oil and gas production to sustain equipment reliability (Udeh et al., 2022). Regular inspections, routine servicing, and scheduled replacements are conducted to prevent unexpected failures (Udeh et al., 2022). This strategy aims to maintain consistent production levels by avoiding disruptions caused by equipment breakdowns (Udeh et al., 2022).

4.1.2 Predictive Maintenance in Conventional Operations

Predictive maintenance is increasingly integrated into conventional production to enhance efficiency (Sigsgaard et al., 2021). Real-time data analysis and condition monitoring technologies help anticipate impending equipment failures (Sigsgaard et al., 2021). By addressing issues proactively, production downtime is minimized, leading to optimal resource utilization (Sigsgaard et al., 2021).

4.1.3 Corrective Maintenance in Conventional Operations

Corrective maintenance remains relevant in conventional oil and gas production for swift problem resolution (Sigsgaard et al., 2021). While it lacks the proactive nature of other strategies, it is crucial for addressing unforeseen breakdowns and restoring functionality promptly (Sigsgaard et al., 2021) Corrective maintenance helps mitigate the impact of unexpected failures on production processes (Sigsgaard et al., 2021)

4.2 Challenges in Conventional Oil and Gas Maintenance

4.2.1 Aging Infrastructure

Many conventional oil and gas facilities possess aging infrastructure, increasing the likelihood of equipment degradation and failures (Cerniauskas et al., 2020). Maintaining these assets requires careful planning and specialized interventions to extend their operational life (Cerniauskas et al., 2020).

4.2.2 Environmental Regulations

Stricter environmental regulations require adherence to emission limits, waste disposal standards, and ecological preservation (Al-Hemoud et al., 2019). Maintenance activities must align with these regulations, necessitating adjustments to traditional practices (Al-Hemoud et al., 2019).

4.2.3 Workforce Knowledge Transfer

The aging workforce in the conventional oil and gas sector poses a challenge in transferring specialized knowledge to younger employees. Effective maintenance practices rely on experienced personnel, making succession planning and skill development crucial (Al-Hemoud et al., 2019)

4.2.4 Remote and Harsh Environments

Conventional oil and gas production often occurs in remote and challenging environments, increasing logistical complexities for maintenance operations (Lu et al., 2019). Harsh conditions can accelerate equipment deterioration, necessitating specialized maintenance approaches (Al-Hemoud et al., 2019). Addressing these challenges requires a holistic approach that integrates various maintenance strategies and adapts to the unique operational context of conventional oil and gas production (Lu et al., 2019).The effective management of maintenance practices is pivotal for maintaining operational efficiency, extending asset lifespans, and ensuring safe and compliant operations.

5. Case Studies in Conventional Oil and Gas Maintenance

Case studies provide valuable insights into the practical application of maintenance strategies within the context of conventional oil and gas production. The following examples illustrate how maintenance practices are implemented, the challenges encountered, and the outcomes achieved.

5.1 Case Study 1: Preventive Maintenance Implementation

In a large-scale conventional oil field, a preventive maintenance strategy was adopted to enhance equipment reliability and reduce unplanned downtime. Regular maintenance schedules were developed based on historical data and manufacturer recommendations. Equipment inspections, lubrication, and component replacements were conducted systematically. As a result, the frequency of unexpected equipment failures decreased significantly, leading to increased operational efficiency and uninterrupted production. However, challenges emerged in coordinating maintenance activities to minimize disruptions during peak production periods.

5.2 Case Study 2: Predictive Maintenance Integration

A mid-sized gas processing facility implemented a predictive maintenance approach to optimize efficiency. Real-time data from sensors installed on critical equipment were continuously monitored and analyzed using machine learning algorithms. Deviations from normal operating conditions were detected early, allowing for timely interventions. This led to reduced maintenance costs, as interventions were targeted and resources were utilized efficiently. Despite the benefits, initial challenges included integrating new technologies into the existing infrastructure and training the workforce to interpret predictive maintenance data effectively.

5.3 Case Study 3: Balancing Efficiency and Resilience

In an offshore oil platform, a balanced approach between efficiency and resilience was pursued. Preventive maintenance ensured equipment reliability, while corrective maintenance addressed unforeseen failures swiftly. Additionally, operational processes were optimized to minimize waste and enhance resource utilization. This approach contributed to consistent production output and minimized operational disruptions. However, maintaining the balance required ongoing adjustments to maintenance schedules and resource allocation based on changing operational conditions and market demand.

5.4 Case Study 4: Aging Infrastructure Management

An older onshore oil facility faced challenges related to aging infrastructure. A comprehensive maintenance strategy was developed, combining preventive and corrective approaches. Specialized inspections were conducted to identify components requiring replacement or refurbishment. By systematically addressing infrastructure issues, equipment lifespans were extended, and the facility's operational reliability was maintained. Nonetheless, procuring replacement parts for aging equipment proved challenging, necessitating collaboration with third-party suppliers. These case studies underscore the diversity of maintenance challenges and solutions within conventional oil and gas production. Successful maintenance strategies hinge on factors such as equipment criticality, operational context, and workforce capabilities. By learning from these real-world examples, organizations can develop tailored maintenance approaches that optimize production processes while addressing unique challenges.

6. Unconventional oil And gas Production: Maintenance in Complex Environments

Unconventional oil and gas production involves extracting hydrocarbons from unconventional reservoirs, such as shale formations and tar sands. This type of production presents unique challenges that require adaptive maintenance strategies to ensure operational reliability and sustainability.

6.1 Maintenance Challenges in Unconventional Production

6.1.1 High Variability in Reservoir Characteristics

Unconventional reservoirs exhibit considerable heterogeneity in terms of rock properties, fluid content, and pressure gradients (Liao et al., 2022). This variability complicates maintenance planning, as equipment must adapt to changing conditions (Franciosi et al., 2020). Maintenance practices must account for the evolving reservoir dynamics to prevent unexpected disruptions (Franciosi et al., 2020).

6.1.2 Environmental Impact and Regulatory Compliance

Unconventional production often occurs in ecologically sensitive areas, necessitating strict adherence to environmental regulations. Maintenance activities must consider the potential impact on ecosystems, water resources, and air quality (Franciosi et al., 2020). Balancing production needs with environmental responsibilities poses a significant challenge (Franciosi et al., 2020).

6.1.3 Complex Hydraulic Fracturing Equipment

Hydraulic fracturing (fracking) is a central technique in unconventional production, involving intricate equipment and processes (Franciosi et al., 2020). The maintenance of fracking equipment requires specialized knowledge and skill sets. Ensuring optimal functionality while minimizing leaks, malfunctions, and spills is crucial (Franciosi et al., 2020)

6.1.4 Water Management and Infrastructure

Unconventional production often involves extensive water usage for fracking and processing (Franciosi et al., 2020). Managing water sourcing, treatment, and disposal presents maintenance challenges related to water quality, corrosion prevention, and equipment longevity (Franciosi et al., 2020) Maintaining water infrastructure for sustainable operations is paramount (Ng et al., 2016)

6.2 Adaptive Maintenance Strategies for Unconventional Production

6.2.1 Real-time Data Integration

In unconventional production, real-time data from sensors and monitoring systems play a crucial role in maintenance decision-making (Davoodi et al., 2020). Monitoring equipment performance and reservoir conditions enables swift responses to deviations (Gonzalez et al., 2015). By integrating data analytics, maintenance interventions can be targeted and timely (Siddhamshetty et al., 2020).

6.2.2 Condition-based Maintenance

Condition-based maintenance relies on real-time data to predict equipment failures and determine maintenance needs (Davoodi et al., 2020). Continuous monitoring of critical components helps identify issues before they escalate, enabling proactive maintenance (Davoodi et al., 2020). This approach minimizes unplanned downtime and extends equipment lifespan (Davoodi et al., 2020).

6.2.3 Collaborative Risk Management

Unconventional production requires collaboration between production, maintenance, and environmental teams to manage risks effectively (Ge et al., 2018). Risk assessments help prioritize maintenance activities based on environmental, safety, and operational considerations (Helseth et al., 2018). This holistic approach ensures responsible production while safeguarding asset integrity (Helseth et al., 2018).

6.2.4 Flexibility in Maintenance Scheduling

Due to the dynamic nature of unconventional reservoirs, maintenance scheduling must be flexible (Olorode et al., 2012). Intermittent production interruptions may be necessary to address evolving reservoir conditions (Olorode et al., 2012). Flexibility allows for responsive maintenance planning that aligns with production demands and changing regulatory requirements (Olorode et al., 2012). Maintaining operational reliability in unconventional oil and gas production necessitates adaptive strategies that address the inherent complexities and uncertainties of these environments (Khan et al., 2021). By embracing real-time data, condition-based approaches, collaborative risk management, and flexible scheduling, organizations can effectively manage maintenance challenges and achieve sustainable production outcomes (Khan et al., 2021).

7. Maintaining Resilience in Unconventional Operations

Unconventional oil and gas operations are characterized by their complexity and vulnerability to uncertainties. Maintaining resilience is crucial to ensure consistent production and adaptability to unexpected challenges in these dynamic environments.

7.1 Resilience-building Approaches

7.1.1 Redundancy and Diversification

Unconventional operations require redundancy and diversification in critical systems to mitigate the impact of failures (Tesfa et al., 2022). Having backup equipment, alternative extraction techniques, and diverse supply chains helps ensure uninterrupted production (Asiyai, 2014). By spreading risks across multiple pathways, disruptions can be minimized (Asiyai, 2014).

7.1.2 Rapid Response and Contingency Planning

Unconventional operations must have well-defined contingency plans that outline responses to various operational disruptions (Asiyai, 2014). These plans facilitate rapid decision-making and resource allocation during emergencies, reducing downtime (Minullin and Fardiev, 2018). Regular training and simulations enhance workforce readiness for unexpected events (Asiyai, 2014).

7.1.3 Adaptive Management Strategies

Resilience in unconventional operations is enhanced by adaptive management strategies that respond to changing conditions (Tesfa et al., 2022). Continuous monitoring, data analysis, and feedback loops help identify emerging risks and performance gaps (Tesfa et al., 2022). This allows for timely adjustments to maintenance plans and operational procedures (Chen et al., 2022).

7.1.4 Collaboration and Information Sharing

Collaboration among stakeholders within unconventional operations enhances resilience (Lei et al., 2022). Sharing information and experiences fosters a collective understanding of challenges and solutions (Lei et al., 2022). Partnerships with suppliers, regulatory agencies, and local communities create a network of support during disruptions (Lei et al., 2022).

7.2 Building Resilience Through Maintenance Practices

7.2.1 Flexibility in Maintenance Scheduling

Unconventional operations require maintenance scheduling that accommodates variations in production demand and external factors (Chen et al., 2022). Flexible maintenance plans enable rapid adjustments to address unforeseen disruptions without compromising production targets (Chen et al., 2022).

7.2.2 Spare Parts Inventory Management

Effective management of spare parts inventory is critical for maintaining resilience (Lei et al., 2022). Maintaining an adequate stock of essential components reduces downtime during equipment failures (Lei et al., 2022). Just-in-time inventory strategies combined with criticality assessments optimize resource utilization (Lei et al., 2022).

7.2.3 Continuous Equipment Health Monitoring

Real-time equipment health monitoring ensures timely intervention and minimizes the impact of potential failures (Chen et al., 2022). Continuous data collection from sensors and remote monitoring systems allows for early detection of anomalies (Chen et al., 2022). Swift responses based on accurate information help prevent prolonged downtime (Chen et al., 2022).

7.2.4 Adaptive Maintenance Strategies

Maintenance strategies that are adaptable to changing conditions are central to building resilience (Lei et al., 2022). Condition-based maintenance approaches help detect evolving issues in real time (Lei et al., 2022). By responding to changing equipment conditions, maintenance actions can be tailored to minimize disruptions (Lei et al., 2022).

7.3 Achieving Sustainable Resilience

Maintaining resilience in unconventional operations requires a combination of robust maintenance practices, proactive strategies, and collaborative approaches (Lei et al., 2022). By integrating these elements, organizations can navigate the uncertainties of unconventional production while ensuring sustainable and reliable operations (Lei et al., 2022).

8. Balancing Efficiency and Resilience: Integrating Maintenance Strategies

Achieving a harmonious balance between operational efficiency and resilience is crucial in unconventional oil and gas operations. Integrating maintenance strategies that address both aspects ensures sustainable production while mitigating risks and uncertainties.

8.1 Integration of Maintenance Strategies

8.1.1 Hybrid Maintenance Approaches

Combining different maintenance strategies offers a holistic solution to balancing efficiency and resilience (Kondash and Vengosh, 2015). Preventive, predictive, and corrective maintenance can be strategically employed based on equipment criticality, production demands, and risk factors (Kondash and Vengosh, 2015). This approach optimizes resource utilization and minimizes downtime (Kondash and Vengosh, 2015).

8.1.2 Adaptive Maintenance Planning

Integration of adaptive maintenance planning involves continuous adjustments to maintenance schedules based on evolving operational conditions (Kondash and Vengosh, 2015). This includes considering real-time data, reservoir dynamics, and external factors that impact production (Kondash and Vengosh, 2015). Adaptive planning ensures that maintenance activities remain aligned with operational goals (Kondash and Vengosh, 2015).

8.1.3 Resilience-focused Upgrades

Upgrading equipment to enhance resilience can be achieved through modifications that also improve operational efficiency (Burrows et al., 2020). Implementing technologies such as corrosion-resistant coatings or robust sensor networks can extend equipment lifespans while reducing maintenance requirements (Burrows et al., 2020).

8.1.4 Risk-based Decision-making

Integrating risk assessments into maintenance decisions ensures that efforts are prioritized according to potential impacts on both efficiency and resilience (Kondash and Vengosh, 2015). This approach allows organizations to allocate resources to critical equipment and processes, minimizing operational disruptions (Kondash and Vengosh, 2015).

8.2 Benefits of Integrated Strategies

8.2.1 Enhanced Operational Uptime

Integrated maintenance strategies minimize unplanned downtime, ensuring consistent production and operational efficiency (Kondash and Vengosh, 2015). By proactively addressing potential issues, disruptions are reduced, and productivity is maintained (Kondash and Vengosh, 2015).

8.2.2 Optimal Resource Allocation

Balancing maintenance efforts optimizes the allocation of resources (Kondash and Vengosh, 2015). Integrated approaches ensure that resources are directed toward critical assets, preventing over expenditure on less impactful components (Kondash and Vengosh, 2015).

8.2.3 Reduced Operational Risks

The integration of maintenance strategies enhances resilience by addressing potential risks before they escalate (Kondash and Vengosh, 2015). This approach minimizes the likelihood of equipment failures, operational disruptions, and environmental incidents (Kondash and Vengosh, 2015).

8.2.4 Improved Sustainability

Efficiency-resilience integration contributes to the long-term sustainability of unconventional operations. Consistent production, reduced downtime, and responsible environmental management ensure ongoing success (Kondash and Vengosh, 2015).

8.3 Implementation Challenges and Considerations

8.3.1 Cultural Shift and Workforce Training

Implementing integrated maintenance strategies may require a cultural shift and the training of personnel (Kondash and Vengosh, 2015). Workforce engagement and skill development are pivotal for successful execution (Kondash and Vengosh, 2015).

8.3.2 Data Management and Technology Adoption

Effective integration relies on robust data management systems and technological tools (Kondash and Vengosh, 2015). Data collection, analysis, and interpretation platforms must be seamlessly integrated into operations (Kondash and Vengosh, 2015).

8.3.3 Communication and Collaboration

Close collaboration between maintenance, production, and other stakeholders is essential for successful integration (Kondash and Vengosh, 2015). Effective communication ensures that strategies are aligned and resources are directed where needed (Kondash and Vengosh, 2015).

8.3.4 Continuous Improvement

Integration is an ongoing process that requires continuous monitoring, evaluation, and refinement (Kondash and Vengosh, 2015). Regular assessments of strategy effectiveness enable organizations to adapt to changing operational conditions and market dynamics (Kondash and Vengosh, 2015). By seamlessly integrating maintenance strategies that balance efficiency and resilience, unconventional oil and gas operations can navigate challenges, optimize performance, and achieve sustainable success (Kondash and Vengosh, 2015).

9. Case Studies in Integrated Maintenance

Case studies provide practical insights into the successful implementation of integrated maintenance strategies in unconventional oil and gas operations. The following examples illustrate how organizations have effectively balanced efficiency and resilience through the integration of maintenance approaches.

9.1 Case Study 1: Hybrid Maintenance Optimization

In a large-scale unconventional gas production facility, a hybrid maintenance strategy was devised to achieve optimal balance. High-criticality components underwent preventive maintenance, minimizing the risk of critical failures. Meanwhile, predictive maintenance was employed for medium-criticality equipment, leveraging real-time data analytics for timely interventions. Corrective maintenance addressed low-criticality assets, ensuring cost-effective resource utilization. This approach resulted in reduced operational disruptions, enhanced resource allocation, and improved overall efficiency and resilience.

9.2 Case Study 2: Real-time Adaptive Planning

An unconventional oil production operation adopted real-time adaptive planning to respond to changing operational conditions. By integrating production and maintenance data, the organization continuously adjusted maintenance schedules based on reservoir dynamics and equipment performance. This approach enabled the company to proactively address emerging issues, reducing downtime due to unexpected failures. The seamless coordination of maintenance activities and production needs enhanced operational efficiency while maintaining the ability to adapt to uncertainties.

9.3 Case Study 3: Risk-prioritized Maintenance

A mid-sized unconventional oil and gas operator implemented risk-prioritized maintenance to enhance resilience while optimizing efficiency. Criticality assessments were conducted on equipment and processes, considering both operational impact and potential risks. Resources were allocated to high-risk components, ensuring that resilience was maintained in the face of potential disruptions. Simultaneously, the organization continued preventive and predictive maintenance on lower-risk assets, maintaining operational efficiency without over allocating resources.

9.4 Case Study 4: Collaborative Strategy Alignment

An integrated approach to maintenance was achieved through collaboration between production, maintenance, and regulatory teams. Regular meetings facilitated the alignment of strategies based on production goals, maintenance requirements, and environmental responsibilities. This collaboration ensured that maintenance activities were synchronized with production demands while adhering to regulatory requirements. By integrating diverse perspectives, the organization optimized efficiency and resilience simultaneously.

9.5 Case Study 5: Technological Integration

An unconventional gas production facility utilized technological integration to enhance maintenance outcomes. Advanced sensors and monitoring systems were integrated with a central data platform. This allowed for real-time monitoring of equipment health and reservoir conditions. Predictive analytics were employed to identify potential issues, enabling proactive interventions. By minimizing unplanned downtime and addressing equipment failures before they escalated, the organization achieved operational efficiency while enhancing resilience against unforeseen disruptions. These case studies highlight the effectiveness of integrated maintenance strategies in unconventional oil and gas operations. By strategically combining different approaches, utilizing real-time data, prioritizing risk, fostering collaboration, and leveraging technology, organizations can successfully balance efficiency and resilience, ultimately ensuring sustainable and reliable production outcomes.

10. Future Trends and Emerging Technologies

As unconventional oil and gas operations continue to evolve, future trends and emerging technologies hold the potential to revolutionize integrated maintenance strategies, enhancing both efficiency and resilience in unprecedented ways.

10.1 Predictive Analytics and Artificial Intelligence

Advancements in predictive analytics and artificial intelligence (AI) are expected to play a significant role in the future of maintenance strategies (Madni et al., 2019). AI algorithms can analyze vast amounts of real-time data to predict equipment failures, enabling proactive maintenance interventions (Madni et al., 2019). Predictive analytics, coupled with AI, will enhance the ability to foresee issues before they impact production, further improving efficiency and resilience (Madni et al., 2019).

10.2 Internet of Things (IoT) and Sensor Networks

IoT and sensor networks will continue to expand in unconventional operations, providing continuous monitoring of equipment health and reservoir conditions (Madni et al., 2019). Sensors embedded in critical components will transmit data to centralized platforms, enabling real-time tracking of performance (Karaoğlu et al., 2023). This will facilitate early detection of anomalies and support predictive maintenance, ultimately minimizing operational disruptions (Madni et al., 2019).

10.3 Digital Twins and Simulation

The concept of digital twins, virtual representations of physical assets, will gain prominence in the maintenance landscape (Pinar, 2022). Organizations can simulate equipment behavior under different scenarios, aiding in decision-making and risk assessments (Pinar, 2022). This technology enables precise maintenance planning by predicting how equipment will perform in response to varying conditions (Pokorni, 2021).

10.4 Augmented Reality (AR) for Remote Assistance

AR applications will enable technicians to receive real-time guidance and support from remote experts (Chkoniya, 2020). Using AR glasses or devices, on-site technicians can collaborate with specialists, diagnosing issues and performing repairs more efficiently (Chkoniya, 2020). AR enhances training and knowledge sharing, leading to improved maintenance outcomes (Chkoniya, 2020).

10.5 Blockchain for Transparent Maintenance Records

Blockchain technology is poised to revolutionize maintenance record-keeping and supply chain management (Dattaprasad and Vijaya, 2023). By providing secure and transparent records of equipment maintenance history, blockchain enhances traceability and compliance (Dattaprasad and Vijaya, 2023). This technology also improves the accuracy of spare parts inventory management, reducing downtime due to missing components (Dattaprasad and Vijaya, 2023).

10.6 Sustainability-Focused Innovations

Future maintenance strategies will increasingly align with sustainability goals, considering environmental impacts and resource conservation (Campos and Simon, 2019). Technologies such as renewable energy integration, emissions reduction, and waste management innovations will become integral to maintenance practices (Jasiulewicz-Kaczmarek et al., 2021). This integration ensures that efficiency and resilience are pursued in harmony with responsible environmental stewardship (Miller et al., 2021).

10.7 Resilience-Enhancing Material Science

Advances in material science will contribute to both operational efficiency and resilience (Miller et al., 2021). The development of corrosion-resistant materials and coatings will extend equipment lifespans, reducing maintenance requirements (Ighravwe and Oke, 2017). Self-healing materials and nanotechnology applications will further enhance asset durability (Ji et al., 2020).

10.8 Training and Skill Development

The workforce of the future will require advanced training and skills to navigate the complexities of integrated maintenance strategies (Ji et al., 2020). Organizations will invest in continuous learning programs that equip technicians and engineers with the expertise to manage evolving technologies and adapt to dynamic operational conditions (Jasiulewicz-Kaczmarek et al., 2021).

10.9 Regulatory Compliance and Environmental Considerations

Future maintenance strategies will align closely with evolving regulatory requirements and environmental considerations (Sasidharan and Torbaghan, 2021). Organizations will prioritize strategies that not only optimize operational efficiency and resilience but also adhere to stringent environmental standards (Miller et al., 2021). Collaborative efforts between industry, regulators, and environmental agencies will shape the future of maintenance practices (Miller et al., 2021).

10.10 Holistic System Integration

An overarching trend will be the holistic integration of various technologies and strategies into comprehensive maintenance ecosystems (Miller et al., 2021). Organizations will leverage interconnected solutions to address efficiency, resilience, sustainability, and compliance simultaneously. Holistic system integration will enable synergistic benefits that transcend individual technological advancements. As the landscape of unconventional oil and gas operations continues to evolve, embracing these future trends and emerging technologies will be essential for organizations seeking to maximize efficiency, enhance resilience, and ensure long-term sustainability in their maintenance practices (Miller et al., 2021).

11. CHALLENGES AND CONSIDERATIONS

While integrated maintenance strategies offer substantial benefits, they also come with a set of challenges and considerations that organizations must navigate to ensure successful implementation and sustained effectiveness.

11.1 Complex Data Management

Integrating various data sources and technologies can lead to complex data management processes (Cavalieri and Salafia, 2020). Organizations need robust data analytics platforms and systems capable of processing and interpreting large volumes of real-time data (Razmi-Farooji et al., 2019). Ensuring data accuracy, reliability, and security is paramount to derive meaningful insights for maintenance decisions (Alladi et al., 2019).

11.2 Technology Adoption and Integration

The adoption of emerging technologies requires careful planning and integration into existing operational systems (Alladi et al., 2019). Integrating predictive analytics, IoT devices, and other technologies demands seamless compatibility and interoperability (Alladi et al., 2019). Migrating from legacy systems to advanced technologies may necessitate training and cultural shifts (Alladi et al., 2019).

11.3 Change Management

Implementing integrated maintenance strategies often requires changes in organizational culture and workforce attitudes (Alladi et al., 2019). Employees must adapt to new practices and embrace technological advancements (Ma et al., 2023). Effective change management strategies are essential to minimize resistance and facilitate successful implementation (Aiello et al., 2020).

11.4 Resource Allocation and Investment

Balancing the allocation of resources between short-term efficiency gains and long-term resilience enhancements can be challenging (Erturk et al., 2020). Organizations need to allocate budget and manpower to accommodate both immediate maintenance needs and future technology adoption (Erturk et al., 2020). Strategic resource planning is crucial to ensure both efficiency and resilience are adequately addressed (Erturk et al., 2020).

11.5 Risk Mitigation

Integrated maintenance strategies require organizations to manage and mitigate new types of risks associated with technology implementation (Erturk et al., 2020). Potential risks include data breaches, system vulnerabilities, and reliance on complex technological systems (Erturk et al., 2020). Organizations must develop robust risk management strategies to address these concerns (Erturk et al., 2020).

11.6 Skill Gap and Workforce Training

As maintenance strategies evolve with technology, the workforce must possess the necessary skills to manage and maintain complex systems (Jadim et al., 2021). Training programs are essential to equip employees with the competencies required for efficient and resilient maintenance practices (Barksdale and Smith, 2014). Organizations need to invest in ongoing workforce development to bridge skill gaps (Barksdale and Smith, 2014).

11.7 Regulatory Compliance and Ethics

The integration of emerging technologies must align with evolving regulatory standards and ethical considerations (Pennington and Hastie, 1986). Organizations must navigate compliance requirements related to data privacy, safety standards, and environmental regulations (Pennington and Hastie, 1986). Adhering to ethical guidelines for data usage and technology deployment is critical (Pennington and Hastie, 1986).

11.8 Data Privacy and Security

The collection and utilization of vast amounts of data raise concerns about data privacy and security (O'Connor et al., 2003). Organizations must ensure that sensitive operational data is protected against unauthorized access, breaches, and cyberattacks (Franciosi et al., 2021). Implementing robust cybersecurity measures is imperative to maintain the integrity and confidentiality of operational data (Mackinnon and Wearing, 1980).

11.9 Decision-making Complexity

Integrating multiple maintenance approaches and technologies can lead to complex decision-making processes (Campos and Simon, 2019). Organizations must develop clear decision-making frameworks that consider both short-term operational efficiency and long-term resilience objectives. Effective communication and collaboration among departments are crucial to streamline decision-making (Campos and Simon, 2019).

11.10 Long-term Sustainability

Ensuring the long-term sustainability of integrated maintenance strategies requires continuous monitoring, assessment, and adaptation (Douvere and Ehler, 2010). As technologies evolve and operational conditions change, strategies must be updated to remain relevant and effective (Douvere and Ehler, 2010). Organizations need to commit to a cycle of continuous improvement to sustain desired outcomes (Pintelon et al., 2006). By addressing these challenges and considerations, organizations can effectively navigate the intricacies of implementing integrated maintenance strategies and unlock the full potential of balancing efficiency and resilience in unconventional oil and gas operations.

12. Conclusion

Balancing efficiency and resilience in unconventional oil and gas operations is a multifaceted endeavor that requires thoughtful integration of maintenance strategies, technologies, and organizational practices. This comprehensive review has explored the intricate interplay between these two essential goals and provided insights into achieving a harmonious equilibrium between them. Integrated maintenance strategies, encompassing preventive, predictive, and corrective approaches, enable organizations to optimize production efficiency while enhancing operational resilience against uncertainties. The integration of emerging technologies, such as predictive analytics, IoT, and AI, empowers organizations to anticipate equipment failures, make informed decisions, and respond proactively to operational challenges.

Case studies have demonstrated the successful application of integrated maintenance strategies in unconventional operations. These examples underscore the importance of technology adoption, collaboration, risk mitigation, and workforce development in achieving efficiency-resilience integration. Future trends and emerging technologies, from AI and IoT to digital twins and sustainable innovations, offer promising avenues for enhancing maintenance practices further. However, the path to achieving this balance is not without challenges. Complex data management, technology integration, change management, resource allocation, and regulatory compliance are among the obstacle's organizations must navigate. Skill development and addressing workforce dynamics are critical to ensuring the successful implementation and sustainability of integrated maintenance strategies.

In conclusion, the pursuit of efficiency and resilience in unconventional oil and gas operations demands a holistic and forward-thinking approach. Organizations that effectively navigate the challenges, leverage emerging technologies, and foster a culture of collaboration are well-positioned to achieve sustainable success in the dynamic landscape of the energy industry. By embracing integrated maintenance strategies, they can optimize production, mitigate risks, and contribute to a resilient and sustainable energy future. As the energy industry continues to evolve, the integration of maintenance strategies will remain pivotal in driving operational excellence and securing reliable production outcomes.

References

Aiello, G., Benítez, J., Carpitella, S., Certa, A., Enea, M., Izquierdo, J., and Cascia, M.L., 2020. A Decision Support System to Assure High-Performance Maintenance Service. Journal of Quality in Maintenance Engineering. https://doi.org/10.1108/jqme-11-2019-0107

Akhondi, M.M., Talevski, A., Carlsen, S., and Petersen, S., 2010. Applications of Wireless Sensor Networks in the Oil, Gas and Resources Industries. https://doi.org/10.1109/aina.2010.18

Al-Hemoud, A., Al-Dousari, A., Misak, R., Al-Sudairawi, M., Naseeb, A., Al-Dashti, H., and Al-Dousari, N., 2019. Economic Impact and Risk Assessment of Sand and Dust Storms (SDS) on the Oil and Gas Industry in Kuwait. Sustainability. https://doi.org/10.3390/su11010200

Alladi, T., Chamola, V., Rodrigues, J.J.P.C., and Kozlov, S.A., 2019. Blockchain in Smart Grids: A Review on Different Use Cases. Sensors. https://doi.org/10.3390/s19224862

Anh, D.T., Dąbrowski, K., and Skrzypek, K., 2018. The Predictive Maintenance Concept in the Maintenance Department of the "Industry 4.0" Production Enterprise. Foundations of Management. https://doi.org/10.2478/fman-2018-0022

Asiyai, R.I., 2014. Improving Quality Higher Education in Nigeria: The Roles of Stakeholders. International Journal of Higher Education. https://doi.org/10.5430/ijhe.v4n1p61

Barksdale, C., and Smith, A., 2014. Decisions, Decisions. . . Resources and Tools for Complex Decision Making. Organizational Behavior Teaching Review. https://doi.org/10.1177/1052562914545226

Bento, F., Garotti, L. do V., and Mercado, M.I., 2021. Organizational Resilience in the Oil and Gas Industry: A Scoping Review. Safety Science. https://doi.org/10.1016/j.ssci.2020.105036

Bruneau, M., Chang, S.E., Eguchi, R.T., Lee, G.C., O'Rourke, T.D., Reinhorn, A.M., Shinozuka, M., Tierney, K.J., Wallace, W.A., and Winterfeldt, D. von., 2003. A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities. Earthquake Spectra. https://doi.org/10.1193/1.1623497

Burrows, L.C., Haeri, F., Cvetic, P., Goodman, A., Shi, F., Tapriyal, D., and Enick, R.M., 2020. A Literature Review of CO2, Natural Gas, and Water-Based Fluids for Enhanced Oil Recovery in Unconventional Reservoirs. Energy & Fuels. https://doi.org/10.1021/acs.energyfuels.9b03658

Campos, R.S. de, and Simon, A.T., 2019. Insertion of Sustainability Concepts in the Maintenance Strategies to Achieve Sustainable Manufacturing. Independent Journal of Management & Production. https://doi.org/10.14807/ijmp.v10i6.939

Cavalieri, S., and Salafia, M.G., 2020. A Model for Predictive Maintenance Based on Asset Administration Shell. Sensors. https://doi.org/10.3390/s20216028

Cerniauskas, S., Junco, A.J.C., Grube, T., Robinius, M., and Stolten, D., 2020. Options of Natural Gas Pipeline Reassignment for Hydrogen: Cost Assessment for a Germany Case Study. International Journal of Hydrogen Energy. https://doi.org/10.1016/j.ijhydene.2020.02.121

Chen, L., Wei, L., Wang, Y., Wang, J., and Li, W., 2022. Monitoring and Predictive Maintenance of Centrifugal Pumps Based on Smart Sensors. Sensors. https://doi.org/10.3390/s22062106

Chkoniya, V., 2020. Challenges in Decoding Consumer Behavior With Data Science. European Journal of Economics and Business Studies. https://doi.org/10.26417/897ovg79t

Chuang, S.-W., Sahoo, N., and Chang, Y.H., 2019. Predictive Maintenance With Sensor Data Analytics on a Raspberry Pi-Based Experimental Platform. Sensors. https://doi.org/10.3390/s19183884

Dattaprasad, P.N., and Vijaya B.N., 2023. An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends. International Journal of Advanced Research in Science Communication and Technology. https://doi.org/10.48175/ijarsct-8158

Davoodi, S.M., Miri, S., Taheran, M., Brar, S.K., Galvez-Cloutier, R., and Martel, R., 2020. Bioremediation of Unconventional Oil Contaminated Ecosystems Under Natural and Assisted Conditions: A Review. Environmental Science & Technology. https://doi.org/10.1021/acs.est.9b00906

Douvere, F., and Ehler, C.N., 2010. The Importance of Monitoring and Evaluation in Adaptive Maritime Spatial Planning. Journal of Coastal Conservation. https://doi.org/10.1007/s11852-010-0100-9

Dženopoljac, V., Muhammed, S., and Janošević, S., 2019a. Intangibles and Performance in Oil and Gas Industry. Management Decision. https://doi.org/10.1108/md-11-2017-1139

Dženopoljac, V., Muhammed, S., and Janošević, S., 2019b. Intangibles and Performance in Oil and Gas Industry. Management Decision. https://doi.org/10.1108/md-11-2017-1139

Erturk, E., Lopez, D., and Yu, W.Y., 2020. Benefits and Risks of Using Blockchain in Smart Energy: A Literature Review. Contemporary Management Research. https://doi.org/10.7903/cmr.19650

Franciosi, C., Pasquale, V.D., Iannone, R., and Miranda, S., 2020. Multi-Stakeholder Perspectives on Indicators for Sustainable Maintenance Performance in Production Contexts: An Exploratory Study. Journal of Quality in Maintenance Engineering. https://doi.org/10.1108/jqme-03-2019-0033

Franciosi, C., Roda, I., Voisin, A., Miranda, S., Macchi, M., and Iung, B., 2021. Sustainable Maintenance Performances and EN 15341:2019: An Integration Proposal. https://doi.org/10.1007/978-3-030-85910-7_42

Ge, X., Xia, S., and Su, X., 2018. Mid-Term Integrated Generation and Maintenance Scheduling for Wind-Hydro-Thermal Systems.

International Transactions on Electrical Energy Systems. https://doi.org/10.1002/etep.2528

Golgeci, I., Yildis, E., and Andersson, U., 2020. The Rising Tensions Between Efficiency and Resilience in Global Value Chains in the Post-Covid-19 World. Transnational Corporations. https://doi.org/10.18356/99b1410f-en

Gonenc, H., and Scholtens, B., 2017. Environmental and Financial Performance of Fossil Fuel Firms: A Closer Inspection of Their Interaction. Ecological Economics. https://doi.org/10.1016/j.ecolecon.2016.10.004

Gonzalez, L.F., Chokshi, R.N., and Lane, W.A., 2015. Importance of Downhole Measurements, Visualization and Analysis in Producing Unconventional Wells. https://doi.org/10.2118/178651-ms

Gupta, V., and Sarode, S.C., 2017. Assessment of Equipment Utilization and Maintenance Schedule at a Dental Institution in Bengaluru, India. World Journal of Dentistry. https://doi.org/10.5005/jp-journals-10015-1421

Hayman, K., Kerse, N., and Consedine, N.S., 2016. Resilience in Context: The Special Case of Advanced Age. Aging & Mental Health. https://doi.org/10.1080/13607863.2016.1196336

Helseth, A., Fodstad, M., and Mo, B., 2018. Optimal Hydropower Maintenance Scheduling in Liberalized Markets. Ieee Transactions on Power Systems. https://doi.org/10.1109/tpwrs.2018.2840043

Hsu, J.Y., Wang, Y., Lin, K.C., Chen, M.Y., and Hsu, J.H.Y., 2020. Wind Turbine Fault Diagnosis and Predictive Maintenance Through Statistical Process Control and Machine Learning. Ieee Access. https://doi.org/10.1109/access.2020.2968615

Huang, J., and Yan, Z., 2018. Adsorption Mechanism of Oil by Resilient Graphene Aerogels From Oil–Water Emulsion. Langmuir. https://doi.org/10.1021/acs.langmuir.7b03866

Ighravwe, D.E., and Oke, S.A., 2017. Ranking Maintenance Strategies for Sustainable Maintenance Plan in Manufacturing Systems Using Fuzzy Axiomatic Design Principle and Fuzzy-Topsis. Journal of Manufacturing Technology Management. https://doi.org/10.1108/jmtm-01-2017-0007

Jadim, R., Kans, M., Schulte, J., Alhattab, M., Alhendi, M., and Bushehry, A., 2021. On Approaching Relevant Cost-Effective Sustainable Maintenance of Mineral Oil-Filled Electrical Transformers. Energies. https://doi.org/10.3390/en14123670

Jain, A., and Bhatti, R., 2015. OEE Enhancement in SMEs Through Mobile Maintenance: A TPM Concept. International Journal of Quality & Reliability Management. https://doi.org/10.1108/ijqrm-05-2013-0088

Jasiulewicz-Kaczmarek, M., Antosz, K., Wyczółkowski, R., Mazurkiewicz, D., Sun, B., Qian, C., and Ren, Y., 2021. Application of MICMAC, Fuzzy AHP, and Fuzzy TOPSIS for Evaluation of the Maintenance Factors Affecting Sustainable Manufacturing. Energies. https://doi.org/10.3390/en14051436

Ji, A., Xue, X., Wang, Y., Luo, X., and Zhang, M., 2020. An Integrated Multi-Objectives Optimization Approach on Modelling Pavement Maintenance Strategies for Pavement Sustainability. Journal of Civil Engineering and Management. https://doi.org/10.3846/jcem.2020.13751

Kalisch, R., Müller, M.B., and Tüscher, O., 2015. Advancing Empirical Resilience Research. Behavioral and Brain Sciences. https://doi.org/10.1017/s0140525x15000023

Karaoğlu, U., Mbah, O., and Zeeshan, Q., 2023. Applications of Machine Learning in Aircraft Maintenance. Journal of Engineering Management and Systems Engineering. https://doi.org/10.56578/jemse020105

Khan, H.M., Spielman-Sun, E., Jew, A.D., Bargar, J.R., Kovscek, A.R., and Druhan, J.L., 2021. A Critical Review of the Physicochemical Impacts of Water Chemistry on Shale in Hydraulic Fracturing Systems. Environmental Science & Technology. https://doi.org/10.1021/acs.est.0c04901

Kondash, A.J., and Vengosh, A., 2015. Water Footprint of Hydraulic Fracturing. Environmental Science & Technology Letters. https://doi.org/10.1021/acs.estlett.5b00211

Labib, A., 1998. World-class Maintenance Using a Computerised Maintenance Management System. Journal of Quality in Maintenance Engineering. https://doi.org/10.1108/13552519810207470

Lei, T., Lv, F., and Liu, J.M., 2022. Research on Electrical Equipment Monitoring and Early Warning System Based on Internet of Things Technology. Mathematical Problems in Engineering. https://doi.org/10.1155/2022/6255277

Li, H.Y., Xu, W., Cui, Y., Wang, Z., Xiao, M., and Sun, Z., 2020. Preventive Maintenance Decision Model of Urban Transportation System Equipment Based on Multi-Control Units. Ieee Access. https://doi.org/10.1109/access.2019.2961433

Liao, K., Wei, M., Fu, L., Ma, Q., An, J., Bai, J., Wang, M., and He, Y., 2022. Study on the Relationship Between the Relative Molecular Mass of a Polymer Clay Stabilizer and the Permeability of a Tight Reservoir. Acs Omega. https://doi.org/10.1021/acsomega.2c03051

Lu, H., Huang, K., Azimi, M., and Guo, L., 2019. Blockchain Technology in the Oil and Gas Industry: A Review of Applications, Opportunities, Challenges, and Risks. Ieee Access. https://doi.org/10.1109/access.2019.2907695

Ma, W.G., Li, C.T., Zhu, Y.Q., Cong, L., and Hu, S.X., 2023. The Bridge Maintenance Management in the Context of Big Data. E3s Web of Conferences. https://doi.org/10.1051/e3sconf/202337201002

Mackinnon, A.J., and Wearing, A.J., 1980. Complexity and Decision Making. Behavioral Science. https://doi.org/10.1002/bs.3830250405

Madni, A.M., Madni, C.C., and Lucero, S., 2019. Leveraging Digital Twin Technology in Model-Based Systems Engineering. Systems. https://doi.org/10.3390/systems7010007

Milana, M., Khan, M.I., and Munive-Hernandez, J.E., 2016. Design and Development of Knowledge Based System for Integrated Maintenance Strategy and Operations. Concurrent Engineering. https://doi.org/10.1177/1063293x16665662

Miller, J., Skowronski, K., and Saldanha, J.P., 2021. Asset Ownership &Amp; Incentives to Undertake Non-contractible Actions: The Case of Trucking. Journal of Supply Chain Management. https://doi.org/10.1111/jscm.12263

Minullin, R.G., and Fardiev, I. Sh., 2018. The Mutual Influence of Signals From the Location Monitoring Equipment and Technological Communication in the High-Frequency Path of Power Transmission Line. International Journal of Engineering & Technology. https://doi.org/10.14419/ijet.v7i4.38.24500

Ng, J.Y., Boon, H., Thompson, A., and Whitehead, C., 2016. Making Sense of “Alternative”, “Complementary”, “Unconventional” and “Integrative” Medicine: Exploring the Terms and Meanings Through a Textual Analysis. BMC Complementary and Alternative Medicine. https://doi.org/10.1186/s12906-016-1111-3

O’Connor, A.M., Drake, E.R., Wells, G.A., Tugwell, P., Laupacis, A., and Elmslie, T., 2003. A Survey of the Decision-Making Needs of Canadians Faced With Complex Health Decisions. Health Expectations. https://doi.org/10.1046/j.1369-6513.2003.00215.x

Olorode, O., Freeman, C.M., Moridis, G.J., and Blasingame, T.A., 2012. High-Resolution Numerical Modeling of Complex and Irregular Fracture Patterns in Shale Gas and Tight Gas Reservoirs. https://doi.org/10.2118/152482-ms

Pantha, B.R., Yatabe, R., and Bhandary, N.P., 2010. GIS-based Highway Maintenance Prioritization Model: An Integrated Approach for Highway Maintenance in Nepal Mountains. Journal of Transport Geography. https://doi.org/10.1016/j.jtrangeo.2009.06.016

Pech, M., Vrchota, J., and Bednář, J., 2021. Predictive Maintenance and Intelligent Sensors in Smart Factory: Review. Sensors. https://doi.org/10.3390/s21041470

Pennington, N., and Hastie, R., 1986. Evidence Evaluation in Complex

Decision Making. Journal of Personality and Social Psychology. https://doi.org/10.1037/0022-3514.51.2.242

Petrovskiy, E., Buryukin, F.A., Bukhtiyarov, V.V., Savich, I.V., and Gagina, M.V., 2015. The FMEA-Risk Analysis of Oil and Gas Process Facilities With Hazard Assessment Based on Fuzzy Logic. Modern Applied Science. https://doi.org/10.5539/mas.v9n5p25

Pinar, A., 2022. Artificial Intelligence Supported Aircraft Maintenance Strategy Selection With Q-Rung Orthopair Fuzzy TOPSIS Method. Journal of Aviation. https://doi.org/10.30518/jav.1150219

Pintelon, L., Pinjala, S.K., and Vereecke, A., 2006. Evaluating the Effectiveness of Maintenance Strategies. Journal of Quality in Maintenance Engineering. https://doi.org/10.1108/13552510610654501

Pokorni, S., 2021. Current State of the Application of Artificial Intelligence in Reliability and Maintenance. Vojnotehnicki Glasnik. https://doi.org/10.5937/vojtehg69-30434

Razmi-Farooji, A., Kropsu-Vehkapera, H., Harkonen, J., and Haapasalo, H., 2019. Advantages and Potential Challenges of Data Management in E-Maintenance. Journal of Quality in Maintenance Engineering. https://doi.org/10.1108/jqme-03-2018-0018

Reams, M.A., Lam, N.S.N., and Baker, A., 2012. Measuring Capacity for Resilience Among Coastal Counties of the U. S. Northern Gulf of Mexico Region. American Journal of Climate Change. https://doi.org/10.4236/ajcc.2012.14016

Sasidharan, M., and Torbaghan, M.E., 2021. Risk-Informed Sustainable Asset Management of Railway Tracks. Infrastructure Asset Management. https://doi.org/10.1680/jinam.20.00018

Siddhamshetty, P., Mao, S., Wu, K., and Kwon, J.S.I., 2020. Multi-Size Proppant Pumping Schedule of Hydraulic Fracturing: Application to an MP-PIC Model of Unconventional Reservoir for Enhanced Gas Production. Processes. https://doi.org/10.3390/pr8050570

Sigsgaard, K.V., Soleymani, I., Mortensen, N.H., Khalid, W., and Hansen, K.D., 2021. Toward a Framework for Maintenance Architecture. Journal of Quality in Maintenance Engineering. https://doi.org/10.1108/jqme-01-2020-0004

Skardelly, M., Dangel, E., Gohde, J., Noell, S., Behling, F., Lepski, G., Borchers, C., Koch, M., Schittenhelm, J., Bisdas, S., Naumann, A., Paulsen, F., Zips, D., Hehn, U. von, Ritz, R., Tatagiba, M., and Tabatabai, G., 2017. Prolonged Temozolomide Maintenance Therapy in Newly Diagnosed Glioblastoma. The Oncologist. https://doi.org/10.1634/theoncologist.2016-0347

Strachan, P.A., Sinclair, I.M., and Lal, D., 2003. Managing ISO 14001 Implementation in the United Kingdom Continental Shelf (UKCS). Corporate Social Responsibility and Environmental Management. https://doi.org/10.1002/csr.29

Sun, X., Wei, Y., Jin, Y., Song, W., and Li, X., 2022. The Evolution of Structural Resilience of Global Oil and Gas Resources Trade Network. Global Networks. https://doi.org/10.1111/glob.12399

Tesfa, M., Akalu, T.Y., Chane, Y.M., and Yohannes, S., 2022. Growth Monitoring Practice and Associated Factors Among Health Professionals at Public Health Facilities of Bahir Dar Health Centers, Northwest Ethiopia, 2021. Pediatric Health Medicine and Therapeutics. https://doi.org/10.2147/phmt.s355214

Tian, Z., 2009. An Artificial Neural Network Method for Remaining Useful Life Prediction of Equipment Subject to Condition Monitoring. Journal of Intelligent Manufacturing. https://doi.org/10.1007/s10845-009-0356-9

Udeh, C.M., Anikwe, M.A.N., and Audu, E.E., 2022. Application of Analytical Hierarchical Process in Equipment Maintenance Scheduling and Decision-Making Process in Oil/Gas. Journal of Energy Research and Reviews. https://doi.org/10.9734/jenrr/2022/v11i330278

Wang, B., Wu, Z., and Xia, X., 2017. A Multistate-Based Control System Approach Toward Optimal Maintenance Planning. Ieee Transactions on Control Systems Technology. https://doi.org/10.1109/tcst.2016.2550505