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Implementing Automation and Robotics for Safe and More Efficient Drilling Operations

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Abstract

The drilling industry faces significant challenges, including high operational costs, safety concerns, and the need for enhanced efficiency amid complex geological conditions. This review examines the transformative role of automation and robotics in addressing these challenges while emphasizing safety, operational optimization, adaptability, and reliability. The study synthesizes findings from a comprehensive analysis of recent advancements, leveraging case studies such as NASA's robotic innovations and National Oilwell Varco's Automated Drilling System (ADS II) to evaluate their impact on drilling operations. Key findings reveal that automation technologies, including real-time data analytics, machine learning, and collaborative robotics, significantly reduce non-productive time, improve decision-making, and minimize human exposure to hazardous environments. Despite economic and technical barriers to implementation, integrating automation aligns with global sustainability goals and supports long-term energy resource development. Future advancements will depend on cross-industry collaboration, regulatory compliance, and comprehensive training programs to equip the workforce with the skills needed for automated systems.

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Introduction

The cost of drilling wells is quite high due to the labour-intensive nature of the process, the extensive lead times required, and the expensive equipment involved (Liu *et al.,* 2023). The drilling industry heavily relies on the effective utilization of BHA (Bottom Hole Assembly) and other drilling equipment, which are constantly subjected to formidable forces during operation (Shao *et al*., 2021). Thus, in an effort to minimize the overall expenditure, organizations cannot afford to make personnel costs a major component; therefore, hiring and training must be conducted most effectively. Furthermore, there is also a need to focus on staffing which seeks to improve the contractor's capability concerning drilling in an efficient manner (Van *et al.,* 2022).

Computers have therefore become important items in drilling to make the overall drilling process easier and efficient. Additionally, related literature reviews and analyses of automation and robotics of well completion have been carried out to realize the potential for further development in this sector (Zheng *et al.,* 2020). This aligns with frameworks such as the Catoosa Performance Model, which emphasizes leveraging advanced technologies like automation and robotics to optimize operational. For instance, real-time data analytics can be employed to minimize downtime and improve decision-making during critical operations, ensuring that resources are used efficiently and safely.

Exploration and exploitation of petroleum resources have been done for about 50 years now, and the need for efficient drilling technologies remains an industry demand (Li *et al*., 2022). The industry requires ongoing improvement of drilling technology along with well-established drilling methods because of this permanent need. Staff members encounter substantial occupational risks during the drilling operations for oil and gas wells which hinder both productivity and create safety hazards for personnel (Adeola *et al.,* 2022). These problems involving dangers and insufficient skilled employees detrimentally impact the country's energy resource exploitation. Issues in oil exploration and gas drilling lead to higher pricing structures because the unstable supply develops from repeated drilling defects.

The SOAR Performance Indicators serve as a system to achieve structured measurements of drilling performance effectiveness. SOAR establishes a standardized assessment method through its acronym Safety, Operations, Adaptability, and Reliability that evaluates automatic systems in conjunction with human operators. Under the Safety category SOAR tracks both incident frequency and severity factors but Operations tracks drilling speed alongside equipment utilization levels. The concept of "Adaptability" now

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includes geological anomalies within its evaluation scope but "Reliability" maintains system operational stability throughout its operating period. Multiple performance benchmarks provide complete information about drilling operations which enables stakeholders to create sound strategic decisions that enhance security and operational performance.

The drilling industry implements strategies to employ top professionals and maintain accessible equipment to achieve safe surface hole drilling operations according to Yongsheng *et al.,* (2022). The industry places safety together with efficiency at the top position for solving operational issues. Businesses use qualified personnel together with widely accessible tools to improve their drilling operations and maintain workplace safety alongside enhanced production. This method drives the industry toward petroleum exploration advancement which aims to deliver energy needs of present times and future requirements.

This vision finds support from the Catoosa Performance Model which establishes a framework that helps drilling operations achieve operational success through efficiency improvement along with safety measures and cost reduction. By identifying areas for improvement and implementing targeted strategies, organizations can achieve better results, ensuring that both technological advancements and human expertise contribute to the industry's success.

Background of Drilling Operations

Automation and robotics could play a pivotal role in surmounting and addressing these aforementioned challenges and obstacles (de Holanda Araujo, 2024). The sheer potential of automation and robotics lies in their profound ability to effectively tackle, endure, and manage risky, arduous, and unideal tasks, thereby relieving workers from the burdens associated with physical exertion and health-related concerns. Moreover, their capabilities allow them to surpass human workers in the domain of drilling work, showcasing superior performance in terms of delivering prompt feedback and showcasing unwavering resilience within the realm of an automatic control system. It is worth emphasizing that the enhanced utilization and integration of automation and robotics within the engineering disciplines, particularly in the context of drilling operations, serve to unlock an entirely novel dimension of research prospects and workforce prerequisites (Josef, 2023). The use of automation and robotics unfolds many possibilities and offer themselves and opens a new domain that attracts researchers as well as professionals to study this emerging field. More importantly, the adoption and deployment of automation and robotics in the process of drilling also ensure that there are characteristics other than improved efficiency that were speaking of as saving and rationalizing the use of human labour in this specific area of work (Zuo *et al.,* 2023). Less manpower required for drilling activities also helps to free up other resources elsewhere which will go a long way in creating better personnel productivity, which will also clearly define the overall efficiency of operations. Drilling operations are of considerable significance in the extraction of energy resources such as coal, oil, and natural gas. These operations play a vital role in meeting the growing global energy demand (Onwuka and Adu, 2024). However, drilling work is far from easy. It is performed in an environment that is often monotonous, dirty, greasy, and hazardous, making it extremely challenging for the workers involved. The risks associated with drilling work are plentiful. These operations involve the use of heavy and insensitive machinery which always endangers the lives of the workers. These animals are vulnerable to various risks for instance exertion, getting trapped and falling. These risks are mainly associated with loading and unloading work, the swap of drills, right-hand operations of drills, unexpected receptacle outflow of drilling fluids, an ineffective threat of tripping at the wellhead. Additionally, the drilling workers reached several problems such as high temperatures and reduced workplace space (Li *et al.,* 2022). He also said that the dogs are exposed to extreme heat which affects their energy levels, mostly becoming tired and dehydrated. Besides, being confined in the synchronization cylinder is also unhealthy sinceone can develop various medical complications.

Both physical and health-related barriers that exist in connection to drilling work have taken a huge toll on the hiring and keeping of professional drilling workers. This has led to high competitiveness and direness of the occupation which has limited novices to join the business environment (Shamoon *et al.,* 2022). Also, many of the drilling workers are aging and the current workforce lacks requisite skills due to significant retirement ages. To overcome these challenges and make the drilling industry sustainable investments must be made and changes have to be made. Technological and automation enhancement plays a vital role in reducing the threats associated with rilling workers. Robotics can be used in industry for example to movements of heavy equipment to minimize the muscular exertion of people. Also, it shows that by applying sensor technology, the monitoring of the drilling process can be done in real-time, and potential threats may be identified quickly. Enhancing the training, and education of individuals involved in drilling activity is also another

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consideration. By training them with the right ND skills and knowledge they can easily cope with the challenging ND workplace and monitor risks. Moreover, safety must be maintained as the primary focus of the industry across various organizations. This is to stress that through thus following safety measures as well as maintenance and inspection of all the used equipment, it is possible to reduce of accidents and persons' injuries to the lowest possible level. In summary, the drilling operation seems to have a significant role in the generation and supply of energy resources. However, the physical and health risks linked to doing this kind of work have led to the scarcity of competent drilling employees. These challenges can be met by drilling the industry using advanced technologies and practices to allow comprehensive training and safety to come up with the necessary changes for a sustainable future.

Importance of Safety and Efficiency in Drilling Operations

There is no doubt that the management of software and hardware for directional drilling and drilling operations has without doubt, risen to a marvellously well-articulated level in an oil and gas drilling environment as observed by Whatley *et al.*, (2022) and Goodkey *et al.*, (2024) among other authors. As such, fully equipped and newly built drilling rigs are meticulously designed to efficiently manage the constantly growing and increasingly complex drilling and well operations. These cutting-edge facilities not only facilitate the primary activities but also enable the execution of numerous auxiliary activities more effectively and comprehensively Consequently, industry analysts unanimously agree that the most challenging and demanding operations and activities on rigs are undoubtedly those involving real-time rig operations. With the implementation of state-of-the-art automation and robotics in real-time rig operations, as explored by Bogue (2020) and McCoy *et al.*, (2021), there is a tremendous potential to prevent work-related incidents without imposing substantial additional costs on drilling and well operations. In the unfortunate event that incidents do occur, they will either be considered less critical due to the enhanced safety measures or can be promptly addressed with innovative and effective design solutions, a point highlighted by researchers such as DONG *et al.*, (2020) and Magana-Mora *et al.*, (2021). This commendable synergy between technology and operation makes it possible to enhance the overall safety and performance in drilling and well operations beyond the existing industry standards.

The drilling industry is currently one of the most dangerous industries in the oil and gas supply chain as observed by Mrozowska (2021) & Njuguna *et al.*, (2022). It comprises a range of operations affecting drilling and wells and places the workers at risk of multiple threats. Consequently, the risk levels of this industry are considerably high. Generally drilling rigs run 24/7 with the continuous intention of getting to and through a pay zone in the shortest time possible. However, the working environment of the crews that implement the drilling process may bear very adverse and complicated conditions. The wiring cable, high-pressure lines, and high-temperature flow lines are necessary to power the rig when combined either with rotating or casing, drilling and supply vessels posed a high risk of entanglement. There is also the feeling that a link may be shifted or disconnected creating an unsafe situation or an accident. Apart from these risks, the hand-operated tools utilized on drilling rigs could be very massive, bulky and physically demanding to manage or operate as highlighted by Osarogiagbon *et al.*, (2021) and Iqbal *et al.*, (2021). This causes a possibility of injuries to the musculoskeletal system, and possible open wounds, cuts, bruising or even haemorrhages on the side of the workers. Since the drilling industry is a high-risk sector, a lot of emphasis must be placed on safety measures that should be strongly observed by standard operating procedures, as Benson *et al.*, (2021), and Yang *et al.*, (2023) argued. These measures range from mandatory safety training by all the workers, proper inspection of equipment coupled with the implementation of a culture of workplace safety and careful observation of the drilling sites. Although, enough safety measures have been taken and the drilling industry should endeavourr to reduce accidents or enhance the safety measures for its employees.

Enhancing Drilling Efficiency and Safety Through the SOAR Framework

The SOAR framework consists of four essential elements that integrate solutions for modern drilling operation intricacies through its Safety, Operations and Adaptability and Reliability components. Real-time analysis of sensor data helps reduce risks in advance because safety stands as the top organizational priority. The company combines robotic arms for machinery operations with AI algorithms and electronic tools for better management of drilling path trajectory control. The use of machine learning predictions enhances the geological formation adaptability through continuous operational operations maintenance. Standard evaluation methods along with proper maintenance procedures combine to achieve reliability by enabling automatic system functioning in different operational settings.

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LOAR implements three vital technological components: Internet of Things (IoT) devices for continuous monitoring and predictive modeling with machine learning applications in combination with cooperative robots that act as help for risky repetitive operations. Organizations should use IoT sensors to detect equipment deterioration before equipment failure to prevent time-consuming equipment downtime through proactive activities. Machine learning models evaluate historical data through which they detect borehole instability to generate ahead-of-time cautioning recommendations. The deployment of collaborative robots as cobots serves with human operators to perform difficult physical labor that minimizes risks of work-related musculoskeletal injuries. Modern methodologies provide organizations with increased operational safety as well as enhanced operational performance benefits for their staff.

The implementation of SOAR framework shows strong potential to bring major advancements throughout drilling operations. Safety measures that enhance performance reduce both insurance expenses and enhance employee spirit at work. Operation efficiency from automated real-time data assessment reduces drilling times while lowering industrial waste output. The ability to adapt helps drilling operations maintain their stability while dealing with unpredicted problems occurring in rock properties. Total reliability extends equipment lifespans by reducing equipment breakdowns which in turn decreases costly maintenance expenses for drilling rigs. The drilling industry achieves greater sustainability alongside profitability because these benefits work together as a whole.

Automation and Robotics in the Oil and Gas Industry

The drilling industry is progressing through the learning level and automation and robotics adoption as criticized by Gooneratne *et al.,* (2020) together with Wang *et al.,* (2022) due to society changes and technological advancements. Better drilling operations in onshore systems can be achieved by investigating potential applications of robotic systems. These systems are often defined by extraordinary scalability, modularity, integrability, and availability of numerous options for the automation and control of the drill string. While adopting high-accuracy digital to analog instrumentation and Adjustable control techniques, as described by Epelle & Gerogiorgis (2020), and Goodkey *et al.,* (2020) the drilling activities can find progressive enhancement from perspectives of effectiveness and safety. Such drilling automation success depends on the following factors. First of all, it relies on a carefully planned internet-based system that provides for effective means of communication between students and industries and compatibility of the requirements with industry requirements in all its courses. Available technology, innovative applications, and support are also equally important and should be pursued using state-of-art as evidenced by Gomez *et al.,* (2021) and Kuang *et al.,* (2021). Moreover, he has identified that the promotion of business models that can act as a tool that can stimulate further progress in the drilling operations' potential is another key factor that has not been addressed to the full extent yet. When backed by the growing industry support, integration of automation in drilling could extend its applications across different facets of O&G exploration, appraisal, development and production, as a high-value utility. Such a dramatic transition to technology presents the oil and gas industry with possibilities for growth, reducing vulnerability to risks and enhancing production efficiencies. This comes because as the industry explores the reasons to employ robotics and automation in the drilling processes a new dawn of operational efficiency is just around the corner. The drilling automation systems are thus becoming more and more encompassing for the multiple system-level as well as the machine control as well as the D/A interface at the machine point of operation further affirming the observations made by Vincent (2021) and Pharasi *et al.,* (2020). These sophisticated systems put in place enable the onboard driller and even the operators to have full control of the drilling process having included software protection enhanced by observing monitoring control systems to deliver an optimum performance regardless of the prevailing conditions and the modes of operations. The last major technological advancement by National Oilwell Varco to increase drilling automation is referred to as the Automated Drilling System (ADS II) it comes with touch screen technology that customers can vividly operate with ease in front of the drilling crew, and will enable them to monitor all the characteristics of the drilling process. Demonstrating the industry's commitment to technological advancement, as highlighted by Bejger and Piasecki (2020) and Buer *et al.,* (2023), one recent project undertaken by the esteemed ROSEN Group involved the development of a Collaborative and Robotic NDT Inspection specifically designed to enhance the safety and efficiency of Drilling Risers.

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Current Technologies and Trends in Drilling Automation

The primary objective of this review is to foster deeper involvement with the geological heterogeneity found in local regions, while also facilitating rapid adjustment of the depth of cut and implementing control approaches that are characteristic of process automation. The optimization of control performance focuses on ensuring stability, effectively achieved through constant updates of the spindle speed to facilitate smooth execution of drilling trajectories. In contrast to conventional automated drilling techniques and geostationary actuators primarily designed for downhole applications, this research explores the adaptation of robotics concepts for deployment in the bottom-hole assembly (BHA). The control strategies employed draw upon best practices in automation and are carefully tuned to enable hardware-in-the-loop simulations, thereby allowing for meaningful real-time control tuning.

Research looks toward the future by promoting both novel ideas and existing method alterations for robotics development in intelligent drilling technology. The Drilling Automation Sandbox operates as an essential virtual testing facility used to enhance and test the development of new automation technologies before their deployment in actual drilling operations. Through virtual testing designers and developers can work on different configurations and control systems while maintaining safety of human operators and preserving expensive equipment. Drilling scenarios receive detailed representation in the Sandbox while detailed feedback systems operate in real time. Also, the Sandbox supports multiple software systems. Such features help stakeholders detect potential difficulties during development which leads them to select only powerful solutions to deploy on real rigs.

Recent research shows that multiple organizations and business entities work toward drilling automation progress (Vincent, 2021 along with Goodkey *et al*., 2024). The Drilling Automation Sandbox provides industry members such as drilling contractors and equipment manufacturers together with regulatory bodies to verify new technological advancements and verify safety compliance. Manufacturers implement the Sandbox for checking product interoperability among existing systems yet regulators use it to assess safety protocol effectiveness. The Sandbox makes it possible for training programs to introduce operators to new tools and procedures through simulation which improves their capability to work with automated systems. The Sandbox becomes a vital instrument in expanding drilling automation because it promotes innovative cooperation between stakeholders.

The Drilling Automation Sandbox provides more than direct implementation value by shaping industry direction for upcoming industry development. The Drilling Automation Sandbox speeds up the process of implementing advanced technologies thus enabling an industry culture that emphasizes continuous improvement. Experiments can be conducted within this platform to develop completely autonomous drilling capabilities in a safe controlled environment. The Sandbox serves as an essential tool as the industry advances toward complete automation potential.

The following sections of this text will explore meticulously developed robotic methodologies for drilling automation because the research focuses on robotic automation within the automation field. The text expands its focus by analyzing different implementation methods and advanced robotic technologies according to research by Magana-Mora *et al.,* (2021) and Forshaw *et al.,* (2023) which shows successful deployment and thorough evaluation. The Drilling Automation Sandbox serves as a vital testing platform for robot systems development which translates to their effective implementation into drilling automation advancements.

Advantages and Challenges of Implementing Automation and Robotics

It is widely accepted that the cost per foot drilled in offshore drilling operations is still too high, a concern explored by researchers such as Kaiser (2022) and Jablonowski and MacEachern (2023). It may be argued that commands and handling activities in onshore manufacturing were replaced by programmable machines only after the controlling and programming technology had become viable, and economic installation and operation of programmable manufacturing machines was paramount for the evolution of the total cost per product manufactured. In drilling, the conditions for replacing human employees by complete automation of the drilling process are not yet fulfilled. In numerous cases, what is more relevant to decide upon concerns marginal installations or partial automation. Here, mere technological feasibility may or may not shape the economic boundary limits. Anyhow, in the world of offshore drilling, the use of automation technologies to reduce cost per foot drilled has to be considered as the absolute top priority of automation applications. A closer insight into the economic potential of automation applications under diverging conditions may result from a summary of the limitations and the economic potential of different forms of automation applications.

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Despite the potential drawbacks concerning the installation of automation technologies in drilling rigs, one might claim that the benefits of automation mainly lie within three areas: (a) safety; (b) performance; and (c) additional increased flexibility, as highlighted by researchers like Said *et al.*, (2022) and Biadi *et al.*, (2024). It is widely accepted that drilling operations at sea are hazardous, but according to statistics, serious accidents are still relatively rare. Even though the day-to-day safety situation on drilling units is in good condition, it is not acceptable if one serious incident takes place, considering the potential consequences. When the challenges requiring a high rate of changes at rig installations escalate, it is hard to pick up any other measure that is more promising for enhancing safety than technological measures, including the implementation of automation technologies, a point emphasized by studies from Løken *et al.*, (2020) and Cayeux *et al.* (2021).

Safety Considerations in Automated Drilling Operations: Being prepared to deliver the necessary operational discipline without compromising safety for such increased performances can be supported through the understanding of employees' trust in autonomous systems, as explored by Mitchell *et al.*, (2022) and Berx *et al.*, (2022). We have learned from the robot industry, the automotive industry, etc. that this journey requires an orchestrated effort not only between the main contractor and the subcontractors but also with other service providers. When the joint efforts include the employees' organizations and align with government policy objectives and guidelines, these improvements add value to society in a broader context by reducing the risk of related incidents, the environmental risks, and the effective use of energy resources. Ultimately, for remote drilling or autonomous drilling to be considered efficient, such developments are not allowed to increase the risk related to the operator's exposure. Therefore, further developments in drilling and well-servicing operations could also be expected to contribute to more sustainable and reliable energy delivery to the benefit of human welfare and the Earth's environment. The potential value contribution from fully automated drilling operations through smaller crew sizes, fewer people aboard, reduced environmental risks, reduced human exposure risks, reduced travel and decision times, decreased use of chemicals, etc. can hence not be underestimated, a point emphasized by researchers like Khosravani and Haghighi (2022) and de Soto and Skibniewski (2020).

Given the rapid evolution of hardware, sensors, and algorithms and the widespread engineering and technical initiatives by operators, services, and manufacturers, as highlighted by Gooneratne *et al.*, (2020) and Li *et al.*, (2022), it is a clear development pathway to automate today's drilling operations within the boundaries of drilling programs. However, to fully benefit from these advances, it is of utmost importance to ensure that the performance and safety advancements become enablers for changing the way of work and for increased management flexibility, both at conventional remote operations centers and for different levels of autonomously managed operations. It is also necessary to ensure organizational readiness to capitalize on technological advancements. This requires well-defined roles and responsibilities, effective authority and accountability principles, efficient communication and knowledge sharing, and pre-job/practice planning within a seamless interface between the drilling contractor, the operator, and the service/service equipment company to ensure collaboration towards clearly defined and mutually beneficial shared goals, as demonstrated by studies from D'Almeida *et al.*, (2022) and Magana-Mora *et al.*, (2021).

Case Studies of Successful Implementations

The development of these technological advances has led to addressing the main barriers identified: the labour intensity of operations, the loss of time due to security issues, and the inconsistency of logging data, as highlighted by researchers such as Flechsig *et al.*, (2022) and Huang *et al.*, (2022). However, the absence of an integrated view of the drilling process and the short-term perspective of business processes continue to pose significant obstacles to the efficiency of the industry. The results show that the economic perspective of the industry is still myopic, with a focus on minimizing personnel rather than minimizing drilling time and maximizing data quality. The business model needs transformation to support process industry principles in drilling procedures according to Aguiar Noury *et al.*, (2021) and Pradhananga *et al.*, (2021).

NASA Robotics in Drilling Automation

NASA derived its expertise in robotics through space exploration to develop automated drilling technology suitable for the oil and gas sector. NASA turned its space exploration robotic systems into heavy equipment handlers and precise task operators in drilling operations. Underground drilling conditions become manageable through robotic arm operation

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with their state-of-the-art sensor technology. The technology has demonstrated outstanding performances during deepwater drilling operations because humans cannot safely reach those areas because of high pressures and extreme temperatures. David Hitzinger of Transocean Deepwater Inc. mentioned how companies speed up drilling processes while lowering equipment deterioration and improving safety performance through NASA-developed technology. The developments follow the broader industry objective of minimizing non-productive periods and optimizing operational effectiveness which agrees with research by Wang *et al.,* (2022) and Qun *et al.,* (2022).

Automated Drilling Systems in Offshore Operations

National Oilwell Varco implemented their ADS II Automated Drilling System as a compelling example for offshore drilling operations. All aspects of remote drilling control are accessible through touch-screen interfaces in this automated system. The Gulf of Mexico received ADS II for well drilling operations which produced a 20% decrease in non-productive time and a 15% rise in total operational efficiency. Real-time data analytics working together with automated controls in the system allowed operators to speed up their informed decision-making which reduced the chance of making errors. The absence of on-site personnel together with reduced operational expenses created a safer working environment because workers avoided dangerous drill-site situations. Such innovations prove that automation advances safety and efficiency through its dual purpose according to research from Gooneratne *et al.,* (2020) and Igbinenikaro *et al.,* (2024).

Impact on Industry Trends

The discussed case studies show how automation and robotics create significant changes for drilling operations. Companies exhibit real-life benefits from their adopted technologies to push forward acceptance of similar automated solutions among other businesses. The case studies show the critical need for industrial organizations to work together through examples of NASA robotics being adapted for drilling purposes. The industry will transition toward better and more effective drilling practices once organizations start utilizing automation mechanisms to reach sustainability targets globally. The industry advances its commitment to implement mechanized jack-ups together with rig floor skidding systems and active heave cranes which demonstrate enhanced operational efficiency and productivity.

According to research by Gooneratne *et al.,* (2020) alongside Igbinenikaro *et al.,* (2024) the successful applications mainly focus on KFELS B Class and Pacific Class families of jack-ups. The rig floor skidding system coupled with the mechanical tensioner that utilizes power catwalk forms one of the successful applications. Jack-up systems based on mechanization remain under development because engineers focus on creating improvements to realize better operational productivity and performance. Active heave cranes are now integral to semisubmersible platforms after developers introduced these critical tools for handling operations in challenging offshore scenarios. The platform benefits from multiple power and control systems through umbilicals that establish efficient communication and transmission of power throughout different platform components. The introduction of improved skidding systems within drilling equipment will enable simplified equipment movement to cut down operational hassle times.

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The development of these applications relies on the constant drive for automation according to Wang *et al.,* (2022) and Qun *et al.,* (2022). During drilling move-in operations these interventions demonstrate their maximum performance by cutting down non-productive time and making operations more efficient. These modern innovations along with their technological improvements have transformed the offshore drilling sector into a new operational dimension. These solutions have simultaneously achieved two goals: they increase operational safety and effectiveness and significantly reduce unnecessary time consumption which results in productivity gains. The offshore sector represents an active field of development with great potential for future innovations to take place. Offshore work will advance towards lower costs and less environmental impact and better efficiency through the integration of robotics together with artificial intelligence and advanced automation systems.

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Future Prospects and Emerging Technologies

Advanced data collection techniques, computer science, mathematics, statistics, and cognitive science are some of the elements utilized in exploring AI applications for drilling operations, as highlighted by Himeur *et al.,* (2023) and Sarker (2023). Drilling operations could gain significant advancements from the latest AI breakthroughs if these technologies are applied with time and cost-effectiveness. More specifically, AI and automation can be employed in real-time well data analysis and computational performance optimization, in well trajectory and automated placement optimization, inaccurate and intelligent machine fault diagnostics, in process variation problem solutions, in risk and uncertainty quantification, in near-future event forecasting and decision making, in 3D geological modelling (i.e. installation, system architecture simulations, *et al.,*), in continuous drilling risk assessment on and risk prioritization, and in integration to well design optimization and technology selection models. These technologies can bring further development and unrivalled performance profits to drilling assembly applications, programs, and other related industries. New technologies in automation, robotics, and artificial intelligence provide findings with the capability to revolutionize drilling operations, and the authors hope that the present study will provide a direction for future research boosts in this area, as noted by D'Almeida *et al.,* (2022) and Olajiga *et al.,* (2024). The terms "artificial intelligence" and "machine learning" are used interchangeably in this paper. At a fundamental level, AI is about enhancing human-like intelligence in machines to achieve high levels of accuracy in activities such as perception, reasoning, and prediction. AI includes all those technologies and solutions needed to create intelligent systems and to develop innovative applications related to activities of any complexity. An AI system perceives its environment and makes decisions based on its observations. AI technologies enable the creation of both autonomous systems and systems that assist and support human operators in tasks that are too complex or too dangerous for them to carry out unaided, a point emphasized by researchers such as Musa (2023) and Abdalla (2023).

Regulatory and Compliance Aspects

There also are extra concerns which need to be followed when it comes to the applications, design and operation of PES, as stated in the recent studies by Tang Mayrhofer et al (2023) & (2024). However, there are special provisions for by-wire systems connected to pressure sensors, especially regarding their reliability and efficiency in connection with a blowout preventer equipment. One of the important issues that these regulations raise is the requirement for the ability to avoid collisions in the studied systems. They should ensure that they have installed higher-level mechanisms that will be able to sense and avoid contact with human beings. These measures ensure that there are very few mistakes or as much as possible reduce on any loss that may come along with such events. In addition to the nearly requirements, there are also requirements for the function and performance of a blowout preventer in a well-controlled situation. Accordingly, the regulations specify that these programmable systems must have the capability to undertake tasks and functions in terms of an operator of such a situation. The rationale of this work is to present certain recommendations that would guarantee the highest levels of protection and effectiveness in using those systems. Furthermore, there might be other pertinent rules regarding the operation of robotics which have been laid down by OSHA, as highlighted by the researchers Risi and Veera (2023). Based on the information available it can be concluded about the necessity of an urgent and in-depth analysis of OSHA provisions for this industry. By using this analysis, it will be easier to recommend any other measures that need to be put in place so that compliance and safety of robotics operations are achieved.

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(2024). The terms "artificial intelligence" and "machine learning" are used interchangeably in this paper. At a fundamental level, AI is about enhancing human-like intelligence in machines to achieve high levels of accuracy in activities such as perception, reasoning, and prediction. AI includes all those technologies and solutions needed to create intelligent systems and to develop innovative applications related to activities of any complexity. An AI system perceives its environment and makes decisions based on its observations. AI technologies enable the creation of both autonomous systems and systems that assist and support human operators in tasks that are too complex or too dangerous for them to carry out unaided, a point emphasized by researchers such as Musa (2023) and Abdalla (2023).

Regulatory and Compliance Aspects

There also are extra concerns which need to be followed when it comes to the applications, design and operation of PES, as stated in the recent studies by Tang Mayrhofer et al (2023) & (2024). However, there are special provisions for by-wire systems connected to pressure sensors, especially regarding their reliability and efficiency in connection with a blowout preventer equipment. One of the important issues that these regulations raise is the requirement for the ability to avoid collisions in the studied systems. They should ensure that they have installed higher-level mechanisms that will be able to sense and avoid contact with human beings. These measures ensure that there are very few mistakes or as much as possible reduce on any loss that may come along with such events. In addition to the nearly requirements, there are also requirements for the function and performance of a blowout preventer in a well-controlled situation. Accordingly, the regulations specify that these programmable systems must have the capability to undertake tasks and functions in terms of an operator of such a situation. The rationale of this work is to present certain recommendations that would guarantee the highest levels of protection and effectiveness in using those systems. Furthermore, there might be other pertinent rules regarding the operation of robotics which have been laid down by OSHA, as highlighted by the researchers Risi and Veera (2023). Based on the information available it can be concluded about the necessity of an urgent and in-depth analysis of OSHA provisions for this industry. By using this analysis, it will be easier to recommend any other measures that need to be put in place so that compliance and safety of robotics operations are achieved.

Future robotic drilling operations require a moisture-resistant connector. OSHA is the federal agency created in 1970 to ensure that working people in the nation are protected from on-the-job injury and illness through the developing of standards, inspection, training, education, and assistance as described by various scholars including Reid (2022) as well as Johannes *et al.,* (2023). This organization tries to impose and maintain rules governing drilling operations that spur authoritative benchmarks. This includes defining legal requirements for the environment where the robotic devices may operate, environments which are necessary for the protection of human employees when in the vicinity of active robotic devices, qualification and licensing of personnel operating robotic or related devices that must work alongside robotic devices, equipment which must function together with or near robotic devices such as lift equipment, and enclosures or guards and temporary barriers or obstacles. It also contains specific performance characteristics that are put in to make certain that sensors and other identification and recognition devices required in the operation of the robotic devices are within the prescribed OSHA standards to protect the human workers. It also contains the conditions that have to be fulfilled to safeguard the workforce and the public that has to be fulfilled to operate the individual or the cooperative team of robotic devices. Future requirements may involve a capability to identify and address violations of OSHA regulations by the infected with ill intentions towards workers, the public and infrastructure as may be required by a robotic device or system.

Occupational Safety and Health Administration (OSHA)

The introduction and use of robotics and automation in drilling activities must be achieved within a context of conformity with the current and future regulatory framework of drilling operations as recommended by Ochulor *et al.,* (2024) and Olajiga *et al.,* (2024). So, for operations the development and the related systems of the robotic devices will have to fulfil the standards set by EPA, OSHA and the norms that accompany by the ISO set. These requirements will have to regard objects like the electronic apparatus which supervises drilling processes, the control and command systems which govern the robotic apparatus, the robotic apparatus, and the chemical and mechanical bend mechanisms which are expected to replace current blasting practices. These and other new devices and technologies add extra dimensions to achieving the goals of the regulatory requirements, as pointed out by Xu *et al.,* (2022) as well as Francis (2022).

Training and Skill Development for Automated Drilling

As drilling rigs move to increased dependency on automation systems and away from human control,

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human reliability becomes a significant issue. The engineers behind the technology often overlook the reliance on and need for the human interface. The development of advanced education and training programs for all drilling stakeholders could encourage the motivation and competencies of the workforce in the business, operations, and production sectors (França *et al.,* 2021). Assessment of competency could involve activities such as education and training that align with the development of learning and assessment methods. It could also facilitate the employment of drilling automation requirements and an efficient, safe, and high-performance workplace. Task-specific skills training, combined with operational and process control knowledge, contributes to industry personnel's readiness to work with sophisticated automated systems (Tucker, 2023; Earley, 2022). Information sharing among different stakeholders within the education sector is needed to anticipate and counteract barriers and bottlenecks and to promote knowledge transfer and technology acceptance in training and education. Cross-partnerships between the education and training sector and equipment manufacturers are encouraged to promote standardized technology courses. Such courses, if certified, would earn credits toward professional licenses (Herlinda *et al.,* 2024; Rossouw and Goldman, 2023). Educational content should be subjected to validation and curriculum reviews. After successful implementation, industry-driven education and training programs could be reviewed by third-party accreditation services like the International Association for Continuing Education and Training or the National Institute for Metalworking Skills. A unified and harmonized training and educational system between different institutions and government agencies would avoid redundancy, ensure consistency, and maximize cost-benefit. Relevant industries or organizations would benefit most from automation education and training, needing to invest in personnel development with a view on future requirements and associated growth potentials to ensure the efficient operation of the automation system (Lapetino, 2023; Davis *et al.,* 2023). Different sources of drilling automation deliverables should be considered, and a common standard for instructional content development is required. The content should provide extensive knowledge and understanding in terms of physical connection, procedures for system components, and programming logic, and support the curriculum and resource requirements of different levels of personnel serving various functions related to drilling automation. These could include educational institutions, regional sectors offering vocational education and training programs, state and federal labour departments responsible for workforce development, and professional societies (Jallorina *et al.,* 2024; Forshaw *et al.,* 2023). Comprehensive education programs and courses involving key enabling technologies have to be developed and offered considering different levels of personnel, such as university/college graduates, practising engineers, equipment technicians, field personnel, and end users. The development of education and training programs is essential for the successful introduction of automation in academia, vocational training centers, and industry to enable knowledge transfer and experience sharing in drilling automation (Xu *et al.,* 2022; D'Almeida *et al.,* 2022). Education and training of competent personnel are essential for automated drilling operations to ensure drilling efficiency and safety. Knowledge and understanding of process functions are still required, although human interaction will diminish as automation systems perform tasks. Personnel from all disciplines and levels experience different needs for education and training in automation implementation. Accordingly, a systematic training and skill development plan is essential for successful automation implementation and operation. Training and skill improvement influence drilling technology governance by fostering a skilled workforce (Wang *et al.,* 2022; Bergamo *et al.,* 2022).

Cost-Benefit Analysis of Automation and Robotics in Drilling OperationsA cost-benefit study is to be performed for automation and robotics in drilling by taking into account investments in automation and robotics and operations with rigs used in the present. Information at this point, for new tasks given into the responsibility of programmable units on the rig, shows that some automation and robotics solutions require a minimum drilling depth to become cost-efficient. The new rig design, implementation, and training provide the possibility of having automated and robotic operations to go down and meet the business for shallow waters. For offshore operations with depths bigger than 3,500 m (11,500 ft), harsh conditions, and deepwater environments, there is potential to obtain increased profitability, particularly by having fewer people exposed to accidents through real-time health monitoring systems (Pereira *et al.,* 2022; Xu *et al.,* 2022). Automation and robotics in drilling operations are to a considerable extent new units on an oil rig, where it is crucial to establish their accuracy and guaranteed performance. As long as automation and robotics imply programmed tasks, a major concern comes from the fact that uncompensated or poorly compensated work orders can result in higher operational costs. The high investment in automation and robotics must be met by reducing drilling costs using a combination of drilling optimization and maintaining a smaller and

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smarter crew. By keeping a minimum number of working hours on the rig, the number of risk combinations between workers moving rigs and handling drill pipe and casings used for additional interventions is also reduced (Whatley *et al.,* 2022; Ayyad *et al.,* 2023).

Environmental Impact and Sustainability in Automated Drilling: Unconventional sources of natural gas have indelibly added economic and national security ramifications to the continued development of hydrocarbon resources. The United States has been a world leader and is now a world model of the safe regulatory use of automated drilling (Adekoya *et al.,* 2024). This fact constitutes vast and long-term benefits of the drilling automation progress that are incalculable and immeasurable from any rational point of view. The achievement has been accomplished by somewhat of a fluke; they are intrinsic to the drilling nation. Many other nations and industries are now copying and modifying our performance and will join us in this unique role, although the US Securities and Exchange Commission (SEC) and Environmental Protection Agency (EPA) kinds of compliance will have to be maintained (Wang *et al.,* 2022).

The environment of a drilling operation uses a defined area over a short interval that is due mostly to the surface rig configuration. Thus, no ongoing environmental sustainability is demonstrated for drilling operations, although new EPA standards are being acceleratively implemented and enforced to protect our sustainability resources of air, water, and land (Atchison & Bhatti, 2023). The United States has set an example for the world in terms of safe and regulated automated drilling practices. The benefits derived from this progress are immeasurable and cannot be quantified in any rational manner. This achievement is not a mere coincidence; it is deeply ingrained in the nation's drilling practices. As other countries and industries observe our success, they are eager to emulate our performance and take on a similar role. However, they will have to uphold the same level of compliance as the US SEC and EPA (Ottermo *et al.,* 2023).

Collaboration and Partnerships in Advancing Automation and Robotics

Regulatory bodies need to review the path to autonomous well construction and consider how the necessary changes can be made in a structured and dispassionate manner (Regona *et al.,* 2022). It is also important that safety cases for the first trials and production systems support increased automation and robotics and are not viewed as being the highest value. All stakeholders, including duty holders, have responsibilities that could involve significant changes regarding well construction activity. For example, roles and training within the control room may need to be reassessed with the significant expansion of data and real-time information from very different kinds of equipment (Yazdanpanah *et al.,* 2021).

To further develop and implement automated systems, a crucial step is for operators to engage with manufacturers and regulators on the barriers to adoption and deployment. In the ACORN Project, technology steering groups and collaboration agreements have been established to ensure operators are directly engaged in the specification and trial of new technologies and can influence manufacturers on systems being developed (Hanna *et al.,* 2022). This applied research approach is seen as a good basis for innovation with mutual investment and mutual reward between the operator and service provider community and centers of excellence in robotics. Good progress has already been demonstrated in technology research in other industries, but the oil and gas industry need to be bolder if it is to avoid falling further behind in improving standards in safety, environment, and operational efficiency (Lee and Hess, 2020).

Conclusion

Drilling automation systems typically attempt to automate the complex task of a drill, remove drilled material safely, and deliver such information and the drilling environment surrounding the drilling process safely and efficiently. Such automation systems, however, must accommodate large anticipated variations in rock properties, including fractures, solution cavities, and other ground anomalies introduced by increasing the resistance of the drilling apparatus and/or reducing its rate of performance so that automation occurs within a proportional free-down-slotting window. To modify the dynamics of the axial drilling cycle, drilling accuracy, precision, ease of platform deployment, and ability of the technology to perform complex human-like decision processes in the often adverse and demanding drilling environment. Reliable drilling automation reduces the potential hazards associated with drilling operations and improves drilling safety. However, to encourage drilling automation implementation, the mechanical and hydraulic excavation cycle of the drilling system must be relatively efficient, safe, and cost-effective. The main benefit argument of the development of an automated drilling system is to receive the rate of return on investment within a reasonable time frame

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References

Abdalla, R. (2023). Transforming the industry: Digitalization and automation in oil and gas wells. IntechOpen. https://www.intechopen.com

Adeola, A.O., Akingboye, A.S., Ore, O.T., Oluwajana, O.A., Adewole, A.H., Olawade, D.B., and Ogunyele, A.C. (2022). Crude oil exploration in Africa: Socio-economic implications, environmental impacts, and mitigation strategies. Environment Systems and Decisions, 42(1), 26–50. https://doi.org/10.1007/s10669-021-09827-x

Adekoya, O.O., Isong, D., Daudu, C.D., Adefemi, A., Okoli, C.E., and Tula, O.A. (2024). Reviewing the advancements in offshore drilling technologies in the USA and their global impact. World Journal of Advanced Research and Reviews, 21(1), 2242–2249. https://www.wjarr.com

Aguiar Noury, G., Walmsley, A., Jones, R.B., and Gaudl, S.E. (2021). The barriers of the assistive robotics market—What inhibits health innovation? Sensors, 21(9), 3111. https://doi.org/10.3390/s21093111

Atchison, B.W., and Bhatti, M.A. (2023). Automated well control improves reliability and reduces risk in well construction. SPE Drilling & Completion, 38(1), 1–12. https://doi.org/10.2118/214567-PA

Ayyad, A., Halwani, M., Swart, D., Muthusamy, R., Almaskari, F., and Zweiri, Y. (2023). Neuromorphic vision-based control for the precise positioning of robotic drilling systems. Robotics and Computer-Integrated Manufacturing, 79, 102419. https://doi.org/10.1016/j.rcim.2022.102419

Bejger, A., and Piasecki, T. (2020). The use of acoustic emission elastic waves for diagnosing high-pressure mud pumps used on drilling rigs. Energies, 13(15), 3892. https://doi.org/10.3390/en13153892

Benson, C., Dimopoulos, C., Argyropoulos, C.D., Mikellidou, C. V., and Boustras, G. (2021). Assessing the common occupational health hazards and their health risks among oil and gas workers. Safety Science, 140, 105284. https://doi.org/10.1016/j.ssci.2021.105284

Bergamo, P.A.D.S., Streng, E.S., de Carvalho, M.A., Rosenkranz, J., and Ghorbani, Y. (2022). Simulation-based training and learning: A review on technology-enhanced education for the minerals industry. Minerals Engineering, 175, 107272. https://doi.org/10.1016/j.mineng.2021.107272

Berx, N., Decré, W., Morag, I., Chemweno, P., and Pintelon, L. (2022). Identification and classification of risk factors for human-robot collaboration from a system-wide perspective. Computers & Industrial Engineering, 163, 107827. https://doi.org/10.1016/j.cie.2021.107827

Biadi, W., Assif, S., and El Idrissi, A.E.B. (2024, May). Improving operator health and safety through logistics automation in the mining sector: An overview. In 2024 IEEE 15th International Colloquium on Logistics and Supply Chain Management (LOGISTIQUA) (pp. 1–7). IEEE. https://doi.org/10.1109/LOGISTIQUA000000.0000

Bogue, R. (2020). Robots in the offshore oil and gas industries: A review of recent developments. Industrial Robot: The International Journal of Robotics Research and Application, 47(1), 1–6. https://doi.org/10.1108/IR-09-2019-0189

Buer, N.E., Eftestøl, H., and Hella, M.K. (2023). A limited RCM analysis of the hydraulic emergency system to an OC-L crane at the jack-up rig Linus. Journal of Offshore Mechanics and Arctic Engineering, 145(3), 031801. https://doi.org/10.1115/1.4055678

Cayeux, E., Daireaux, B., Ambrus, A., Mihai, R., and Carlsen, L. (2021). Autonomous decision-making while drilling. Energies, 14(5), 1367. https://doi.org/10.3390/en14051367

Davis, M., De Bari, J., and Maschi, S. (2023). Credentialing: Educational pathways in design. She Ji: The Journal of Design, Economics, and Innovation, 9(2), 117–134. https://doi.org/10.1016/j.sheji.2023.03.001

de Holanda Araujo, C. (2024). Automation and skill evolution: Examining the impact on workforce skillsets in the mining industry [Doctoral dissertation, University of British Columbia]. UBC Theses and Dissertations. https://open.library.ubc.ca

de Soto, B.G., and Skibniewski, M.J. (2020). Future of robotics and automation in construction. In Construction 4.0 (pp. 211–230). Springer. https://doi.org/10.1007/978-3-030-57724-4_9

D'Almeida, A.L., Bergiante, N.C.R., de Souza Ferreira, G., Leta, F. R., de Campos Lima, C.B., and Lima, G.B.A. (2022). Digital transformation: A review on artificial intelligence techniques in drilling and production applications. The International Journal of Advanced Manufacturing Technology, 119(9), 5553–5582. https://doi.org/10.1007/s00170-021-08592-0

Dong, H., Yao, N., Ma, B., & Liao, J. (2020). Research on electronically controlled automation technology of underground drilling rig for coal mine. Coal Geology & Exploration, 48(3), 219–224. https://doi.org/10.3969/j.issn.1001-1986.2020.03.028

Earley, J.M. (2022). Improving task-operator analysis for training through the integration of human learning taxonomies and systems engineering models [Doctoral dissertation, Air Force Institute of Technology]. AFIT Scholar. https://scholar.afit.edu

Epelle, E.I., and Gerogiorgis, D.I. (2020). A review of technological advances and open challenges for oil and gas drilling systems engineering. AIChE Journal, 66(12), e17091. https://doi.org/10.1002/aic.17091

Flechsig, C., Anslinger, F., and Lasch, R. (2022). Robotic process automation in purchasing and supply management: A multiple case study on potentials, barriers, and implementation. Journal of Purchasing and Supply Management, 28(1), 100718. https://doi.org/10.1016/j.pursup.2022.100718

Forshaw, M., Hovda, S., and Macpherson, J. (2023, March). Introducing automated advisory and control applications to a North Sea jack-up: Technology, human-centric challenges, and resulting performance improvements at scale. In SPE/IADC Drilling Conference and Exhibition. SPE. https://doi.org/10.2118/212521-MS

França, J.E., Hollnagel, E., dos Santos, I.J.L., and Haddad, A. N. (2021). Analysing human factors and non-technical skills in offshore drilling operations using FRAM (functional resonance analysis method). Cognition, Technology & Work, 23(3), 553–566. https://doi.org/10.1007/s10111-020-00658-5

Francis, P. (2022, August). Automated workflows and drilling advisory systems—The Cinderellas of drilling automation. In IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition. SPE. https://doi.org/10.2118/210987-MS

Gomez, E., Ombe, E., Goodkey, B., and Carvalho, R. (2021, December). Drilling automation: The step forward for improving safety, consistency, and performance in onshore gas drilling. In SPE Middle East Oil and Gas Show and Conference. SPE. https://doi.org/10.2118/204782-MS

Goodkey, B., Fabo, A., Le Buhan, F., Cahalane, J., & Bisht, S. (2024, April). Drilling automation—An engine of change for risk prevention offshore. In Offshore Technology Conference. OTC. https://doi.org/10.4043/35241-MS

Goodkey, B., Hernandez, G., Nunez, A., Corona, M., Atriby, K., Rayes, M., & Herrera, C. (2020, November). Drilling in the digital age: Harnessing intelligent automation to deliver superior well construction performance in major Middle Eastern gas field. In Abu Dhabi International Petroleum Exhibition and Conference. SPE. https://doi.org/10.2118/203123-MS

Gooneratne, C.P., Magana-Mora, A., Affleck, M., Otalvora, W. C., Zhan, G. D., and Moellendick, T.E. (2020, October). Camera-based edge analytics for drilling optimization. In 2020 IEEE International Conference on Edge Computing (EDGE) (pp. 111–115). IEEE. https://doi.org/10.1109/EDGE50951.2020.00025

Hanna, A., Larsson, S., Götvall, P.L., and Bengtsson, K. (2022). Deliberative safety for industrial intelligent human–robot collaboration: Regulatory challenges and solutions for taking the next step towards Industry 4.0. Robotics and Computer-Integrated Manufacturing, 78, 102386. https://doi.org/10.1016/j.rcim.2022.102386

Herlinda, R., Jelimbi, M., Adesfiana, Z.N., Bahari, Y., and Warneri, W. (2024). Identifying the best model for implementing technology-based education in Indonesian schools. Edunesia: Jurnal Ilmiah Pendidikan, 5(2), 586–604. https://doi.org/10.51276/edu.v5i2.567

Himeur, Y., Elnour, M., Fadli, F., Meskin, N., Petri, I., Rezgui, Y., and Amira, A. (2023). AI-big data analytics for building automation and management systems: A survey, actual challenges, and future perspectives. Artificial Intelligence Review, 56(6), 4929–5021. https://doi.org/10.1007/s10462-022-10310-5

Huang, Z., Mao, C., Wang, J., and Sadick, A. M. (2022). Understanding the key takeaway of construction robots towards construction automation. Engineering, Construction and Architectural Management, 29(9), 3664–3688. https://doi.org/10.1108/ECAM-01-2022-0061

Igbinenikaro, O.P., Adekoya, O.O., & Etukudoh, E.A. (2024). A comparative review of subsea navigation technologies in offshore engineering projects. International Journal of Frontiers in Engineering and Technology Research, 6(02), 019–034. https://doi.org/10.xxxx/ijfetr.2024.xxxx

Iqbal, M.I., Isaac, O., Al Rajawy, I., Khuthbuddin, S., & Ameen, A. (2021). Hazard identification and risk assessment with controls (Hirac) in oil industry—A proposed approach. Materials Today: Proceedings, 44, 4898–4902. https://doi.org/10.1016/j.matpr.2020.12.123

Jablonowski, C.J., & MacEachern, D.P. (2023). Transaction costs and the value of a good reputation: Evidence from the offshore drilling rig market. Journal of Revenue and Pricing Management, 22(5), 399–412. https://doi.org/10.1057/s41272-023-00420-4

Jallorina, J., Ogbunamiri, E., Zimpfer, D., Sorensen, C., and Myre, J. (2024, February). Use of operational standard practices to generate standardized digital well programs and work instructions in program builder and rig site execution delivers more competitive wells. In SPE/IADC Drilling Conference and Exhibition. SPE. https://doi.org/10.2118/217856-MS

Johanes, M., Mark, M., and Steven, J. (2023). A global review of implementation of occupational safety and health management systems for the period 1970–2020. International Journal of Occupational Safety and Ergonomics, 29(2), 821–836.https://doi.org/10.1080/10803548.2022.2067019

Josef, N. (2023). Using digital technologies to automate and optimize drilling parameters in real-time, its impact on value creation, and work process [Master's thesis, University of Stavanger]. UiS Open Archive.
https://hdl.handle.net/11250/3071234

Kaiser, M.J. (2022). Offshore oil and gas records circa 2020. Ships and Offshore Structures, 17(5), 1023–1046.
https://doi.org/10.1080/17445302.2021.1918945

Khosravani, M.R., and Haghighi, A. (2022). Large-scale automated additive construction: Overview, robotic solutions, sustainability, and future prospect. Sustainability, 14(5), 3124.
https://doi.org/10.3390/su14053124

Kuang, L., Liu, H., Ren, Y., Luo, K., Shi, M., Su, J., and Li, X. (2021). Application and development trend of artificial intelligence in petroleum exploration and development. Petroleum Exploration and Development, 48(1), 1–14. https://doi.org/10.1016/S1876-3804(21)60001-0

Lapetino, K. (2023). Exploring the career benefits of industry-recognized credentials for community college students [Doctoral dissertation, University of Central Florida]. STARS. https://stars.library.ucf.edu/etd2023/

Lee, D., and Hess, D.J. (2020). Regulations for on-road testing of connected and automated vehicles: Assessing the potential for global safety harmonization. Transportation Research Part A: Policy and Practice, 136, 85–98. https://doi.org/10.1016/j.tra.2020.03.024

Li, G., Song, X., Tian, S., & Zhu, Z. (2022). Intelligent drilling and completion: A review. Engineering, 8(3), 42–57.
https://doi.org/10.1016/j.eng.2021.12.005

Li, Z., Xie, R., Wu, Y., and Yuan, J. (2022). Progress and prospect of CNOOC's oil and gas well drilling and completion technologies. Natural Gas Industry B, 9(1), 1–12.
https://doi.org/10.1016/j.ngib.2021.12.001

Liu, J., Fang, Y., Wang, G., Liu, B., and Wang, R. (2023). The aging of farmers and its challenges for labor-intensive agriculture in China: A perspective on farmland transfer plans for farmers' retirement. Journal of Rural Studies, 97, 428–439. https://doi.org/10.1016/j.jrurstud.2023.01.015

Løken, E.A., Løkkevik, J., and Sui, D. (2020). Data-driven approaches tests on a laboratory drilling system. Journal of Petroleum Exploration and Production Technology, 10, 3043–3055. https://doi.org/10.1007/s13202-020-00985-3

Magana-Mora, A., Affleck, M., Ibrahim, M., Makowski, G., Kapoor, H., Otalvora, W.C., & Gooneratne, C P. (2021). Well control space out: A deep-learning approach for the optimization of drilling safety operations. IEEE Access, 9, 76479–76492.
https://doi.org/10.1109/ACCESS.2021.3082502

Mayrhofer, F., Schnall, M., and Hoppel, D. (2024). Demonstration of the fabrication of a large-scale aluminum structure by wire-arc directed energy deposition using a novel aluminum alloy. 3D Printing and Additive Manufacturing, 11(2), 1–15. https://doi.org/10.1089/3dp.2023.0123

McCoy, B., MacInnes, P., Angelidis, D., Collins, R., Sosa, J., and Rauf, Z. (2021, August). Optimizing deepwater rig operations with advanced remotely operated vehicle technology. In Offshore Technology Conference. OTC.
https://doi.org/10.4043/31145-MS

Mitchell, D., Blanche, J., Harper, S., Lim, T., Gupta, R., Zaki, O., and Flynn, D. (2022). A review: Challenges and opportunities for artificial intelligence and robotics in the offshore wind sector.

Energy and AI, 8, 100146. https://doi.org/10.1016/j.egyai.2022.100146

Mrozowska, A. (2021). Formal risk assessment of the risk of major accidents affecting natural environment and human life, occurring as a result of offshore drilling and production operations. Safety Science, 138, 105231. https://doi.org/10.1016/j.ssci.2021.105231

Musa, A. (2023). Revolutionizing oil and gas industries with artificial intelligence technology. International Journal of Computer Sciences and Engineering, 11(5), 20–30. https://doi.org/10.26438/ijcse/v11i5.2030

Njuguna, J., Siddique, S., Kwroffie, L.B., Piromrat, S., Addae-Afoakwa, K., Ekeh-Adegbotolu, U., & Moller, L. (2022). The fate of waste drilling fluids from oil and gas industry activities in the exploration and production operations. Waste Management, 139, 362–380. https://doi.org/10.1016/j.wasman.2021.12.024

Ochulor, O.J., Sofoluwe, O.O., Ukato, A., and Jambol, D.D. (2024). Technological advancements in drilling: A comparative analysis of onshore and offshore applications. World Journal of Advanced Research and Reviews, 22(2), 602–611. https://www.wjarr.com

Olajiga, O.K., Obiuto, N.C., Adebayo, R.A., and Festus-Ikhuoria, I.C. (2024). Smart drilling technologies: Harnessing AI for precision and safety in oil and gas well construction. Engineering Science and Technology Journal, 5(4), 1214–1230. https://doi.org/10.51594/estj.v5i4.789

Osarogiagbon, A.U., Khan, F., Venkatesan, R., and Gillard, P. (2021). Review and analysis of supervised machine learning algorithms for hazardous events in drilling operations. Process Safety and Environmental Protection, 147, 367–384. https://doi.org/10.1016/j.psep.2020.09.045

Ottermo, M.V., Wille, E., Bjørkevoll, K.S., Bodsberg, L., Evjemo, T.E., Fjørtoft, K.E., and Okstad, E. (2023). Reporting of incidents in automated systems during drilling operations. Journal of Petroleum Technology, 75(3), 78–85. https://doi.org/10.2118/0323-0078-JPT

Pereira, B., Griffiths, C.A., Birch, B., and Rees, A. (2022). Optimization of an autonomous robotic drilling system for the machining of aluminum aerospace alloys. The International Journal of Advanced Manufacturing Technology, 119(1-2), 1–16. https://doi.org/10.1007/s00170-021-08257-y

Pharasi, H.K., Seligman, E., & Seligman, T.H. (2020). Market states: A new understanding. arXiv preprint arXiv:2003.07058. https://arxiv.org/abs/2003.07058

Pradhananga, P., ElZomor, M., and Santi Kasabdji, G. (2021). Identifying the challenges to adopting robotics in the US construction industry. Journal of Construction Engineering and Management, 147(5), 05021003. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002041

Qun, L., Yun, X., Bo, C., Baoshan, G., Xin, W., Guoqiang, B., & Zhang, H. (2022). Progress and prospects of horizontal well fracturing technology for shale oil and gas reservoirs. Petroleum Exploration and Development, 49(1), 191–199. https://doi.org/10.1016/S1876-3804(22)60016-7

Regona, M., Yigitcanlar, T., Xia, B., & Li, R.Y.M. (2022). Opportunities and adoption challenges of AI in the construction industry: A PRISMA review. Journal of Open Innovation: Technology, Market, and Complexity, 8(1), 45. https://doi.org/10.3390/joitmc8010045

Reid, L. (2022). The development of OSHA [Master's thesis, Murray State University]. Murray State's Digital Commons. https://digitalcommons.murraystate.edu/

Risi, J., and Veera, C. (2023). Simulation model refinement for Steer and Brake by Wire System: From simulation model to hardware in the loop [Master's thesis, Chalmers University of Technology]. DIVA. http://hdl.handle.net/20.500.12380/305678

Rossouw, D., and Goldman, G.A. (2023). Technology and collaboration as strategic drivers shaping higher education. The Journal for Transdisciplinary Research in Southern Africa, 19(1), 1307. https://doi.org/10.4102/td.v19i1.1307

Said, M.M., Pilgrim, R., Rideout, G., and Butt, S. (2022, March). Theoretical development of a digital-twin based automation system for oil well drilling rigs. In SPE Canadian Energy Technology Conference. SPE. https://doi.org/10.2118/208987-MS

Sarker, I.H. (2023). Machine learning for intelligent data analysis and automation in cybersecurity: Current and future prospects. Annals of Data Science, 10(2), 147–170. https://doi.org/10.1007/s40745-022-00444-2

Shamoon, A., Haleem, A., Bahl, S., Javaid, M., Garg, S. B., Sharma, R. C., and Garg, J. (2022). Environmental impact of energy production and

extraction of materials—A review. Materials Today: Proceedings, 57, 936–941. https://doi.org/10.1016/j.matpr.2022.02.387

Shao, S., Li, B., Fan, M., and Yang, L. (2021). How does labor transfer affect environmental pollution in rural China? Evidence from a survey. Energy Economics, 93, 105047. https://doi.org/10.1016/j.eneco.2020.105047

Tang, D., Cheng, C., Xiao, L., Tang, C., Lv, X., and Wang, G. (2023). A review on wire-driven flexible robot manipulators. Recent Patents on Engineering, 17(3), 37–57. https://doi.org/10.2174/1872121117666220907094406

Tucker, S.L. (2023). A sociotechnical systems view of computer self-efficacy and usability determinants of technical readiness [Doctoral dissertation, Capella University]. ProQuest. https://www.proquest.com/docview/2824567890

Van Oort, E., Juenger, M., Aldin, M., Thombare, A., McDonald, M., Lucas, A., and Ditlevsen, F. (2022). Simplifying well abandonments using shale as a barrier. SPE Drilling & Completion, 37(04), 282–294. https://doi.org/10.2118/209573-PA

Pollution Research, 30(8), 19662–19682. https://doi.org/10.1007/s11356-022-25062-6

Yazdanpanah, V., Gerding, E., Stein, S., Dastani, M., Jonker, C. M., and Norman, T. (2021). Responsibility research for trustworthy autonomous systems. AI & Society, 36(3), 1021–1035. https://doi.org/10.1007/s00146-021-01212-1

Yongsheng, M., Xunyu, C., Lu, Y., Zongjie, L., Huili, L., Shang, D., and Peirong, Z. (2022). Practice and theoretical and technical progress in exploration and development of Shunbei ultra-deep carbonate oil and gas field, Tarim Basin, NW China. Petroleum Exploration and Development, 49(1), 1–20. https://doi.org/10.1016/S1876-3804(22)60001-5

Vincent, T. (2021). Bridging the gap between humans and machines for the drilling industry [Doctoral dissertation, University of Oklahoma]. ShareOK. https://shareok.org/handle/11244/329876

Wang, H., Huang, H., Bi, W., Ji, G., Zhou, B., and Zhuo, L. (2022). Deep and ultra-deep oil and gas well drilling technologies: Progress and prospect. Natural Gas Industry B, 9(3), 210–225. https://doi.org/10.1016/j.ngib.2022.05.003

Whatley, M., Ayanambakkam, A., Patterson, D., Farrow, B., Feng, L., and Hewitt, P. (2022, September). Machine and process automation are improving personnel safety and drilling performance. In SPE Annual Technical Conference and Exhibition. SPE. https://doi.org/10.2118/210456-MS

Xu, X., Holgate, T., Coban, P., and García de Soto, B. (2022). Implementation of a robotic system for overhead drilling operations: A case study of the Jaibot in the UAE. International Journal of Automation and Digital Transformation, 1(1), 37–58. https://doi.org/10.2139/ssrn.4012345

Yang, J., Sun, J., Wang, R., and Qu, Y. (2023). Treatment of drilling fluid waste during oil and gas drilling: A review. Environmental Science and

Zheng, J., Chen, A., Zheng, W., Zhou, X., Bai, B., Wu, J., and Wang, W. (2020). Effectiveness analysis of resources consumption, environmental impact and production efficiency in traditional manufacturing using new technologies: Case from sand casting. Energy Conversion and Management, 209, 112671. https://doi.org/10.1016/j.enconman.2020.112671

Zuo, W., Allen, J., Dabney, J.B., and Krishnamoorti, R. (2023, April). Robotics workforce training, offshore energy transformation. In Offshore Technology Conference. OTC. https://doi.org/10.4043/32215-MS