Exploring the Challenges of IoT-Based Predictive Maintenance Strategies for Operational Efficiency in Oil and Gas Industry in Malaysia

Sumayyah Murad[1], Ivy Deirdre Mangkau[2], Mohamad Zamhari Tahir[3]

[1]Faculty of Technology Management and Technopreneurship, Universiti Teknikal Malaysia Melaka,

[2]Sekolah Asasi Teknikal dan Pengajian Diploma, Universiti Teknikal Malaysia Melaka,

[3]Faculty of Entrepreneurship and Business, Universiti Malaysia Kelantan

***Corresponding Author:**

DOI: https://doi.org/10.47772/IJRISS.2026.101000356

Received: 13 October 2026; Accepted: 21 October 2026; Published: 03 November 2026

ABSTRACT

The oil and gas industry increasingly adopts Internet of Things (IoT) technologies for predictive maintenance to improve operational efficiency. However, implementation faces significant challenges in real-world operational contexts. This qualitative study explores the challenges, activities, and impacts of IoT-based predictive maintenance in Malaysia's oil and gas industry through semi-structured interviews with four experienced practitioners (9-30 years' experience) in maintenance and pipeline operations. Findings reveal three primary challenges: data accuracy and sensor reliability issues, false alarms from IoT systems, and integration difficulties with legacy infrastructure. Key activities include continuous monitoring via IoT/SCADA systems, alarm management, manual verification alongside automated monitoring, and data analysis for maintenance coordination. Despite challenges, practitioners reported positive impacts including improved decision-making, reduced downtime, cost savings, and enhanced safety. The study emphasizes that successful IoT implementation requires a hybrid approach combining automated monitoring with human expertise rather than full automation. These findings provide practical insights for industry practitioners and contribute to understanding the gap between IoT's theoretical capabilities and operational realities in Malaysia's oil and gas industry.

Keywords: IoT; Predictive Maintenance; Oil and Gas; Operational Efficiency; Qualitative Research

INTRODUCTION

The oil and gas industry represents one of the most critical and complex sectors globally, requiring advanced technologies for production and distribution processes (Burclaff, 2021). To remain competitive and efficient, companies increasingly adopt digital technologies such as Internet of Things (IoT), artificial intelligence, and predictive analytics to optimize operations and reduce downtime (Arinze et al., 2024). The global market for these innovations is projected to grow from USD 2.5 billion in 2024 to USD 9.3 billion by 2034 (Market.US, 2025).

Predictive maintenance has gained significant attention across asset-intensive sectors like oil and gas. It involves continuously tracking the state and functionality of vital equipment using real-time monitoring technology, such as sensors and IoT devices (Babayeju et al., 2024). By analyzing data collected from these devices, organizations can detect early signs of wear, stress, or malfunction, allowing timely maintenance interventions before complete failure occurs.

In Malaysia, the oil and gas sector plays a crucial role in driving the national economy. The industry has

actively embraced digital transformation by adopting predictive maintenance strategies powered by IoT technologies through strategic partnerships and deployment of private 5G networks (TM One, 2024). Despite these efforts, recurring incidents such as pipeline leaks and equipment failures reveal persistent weaknesses in detection, monitoring, and emergency response systems (The Edge Malaysia, 2025; SOGCE, 2025).

While IoT-based predictive maintenance offers benefits such as real-time monitoring and early fault detection, its effectiveness is limited by data accuracy issues, sensor reliability problems, false alarms, integration challenges with legacy systems, and continued reliance on human verification. Most IoT studies in the oil and gas industry use quantitative methods and fail to incorporate real-world insights from industry workers (Yusuf et al., 2024; Waqar et al., 2023). This study addresses this gap by exploring the operational challenges, key activities, and real impacts of IoT-based predictive maintenance through qualitative insights from maintenance specialists, pipeline managers, operations supervisors, and process engineers working directly with IoT systems in Malaysia's oil and gas industry.

LITERATURE REVIEW

IoT-based predictive maintenance represents a significant technological advancement in industrial asset management, combining real-time sensor data, advanced analytics, and automated monitoring systems to optimize maintenance operations. This section reviews existing literature on IoT-based predictive maintenance in the oil and gas industry, focusing on three key areas: the challenges encountered during implementation, the essential activities involved in successful deployment, and the impacts on operational efficiency. Understanding these aspects provides the theoretical foundation for examining how IoT-based predictive maintenance functions in Malaysia's oil and gas operational context and helps identify gaps between theoretical expectations and practical realities.

Challenges of IoT-Based Predictive Maintenance in Oil and Gas Industry

The implementation of IoT-based predictive maintenance in the oil and gas industry faces several significant challenges. Cybersecurity risks represent a major concern as IoT devices connect various parts of operations, exposing critical infrastructure to cyber-attacks that can lead to data breaches, system malfunctions, and safety hazards (Ramzey et al., 2023; Waqar et al., 2023). Integration challenges arise when modern IoT technologies must interact with legacy systems not originally designed for such connectivity, complicating implementation and delaying adoption (Abran & Christopher, 2024; Solanke et al., 2024).

Data management presents another challenge, as IoT systems generate massive amounts of data that can be difficult to manage and analyze efficiently (Waqar, Alharbi et al., 2023). Without effective data management systems, organizations struggle to gain useful insights quickly and integrate data into decision-making processes. Staffing and training gaps create barriers to implementation, as IoT-driven maintenance systems demand a multidisciplinary workforce with expertise in IT, data analytics, and engineering (Tariq & Khan, 2024; Yusuf et al., 2024). Finally, cost and scalability concerns affect especially smaller operators, as high initial costs of implementing IoT infrastructure, sensors, and data management systems create financial barriers (Solanke et al., 2024; Zakaria et al., 2024).

Activities of IoT-Based Predictive Maintenance in Oil and Gas Industry

IoT-based predictive maintenance involves several key activities that improve equipment management in the oil and gas industry. Real-time monitoring through IoT sensors continuously tracks critical equipment performance, monitoring parameters like pressure, temperature, and flow rates to identify early signs of failure (Juliet et al., 2024; Elete et al., 2024). Predictive analytics combines IoT systems with advanced data analytics to predict when maintenance is required by analyzing both real-time and historical data, enabling proactive rather than reactive maintenance (Arinze et al., 2024; Odili et al., 2024).

Remote monitoring and control capabilities enable equipment oversight in hard-to-reach or hazardous areas

like offshore rigs, reducing the need for onsite inspections and increasing safety (Anaba et al., 2024; Elete et al., 2024). System integration ensures data compatibility between various platforms like IoT sensors, SCADA, and AI tools, enabling effective data combination and analysis (Juliet et al., 2024; Anaba et al., 2024). Automated anomaly detection powered by AI and machine learning continuously analyzes data to detect irregular patterns or potential failures, allowing companies to prioritize maintenance and avoid unnecessary interventions (Juliet et al., 2024; Odili et al., 2024).

Impacts of IoT-Based Predictive Maintenance in Oil and Gas Industry

IoT-based predictive maintenance delivers several significant impacts on operational efficiency in the oil and gas industry. Downtime reduction occurs through early detection of potential failures before they happen, allowing proactive maintenance that avoids unplanned disruptions (Elozana & Adaku, 2025; Arinze et al., 2024) predicting faults and scheduling repairs at optimal times, IoT improves asset performance particularly in critical infrastructure (Wanasinghe et al., 2020; Cheng et al., 2024).

Cost savings result from performing maintenance based on real-time data rather than fixed schedules, avoiding costly repairs and extending equipment life (Huang et al., 2024; Aneke & Oboho, 2024). Automated data collection and real-time analysis reduce the need for frequent manual inspections, eliminating resource wastage and lowering operating costs (Egbumokei et al., 2024). Equipment lifespan extension occurs through real-time monitoring that enables condition-based maintenance rather than fixed-interval approaches, ensuring machinery operates at optimal levels and preventing excessive wear (Stepanov, 2024; Rahman et al., 2024).

Improves safety and risk management comes from continuous monitoring of critical parameters like pressure, temperature, and gas emissions, ensuring early hazard detection and reducing accident risk (Anaba et al., 2024; Elete et al., 2024). Remote monitoring systems provide vital data to mitigate risks associated with oil and gas extraction, enabling quicker emergency responses and improving compliance with safety regulations (Tariq & Khan, 2024; Zuo & Qi, 2021). Finally, improved decision-making results from real-time, actionable insights into operational performance, with IoT integration enabling smart data analytics that leads to more informed decisions regarding asset health, resource allocation, and scheduling (Juliet et al., 2024; Waqar et al., 2023).

METHODOLOGY

This section outlines the research methodology employed to explore the challenges, activities, and impacts of IoT-based predictive maintenance in Malaysia's oil and gas industry. A qualitative approach was adopted to capture in-depth insights from practitioners with direct experience in implementing and managing IoT systems. The methodology encompasses the research design, participant selection strategy, data collection procedures through semi-structured interviews, and the thematic analysis process used to identify key patterns and themes from the interview data.

Research Design

This study adopts a qualitative research approach to explore the experiences and perceptions of practitioners involved in IoT-based predictive maintenance at oil and gas companies in Malaysia. Qualitative research is suitable for exploring complex phenomena by observing, documenting, analyzing, and interpreting characteristics, patterns, and meanings associated with human behaviors (Makateng & Mokala, 2025). This approach provides in-depth descriptions of context and individual experiences, allowing deeper understanding of the dynamics at play in IoT-based predictive maintenance implementation. The study employed purposive expert sampling to focus on relevant participants within the oil and gas workforce. From the Maintenance Department cluster identified as most relevant to the research topic, four individuals were selected consisting of engineers and technicians directly involved in equipment maintenance and pipeline operations. This sampling approach ensures participants have hands-on experience and practical insights aligned with the study objectives (Sedgwick, 2014). The respondents possess professional experience

ranging from 9 to 30 years in the oil and gas industry, providing valuable insights based on substantial practical knowledge. This study employed purposive expert sampling to recruit participants with relevant professional experience in equipment maintenance and operational activities within Malaysia's oil and gas industry. The selection criteria focused on participants' direct involvement in maintenance, pipeline operations, process supervision, or engineering activities relevant to IoT-based predictive maintenance. The four participants held different professional roles and possessed between 9 and 30 years of industry experience, enabling the study to draw on perspectives from different areas of operational practice (refer Table 1). The decision to include four participants was guided by the exploratory nature of the study and the aim of obtaining detailed accounts from practitioners with relevant industry experience. Rather than seeking statistical representativeness, the study sought to develop an in-depth understanding of participants' experiences and perceptions of the challenges, activities, and operational impacts associated with IoT-based predictive maintenance. Nevertheless, the small sample size limits the breadth of perspectives represented and should be considered when interpreting the findings.

Table 1: Job roles and years of experience

Participant	Professional role	Industry experience
A	Maintenance Specialist	30 years
B	Pipeline Manager	17 years
C	Operation Supervisor	10 years
d	Process Engineer	9 years

Interview Design

Data was collected through semi-structured interviews conducted via Google Meet. Each session lasted between approximately 30 minutes to 2 hours and was recorded using two mobile devices as a precaution against technical failures. An interview guide was used to maintain consistency while allowing flexibility in responses, ensuring a structured yet open environment for respondents to share their views freely (Saunders et al., 2016/2023). The interview questions were organized into three parts: background information about respondents' roles, responsibilities, and experience; main questions addressing challenges, activities, and impacts based on the research objectives; and future outlook questions. The semi-structured format allowed the researcher to ask follow-up questions and seek clarification where necessary while maintaining alignment with the research objectives. Interview questions were developed by referring to Johnson (2025) and Zakaria et al. (2024), ensuring alignment with the study's research questions on IoT-driven predictive maintenance.

The interview data were analysed using thematic analysis. Following transcription, the transcripts were read and re-read to familiarise the researcher with the participants' accounts. Initial codes were then developed in Taguette software to identify meaningful statements relating to the research objectives. Codes with similar meanings were compared and grouped into subthemes, which were subsequently organised into three overarching themes: challenges, activities, and impacts of IoT-based predictive maintenance. The coding process focused on identifying recurring patterns as well as differences in participants' experiences. The emerging themes were reviewed against the coded extracts and the original transcripts to assess whether they adequately represented the interview data. The final thematic structure was used to organise the findings presented in the Results and Discussions section. The study also examined the occurrence of themes across participants. The original analysis retained themes appearing in at least three of the four interviews. This frequency criterion was used as an indicator of recurrence within the dataset rather than as the sole measure of analytical credibility. Less frequently reported experiences, where relevant, should also be considered to avoid overlooking important differences between participants.

Assessment of Sample Adequacy

Sample adequacy was assessed by examining the richness and relevance of the interview data in relation to the research questions. During analysis, the researchers compared the codes and themes identified across the four interviews to determine whether subsequent interviews contributed new concepts or substantially

extended existing themes. The assessment considered both the recurrence of patterns and the depth of information provided by participants. Given the small sample and the focused group of experienced practitioners, the findings are interpreted as exploratory insights rather than an exhaustive account of IoT-based predictive maintenance across the Malaysian oil and gas industry.

RESULTS AND DISCUSSIONS

The findings presented in this section are derived from the thematic analysis of semi-structured interviews with four experienced operational personnel in Malaysia's oil and gas industry, who are coded as Respondents A, B, C, and D. These respondents include a Maintenance Specialist (30 years' experience), Pipeline Manager (17 years' experience), Operation Supervisor (10 years' experience), and Process Engineer (9 years' experience). The analysis revealed that IoT-based predictive maintenance implementation is characterized by three distinct dimensions: the operational challenges encountered during system deployment, the key activities essential for effective implementation, and the significant impacts on operational efficiency. A comprehensive summary of the developed themes and their associated codes is presented in Table 3.

Table 3: Summary of Thematic Analysis Findings

Main Themes	Sub-Themes	Key Codes
Challenges in using IoT-Based predictive maintenance	Technical Challenges	• Data accuracy & sensor issues • False alarms from IoT system
	Integration Challenges	• Integration with legacy/existing systems
Activities in IoT-based predictive maintenance	Monitoring activities	• Continuous monitoring using IoT/SCADA • Alarm monitoring & management
	Inspection activities	• Manual verification & physical inspection
	Analysis activities	• Data analysis & maintenance coordination
Impact of IoT-Based predictive maintenance	Operational Impacts	• Improved operational decision-making • Reduced downtime/shutdown prevention
	Financial Impacts	• Cost reduction & cost control
	Safety Impacts	• Improved safety & risk mitigation

Theme1: Challenges in Using IoT-Based Predictive Maintenance in Oil and Gas Industry

Data Accuracy and Sensor Reliability Issues

All respondents identified data accuracy and sensor reliability as primary concerns. Respondent C, who oversees retail station operations, explained that sensor readings often do not match manual measurements: "The first challenge I can say is data accuracy. For this data accuracy, I don't know whether to say my station tank has problems or the sensor has problems. Because compared to before when we did manual dipping, there was already instability." This uncertainty undermines confidence in technology, as staff cannot fully rely on sensor reading.

Respondent D confirmed similar issues across larger operations: "For pressure and temperature, those are the most important parameters we monitor in the process. Sometimes the challenge is data accuracy. Sometimes readings are not precise or required data cannot be detected." Respondent A, with 30 years of maintenance experience, emphasized that sensor reliability issues relate to environmental exposure: "Sensors are exposed to the environment. So, they need to be checked, sensors need regular checking, sometimes they're faulty. So, when they're faulty then they need to do what's called data drift, they need to do preventive maintenance like that."

These findings strongly support existing literature regarding data reliability challenges (Babayeju et al., 2024; Waqar et al., 2023). However, while literature emphasized data volume management, practitioners

focused more on data quality and reliability. The environmental exposure factor adds a practical dimension not prominently discussed in reviewed literature, particularly relevant in Malaysia's tropical environment where sensors face extreme temperatures, humidity, corrosion, and vibration

False Alarms from IoT Systems

Most respondents mentioned false alarms as a disruptive challenge affecting operations. Respondent D described how gas detector sensitivity triggers unnecessary alarms: "For gas detectors, when they detect something, we usually have issues with the sensors. For example, sensor sensitivity. Sometimes it's not an actual gas leak but it gives false alarms. And this can impact production." She explained that false alarms cause two major problems: unnecessary production shutdowns resulting in financial losses, or operators becoming less responsive and risking overlooking real emergencies.

Respondent C shared similar concerns: "The fuel truck should arrive today, but the fuel in the tank is at an appropriate level. It doesn't seem critically low. But in the ATG system, it detects very low levels. So that's one challenge regarding the sensor part." This mismatch between sensor warnings and actual conditions forces operational staff to conduct manual verification before taking action, reducing efficiency gains that IoT systems promise.

This challenge represents a gap in existing research, as the literature review did not explicitly address false alarm issues and their operational consequences. The concern about alarm fatigue, where repeated false alarms may cause operators to become less responsive to real emergencies, presents a serious safety risk in the oil and gas industry.

Integration with Legacy Systems

All respondents discussed challenges integrating IoT technologies with existing operational infrastructure. Respondent B, who manages pipeline operations, described compatibility issues: "The issue now is, sometimes between old and new systems, what's happening now is we're forced to use something like a modem. For example, if we use A brand IoT, we must use A brand modem to interpret data to our computer. Right? So, this results in us having to rely on only one contractor."

This vendor lock-in situation creates both technical and commercial problems. Technically, companies must maintain multiple incompatible systems when equipment from different manufacturers cannot communicate. Commercially, dependence on single vendors reduces negotiating power and potentially increases long-term costs. Respondent A described communication reliability challenges: "There are issues about communication, how it communicates, whether it sends signals or not. So, these signals communicate, do these signals arrive or not".

These findings align with integration challenges identified in literature (Abran & Christopher, 2024; Solanke et al., 2024). However, practitioners emphasized vendor lock-in and interoperability issues more strongly than reviewed literature, suggesting that standardization and open communication protocols should be prioritized in IoT system design.

Importantly, several challenges emphasized in literature were not prominently mentioned by practitioners. Cybersecurity risks and staffing gaps, highlighted by Ramzey et al. (2023) and Tariq & Khan (2024), did not emerge as immediate operational challenges. This suggests these issues may be addressed at different organizational levels (IT departments, human resources) rather than being visible as daily obstacles to field staff.

Theme 2: Activities in IoT-Based Predictive Maintenance in Oil and Gas Industry

The findings demonstrate that successful IoT-based predictive maintenance depends on several key operational activities: continuous monitoring, alarm management, manual verification, and data analysis coordination.

Continuous Monitoring Using IoT and SCADA Systems

All respondents emphasized continuous 24/7 monitoring as the foundation of predictive maintenance strategy. Respondent B explained SCADA system functions: "SCADA function has two purposes. First, it allows us to remotely operate some systems from our control system. For example, we sit in Kimanis, but we can control any valve opening or closing from there all the way to Sarawak. So that's SCADA. Besides that, we can use SCADA for communication, communication with our tools and we see, we collect data on the pressure and temperature of the system."

Respondent A described monitored parameters: "If there is IoT or SCADA detection system, they provide or collect data online. Online means they detect flow, temperature, pressure, and sometimes they are so intelligent they detect pipe thickness, they detect internal piping conditions." This continuous parameter monitoring allows companies to track equipment health trends over time rather than relying solely on periodic inspections.

These findings strongly align with real-time monitoring activities discussed in literature (Juliet et al., 2024; Elete et al., 2024). However, practitioners provided more specific technical details about SCADA integration and parameter selection than general descriptions found in literature.

Alarm Monitoring and Management

All respondents highlighted alarm management as critical activity requiring immediate response protocols. Respondent B provided detailed descriptions of control room procedures: "When there's an anomaly, first, if the person is called a panel operator, when there's an anomaly there will be a siren 'wee wee wee.' That's a process upset, meaning there's an anomaly in the process. So, lights will flash like police cars. So, the panel operator's responsibility is to look at the screen and verify."

He also explained tiered alarm systems: "In the system we have low-low settings. Low-low settings mean when equipment reaches the lowest setting point. For example, we operate at 80 bar, we set 60 bar. When there's a leak, if pressure drops to 60, it will automatically trigger the valve to close." These automated responses provide immediate equipment protection without requiring human intervention, critical during emergencies.

While literature discussed anomaly detection (Juliet et al., 2024; Odili et al., 2024), it did not extensively discuss the human-centered alarm management activities that practitioners emphasized. This finding extends literature by showing that effective IoT-based predictive maintenance depends on well-designed human machine interfaces and response protocols, not just sensor technology and data analytics.

Manual Verification and Physical Inspection

Despite advanced IoT capabilities, all respondents emphasized that manual verification remains essential. Respondent C explained continuing need for manual measurements: "Yes, correct. Still need manual dipping to ensure the fuel in the tank matches what the sensor shows. So, since sensor installation, we've definitely noticed it often differs from manual dipping."

Respondent D confirmed verification protocols apply across operations: "Yes, normally we will definitely double-check first when there's an alert. The emergency or operations team will go to the location to ensure the alarm is accurate or not." Respondent A described detailed inspection schedules: "In one year, there are weekly inspections, monthly inspections, quarterly inspections, six monthly inspections, and yearly inspections."

This finding reveals an important reality not fully addressed in literature. While literature discussed remote monitoring capabilities reducing onsite inspections (Anaba et al., 2024; Elete et al., 2024), practitioners emphasized that IoT has not eliminated manual verification but created a hybrid approach combining automated and human inspection. The continued reliance on manual verification stems from data accuracy

challenges discussed earlier.

Data Analysis and Maintenance Coordination

Most respondents discussed activities involving analyzing IoT data and coordinating maintenance actions. Respondent A explained how maintenance planners use data patterns: "This data is given to maintenance people like me, we have trending or patterns from point A to point B, we found corrosion. So, it gives data, meaning when given for planning, planning means okay we plan when we want to do it, when we want to replace this part."

Respondent B described predictive failure calculations: "We do that year, we calculate based on the corrosion present, when failure will occur. For example, in 10 more years, the deepest corrosion will cause leakage if nothing is done." These activities align with predictive analytics discussed in literature (Arinze et al., 2024; Odili et al., 2024), but practitioners provided more detailed descriptions of how data analysis supports organizational coordination between operations, maintenance, and engineering teams.

Theme 3: Impact of IoT-Based Predictive Maintenance in Oil and Gas Industry

Despite technical challenges, IoT-based predictive maintenance delivers positive impacts on operational efficiency across four key areas: improved decision-making, reduced downtime, cost savings, and enhanced safety.

Improved Operational Decision-Making

All respondents emphasized how IoT data improves both decision quality and speed. Respondent A explained: "This IoT data analyzer really, really helps maintenance people from a decision-making perspective. The data we receive in real time really helps a lot. Imagine if there's no IoT or sensors, no SCADA, how can we read it, because this data provides input on equipment for us to take action."

Respondent B described how IoT systems pinpoint problems and solutions: "Automatically if there's a problem we immediately know where and we can directly rectify it because IoT will propose to us what steps we need to take. So, we save time." These findings strongly align with improving the decision-making discussed in literature (Juliet et al., 2024; Waqar et al., 2023; Arinze, Ajala, et al., 2024).

Reduced Downtime and Shutdown Prevention

Most respondents highlighted how early problem detection prevents expensive production interruptions. Respondent B explained financial benefits: "Imagine if there's downtime, meaning the compressor trips for two days. So, we've lost how many millions. Millions, lost. But with IoT, we can save. We don't need to shut down. Maybe we can directly repair."

Respondent A referenced the Putra Heights incident: "For example, like recent incident, the leak had already happened, but the people controlling hadn't noticed yet, but the sensors had already informed about pressure drop, compression trip, gas leak. So, it had detected early." These findings validate downtime reduction benefits discussed in literature (Elozana & Adaku, 2025; Arinze et al., 2024; Wanasinghe et al., 2020).

Cost Reduction and Cost Control

Most respondents shared specific cost savings examples. Respondent B provided detailed financial comparisons: "Imagine if for two weeks, we have to pay per day people need to bring two technicians and one supervisor, two technicians for example one day RM800, times two equals RM1,600, one supervisor RM2,200, plus RM5,000 for example, accommodation RM4,000, they need to work two weeks, we've already spent RM36,000 for mobilization alone, not including their tools, hotels, and so on. But with IoT, within one to two hours we can settle it."

He also described unmanned platform operations: "What we did in, previously we had to send people to the platform, so every day people stayed there to operate. Now, because oil is running out, gas is also running out, we cannot keep people working there because we have to pay salaries. So, we removed all people, and we control remotely from land or from another offshore location."

These findings strongly support cost reduction impacts discussed in literature (Huang et al., 2024; Aneke & Oboho, 2024; Egbumokei et al., 2024), with practitioners providing concrete financial examples that validate and quantify theoretical benefits.

Improved Safety and Risk Mitigation

Most respondents highlighted safety improvements as key benefits. Respondent A strongly emphasized detection systems' importance: "Protect before it happens. Protect people, protect environment before disaster. We really, really need this IoT detection system for piping, really, really need it. Without this system we cannot sustain in this business."

Respondent B explained how incidents drive technology adoption: "Because if an incident like the recent happens again, the companies will be damaged in terms of image, and safety of course. So, we need to explore whether there's new technology that makes it easier for us to find problems. Because first of all, we want safety."

These findings align closely with improved safety and risk management impacts discussed in literature (Anaba et al., 2024; Elete et al., 2024; Tariq & Khan, 2024), with practitioners' emphasis on safety being particularly strong and emotionally resonant, reflecting the industry's recognition that safety is a fundamental operational necessity.

CONCLUSION

This study explored the challenges, activities, and impacts of IoT-based predictive maintenance in Malaysia's oil and gas industry through qualitative insights from experienced practitioners. The findings reveal that while IoT based predictive maintenance offers significant benefits, implementation faces notable operational challenges that differ from those emphasized in academic literature. Three primary challenges emerged: data accuracy and sensor reliability issues caused by harsh environmental conditions, false alarms leading to operational disruptions and potential alarm fatigue, and integration difficulties with legacy systems creating vendor lock-in situations. Interestingly, challenges emphasized in literature such as cybersecurity risks and staffing gaps were not prominent in practitioner experiences, suggesting these may be addressed at different organizational levels. Activities supporting IoT-based predictive maintenance include continuous 24/7 monitoring via IoT and SCADA systems, alarm management with tiered response protocols, manual verification and physical inspection alongside automated monitoring, and data analysis supporting maintenance coordination across teams. The persistence of manual verification activities indicates that IoT systems augment rather than replace human expertise, creating hybrid approaches that combine technological capabilities with human judgment. Despite challenges, practitioners reported strong positive impacts including improved operational decision making through real-time equipment data, reduced downtime preventing expensive production interruptions, significant cost savings through remote troubleshooting and targeted repairs, and improved safety through early hazard detection. These impacts validate theoretical expectations discussed in literature while providing concrete operational examples from Malaysia's oil and gas context. The study contributes practical insights into the gap between IoT's theoretical capabilities and operational realities. Successful implementation requires not only technological investment but also attention to data reliability, effective human-technology collaboration models, realistic expectations about system capabilities, and organizational processes supporting both automated monitoring and human expertise. For industry practitioners, prioritizing sensor calibration programs, developing comprehensive alarm management systems, addressing integration challenges through standardization, and maintaining hybrid verification approaches are essential. This study has several limitations. First, the findings are based on interviews with four practitioners selected through purposive expert sampling. Although the participants

possessed substantial industry experience, the small sample limits the range of professional perspectives represented. Second, the extent to which the findings reflect experiences across different organisations, offshore and onshore operations, and technical functions remains uncertain. The findings should therefore be interpreted as exploratory insights derived from the participating practitioners rather than as representative conclusions for the entire Malaysian oil and gas industry. Future research could expand the sample to include practitioners from multiple organisations, maintenance teams, offshore and onshore operations, and specialised technical and cybersecurity functions. A broader range of participants would enable comparisons across operational contexts and provide a more comprehensive understanding of the challenges associated with implementing IoT-based predictive maintenance. Future research should focus on operational-level experiences, human-technology collaboration models, false alarm management strategies.

ACKNOWLEDGEMENT

The authors would like to express their appreciation to Universiti Teknikal Malaysia Melaka (UTeM) for providing the resources and academic support required to conduct this research. We also like to express our gratitude to our peer reviewers and colleagues for their insightful comments and valuable suggestions which have significantly improved on the quality and readability of this manuscript.

REFERENCES

1. Abran, T., & Christopher, G. (2024, December 30). Monitoring Oil Pipelines with IoT Technology. ResearchGate. https://www.researchgate.net/publication/387531487_Monitoring_Oil_Pipelines_with_IoT_Technology
2. Ahmed, S. K., Mohammed, R. A., Nashwan, A. J., Ibrahim, R. H., Abdalla, A. Q., Ameen, B. M. M., & Khdhir,R. M. (2025). Using thematic analysis in qualitative research. Journal of Medicine, Surgery, and Public Health, 6(6), 100198. ScienceDirect. https://doi.org/10.1016/j.glmedi.2025.100198
3. Anaba, D. C., Kess-Momoh, A. J., & Ayodeji, S. A. (2024). Digital transformation in oil and gas production: Enhancing efficiency and reducing costs. International Journal of Management & Entrepreneurship Research, 6(7), 2153–2161. https://doi.org/10.51594/ijmer.v6i7.1263
4. Aneke, A., & Oboho, E. (2024). Enhancing operational efficiency in Nigerian oil exploration: The impact of real-time monitoring technologies on non-productive time. Journal of Sustainable Development of Transport and Logistics, 9(2), 43–52. https://doi.org/10.14254/jsdtl.2024.9-2.4
5. Arinze, C. A., Ajala, O. A., Okoye, C. C., Ofodile, O. C., & Daraojimba, A. I. (2024). EVALUATING THE INTEGRATION OF ADVANCED IT SOLUTIONS FOR EMISSION REDUCTION IN THE OIL AND GAS SECTOR. Engineering Science & Technology Journal, 5(3), 639–652. https://doi.org/10.51594/estj.v5i3.862
6. Arinze, C. A., Onuegbu, V., Isong, D., Daudu, C. D., Adefemi, A., & Izionworu. (2024). Predictive maintenance in oil and gas facilities, leveraging ai for asset integrity management. International Journal of Frontiers in Engineering and Technology Research, 6(1), 016–026. https://doi.org/10.53294/ijfetr.2024.6.1.0026
7. Babayeju, O. A., Adefemi, A., Ekemezie, I. O., & Sofoluwe, O. O. (2024). Advancements in predictive maintenance for aging oil and gas infrastructure. World Journal of Advanced Research and Reviews, 22(3), 252– 266. https://doi.org/10.30574/wjarr.2024.22.3.1669
8. Burclaff, N. (2022, August). Research Guides: Oil and Gas Industry: A Research Guide: Introduction. Library of Congress. https://guides.loc.gov/oil-and-gas-industry
9. Cheng, Y.-T., Lin, J.-H., & Tang, S.-T. (2024). The prototype design is based on IoT and integrates physiological information and gas monitoring alarms. IET Conference Proceedings., 2024(22), 154–155. https://doi.org/10.1049/icp.2024.4327
10. Egbumokei, P. I., Dienagha, I. N., Digitemie, W. N., Onukwulu, E. C., & Oladipo, O. T. (2024, January 1). The role of digital transformation in enhancing sustainability in oil and gas business operations. Allmultidisciplinaryjournal.com. https://www.allmultidisciplinaryjournal.com/search?q=MGE-2025-1-066&search=search
11. Elete, T. Y., Nwulu, E. O., Erhueh, O. V., Akano, O. A., & Aderamo, A. T. (2024). Digital

transformation in the oil and gas industry: A comprehensive review of operational efficiencies and case studies. International Journal of Applied Research in Social Sciences, 6(11), 2611–2643. https://doi.org/10.51594/ijarss.v6i11.1692

12. Elozana, E. A., & Adaku, D. G. (2025). Impact of Internet of Things (IOT) and Artificial Intelligence (AI) on National Development Through Science and Technology; A Systematic Review. Preprints.org. https://doi.org/10.20944/preprints202501.0933.v1
13. Huang, Z., Zhao, H., Nan, Z., Ma, H., Li, X., Li, H., & Nie, S. (2024). Application and practice of industrial IoT cloud platform in oilfield intelligent transformation. Journal of Physics Conference Series, 2874(1), 012004–012004. https://doi.org/10.1088/1742-6596/2874/1/012004
14. Johnson, O. (2025, January 13). A Qualitative Study of IoT-Enabled Predictive Maintenance and Its Influence on Supply Chain Sustainability. Preprints.org. https://www.preprints.org/frontend/manuscript/53c611335fac0c86f9429018fce3451e/download_pub
15. Juliet, A. Hency., Legapriyadharshini, N., & Malathi, P. (2024). IoT Enhanced Resilience: Advanced AI Technique for Leak Detection and Predictive Maintenance in Oil and Gas Pipeline. ResearchGate. https://doi.org/10.1109/iccsp60870.2024.10544329
16. Makateng, D. S., & Mokala, N. T. (2025). Understanding Qualitative Research Methodology: A Systematic Review. E-Journal of Humanities, Arts and Social Sciences, 6(3), 327–335. https://doi.org/10.38159/ehass.2025637
17. Market.US. (2025, January). IoT in Oil and Gas Market. Market.us. https://market.us/report/iot-in-oil-and-gas-market/
18. Odili, P. O., Daudu, C. D., Adefemi, A., Ekemezie, I. O., & Usiagu, G. S. (2024). INTEGRATING ADVANCED TECHNOLOGIES IN CORROSION AND INSPECTION MANAGEMENT FOR OIL AND GAS OPERATIONS. Engineering Science & Technology Journal, 5(2), 597–611. https://doi.org/10.51594/estj.v5i2.835
19. Rahman, S. M. M., Oyon, Md. S. S., Ahmed, A., Ahamed, I., & Hazari, R. (2024). An IoT-Based Autonomous System for Oil Spill Detection. Emerging Science Innovation, 4, 41–55. https://doi.org/10.46604/emsi.2024.13760
20. Ramzey, H., Badawy, M., Elhosseini, M., & A. Elbaset, A. (2023). I2OT-EC: A Framework for Smart Real-Time Monitoring and Controlling Crude Oil Production Exploiting IIOT and Edge Computing. Energies, 16(4), 2023. https://doi.org/10.3390/en16042023
21. Saunders, M., Lewis, P., & Thornhill, A. (2023). Research Methods for Business Students (9th ed.). Pearsonhttps://www.researchgate.net/publication/240218229_Research_Methods_for_Business_Students (Original work published 2016)
22. Sedgwick, P. M. (2014). Cluster sampling. BMJ, 348(jan31 2), g1215–g1215. https://doi.org/10.1136/bmj.g1215 SOGCE. (2025, January 30). Sabah to retain gas after Petronas decommissions 11-year-old pipeline to Sarawak. Sabahoilandgas. https://www.sabahoilandgas.com.my/post/sabah-to-retain-gas-after-petronas-decommissions-11-year-old-pipeline-to-sarawak
23. Solanke, B., Onita, F. B., Ochulor, O., & Iriogbe, H. O. (2024). Comprehensive safety protocols and best practices for oil and gas drilling operations. International Journal of Frontline Research in Engineering and Technology, 2(1), 010–020. https://doi.org/10.56355/ijfret.2024.2.1.0018
24. Stepanov, M. (2024). Digitalization of Adjustment and Maintenance Processes for Optimizing Energy Consumption in the Oil and Gas Sector. Bulletin of Science and Practice, 10(11), 126–132. https://doi.org/10.33619/2414-2948/108/16
25. Tariq, B., & Khan, J. (2024). IoT-Based Predictive Maintenance in Industrial Environments. ResearchGate. https://www.researchgate.net/publication/387085050_IoT Based_Predictive_Maintenance_in_Industrial_Environments
26. The Edge Malaysia. (2025, February 3). Frankly Speaking: Shutdown of SSGP warrants scrutiny. The Edge Malaysia. https://theedgemalaysia.com/node/742982
27. TM One. (2024, August 9). Petronas and TM Drive Successful Private 5G Network Deployment at Petronas LNG Complex Bintulu. TM One. https://www.tmone.com.my/press-release/petronas-and-tm-drive-successful-private-5g-network-deployment-at-petronas-lng-complex-bintulu/?utm_source=chatgpt.com

28. Wanasinghe, T. R., Gosine, R. G., James, L. A., Mann, G. K. I., de Silva, O., & Warrian, P. J. (2020). The Internet of Things in the Oil and Gas Industry: A Systematic Review. IEEE Internet of Things Journal, 7(9), 8654–8673. https://doi.org/10.1109/jiot.2020.2995617
29. Waqar, A., Alharbi, L. A., Abdullah Alotaibi, F., Othman, I., & Almujibah, H. (2023). Impediment to implementation of Internet of Things (IOT) for oil and gas construction project Safety: Structural equation modeling approach. Structures, 57, 105324. https://doi.org/10.1016/j.istruc.2023.105324
30. Waqar, A., Khan, M. B., Shafiq, N., Skrzypkowski, K., Zagórski, K., & Zagórska, A. (2023). Assessment of Challenges to the Adoption of IOT for the Safety Management of Small Construction Projects in Malaysia: Structural Equation Modeling Approach. Applied Sciences, 13(5), 3340. https://doi.org/10.3390/app13053340
31. Yusuf, S. I., Nabil, E. I., & Liao, I. Y. (2024). Evaluating the Potential Adoption of Blockchain and IoT in Nigeria's Oil and Gas Industry Sector: A Technology Acceptance Model Approach. ResearchGate, 1–7. https://doi.org/10.1109/smartblock4africa61928.2024.10779542
32. Zakaria, H. M., Lazim, H. M., & Iteng, R. (2024). A Qualitative Approach to Understanding the Effect of Technology Adoption on the Middle East Upstream Oil and Gas Company's Operational Performance.PaperAsia, 40(3b), 161–168. https://doi.org/10.59953/paperasia.v40i3b.117
33. Zuo, Y., & Qi, Z. (2021). A Blockchain-Based IoT Framework for Oil Field Remote Monitoring and Control. IEEE Access, 10, 2497–2514. https://doi.org/10.1109/access.2021.3139582