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Determinant Preventive Maintenance Practices for Offshore Industrial Vessels Operations in Nigeria

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ABSTRACT

The maintenance of industrial vessels for offshore oil and gas operations is crucial for ensuring prevention of sudden breakdown incidents of vessels engaged in servicing the logistics needs of the oil and gas industry. The study used survey research design method and employed questionnaire and checklist as survey instruments for data collection. The population consists of sampled operators of industrial vessels that rated their extent of use and significances of seven basic preventive maintenance practices identified through critical literature review. The questionnaire elicited the operator's perceptions on the extent of influence of each preventive maintenance activity/practice in achieving reduced breakdown incident rates of offshore industrial vessels. The preventive maintenance practices identified include: Routine Cleaning of equipment and parts, Lubrication, Precision balancing, adherence to oil check/change schedules, accurate alignments, laser detuning/resonating and analysis of equipment lubricating oil quality and system. Primary data on the extent and significance of use of each of the preventive maintenance activities were obtained from the industrial vessel operators in Nigeria's offshore sector using purposive random sampling technique. The data obtained was analysed by the use of principal component factor analysis (PCA) in order to determine the determinant preventive maintenance practices. The results reveal that the determinant industrial vessel preventive maintenance operations by industrial vessel operators to limit the rate of sudden breakdown of industrial vessels include lubrication, accurate alignment, and adherence to oil change schedules, routine cleaning and precision balancing; with each having Eigenvalues of 2.456, 1.258, 1.245, 1.059 and 1.001. Since the identified preventive maintenance operations have Eigenvalues >1), the study infers that they constitute the determinant industrial vessel preventive maintenance operations/activities in the Nigerian offshore sector. It was recommended that offshore industrial vessel operators should prioritize the implementation of the determinant preventive maintenance practices on offshore industrial vessels in Nigeria.

Keywords: Offshore, industrial-vessels, preventive-maintenance, reliability

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Nijerya'daki Açık Deniz Endüstriyel Gemi Operasyonları için Belirleyici Önleyici Bakım Uygulamaları

ÖZ

Açık deniz petrol ve gaz operasyonlarında kullanılan endüstriyel gemilerin bakımı, sektörün lojistik ihtiyaçlarını karşılayan gemilerde ani arıza olaylarının önlenmesi açısından kritik öneme sahiptir. Bu çalışma, veri toplama aracı olarak anket ve kontrol listesi kullanılan anket araştırma yöntemini benimsemiştir. Araştırmaya katkı sunan sektör temsilcileri, kapsamlı bir literatür taraması yoluyla belirlenen yedi temel koruyucu bakım uygulamasının kullanım düzeyini ve önemini değerlendiren endüstriyel gemi operatörlerinden oluşmaktadır. Anket, operatörlerden her bir koruyucu bakım faaliyetinin/uygulamasının açık deniz endüstriyel gemilerindeki arıza oranlarını azaltmadaki etkisine ilişkin algılarını ortaya koymayı amaçlamıştır. Belirlenen koruyucu bakım uygulamaları şunlardır: ekipman ve parçaların rutin temizliği, yağlama, hassas dengeleme, yağ kontrolü/değişimi programlarına uyum, doğru hizalama, lazer detuning/rezonans ayarı ve ekipman yağlama yağı kalitesi ile sisteminin analizi. Her bir koruyucu bakım faaliyetinin kullanım düzeyi ve önemi hakkında birincil veriler, amaca yönelik rastgele örnekleme tekniği kullanılarak Nijerya açık deniz sektöründe faaliyet gösteren endüstriyel gemi operatörlerinden elde edilmiştir. Elde edilen veriler, belirleyici koruyucu bakım uygulamalarını tespit etmek amacıyla temel bileşenler analizi (PCA) ile değerlendirilmiştir. Araştırma sonuçları, endüstriyel gemi operatörleri tarafından ani arıza oranlarını azaltmaya yönelik belirleyici koruyucu bakım işlemlerinin; yağlama, doğru hizalama, yağ değişim programlarına uyum, rutin temizlik ve hassas dengeleme olduğunu göstermektedir. Bu uygulamaların her biri sırasıyla 2.456, 1.258, 1.245, 1.059 ve 1.001 şeklinde özdeğerler (Eigenvalues) üretmiştir. Belirlenen koruyucu bakım uygulamalarının özdeğerleri 1'in üzerinde olduğundan, çalışmada bunların Nijerya açık deniz sektöründe belirleyici koruyucu bakım faaliyetleri olduğu sonucuna varılmıştır. Çalışma, açık deniz endüstriyel gemi operatörlerinin, Nijerya'daki açık deniz operasyonlarında belirleyici nitelikteki bu koruyucu bakım uygulamalarının uygulanmasına öncelik vermeleri gerektiğini önermektedir.

Anahtar Kelimeler: Açık deniz, endüstriyel gemiler, önleyici bakım, güvenilirlik.

1 Introduction

The Nigerian offshore oil and gas industry is a critical component of the nation's economy. However, the operations of offshore industrial vessels in this sector are fraught with challenges, including equipment failures and downtime, which significantly impact productivity and profitability. To mitigate these issues, effective preventive maintenance (PM) practices are essential. This research aims to identify the determinant PM activities for successful use of PM practices in sustaining the seaworthiness of offshore industrial vessels operating in the Nigerian offshore industry. This is in seeking to provide valuable insights for industry stakeholders to enhance vessel reliability, safety, and operational efficiency. The offshore industrial sector in Nigeria plays a critical role in the nation's economy, particularly in relation to the oil and gas industry, which heavily depends on the operational efficiency and safety of offshore vessels. These vessels, including oil rigs, supply boats, and support vessels, are subjected to rigorous environmental conditions and long operational hours, necessitating reliable maintenance practices to prolong their lifespan and ensure safe operations (Yang et al., 2007).

In the perspectives of this study, PM entails the systematic care and servicing of critical vessel equipment and onboard accessories to prevent unexpected failures, sudden breakdown and extend the lifespan of ship machinery. While it covers operations such as scheduled inspections, adjustments, replacements, and servicing to mitigate risks associated with equipment failure, it can equally extent to lubrication of parts and implementation of original Equipment Manufacturers (OEM) directives,

procedures and guide lines related to the use of the industrial vessel types. In the context of offshore industrial vessel supply sector, effective preventive maintenance not only enhances operational efficiency but also safeguards human lives and the marine and coastal ecosystem (Yang et al., 2007).

Studies by Khazraei and Deuse (2011), Velmurugan and Dhingra (2015) and Aluko (2019) are in agreement that the basic preventive maintenance activities or operations implemented onboard industrial vessels in conjunction of the OEM's procedural directives to ensure that ship critical equipment is prevented from sudden failure and frequent breakdown include the following: Routine Cleaning of equipment and parts (RCE), Lubrication (LUB), Precision balancing (PRB), Adherence to oil check/change schedules (OCS), Accurate alignments (ACA), Laser detuning/resonating (LDR), and Analysis of equipment lubricating oil quality and system (AELOS).

Most operators implement these PM activities in varied proportions, giving rise to a mix of implementation of practices and types by individual industrial vessel operators. Consequently, variation in the mix and extent of implementation of preventive maintenance activities and practices gives rise to differences in the performance of and results of implementation of preventive maintenance activities. The effect is that the frequency of failure of vessel critical equipment and breakdown incident rates for individual operators and vessel types may vary, depending on the extent of and mix of preventive maintenance activities and/or practices implemented by individual offshore industrial vessel operators.

As a result, there is the need for an understanding from the perspectives of the industrial vessel operators, what constitutes the determinant preventive maintenance activities that, when implemented, significantly influence the reduction in the extent and frequency of failure and breakdown of industrial vessels in their fleet. Currently, available empirical literature is unable to provide evidence on what constitutes the determinant basic preventive maintenance activities and practices from a host of PM activities that offshore industrial vessel operators implement in order to limit incidents of sudden breakdown of industrial vessels. This information and the resulting knowledge are important in determining the most appropriate mix and extent of implementation of PM practices that operators should basically use to achieve the purpose and goals of preventive maintenance (Åhrén & Parida 2009; Cheng et al., 2013; Aluko, 2018).

It is important to also note that the implementation of a mix of PM practices can be influenced by various other factors, including organizational safety culture, maintenance policy, regulatory frameworks, and the availability of a skilled workforce, technological advancements, resource allocation, and environmental conditions. In Nigeria, operational challenges such as inconsistent regulatory oversight, inadequate training programs, and limited financial resources may also hinder the effective adoption of preventive maintenance practices. But providing insights into what constitutes the determinant PM activities and practices that significantly influence the realization of the goals of preventive maintenance is crucial. Consequently, understanding the determinants of PM activities that enhance effective preventive maintenance practices becomes crucial for improving operational reliability and safety in Nigerian offshore industrial vessel operations (De-Jonge & Scarf, 2020; Cheng et al., 2012).

Through a comprehensive examination of these determinants, this research aims to identify the best operational practices that can be adopted within the Nigerian context to enhance the realization of the goals of preventive maintenance onboard offshore industrial vessels in Nigeria. This will ultimately contribute to the operational success of offshore industrial vessel operators and the overall safety and sustainability of Nigeria's offshore operations in an increasingly competitive global market. In light of the above, the objective of the study is to determine the determinant PM activity types on industrial vessel operations in Nigeria that significantly influence the realization of the goals of implementation

of preventive maintenance onboard offshore industrial vessels in Nigeria.

The existing literature, as highlighted in our introduction (e.g., Khazraei & Deuse, 2011; Velmurugan & Dhingra, 2015; Aluko, 2019), consistently identifies several basic PM activities commonly implemented on industrial vessels. However, a significant gap exists in understanding the determinant nature of these practices, particularly within the specific context of offshore industrial vessel operations in Nigeria. As noted in the previous paragraphs, operators often implement these PM activities in "varied proportions," leading to a "mix of implementation of practices and types." This variation, in turn, results in differences in performance and outcomes, meaning the frequency of equipment failure and breakdown incident rates can differ significantly among operators and vessel types.

Crucially, currently available empirical literature is unable to provide evidence on what constitutes the determinant basic PM activities and practices from a host of PM activities that offshore industrial vessel operators implement in order to limit incidents of sudden breakdown of industrial vessels. There is a lack of understanding, from the direct perspectives of industrial vessel operators, regarding which specific PM activities, when implemented, have the most significant influence on reducing the extent and frequency of failure and breakdown of industrial vessels in their fleet. This absence of knowledge hinders the determination of the most appropriate mix and extent of implementation of PM practices that operators should basically use to achieve the purpose and goals of PM (Åhrén & Parida, 2009; Cheng et al., 2013; Aluko, 2018). While various factors like organizational culture and regulatory frameworks can influence PM implementation, the fundamental identification of the core determinant activities remains underexplored in the Nigerian offshore context.

This study directly addresses the aforementioned research gap by empirically identifying the determinant PM practices for offshore industrial vessel operations in Nigeria. Our primary objective is to determine the determinant PM activity types on industrial vessel operations in Nigeria that significantly influence the realization of the goals of implementation of PM onboard offshore industrial vessels in Nigeria.

To achieve this, we employ a qualitative research approach utilizing a survey method, with questionnaires and checklists as instruments for data collection. We specifically elicit the perceptions of industrial vessel operators in Nigeria's offshore sector on the extent of influence of each identified PM activity in achieving reduced breakdown incident rates. By applying principal component factor analysis (PCA) to the collected primary data, we are able to statistically identify which of the basic PM activities (routine cleaning, lubrication, precision balancing, adherence to oil check/change schedules, accurate alignments, laser detuning/resonating, and analysis of equipment lubricating oil quality and system) emerge as the principal "determinants" of effective PM in this specific operational environment.

The insights gained from this study will provide crucial empirical evidence that is currently lacking. By pinpointing the most impactful PM activities from the operators' perspective, our research will offer actionable recommendations for industry stakeholders. This will enable them to prioritize the implementation of these determinant practices, thereby enhancing vessel reliability, safety, and operational efficiency, and ultimately contributing to the operational success and sustainability of Nigeria's offshore sector.

2 Literature Review

Studies by Dodzo (2017) posit that PM is a critical component of ensuring the safety, reliability, and efficiency of offshore industrial vessels. In Nigeria, there is a heavy reliance on the oil and gas industry;

thus, the performance of these offshore vessels directly impacts economic growth and environmental sustainability. As a result, crucial attention is given to issues surrounding the maintenance of offshore industrial vessels, particularly PM practices that are aimed at limiting the rate of sudden critical equipment failures leading to downtime and operational failure (Aluko, 2019).

The offshore ecosystem presents unique and inherent challenges to vessel maintenance. Available empirical studies have provided insight into the harsh operating conditions, remote locations, skill deficiencies and knowledge gaps, and critical complex equipment as significant factors influencing maintenance practices and strategies. For instance, Anyadiegwu (2023) did an exploratory study on the use of outsourcing and inventory holding strategies in conjunction with basic PM practices in limiting the breakdown incident rate of offshore industrial vessel types in Nigeria. Additionally, the high cost of spare parts and skilled labor in the Nigerian offshore industry has been identified as a major hurdle in implementing effective PM programs (Dodzo, 2017; Soares & Garbatov, 2010).

The necessity for an industry-wide appraisal of recent PM practices and activities is justified by the need for empirically based knowledge on to what extent the implementation of specific PM activities such as Routine Cleaning of equipment and parts (RCE), Lubrication (LUB), Precision Balancing (PRB), Adherence to oil check/change schedules (OCS), Accurate alignments (ACA), Laser detuning/resonating (LDR), and Analysis of equipment lubricating oil quality and system (AELOS) influence the realization of the goals and objectives of PM. This is because the extent of realization of the goals of preventive maintenance has implications on the frequency of failure and breakdown of critical ship equipment, maintenance cost, efficiency and productivity of the offshore industrial vessels sector, and the oil and gas industry. Failure to address the challenges related to the implementation of PM activities by industrial vessel operators in ignorance of how the implementation of each of these activities affects the achievement of the goals of PM (Soares et al., 2010).

Maintenance is necessary for equipment and structures whose performance reduces with time, aiming to counteract those effects. The performance of industrial equipment, i.e., the dilapidation over time, is subject to many suspicions. They consist of but are not limited to operating circumstances, material features, and environmental exposure (Soares et al., 2010). The need for maintenance planning results from the uncertainty factor associated with machinery, equipment, and assets. A prevalent model, the bathtub curve, as shown in Figure 1, depicts a statistical expected reliability measure of engineering equipment.

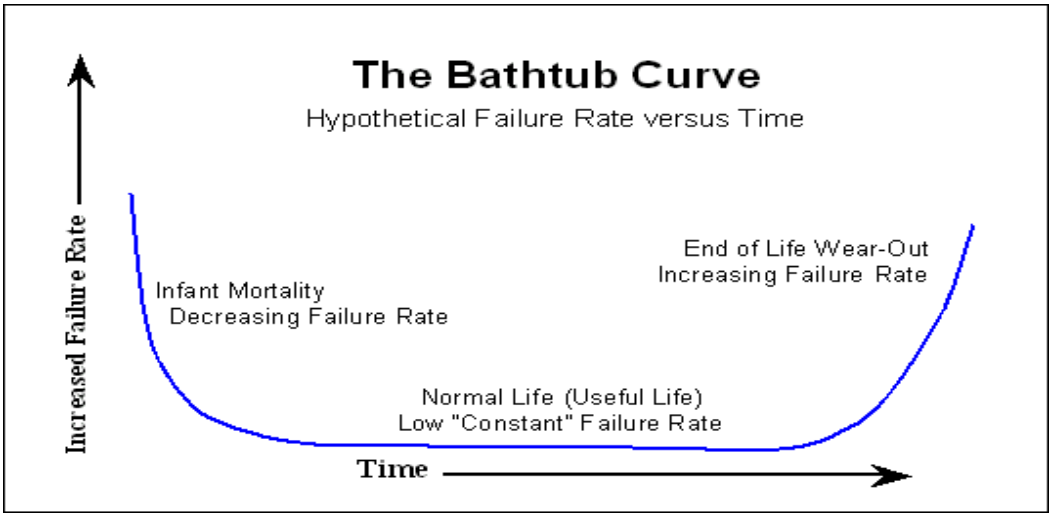

Figure 1: The Bathtub Curve Model I (Soares et al., 2010).

The basic assumption here is that the older the equipment becomes, the more probable it is to fail. However, the routine implementation of PM practices and operations helps to limit the frequency of failure and sudden breakdown of critical equipment, even in the course of aging of the equipment. Thus, in planning the maintenance schedules of critical ship equipment, preventive maintenance measures and practices cannot be ignored. Soares et al. (2010) identified the following stages of equipment failure for which PM measures are also crucial. These stages include:

(i) Infant Mortality Stage: In this stage, there is early failure of machine modules, and it is frequently seen in plants in the first few days or weeks of operation or after a repair. There is a decreasing rate of failure at this stage because the machine is new or due to minor installation errors.
(ii) Normal Life Stage: This stage of a component's life displays a somewhat constant probability of failure. Failures here are seen as random and probabilistic.
(iii) Wear-Out Stage: There is an increasing probability of component failure between equal and successive time intervals. Somewhere within this phase, the failure rate would become unacceptable, and widespread maintenance would be carried out (Wilkins, 2002). The study emphasized the need for the implementation of PM practices at all stages of the equipment life cycle.

Previous studies grouped some factors that influence PM practices to include:

- Organizational factors are further considered to be influenced by management commitment to implementation of PM and organizational culture with regard to safety practices and performance.
- Maintenance Personnel extent of training and skills and inventory of material stock: This has to do with the availability of skilled personnel with requisite PM skills, inventory spare parts and other resources crucial for the effective implementation of PM practices.
- Technological factors have to do with the availability of the technology and critical equipment condition monitoring systems and advanced technology options for implementing PM practices onboard offshore vessels.

Other factors include the availability of computerized and digitalized maintenance management systems, environmental factors, regulatory frameworks, human factors, and maintenance culture. However, these studies failed to address the problem of identifying the determinant PM activities and/or practices that significantly influence the outcomes and goals of implementing PM on vessels' critical equipment (Wu et al., 2015; Yang et al., 2007).

The maritime industry, driven by escalating operational costs, stringent environmental regulations, and the critical need for continuous vessel reliability and safety, has seen a significant evolution in its approach to maintenance. While traditional reactive and fixed-schedule PM practices have historically dominated, recent literature highlights a decisive shift towards more sophisticated, data-driven strategies (DVN, 2024). A key trend in modern maritime maintenance is the increasing adoption of Predictive Maintenance (PdM). Unlike conventional PM, which relies on predetermined schedules, PdM leverages real-time data from sensors, machine learning algorithms, and advanced analytics to predict when equipment failure is likely to occur (Kandemir et al., 2020). This proactive approach allows for maintenance interventions to be performed precisely when needed, minimizing unscheduled downtime, reducing maintenance and repair costs, and extending asset lifespan (James et al., 2025). Studies indicate that PdM can significantly enhance the operational efficiency, safety, and profitability of maritime operations (Kandemir et al., 2020). For instance, an abnormal vibration pattern detected in a ship's engine through sensor data can trigger an alert, prompting inspection before a minor issue escalates into a critical failure (Kandemir et al., 2020).

Closely related to PdM is Condition-Based Maintenance (CBM), which assesses the actual condition of ship machinery and systems through continuous monitoring and data analysis (Maione et al., 2024). This strategy allows maintenance tasks to be executed based on the equipment's real-time state, moving away from rigid, time-based schedules. Research from organizations like Det Norsk Verita (DVN, 2024) consistently demonstrates that robust CBM systems can lead to a reduction in audit preparation time by up to 50% and improve asset reliability by 5-15%, respectively, highlighting the direct financial and operational benefits.

The digitalization of the maritime industry is a pivotal enabler for these advanced maintenance strategies. The rapid growth of Artificial Intelligence (AI), Internet of Things (IoT) devices, and big data analytics is transforming how vessel operations and maintenance are managed (Han et al., 2021). IoT sensors deployed on critical ship components collect real-time data on parameters such as temperature, pressure, vibration, and fuel consumption. This data is then processed using AI and machine learning to detect anomalies, predict potential failures, and optimize maintenance schedules (Han et al., 2021). The integration of "digital twin" technology further enhances this, allowing for virtual replicas of vessels to simulate operational scenarios and test maintenance impacts without disrupting real-time operations (DVN, 2024). However, the successful implementation of these advanced PM practices is not without challenges. Data management, integration complexity, and cybersecurity risks are key considerations (Geurtsena, 2023). Moreover, the need for a skilled workforce capable of interpreting complex data and operating these sophisticated systems is paramount. Despite these, the overwhelming consensus in recent literature emphasizes that data-driven PM is no longer optional but a necessity for the contemporary maritime industry, ensuring compliance with international standards, enhancing safety, and promoting environmental sustainability (DVN, 2024).

Thus, while existing research has provided valuable insights into PM practices in the offshore industry, there exist knowledge gaps that are yet to be addressed. There is a need for more in-depth studies on the specific determinant PM practices in the Nigerian context, with specific attention on the seven basic PM activities identified in existing literature and from the perspectives of the individual operators of offshore industrial vessels in Nigeria. PM is a critical function in the offshore industry, and its effectiveness is influenced by the extent of and mix in the implementation of PM activities.

3 Methodology

The study area of the research is the Nigerian maritime industry, with particular emphasis on the industrial vessel operators that serve the logistics needs of the offshore oil and gas sector in Nigeria. Almost all the industrial vessel operators that own Anchor Handling Tug & Supply (AHTS) Line Handling Tugs (LHT) and Platform Supply Vessels (PSV) fleet types, including Security Escort Vessels (SEV) in Nigeria, were sampled. This is because operators of AHTS, LHT, PSV and SEV fleet types dominate the offshore vessel types in Nigeria. Therefore, the study used a qualitative research approach and survey research design method in which primary data on the extent of use of each of the aforementioned PM practices/activities in the effective actualization of the goals of PM were obtained from the industrial vessel operators, using questionnaire and checklist as survey instruments. The study used the purposive random sampling method to elicit the responses of the industrial fleet operators the PM activities comprising cleaning, good housekeeping, Lubrication, Precision balancing, More accurate alignments, detune resonating, adherence to oil check/change schedules, and Analysis of equipment lubricating oil constitute the determinant or major component of PM activities that significantly influence the industrial vessel operations and achievement of maintenance goals of operators in Nigeria.

Primary data used in the study was sourced from all the operators in the industry using a questionnaire and checklist as survey instruments. While the questionnaire was used to obtain data on respondents' ratings of the extent of use and perceived influence of each PM activity on the overall achievement of the goals of PM, the checklist was used to confirm the very preventive maintenance activities that are applied by individual operators in ensuring the maintenance of the vessels in their fleet over the years. The primary data was obtained from the rate of implementation of the PM activities/operations identified in literature and confirmed by the use of checklist to include:

- Routine Cleaning and good housekeeping (RCE)
- Lubrication (LUB)
- Precision balancing (PRB)
- More accurate alignments (ACA)
- Laser detuning/resonating (LDR)
- Adherence to oil check/change schedules (OCS)
- Analysis of equipment lubricating oil quality and systems (AELOS), etc.

The questionnaire was designed and administered to the industrial vessel operators in Nigeria to elicit their responses as to the implementation of the aforementioned PM activities and the significance of the implementation of each PM activity type in the industrial vessels to limit the frequency of breakdown.

3.1 Population of the Study and Sampling Technique

The population of interest of the research from which primary data was sourced consisted of the industrial vessel operators in Nigeria offshore sector. The population of interest consists of 67 operators of industrial vessels identified in the industry. However, only the operators who are fleet-owning companies were sampled as most of the companies that resort to chartering in vessels at need were not considered because the obligation for vessel maintenance may fall within the responsibilities of the owner, especially in non-time charter contracts. Given that the researcher was unable to determine the exact population of the staff working in the operational departments (Marine Engineers) of the industrial vessel operators, the study used the Z score formula for unknown populations to determine the sample size while adopting a purposive random sampling method in which the operational staff of the major industrial vessel operators in the Nigerian maritime domain were randomly sampled in the survey, interviewed, and administered copies of the questionnaire.

The determination of sample of unknown population using Z score is given as:

$$N = Z^2(P)\,(1\text{-}P)\,/C^2 \quad (1)$$

Where Z = standard normal deviation set at 95% confidence interval =1.96
P = percentage picking a choice or response =50%
C = confidence interval = 0.05
Therefore $N = (1.96)^2(0.5)\,(1\text{-}0.5)/(0.05)^2$
N= 0.9604/0.0025
N= 384.16
=384

About 380 copies of the questionnaire were distributed among the operational staff of the major vessel operators sampled in the study. Recall that the questionnaire was distributed to elicit the responses of the industrial vessel operators in the significant or dominant PM operations/activities consisting of

Cleaning, Lubrication, Precision balancing, more accurate alignments, Laser detune/resonating, adherence to oil check/change schedules, analysis of equipment lubricating oil, etc., that the implementation will most significantly reduce the frequency of breakdown of industrial vessel types.

3.2 Method of Data Analysis (Principal Component factor Analysis)

The study used the PCA to analyze the data obtained in order to provide answers to the research question, which seeks to ascertain the determinant PM activities/operations in industrial vessel operations in Nigeria. The principal component factor analysis (PCA) statistical method was used to analyze the data obtained from the field survey in order to determine the determinant/significant PM operations/activities that operators significantly utilize that limit the rate and frequency of breakdown of industrial vessel types in the Nigerian offshore sector and achieve the goals of PM.

The determinant PM activity types being implemented by operators to significantly influence the reduction in frequency and rate of industrial vessel breakdown were determined by subjecting the data obtained to principal Component Analysis using SPSS version 21 analytical software.

3.3 Testing Reliability of the Instrument

The survey instrument's repeatability and consistency are evaluated by reliability. For instance, if a measurement or survey instrument yields the same output or nearly the same result when repeated under the same or comparable circumstances, it is considered trustworthy. The Cronbach Alpha index and the slit-half reliability index were used to assess reliability. The 384 respondents evaluated their perceptions of the extent of influence of the PM practices on industrial vessel maintenance. Similar to the test-retest reliability approach, the correlation method was used to compare the correlation between the (respondents various responses to determine inter-rater reliability. The correlation coefficient of 0.74 in the result indicates that the data is approximately 74% reliability.

4 Results and Discussion

The results emanating from the analysis carried out to actualize each of the objectives of the study are presented, and findings discussed in this section. The results are organized under different sections in line with the objectives and hypotheses of the study as follows:

Table 1 shows the results of the (PCA) conducted to determine the determinant PM activities/operations implemented by industrial vessels operators in Nigeria in limiting the sudden rate of breakdown of industrial vessels. The results of the study, as shown in Table1 indicate that Lubrication, which involves the dutiful application of lubricating oil/grease to industrial vessel parts and equipment, has a mean value of 26.1667, with standard deviation of 3.72425. Accurate alignment which involves the proper alignment of engine parts and bearings has a mean value of 16.2500 with standard deviation of 3.39803. Adherence to lubrication oil change schedules which involves the compulsory adherence of the industrial vessel operators to the time schedules for change and replacement of lubricating oil has a mean score of 14.6667 with standard deviation of 3.17120. Routine Cleaning of industrial vessel equipment and parts has a mean value of 13.5833 with standard deviation of 3.69283 while precision balancing has a mean value of 11.3333 with standard deviation of 3.89118. Laser detune/resonating and analysis of equipment lubrication oil types has respective mean values of 9.8333 and 9.1667 with respective standard deviations of 3.44037 and 1.87912.

Table 1: *Determinant Industrial Vessels Preventive Maintenance Activities/Operations and Practices*

Operation/Activity	Mean	Std. Deviation	Analysis N
Lubrication	26.1667	3.72425	360
Accurate Alignment	16.2500	3.39803	360
Oil Change Schedule	14.6667	3.17120	360
Routine Cleaning	13.5833	3.69283	360
Precision Balancing	11.3333	3.89118	360
Datuneresonating	9.8333	3.44037	360
Analysis of Equiplus Boil	9.1667	1.87912	360

Total Variance Explained						
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.456	40.812	40.812	2.857	40.812	40.812
2	1.258	20.833	61.644	1.458	20.833	61.644
3	1.245	17.783	79.428	1.245	17.783	79.428
4	1.059	8.545	87.973	1.059	10.402	87.973
5	1.001	7.287	95.259		8.061	95.259
6	.306	4.364	99.624			
7	.026	.376	100.000			

Extraction Method: Principal Component Analysis.

a. 5 components extracted.

Source: Author's Calculation.

The results of the PCA further reveal that the determinant industrial vessel PM operations/activities most implemented by industrial vessel operators to limit the rate of sudden breakdown of industrial vessels in Nigeria include lubrication, accurate alignment, and adherence to oil change schedules, routine cleaning and precision balancing; with each having Eigenvalues of 2.456, 1.258, 1.245, 1.059 and 1.001. Since each of the identified PM operations have Eigenvalues greater than one (Eigenvalue>1), the study infers that they constitute the detainment industrial vessel PM operations/activities in the Nigerian offshore sector. The implementations of the determinant industrial PM operations have implications for the rate of sudden breakdowns of industrial vessels. The findings of the study also indicate that Laser detune/resonating and analysis of equipment lubricating oil types each with respective Eigenvalues of 0.306 and 0.026 which is less than 1 in each case (0.306 < 1; 0.026<1); are not significant industrial vessel PM activities and as such, does not significantly influence or aid the reduction in rate of breakdown of industrial vessels and the actualization of the goals of implementation of PM. Table 2 below present in tabular the answer to the research question that seeks to address what PM activities significantly influence operators effective drive to reduce breakdown incident rates in Nigeria's offshore sector.

The table 2 reveals that the following PM operations Lubrication, Accurate Alignment, Adherence to Oil Change Schedule, Routine Cleaning, and Precision Balancing all have Eigenvalues greater than 1 (Eigenvalue>1). There exist determinant PM operations/activities in industrial vessel operations in Nigeria that operators should prioritize their implementation. These include Lubrication, Accurate Alignment, adherence to Oil Change Schedule, Routine Cleaning, and Precision Balancing. Laser detune/resonating and analysis of equipment lub-oil types have Eigen values that are less than 1, as a result, they are not significant PM operation/practices in the Nigeria industrial vessel sector.

Table 2: *What are the Significant/Determinant Preventive Maintenance Operations/Activities in industrial Vessel Operations in Nigeria?*

Operation/Activity	Initial Eigenvalues	Decision
Lubrication	3.281	Determinant/significant
Accurate Alignment	2.453	Determinant/significant
Adherence to Oil Change Schedule	2.451	Determinant/significant
Routine Cleaning	4.017	Determinant/significant
Precision Balancing	7.688	Determinant/significant
Datune Resonating	0.306	*Non-significant*
Analysis of equip. lub-oil quality and systems	0.026	*Non-significant*

Source: Author's calculation. if Eigenvalue ≥ 1; the operation is significant, if Eigen value<1, the operation is not significant.

5 Conclusions

The findings of the study reveal that Lubrication, Accurate Alignment, Adherence to Oil Change Schedules, Routine Cleaning, and Precision Balancing are the most critical and impactful PM practices. These five activities consistently exhibited Eigenvalues greater than one, underscoring their determinant role in achieving the goals of preventive maintenance in this specific operational context. Conversely, Laser Detune/Resonating and Analysis of Equipment Lubricating Oil Quality and System were found to be less significant in directly influencing breakdown reduction.

These determinant PM practices carry substantial practical implications for offshore industrial vessel operators in Nigeria and, by extension, the broader maritime industry. Prioritizing the consistent and thorough implementation of lubrication, accurate alignment, adherence to oil change schedules, routine cleaning, and precision balancing can lead to tangible benefits such as being used to proactively address potential issues through these determinant PM activities, operators can drastically reduce the incidence of catastrophic equipment failures. This translates directly to lower repair costs, minimized expenditure on emergency spare parts, and a reduction in the financial burden associated with unscheduled dry-docking or towage.

It can also be applied to reduce vessel downtime and enhanced operational efficiency by significantly decreasing the frequency and duration of unscheduled vessel downtime. This ensures higher asset utilization, consistent service delivery, and improved overall operational efficiency, which is crucial in a highly competitive and time-sensitive offshore oil and gas environment; improved safety and environmental protection by ensuring strong adherence to these core PM practices contributes directly to a safer working environment for crew members and minimizes the ecological footprint of offshore operations and achieving increased asset lifespan

Despite its valuable contributions, this study is not without limitations. Firstly, the data collection relied on the perceptions of industrial vessel operators, which, while providing valuable practical insights, may be subject to individual biases or varying levels of technical knowledge. Secondly, the study focused on a specific set of preventive maintenance practices identified through literature review, and while comprehensive, there might be other emergent or context-specific practices not captured. Thirdly, the research was confined to the Nigerian offshore sector, meaning the generalizability of these findings to other geographical regions or different types of maritime operations should be approached with caution. Lastly, the study did not quantify the direct financial impact (e.g., precise cost savings or ROI) of implementing these determinant PM practices, focusing instead on their influence on breakdown reduction.

Building upon the foundations laid by this study, several avenues for future research emerge: such as quantitative impact assessment aimed at precisely measuring the financial benefits (e.g., cost savings, return on investment) associated with the prioritized implementation of these determinants PM practices in the Nigerian offshore sector.

6 Declarations

6.1 Study Limitations

The study evaluated the determinant preventive maintenance practices by offshore industrial vessel operators in Nigeria's offshore oil and gas sector. The study is limited to the use of qualitative research approach and survey instruments to elicit the responses of operators of industrial vessels on the extent of use and significances of seven basic preventive maintenance practices on the extent of influence of each preventive maintenance activity/practice in achieving reduced breakdown incident rates of offshore industrial vessels. The preventive maintenance practices identified include: Routine Cleaning of equipment and parts (RCE), Lubrication (LUB), Precision balancing (PRB), adherence to oil check/change schedules (OCS), accurate alignments (ACA), laser detuning/resonating (LDR), and Analysis of equipment lubricating oil quality and system (AELOS). The extent of accuracy of the results and findings is limited to the accuracy of the data collected from the respondent industrial vessel operators in Nigeria's offshore oil and gas sector.

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6.3 Funding Source

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6.4 Competing Interest

There is no conflict of interest in this study.

6.5 Authors' Contributions

Theophilus C. NWOKEDI: Planning the materials and methods to reach the results.

Charles Ochiabuto ANYADIEGWU: Developing ideas for the research, taking responsibility for the literature review during the research, taking responsibility for the creation of the introduction, and literature review.

Donatus E. ONWUEGBUCHUNAM: Planning the materials and methods to reach the results, taking responsibility for the experiments, organizing and reporting the data, taking responsibility for the explanation and presentation of the results.

Obed C. NDIKOM: Developing ideas for the research, taking responsibility for the creation of the reference list.

7 Human and Animal Related Study

7.1 Ethical Approval

The Post Graduate Board of the Department of Maritime Technology, Federal University of Technology Owerri, approved the work as part of a Post Graduate research Thesis.

7.2 Informed Consent

Informed consent form was obtained from all participants for the study that they agreed to participate in the study.

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