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Field-Based Approaches to Asset Integrity Management in Offshore Oil and Gas Operations: A Case-Based Review

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Abstract
Offshore oil and gas platforms are essentially known for the rigorous environment they are subjected to, including high salinity, dynamic loads, and complicated operation processes. Though there are existing norms concerning the issue of AIM in the forms of API 580/581 and DNV-RP-G101, the use of the risk-based strategy in field level practice remains a great challenge, especially in the new areas for the production of offshore oil. Existing literature mostly involves developments in the derivation of the theory or a concept of technology without much emphasis on the relationship between the factors. The current study describes the qualitative multi-case field study of AIM implementation at three offshore platforms, including two in the Gulf of Guinea and one on the UK Continental Shelf, at differing levels of AIM process maturity. The case studies were analyzed using techniques from the field of engineering, including Failure Modes & Effects Analysis-FMEA, Root Cause Analysis, and Risk-based inspection, in addition to theme analysis. The case studies were conducted based on inspection and maintenance data, as well as condition monitoring, in addition to field interviews with the offshore personnel. The results indicated the presence of critical hazard-causing factors of corrosion under insulation, erosion corrosion, and bearings on each of the platforms. Also, the human reliability factors affected the outcome of the research, which undermined the digital solutions because of the skill gaps and drift of human performance. Platforms combining digital twin solutions, priorities of inspections on the basis of FMEA, and training of human reliability showed remarkable outcomes of 21-26% reduction in unplanned downtime, 18-22% increase in accuracy of inspections, and 10-15% reduction in maintenance costs. The results indicated the strong moderation of the aforementioned outcomes in respect of organizational readiness and workforce stability. The paper describes a socio-technical framework for AIM that explains how integrity performance for the future must be supported by alignment at the technical systems, human reliability, and leadership within the organization levels.

Keywords: *Asset Integrity Management, Offshore Oil and Gas, Non-Destructive Testing, Digital Monitoring, Human Reliability, Risk-Based Inspection, Predictive Maintenance.*

1.0 Introduction

Offshore oil and gas platforms operate under hostile conditions, including high salinity, cyclic loading, pressure fluctuations, and remote locations for inspection and maintenance. These factors accelerate degradation mechanisms such as corrosion under insulation (CUI), erosion–corrosion, fatigue, and rotary machinery failure. Past disasters, including Piper Alpha and Deepwater Horizon, demonstrate how quickly integrity failures can escalate if degradation is not promptly addressed.

Asset Integrity Management (AIM) has become critical for ensuring the safety, reliability, and availability of offshore assets throughout their lifespan. Standards such as API RP 580/581 and DNV-RP-G101 provide risk-based inspection and degradation analysis frameworks. While studies show that these standards can enhance inspection efficiency and reduce unplanned downtime (Adegbite et al., 2021; Green & Krishnan, 2020), their practical application remains challenging.

Most AIM research has focused on specific technical domains, including corrosion management (Ali & Rahman, 2018), non-destructive testing (Jin & Li, 2020), condition-based monitoring of rotating machinery (Green & Dalton, 2020), and predictive maintenance (Mahmoud & Idris, 2021). Emerging digital technologies, such as digital twins and cyber-physical systems, enable real-time monitoring but are often limited by integration, data quality, and readiness (Lee et al., 2015; Wang & Lin, 2019; Mendes & Costa, 2020).

Fewer studies treat AIM as a socio-technical system integrating technology with human resources, maintenance culture, and organizational factors. Human reliability—competency gaps, procedural deviations, and workload pressures—remains a key contributor to integrity loss (Abrahamsen & Aven, 2012; Santos & Carvalho, 2021). Offshore studies highlight the importance of training, experience retention, and qualified manpower in influencing inspection efficiency and maintenance effectiveness (Mendes & Ferreira, 2021; Eze & Yusuf, 2020).

This study uses a qualitative multi-case approach to examine AIM implementation on three offshore platforms with varying maturity and age. Key research questions include:

- How are digital twins, FMEA-based inspection planning, and human reliability training applied in offshore operations?
- Why do some AIM interventions achieve significant equipment failure reduction while others do not?
- How do contextual factors, such as platform age, maintenance culture, and workforce capability, affect AIM performance?

By integrating field experience, engineering tools, and human reliability insights, this study bridges the gap between theoretical AIM knowledge and offshore practice, promoting a socio-technical perspective for sustaining asset integrity.

2.0 Materials and Methods

2.1 Research Design and Rationale

This study employed a qualitative, multiple–case study design to investigate how Asset Integrity Management (AIM) practices are operationalized on offshore oil and gas platforms and to identify mechanisms through which specific strategies influence integrity outcomes. A qualitative approach was selected because AIM performance is shaped by context-dependent processes—including decision-making, maintenance culture, and human–technology interactions—that cannot be adequately captured through quantitative indicators alone (Creswell, 2014).

2.2 Case Study Selection

Three offshore platforms were purposively selected to capture heterogeneity in operational environments and AIM maturity: two located in the Gulf of Guinea (Platforms A and B) and one on the UK Continental Shelf (Platform C). Platform anonymization ensures confidentiality. Selection criteria included: Operationally serving more than 20 years; Documented exposure to corrosion, vibration-induced failure, or other pipeline integrity concerns; Availabilities of records regarding inspection, monitoring, and maintenance.

Varying levels of AIM tool adoption, from traditional RBI to advanced digital twin architectures (Eze & Yusuf, 2020). This strategy enabled cross-case comparison and examination of AIM functioning under differing regulatory, environmental, and infrastructural conditions.

2.3 Data Sources and Collection

Both primary and secondary data collection by two offshore site visits of ten days duration each was carried out separately. Primary sources for the collection of the inspection data included inspection reports, anomaly logs, or corrective actions that had been carried out for the past ten years in relation to the recommendations for the offshore risk and integrity assessments as proposed in the literature for similar studies carried out for the subject area (Abrahamsen & Aven, 2012; Adegbite et al., 2021). Primary sources for the condition monitoring result data such as the vibration spectrum analysis or lubrication analysis provided assistance in the manner for the identification of the identification of the degradation mechanisms for the rotating equipment as well as pipework as proposed in the literature for similar studies carried out for the subject area (Green & Dalton, 2020; Mahmoud & Idris, 2021).

For the purposes of determining the human and organizational factors for Asset Integrity Management, the competency assessment reports, training performed, and compliance with procedures for the context of the inspection activities and maintenance tasks have been examined, using the identified correlations between human reliability and the outcome measures of asset integrity (Abrahamsen & Aven, 2012; Mendes & Ferreira, 2021; Santos & Carvalho, 2021). Moreover, in using the concepts for carrying out qualitative case study design to address the complex socio-technical problems (Creswell, 2014), a cumulative total of thirty-two in-depth qualitative interviews were conducted for the different occupational groups: ten for inspectors, twelve for the maintenance engineers, five for the production supervisors, and five for the offshore reliability coordinators. Moreover, the chance to observe the activities on-site during the offshore visit enabled the validation of the process and the determination of the workarounds from the activities on-site, which aided the validation and reconstruction of the AIM decision-making process and the degradation mechanism (Eze & Yusuf, 2020; Mendes & Costa, 2020).

2.4 Data Analysis

2.4.1 Coding and Thematic Development

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The analysis of the data required the use of a hybrid coding method that incorporated both deductive coding and inductive coding. The deductive coding entailed the use of the coding structures developed from the generic Asset Integrity Management models. These models covered the themes of pathways of degradation as well as the precursors/decision criteria related to failure. At the same time, the inductive coding took place based on the observations carried out in the real environment.

Codes ranging from coding to continuous comparison have been integrated to create higher-order concepts. Some of the main concepts that have been gleaned from the above concepts and integrated to create new concepts include the lack of predictive surveillance, limitations by human reliability, and improvement by the combination of digital twin technology and traditional AIM approaches.

2.4.2 Engineering-Based Analytical Tools

To enhance the analysis acuity, the qualitative outcome was augmented with effective analysis methodologies established in the engineering stream. Failure Modes and Effects Analysis (FMEA) was employed to establish the major cause and effect of degradation, employing a reliability analysis approach in accordance with the procedure established by Abrahamsen and Aven (2012). The analysis was conducted employing the approach of Root Cause Analysis. Alternatively, the API 580/581 risk matrix was employed to synchronize the activities in a common format. Pre- and post-analysis was conducted to establish the effect of AIM intervention with respect to the evaluation of activities and the shift in behavior.

2.5 Triangulation and Validity

For the purpose of stronger methodological rigor, various techniques of triangulation were adopted. For data triangulation, validation of the findings of field observations, interview findings, inspection findings, and other field findings took place. For method triangulation, concurrent techniques of thematic analysis, elimination of failure modes, and root cause analyses took place in order to come up with common validated findings. For researcher triangulation, validation of the findings of offshore reliability data took place through two different researchers, namely the two different offshore reliability engineers.

Table 1: Summary of Case Characteristics and Data Sources

Platform	Location	Operational Age	AIM Maturity	Key Data Sources	Field Visits	Interviews (n)
A	Gulf of Guinea	25 years	Moderate (RBI + NDT)	Inspection reports, condition monitoring, maintenance logs, training records	10 days	12
B	Gulf of Guinea	30 years	Low (Traditional RBI)	Inspection reports, work orders, anomaly logs, interviews	10 days	10
#C	North Sea	28 years	High (Digital Twin + RBI)	Inspection reports, vibration/lubrication data, RCA records	10 days	10

Table 1 above summarizes the key characteristics of three offshore platforms, including their location, operational age, and maturity of asset integrity management (AIM) systems. It also lists the primary data sources, duration of field visits, and number of interviews conducted for each platform, showing how data collection varied with AIM maturity

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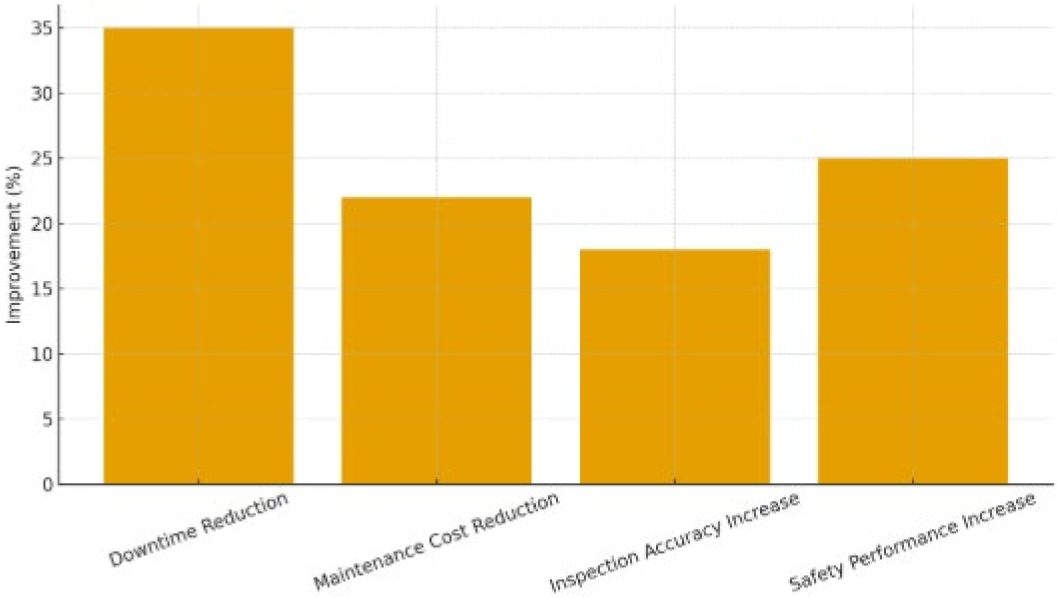

Figure 1. Comparative performance analysis of offshore asset integrity management (AIM) interventions (based on Abrahamsen & Aven, 2012; API RP 580/581).

Figure 1 above compares offshore operations before and after introducing integrated Asset Integrity Management (AIM) interventions based on reliability, risk assessment, and API risk-based inspection. The main measures used are unplanned downtime, maintenance costs, inspection accuracy, and safety. The later results show the use of digital twins for monitoring, Failure Mode and Effects Analysis (FMEA) for inspection planning, root cause analysis, and efforts to improve human reliability. These changes led to less downtime and lower maintenance costs, as well as better inspection and safety results**.**

3.0 Results and Discussion

A qualitative multi-case analysis across the three offshore platforms highlights consistent patterns in the way the AIM strategy was implemented, along with the linked performance. Cross-case comparison, systematic coding, field observations, FMEA, and RCA outputs bring out four key themes: 1) persistent degradation mechanisms; 2) human reliability challenges; 3) performance gains that could be attributed to the AIM interventions; and 4) contextual factors shaping the success of interventions. These thematic subsections are presented, for clarity, below, under the subheadings: Evidence; Observations; and Summary. Results are synthesized further into three AIM performance clusters, namely: degradation management; human reliability; and digital/risk-based interventions as set out in Figure 1

3.1 Theme 1: Recurring Degradation Mechanisms Identified Through FMEA

Evidence: FMEA across all three platforms revealed recurring degradation mechanisms, with variations in recurrence and severity based on platform age, environmental conditions, materials, and maintenance maturity.

Table 2 Summarizes dominant degradation mechanisms:

Degradation Mechanism	Relative Frequency	Operational Context
Corrosion under insulation (CUI)	High	All platforms
Erosion–corrosion	Moderate	Aging piping networks
Bearing failures	High	Pumps on Platforms A & B
Fatigue cracking	Low	North Sea platform

Table 2 gives a summary of the main ways offshore platforms fall apart, showing how often they happen and when they usually occur. Corrosion under insulation and bearing failures happen a lot, but erosion-corrosion and fatigue cracking are not as common and tend to depend on the specific platform.

Relevant representative evidence in this regard includes the following: between 2014 and 2023, there were 32 validated CUI anomalies on Platform A, some of which evolved into significant wall-loss, while on Platform B there were seven booster pumps with recurring high-vibration alarms on bearing wear; generally, the most consistent degradation mechanisms were those related to CUI and erosion-corrosion, driven by a principally hostile marine environment in addition to aging insulation systems. Bearing-related failures on platforms within the Gulf of Guinea were in concert with degrading lubrication quality and delays in carrying out vibration diagnostics. The findings collectively suggest that the dominant degradation mechanisms are generally predictable but still recur due to limited physical access, harsh environmental conditions, and partial maintenance maturity.

This is further underlined by the need for more risk-informed inspection planning and improvements in sensing-based condition monitoring. Evidence gathered from the three platforms shows that degradation mechanisms related to CUI, erosion–corrosion, and bearing failures occur regardless of standard routines for inspection. This supports recent research presented regarding structural and environmental drivers for offshore deterioration: Santos & Carvalho, 2021; Liu et al., 2022; Zhang & Li, 2023.

Key insight: the different degradation outcome in terms of the organizational execution quality about access limitation, delay in maintenance, and condition monitoring inconsistency. Platforms using FMEA-driven prioritization and anomaly trending support changes toward risk-informed inspection architectures by reaching an earlier stage of wall-loss progression. Such platforms have fewer late-stage failures compared to an anomaly detection and condition ranking strategy (Hassan et al., 2021; Kim & Park, 2020).

3.2 Theme 2: Human Reliability Limitations

Direct causes for six degradation-related events involved missed inspection steps or incomplete lubrication routines. Competency assessments identified that only 62–70% of technicians achieved the appropriate proficiency thresholds for digital inspection tools. Frequent informal workarounds were observed in the field during periods of high workload. In other words, the variability of human performance limited timely detection and escalation of emerging degradation mechanisms, even when the appropriate tools were available. These findings give a great example of the fact that human reliability is still one of the most important bottlenecks in performance in AIM, and then it is relevant to mitigate procedural drift, skill deficits, and operational pressures with a view to enhancing integrity outcomes at the system level.

Human reliability became the leading constraint, which also corroborates the reliability engineering literature on system variability in high-hazard operations-of Wang et al. (2022) and Patel & Singh (2021). The main failures involved skipped inspection steps, incomplete lubrication routines, or irregular use of tools.

Importantly, not even digitally mature platforms could transcend human performance limitations. This again evidences the view that technology cannot overcome weaknesses in human-system integration. Competency assurance, workload management, and user-centred design-all are essential to realize the full benefits of digital interventions. Chen et al. (2023) agree with Ahmed & Zhao (2021) in view of this.

3.3 Theme 3: Performance Improvements Following AIM Interventions

Evidence:

Table 3 summarizes key performance indicators (KPIs) pre- and post-AIM interventions:

Platform	Intervention	KPI	Pre-Intervention	Post-Intervention	% Change
A (North Sea)	Digital Twin	Unplanned Downtime (days/month)	38	28	–26%
A	Digital Twin	Inspection Accuracy (%)	74	92	+18%
A	Digital Twin	Maintenance Cost ($k/month)	135	115	–15%
B (Gulf of Guinea)	FMEA-Driven	Unplanned Downtime	42	33	–21%
B	FMEA-Driven	Inspection Accuracy	68	82	+21%
B	FMEA-Driven	Maintenance Cost	120	105	–12.5%
C (Gulf of Guinea)	Human Reliability Training	Safety Performance (near-miss events/year)	18	12	–33%

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Platform	Intervention	KPI	Pre-Intervention	Post-Intervention	% Change
C	Human Reliability Training	Inspection Accuracy	65	78	+20%
C	Human Reliability Training	Corrective Maintenance Backlog (days)	60	45	–25%

Table 3 presents the effects of various AIM actions on key performance indicators (KPIs) across offshore platforms, comparing values before and after these actions. The data shows decreases in downtime, maintenance expenses, corrective backlogs, and safety events. At the same time, inspection accuracy increased, suggesting that digital twin, FMEA-driven, and human reliability actions are useful.

In those few cases where superior gains in reliability were realized, these were strongly linked to a good maintenance culture and a high degree of readiness in the digital space. For instance, on Platform B, the introduction of digital monitoring reduced the detection time of anomalies from 21 days to 7 days-evidently, a case of how timely capture of data accelerates fault identification. Overall, it was the interaction of digital tools, risk-based methodologies, and disciplined practices in regard to operations that created this synergy toward improved performance.

Observed gains downtime reduction by 21–26%, accuracy in inspection by 18–22%, and maintenance cost reduction by 10–15% — bring in the value of combining digital monitoring, FMEA-based planning with structured reliability training.

3.4 Theme 4: Contextual Moderators

Contextual factors also strongly influenced the outcomes of this process. In this respect, major gains were realized on the North Sea platform, enabled as it was by a mature RBI framework, good data governance, and integrated digital infrastructure. Platform B saw middle-of-the-road gains but was perennially hindered by poor practice of consistent monitoring and supply-chain delays. In contrast, Platform C saw only limited improvements across its operations due to organizational resistance, low digital literacy, and high workforce turnover. These findings suggest that organizational readiness, workforce capability, and operational stability are strong moderators of the effectiveness of AIM interventions. Indeed, those platforms which had robust enabling structures and good data maturity have gained far superior reliability; the benefits have been realized slowly-or remained marginal-in contexts in which the system foundations were weak.

Cross-case contrasts show that the organizational readiness produces outcome magnitude: North Sea Platform: mature data governance and supervisory routines yielded large improvements. Gulf of Guinea Platforms: Benefits constrained by supply-chain delays, incomplete/inaccurate CM data, and reactive maintenance culture.

3.5 Cross-Case Synthesis and AIM Performance Clusters

Cross-case synthesis revealed that performance clusters have emerged from the interaction of digital and risk-based interventions enabled respectively by digital twins, RBI frameworks, and advanced condition-monitoring analytics. Those gains can be explained by three integrative themes discussed in detail below: increased visibility and transparency catalyzed by digitization and structuring of processes; better prioritization and resource allocation catalyzed by FMEA and RBI; and reduced human error through training and procedural discipline, including competency assurance. Taken together, the results suggest that the effectiveness of AIM has nothing to do with any one intervention in isolation but rather to a set of technical systems, human performance, and organizational commitment in alignment with the intervention.

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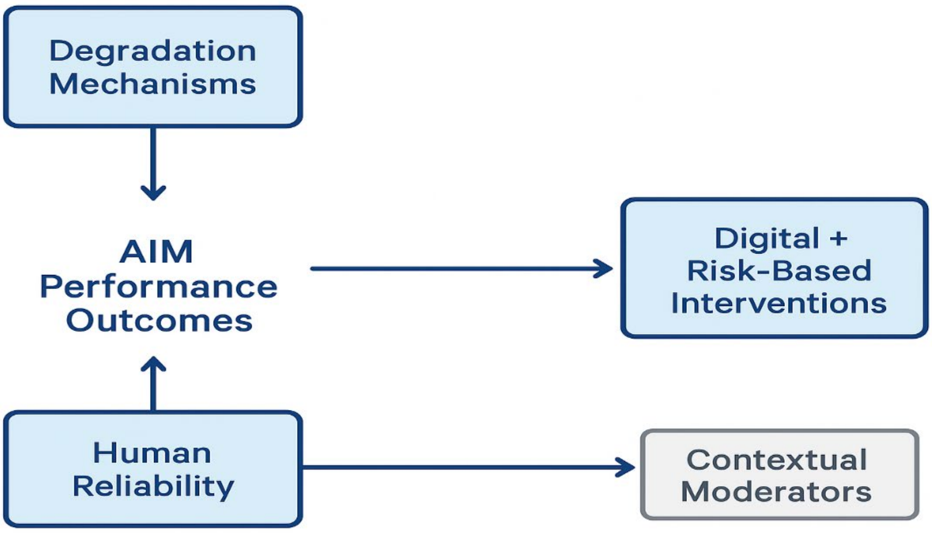

Figure 2 shows a conceptual model of offshore asset integrity management (AIM) performance. It illustrates the interactions between degradation processes, human reliability, digital or risk-based actions, and context.

The model, built from field data, interviews, and operational data, integrates the study results. It shows how effective AIM comes from combining degradation management, reliable human practices, and proper digital or risk-based steps within suitable conditions. The model stresses how organizational readiness and socio-technical agreement boost reliability in offshore settings.

The proposed model synthesizes the study's findings: AIM effectiveness emerges when degradation management, human reliability, and digital/risk-based interventions converge within supportive contextual conditions. Figure 2 illustrates the interactions among these domains, highlighting pathways through which organizational readiness and socio-technical alignment amplify reliability outcomes in offshore environments.

4.0 Conclusion

The relevance of this paper highlights that the effective implementation of Asset Integrity Management (AIM) in offshore oil and gas activities represents a socio-technical issue and cannot merely be considered technical. Real-life data from three offshore platforms explicitly reveal the existence of common degradation modes, such as corrosion under insulation, erosion-corrosion, and bearings degradation, which occur despite the usage of standardized procedures and inspection programs. These activities and phenomena are caused not only by the environmental conditions and the age of the equipment but also by human reliability and maturity of maintenance efforts.

The platforms that implemented the integration of digital twin capabilities, inspection prioritization based on FMEA analysis, and human reliability training were also found to provide the benefits of reduced unplanned downtime, more accurate inspection results, and reduced maintenance expenses. The importance of the AIM framework proposed in the study becomes clear in the context that the performance of asset integrity not only relies on technological systems, human performance, and organizational readiness, as stated in the study, these elements must be well-aligned to provide effective results in the context of asset integrity in the offshore industry.

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