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# Panel Data Approach Evaluation of Outsourcing and Inventory Holding Preventive Maintenance Costs for Industrial Vessel's Operations in Nigeria

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## Abstract

This study investigated the cost implications of maintenance outsourcing (MO) and inventory management (IM) strategies as preventive maintenance measures for industrial vessel operations in Nigeria. Secondary data were gathered through a survey of five major offshore service vessel operators, comprising three anchor handling tug supply (AHTS) operators and two security escort vessel operators The dataset covered 15 years, from 2006 to 2020, detailing fleet size, MO costs, inventory holding costs, and the breakdown rates of vessels. The findings, derived from a panel data regression model and rate of change analysis, indicate that MO and inventory holding costs are significant drivers of breakdown and repair expenditures in both AHTS and security escort vessels. Average fleet-size-to-cost ratios stand at around 1:67,589,220; 1:8,380,329; and 1:14,613,931 for per-vessel breakdown repair costs, outsourcing expenditure, and inventory holding costs, respectively. Outsourcing of maintenance accounts for 12.4% while inventory holding accounts for 21.6% of the total cost of maintenance per vessel, respectively, playing an important role in reducing operational stoppages. These results indicate that the optimization of outsourcing and IM expenditure assumes strategic relevance in improving the preventive maintenance practices in Nigeria's offshore sector. This pursuit aims for more sustainable and efficient operations for its industrial vessels.

**Keywords:** Industrial vessels, Maintenance-outsourcing, Inventory-holding-expenditure

## 1. Introduction

The exploration and survey of oil and gas activities offshore has been sustained largely due to the critical role played by offshore supply vessels (s). These vessels ensure the delivery of essential materials and logistics needed for efficient and safe operations. To maintain the reliability and operational readiness of OSVs, preventive maintenance strategies are indispensable [1]. Preventive maintenance encompasses the implementation of activities, processes, and operations aimed at preventing sudden equipment breakdowns during operations. Given that OSV equipment is subject to wear and tear due to regular use, such degradation can lead to sudden failures if not addressed proactively. This necessitates the adoption of preventive maintenance measures by OSV operators to mitigate the risks of equipment downtime, productivity losses, inefficiency, and increased operational costs [1,2]. Technological advancements in OSV construction, including condition monitoring systems, have significantly enhanced the early detection of potential faults that could lead to equipment failure. Innovations such as green technologies, unmanned ships, energy management solutions, and smart shipping systems have revolutionized vessel maintenance practices. Despite these advancements, fundamental preventive maintenance strategies, including maintenance outsourcing (MO) and inventory management (IM), remain crucial. Even with automated monitoring systems, these complementary strategies are necessary to optimize the performance of OSVs and reduce the likelihood of sudden breakdowns [1,3]. However, the high cost of implementing advanced technologies often limits their widespread adoption, especially among operators seeking to balance efficiency with financial constraints.

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The maintenance of industrial vessels involves a meticulous process that integrates preventive maintenance activities, manufacturers' specifications, and company policies. This approach is critical because the sudden failure of a vessel's critical equipment can result in catastrophic and environmentally damaging consequences, particularly if the failure occurs at sea. The costs associated with repairing critical equipment in a shipyard, combined with the loss of productive time, are substantial. These risks underscore the importance of preventive maintenance as a proactive strategy to limit equipment failures, enhance operational efficiency, and manage costs effectively [4,5].

Empirical studies have identified key preventive maintenance activities implemented by industrial vessel operators to minimize the occurrence of sudden breakdowns [5-7]. These activities include cleaning and housekeeping, lubrication, precision balancing, alignment adjustments, laser detuning, adherence to oil change schedules, and analyzing lubricating oil [5-7]. These practices form the foundation of preventive maintenance strategies and are widely adopted due to their proven effectiveness in sustaining vessel operations and reducing equipment failure rates. However, despite the routine implementation of these basic preventive maintenance activities, the risk of sudden equipment failure persists. Studies indicate that inefficiencies related to human factors, such as lapses in adherence to maintenance protocols, have contributed to unexpected equipment failures, even when preventive measures are in place. This highlights the limitations of relying solely on basic preventive maintenance activities. To address these shortcomings, complementary strategies such as MO and IM have been developed and are widely utilized in Nigeria's offshore industrial vessel sector [6-8].

MO involves contracting third-party companies, such as shipyards or equipment manufacturers, to handle the maintenance of critical equipment. This approach ensures access to specialized expertise while reducing the burden on the operator's internal workforce. Conversely, IM entails the procurement and storage of critical spare parts onboard vessels. This strategy enables operators to replace faulty components promptly, minimizing downtime and avoiding sudden breakdowns. Many operators adopt a hybrid approach, combining MO and IM to optimize maintenance outcomes. While MO and IM are integral to preventive maintenance strategies, their implementation comes with financial implications. The cost of outsourcing maintenance to external experts often differs from the cost of managing inventory internally, as each strategy entails unique resource allocations and operational challenges. These costs, coupled with fleet size considerations, influence an operator's choice of strategy and overall maintenance policy [8].

The adoption of any preventive maintenance strategy-whether MO, IM, or a combination of both-has direct implications for an operator's operational costs, efficiency, and productivity. Consequently, operators must carefully evaluate the cost-benefit trade-offs associated with these strategies to make informed decisions [9,10]. Empirical evidence and insights into the cost implications of preventive maintenance strategies are therefore essential for developing effective maintenance policies. However, a review of existing literature reveals a knowledge gap concerning the cost implications of MO and IM strategies in Nigeria's offshore industrial vessel sector. While studies have extensively documented the benefits of basic preventive maintenance activities, there is limited empirical evidence on how complementary strategies such as MO and IM influence operational costs and maintenance efficiency. This gap in knowledge has created challenges for operators seeking to implement evidence-based maintenance policies that optimize cost-efficiency and reliability [9,11].

This study aims to bridge this knowledge gap by investigating the cost implications of MO and IM strategies for industrial vessels operating in Nigeria's offshore sector. The study seeks to provide insights into the empirical relationship between these strategies and the costs of maintaining different vessel types-such as anchor handling tug supply (AHTS), platform supply vessels (PSV), security escort vessels (SEV), and others, in order for operators to improve their maintenance policies and consequently, improve vessel productivity. The findings of this study will not only contribute to the academic literature on preventive maintenance but also serve as a practical resource for industrial vessel operators in Nigeria and beyond.

### Aim and Objectives of the Study

The aim of the study is to investigate to what extent MO and inventory holding expenditures influence the breakdown repair cost of operating industrial vessels in Nigeria. The specific objectives of the study are to:

i. Determine the extent to which the inventory holding expenditure (inventory cost) influence the breakdown repair cost of industrial vessel operations in Nigeria's offshore OSV sector.

ii. Ascertain the significance of MO expenditure (outsourcing cost) on the breakdown repair cost of operating industrial vessels in Nigerian offshore industry.

### 1.2. Research Questions

i. To what extent does the inventory holding expenditure (inventory cost) influence the breakdown/repair cost of industrial vessel operations in Nigeria's offshore OSV sector?

ii. What is the extent of significance of cost of MO (outsourcing cost) on the breakdown repair cost of operating industrial vessels in Nigerian offshore industry?

Study Hypotheses

i. Hypothesis $H_{01a}$: There is no significant influence of inventory holding expenditure, outsourcing expenditure cum fleet size of OSV operators on the breakdown and repair cost of operators AHTS industrial vessel type over the period.

ii. Hypothesis $H_{01b}$: There is significant effects of inventory holding expenditure, outsourcing expenditure cum fleet size of OSV operators on the breakdown repair cost of SEV industrial vessel types.

## 2. Literature Review

Maintenance of industrial vessels is a critical, policy-driven activity shaped by managerial decisions and influenced by organizational culture and precedents [1,3]. Given the operational sensitivities of the offshore maritime sector, especially in Nigeria's oil and gas ecosystem, maintaining vessels in optimal working condition is vital. Vessel breakdowns during offshore operations often result in considerable delays due to the long lead times required for procuring spare parts, leading to loss of productive hours and increased operational costs [1,4]. To formulate effective maintenance strategies, decision-makers require empirical data concerning fleet types, performance history of maintenance strategies, operational contexts, required skills, and the cost implications of various maintenance approaches. Inadequate access to such data may result in the implementation of inefficient maintenance policies, undermining operational reliability [11].

The maritime sector, central to Nigeria's economy with estimated freight costs of \$5-\$6 billion annually [1,4], continues to face challenges in infrastructure reliability. Preventive maintenance strategies such as MO and IM have emerged as critical tools for improving vessel uptime and reducing unexpected failures [11-13]. These strategies complement core activities like lubrication, housekeeping, alignment, and oil analysis [14,15]. The approaches and use of MO and IM as veritable preventive maintenance strategies by OSVs operators rest on the framework that the efficient and effective use of these strategies have implications on the productivity and risks associated with industrial vessels operations and the overall maintenance and operational cost of industrial vessel operators. Figure 1 below illustrates the conceptual framework and interrelationship between the operational costs, productivity, and risks associated with vessel maintenance of operators of OSVs, and the MO and IM preventive maintenance strategies.

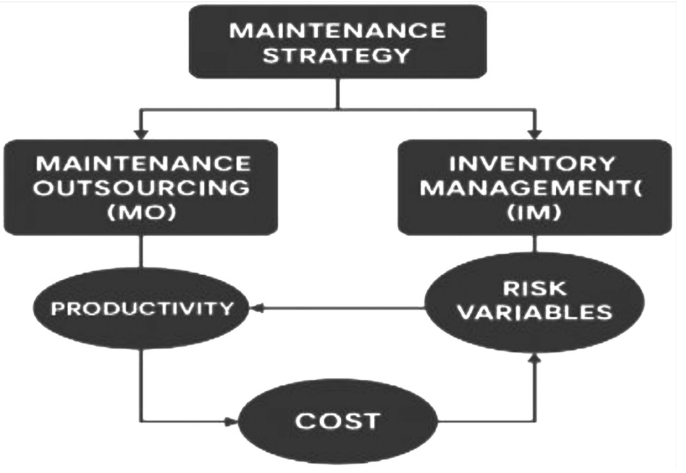


***Figure 1.*** *Conceptual framework showing the relatedness of mo and im on productivity, risk variables and operational cost of offshore vessels operators*

*Source: Prepared by authors*

IM, in this context, entails stocking critical replacement parts onboard vessels to minimize downtime and prevent supply chain disruptions [16,17]. However, maintaining onboard inventory involves several cost components-procurement, warehousing, opportunity cost, depreciation, and obsolescence-requiring optimization for effective cost control [16]. Contemporary inventory strategies, including just-in-time (JIT) and material requirements planning, aim to reduce holding costs and lead times [17,18].

References [19] note that the operational efficiency of industrial vessels is strongly influenced by the ability to manage preventive maintenance activities, which hinge on two critical cost elements, outsourcing and inventory holding. These costs often interact, either complementarily or substitutively, within maritime supply chains. Theoretical groundings help clarify why and how these interactions emerge, justifying the selection of key variables and the causal logic to be tested in the panel data analysis. For example, the transaction cost economics (TCE) theory developed by Williamson in 1985 posits that firms outsource activities when the costs of internal coordination and production exceed the market transaction costs [20]. In the context of industrial vessels, outsourcing preventive maintenance is preferred when internal technical capabilities are limited or when economies of scale in the market reduce costs. Inventory holding costs increase when firms choose to manage maintenance in-house, requiring spare parts storage, skilled labor, and logistics readiness [20,21]. The implication is that there is a trade-off-outsourcing may reduce internal inventory needs but can increase coordination complexity and dependency.

Secondly, the lean maintenance, and JIT theory offer another theoretical underpinning for the use of MO and IM, preventive maintenance strategies in OSV operations. Lean and JIT theories advocate minimizing waste and reducing unnecessary inventory while ensuring maintenance readiness. These theories highlight that inventory holding functions not only as a necessary buffer in uncertain supply chains but also as a cost center. Outsourcing is a JIT strategy to minimize waste and reduce idle resources. The implication is that as OSVs operating firms move toward leaner operations, outsourcing becomes attractive, but only if the reliability of external suppliers is high [22].

The identified theoretical framework supports the development of a panel data model that evaluates how outsourcing and inventory holding costs interact and influence preventive maintenance costs. By grounding the variable selection and relationships in established theories such as TCE, JIT, and systems theory, the study provides a robust causal logic for empirical validation in the context of Nigerian industrial maritime operations [19-22].

However, maritime maintenance challenges cannot be addressed solely through traditional policies. Recent research suggests that advanced decision-support systems and integrated risk assessment tools provide enhanced frameworks for predictive maintenance. For instance, the studies in [22,23] developed a fuzzy inference system to evaluate risk and productivity in public-private partnership projects, offering a relevant methodology for maintenance cost forecasting in uncertain maritime environments. Such tools enable the modeling of ambiguity in operational parameters—an essential capability in offshore settings where risk is high and consequences of failure are severe [22].

Similarly, the integration of project delivery systems, as discussed in [22,23], demonstrates the value of hybrid decision models (e.g., Fuzzy Analytic Hierarchy Process - Fuzzy Technique for Order Preference by Similarity to Ideal Solution) in minimizing inefficiencies and claims in infrastructure projects. These models can be translated to maritime contexts to guide decisions in preventive maintenance, where multiple stakeholders—engineers, contractors, suppliers—must coordinate efficiently under high-risk and time-sensitive conditions.

In addressing productivity, reference [23] highlights the synergy between building information modeling (BIM) and lean construction as a powerful conceptual framework. The model promotes real-time visibility, data integration, and process optimization, which are directly applicable to inventory control and outsourcing decisions in the maritime domain. Lean principles help vessel operators reduce waste, such as overstocking obsolete components or duplicating maintenance processes [23].

From a cost modeling perspective, studies like [24] emphasize the importance of quantitative, integrated decision models that link maintenance, operations, and production strategies. This supports a shift from siloed decision-making to holistic management of vessel operations. MO, therefore, becomes not just a cost-saving measure but a strategic decision grounded in performance data and risk tolerance [25,26].

Despite the value of MO and IM strategies, empirical insights into their effectiveness in Nigeria's offshore maritime sector remain limited. While outsourcing offers competitive advantages—such as enabling firms to focus on core operational competencies [27,28]—the extent to which these strategies improve cost efficiency and operational uptime requires systematic investigation. Additionally, evolving global practices in predictive modeling, digital twin technologies, and cloud-based maintenance platforms present further opportunities for improving offshore vessel maintenance [29].

In the bid to compete effectively in the ever-increasing global market, companies are discovering that they can cut costs and maintain quality by relying on outsourcing [24].

However, there is a seeming lack of empirical information and knowledge on the extent to which MO and IM as preventive maintenance strategies influence the overall maintenance cost and operational efficiency of industrial vessel operators in the Nigerian offshore sector. This is the key knowledge gap that this study addressed by using a panel data approach.

## 3. Data and Methods

Quantitative research design, cross-sectional and time series data covering the period 2006 to 2020 were sourced and analyzed. Data on the fleet size, breakdown repair cost, outsourcing of maintenance, and inventory expenditures were collected from the five biggest operators of OSVs in Nigeria, namely Aquashield Oil and Marine Services, Tamrose Nigeria Limited, Bourbon Nigeria Ltd., Temile & Sons Development Company, and Miden Systems Nigeria Ltd. The first two mainly operate SEVs, while the latter three control AHTS/ line handling tug/PSV fleets. Other operators without a captive fleets have been excluded as their expenditure data does not show consistency. The relationship between preventive maintenance expenditures (MO and IM) and breakdown repair costs was analyzed using panel data regression models and the fixed and random effects models. The other methods are used in analyzing the importance of preventive maintenance expenditure to reduce breakdown repair costs over 15 years.

Time series data on outsourcing expenditure ($OUSEXP_t$), inventory holding expenditure ($INEXP_t$), and breakdown repair costs ($REPCOST_t$) were used. Panel data regression combines both cross-sectional and time series data, thus allowing for examination of variation both across time, and operators. E-Views analytic software was used for the estimation of the models, with a focus on the influence of maintenance strategies on the costs of repairs. The results would give an understanding on how best to apply maintenance practices in Nigeria's offshore industry. The model specification is shown below (Equation 1):

$$REPCOST_t = \beta_0 + \beta_1 OUSEXP_t + \beta_2 INEXP_t + \beta_3 FLEETSZ_t + e\text{---} \quad (1)$$

Where:

$OUSEXP_t$, = outsourcing expenditure of the operators over the period t,

$INEXP_t$, = inventory holding expenditure of the operators over the period t

$REPCOST_t$, = breakdown repair cost of the operators over the period t

$FLEETSZ_t$ = fleet size of operators

The Hausman test was used to compare the efficiency of fixed effects and random effects models in the context of panel data. For each of the AHTS and SEV industrial vessel types operated by the respective companies, the test was implemented, and the result is shown in Table 1 below. Test to determine fixed effect or random effect model for AHTS vessel type.

The Hausman test shown in Table 1 above is used to compare the appropriateness of fixed effects and random effects models in the context of panel data. Specifically, the test helps determine whether the random effects assumptions are valid or if fixed effects should be preferred.

From the test statistics result, the p-value 0.5561 is greater than 0.05; therefore, a random effect model was assumed and used for AHTS OSV type.

The Hausman test shown in Table 2 helps determine whether the random effects assumptions are valid or if fixed effects should be preferred. The test statistic result shows that the p-value 0.7920 is greater than 0.05; therefore, a random effect was assumed. Using the panel data regression method and the random effect model, the data obtained were analyzed.

The dataset was also subjected to a multicollinearity test in order to ascertain the level of correlation between the variables and remove highly correlated variables. Multicollinearity occurs when two or more independent variables in a regression model are highly correlated with each other. This means that one variable can be predicted from another with a high degree of accuracy, making it difficult to determine the individual effect of each variable on the dependent variable. In this study, we used the variance inflation factor (VIF) to test multicollinearity. The decision rule is that if VIF >10, multicollinearity is a concern while, if VIF <10, multicollinearity is not a concern. The result is shown in Table 3 below.

***Table 1.*** *Correlated random effects-Hausman test*

| Test summary | | Chi-square statistic | Chi-square d.f. | Prob. |
|---|---|---|---|---|
| Period random | | 2.079321 | 3 | 0.5561 |
| **WARNING: estimated period random effects variance is zero. | | | | |
| Period random effects test comparisons: | | | | |
| **Variable** | **Fixed** | **Random** | **Var (Diff.)** | **Prob.** |
| $FLEETSZ_t$ | 24359274.986994 | 47446513.218739 | 288596200874920.38 | 0.1741 |
| $INEXP_t$ | 0.534767 | -0.129098 | 0.239359 | 0.1748 |
| $OUSEXP_t$ | -1.014845 | -0.346804 | 0.252933 | 0.1841 |
| Source: Author's calculation | | | | |

***Table 2.*** *Fixed and random effects efficiency test for SEV OSV*

| Test summary | | Chi-square statistic | Chi-square d.f. | Prob. |
|---|---|---|---|---|
| Period random | | 1.038379 | 3 | 0.7920 |
| **WARNING: estimated period random effects variance is zero. | | | | |
| Period random effects test comparisons: | | | | |
| **Variable** | **Fixed** | **Random** | **Var (Diff.)** | **Prob.** |
| $FLEETSZ_t$ | 17959284.510292 | 12334960.822212 | 46194939337538.400 | 0.4079 |
| $INEXP_t$ | -0.698025 | -0.686152 | 0.107015 | 0.9710 |
| $OUSEXP_t$ | 2.066759 | 2.145866 | 0.677104 | 0.9234 |
| Source: Authors | | | | |

From the result shown on Table 3 above, the variables FLETSZt, INEXPt, and OUSEXPt respectively have VIF values of 4.92, 3.01, and 5.01; in each case, the VIF value is less than 10 (4.92<10; 3.01<10; and 5.01<10). Therefore, there is no problem of multicollinearity associated with the dataset, and the regression output is not biased.

### 3.1. Limitations of the Study

The panel data used in this study were obtained from a cross-section of operators of offshore industrial vessels identified earlier. Therefore, the accuracy of these estimations and findings of the study is significantly influenced by the accuracy of the data supplied by the operators and used in this study.

## 4. Results and Discussion

In this section, the results of the study are presented and the findings are discussed as shown in the subsequent tables and sub-sections.

The Hausman test shown in Table 4 above compared fixed and random effects models, with a p-value of 0.5561 (p>0.05), which indicates that the random effects model is most efficient. The resulting quantitative model represents these relationships effectively. The model depicting the random effects of outsourcing expenditure, inventory holding expenditure, and fleet size on the breakdown repair cost of AHTS industrial operators is given as follows:

$$REPCOST_t = 5.89E+08 - 0.346804OUSEXP_t - 0.129098INEXP_t + 4744651FLEETSZ_t + e \text{ ---} \quad (3)$$

***Table 3.*** *Multicollinearity test (VIF results)*

| Variable | VIF Value | Decision |
|---|---|---|
| $FLEETSZ_t$ | 4.92 | Accept |
| $INEXP_t$ | 3.01 | Accept |
| $OUSEXP_t$ | 5.01 | Accept |
| Source: Prepared by the authors | | |

***Table 4.*** *Modeling the significance of the random effects of maintenance outsourcing cum inventory holding expenditure on the breakdown repair cost of operating of AHTS industrial vessel type in Nigeria's offshore sector*

| Variable | Coefficient | Std. error | t-statistic | Prob. |
|---|---|---|---|---|
| Constant | 5.89E+08 | 1.16E+08 | 5.098125 | 0.0000 |
| $FLEETSIZ_t$ | 47446513 | 13545520 | 3.502746 | 0.0011 |
| $INEXP_t$ | -0.129098 | 0.377932 | -0.341592 | 0.7344 |
| $OUSEXP_t$ | -0.346804 | 0.397881 | -0.871627 | 0.3885 |
| | Effects Specification | | | |
| | | | S.D. | Rho |
| | | | | |
| Period random | | | 0.000000 | 0.0000 |
| Idiosyncratic random | | | 1.79E+08 | 1.0000 |
| | Weighted statistics | | | |
| R-squared | 0.654088 | Mean dependent var | | 1.09E+09 |
| Adjusted R-squared | 0.628778 | S.D. dependent var | | 2.80E+08 |
| S.E. of regression | 1.70E+08 | Sum squared resid | | 1.19E+18 |
| F-statistic | 25.84247 | Durbin-Watson stat | | 2.166595 |
| Prob (F-statistic) | 0.000000 | | | |
| | Unweighted Statistics | | | |
| R-squared | 0.654088 | Mean dependent var | | 1.09E+09 |
| Sum squared resid | 1.19E+18 | Durbin-Watson stat | | 2.166595 |
| Source: Author's calculation | | | | |

The t-statistic (5.098125) and p-value (0.0000) confirm the intercept's statistical significance. The positive fleet size coefficient (4744651) indicates a direct relationship, where a unit increase in fleet size raises breakdown repair costs by ₦4,744,651. Conversely, negative coefficients for inventory holding expenditure (-0.129098) and outsourcing expenditure (-0.346804) suggest that increasing these expenditures reduces breakdown repair costs. Specifically, a unit increase in inventory holding expenditure decreases costs by 0.1291 units, while a unit increase in outsourcing expenditure lowers costs by 0.3468 units. The R-squared value (0.6541) reveals that 65.41% of the variation in breakdown repair costs is explained by fleet size and preventive maintenance expenditures. The Durbin-Watson statistic confirms no autocorrelation, ensuring valid regression results. Table 5 illustrates the significance of these maintenance strategies on breakdown repair costs for AHTS vessels.

The Table 5 above indicates a p-value of 0.7920, which is greater than 0.05, and we can therefore infer that a random effect model is most appropriate for modeling the significance of the effects of outsourcing expenditure, inventory holding expenditure and fleet size on the breakdown repair cost of SEV of OSV type operators in the industry. The model showing the random effects of outsourcing expenditure, inventory holding cost, and fleet size on the breakdown repair cost of SEV industrial vessel operators is described as follows:

$$REPCOST_t = 14393164 + 2.145866OUSEXP_t - 0.686152INEXP_t + 12334961FLEETSZ_t \text{ ---} \quad (4)$$

The intercept value of 14,393,164 represents the estimated breakdown repair cost when all independent variables are zero, but a t-statistic of 0.288937 and a p-value of 0.7749 indicate it is non-significant. The positive coefficients of fleet size (12,334,961) and outsourcing expenditure (2.145866) suggest that increases in these variables lead to higher breakdown repair costs for SEV vessels. Specifically, a unit increase in fleet size raises costs by ₦12,334,961, while a unit increase in outsourcing expenditure increases costs by ₦2,145,866.

Conversely, the negative coefficient for inventory holding expenditure (-0.686152) implies that higher spending on inventory reduces breakdown repair costs. A unit increase in inventory holding expenditure decreases costs by ₦0.686152. The R-squared value (0.8150) indicates that approximately 81.50% of the variation in breakdown repair costs is explained by fleet size and preventive maintenance expenditures. A Durbin-Watson statistic of 2.04 confirms no autocorrelation, validating the regression results.

***Table 5.** Modeling the random effects of preventive maintenance expenditure on the breakdown repair cost of operating of SEV industrial vessel type in Nigeria's offshore sector*

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| C | 14393164 | 49814279 | 0.288937 | 0.7749 |
| FLEETSIZE | 12334961 | 6459347. | 1.909630 | 0.0673 |
| INEXP | -0.686152 | 0.487202 | -1.408354 | 0.1709 |
| OUSEXP | 2.145866 | 1.346575 | 1.593574 | 0.1231 |
| | Effects Specification | | | |
| | | | S.D. | Rho |
| Period random | | | 0.000000 | 0.0000 |
| Idiosyncratic random | | | 27266603 | 1.0000 |
| | Weighted Statistics | | | |
| R-squared | 0.815023 | Mean dependent var | | 1.33E+08 |
| Adjusted R-squared | 0.704138 | S.D. dependent var | | 27493917 |
| S.E. of regression | 25525768 | Sum squared resid | | 1.69E+16 |
| F-statistic | 3.548154 | Durbin-Watson stat | | 2.041887 |
| Prob(F-statistic) | 0.077668 | | | |
| | Unweighted Statistics | | | |
| R-squared | 0.227213 | Mean dependent var | | 1.33E+08 |
| Sum squared resid | 1.69E+16 | Durbin-Watson stat | | 0.841887 |
| Source: Author's calculation | | | | |

The descriptive statistics in Table 6 summarize the performance of five major offshore vessel operators in Nigeria from 2006 to 2020. Miden Systems Limited operated an average of 8.13 vessels annually, with a total fleet size of 122 vessels over the specified period. The company spent ₦13.60 billion on breakdown repairs, averaging ₦906.4 million annually. Preventive maintenance expenditures included ₦646.5 million on outsourcing (₦43.1 million/year) and ₦317 million on inventory (₦21.1 million/year).

Tamrose Nigeria Limited maintained an average fleet size of 13.2 vessels, with a total count of 198 vessels. It spent ₦24.8 billion on breakdown repairs, averaging ₦1.6 billion annually. Preventive maintenance costs were ₦5.2 billion for outsourcing (₦346.1 million/year) and ₦7.6 billion for inventory (₦512.3 million/year).

Temile & Sons Ltd. operated approximately 19.5 vessels annually on average, with a total of 293 vessels. It spent ₦21.7 billion on breakdown repairs (₦1.4 billion annually).

***Table 6.*** *Descriptive statistics of preventive maintenance and breakdown repair cost of individual industrial vessel operators*

| COMPANY | | Breakdown Repair Cost | FLEETSIZE | OUSEXP | INEXP |
|---|---|---|---|---|---|
| Miden Systems Limited Company-A | N | 15 | 15 | 15 | 15 |
| | Minimum | 753597450.00 | 5.00 | 38445944.00 | 19300476.00 |
| | Maximum | 1000696600.00 | 10.00 | 53345867.00 | 23400619.00 |
| | Sum | 13596141334.00 | 122.00 | 646564026.00 | 317022572.00 |
| | Mean | 906409422.2667 | 8.1333 | 43104268.4000 | 21134838.1333 |
| | Std. Error | 20085792.53493 | 0.29059 | 1090065.29432 | 312468.60888 |
| | Std. deviation | 77791939.98318 | 1.12546 | 4221804.73118 | 1210185.71841 |
| Tamrose Nigeria Limited Company-B | N | 15 | 15 | 15 | 15 |
| | Minimum | 900211080.00 | 10.00 | 382910.22 | 466535356.00 |
| | Maximum | 11010404900.0 | 14.0 | 390112060.00 | 648010886.00 |
| | Sum | 24304609472.0 | 198.00 | 5192200390.22 | 7685140010.00 |
| | Mean | 1620307298.13 | 13.20 | 346146692.681 | 512342667.333 |
| | Std. error | 671127112.57728 | 0.31168 | 24971315.35977 | 12273737.3806 |
| | Std. deviation | 2599264130.20008 | 1.20712 | 96713488.52129 | 47535980.47104 |
| Temile & Sons Devt. Coy Company-C | N | 15 | 15 | 15 | 15 |
| | Minimum | 1361161728.0000 | 17.5083 | 80723424.0000 | 440626112.0000 |
| | Maximum | 1462690560.0000 | 20.5583 | 85260136.0000 | 503473248.0000 |
| | Sum | 21178891000.00 | 293 | 1244876664.000 | 7080745079 |
| | Mean | 1411926124.9333 | 19.5333 | 82991777.6000 | 472049671.9333 |
| | Std. error | | | | 49856274.32763 |
| | Std. deviation | 253905284.15311 | 1.55226 | 3132196.72857 | 20075783.34009 |
| Aquashield Oil & Marine Services Ltd. Company-D | N | 15 | 15 | 15 | 15 |
| | Minimum | 126300771.00 | 6.00 | 27100000.00 | 20100800.00 |
| | Maximum | 165211450.00 | 8.00 | 31001000.00 | 61373510.00 |
| | Sum | 2025548525.00 | 120.00 | 446414100.00 | 633703777.00 |
| | Mean | 135036568.3333 | 8.0000 | 29760940.0000 | 42246918.4667 |
| | Std. error | 2941887.92758 | 0.37796 | 259267.34461 | 2983150.72349 |
| | Std. deviation | 11393882.94993 | 1.46385 | 1004138.10789 | 11553693.07132 |
| Bourbon Nigeria Ltd. Company-E | N | 15 | 15 | 15 | 15 |
| | Minimum | 111505100.00 | 7.00 | 14796600.00 | 12030358.17 |
| | Maximum | 224033000.00 | 8.00 | 23605560.00 | 42961457.71 |
| | Sum | 1954328812.00 | 134.00 | 297226662.00 | 296137755.5 |
| | Mean | 130288587.4667 | 8.9333 | 19815110.8000 | 19742517.0333 |
| | std. error | | | | |
| | std. deviation | 37734964.31889 | 1.62422 | 2481513.13599 | 7248813.30542 |

Source: Author's calculation

Preventive maintenance costs totaled ₦1.2 billion for outsourcing, (₦82.9 million/year) and ₦7.0 billion for inventory (₦472.0 million/year).

Aquashield Oil & Marine Services Ltd. operated 8 vessels, totaling 120 operations annually, spending ₦2.0 billion on breakdown repairs (₦135 million/year). It allocated ₦446.4 million to outsourcing (₦29.7 million/year) and ₦633.7 million to inventory (₦42.2 million/year).

Bourbon Nigeria Limited operated an average of 8.93 vessels annually (134 total), spending ₦1.9 billion on breakdown repairs (₦130.2 million/year). Preventive maintenance expenditures were ₦297.2 million for outsourcing (₦19.8 million/year) and ₦296.1 million for inventory (₦19.7 million/year).

These findings highlight variations in fleet sizes, repair costs, and maintenance strategies among the operators.

Table 7 presents the average rate of change coefficients for the fleet sizes of selected industrial vessel operators from 2006 to 2020, highlighting fleet size trends. Miden Systems Ltd. (0.036), Temile & Sons (0.004), and Aquashield Oil & Marine (0.079) showed positive trends, with Aquashield having the highest growth. Conversely, Tamrose Nigeria Ltd. (-0.029) and Bourbon Nigeria Ltd. (-0.004) exhibited decreasing trends. These coefficients reflect changes in fleet size, with implications for outsourcing, inventory holding, and maintenance costs. The analysis indicates growth for some operators and contraction for others, influencing their preventive maintenance strategies and associated costs.

Table 8 presents the average rate of change coefficients for inventory holding costs of selected vessel operators from 2006 to 2020, highlighting expenditure trends. Miden Systems Ltd. (-₦53,313.94) and Tamrose Nigeria Ltd. (-₦6,048,823.50) showed declining inventory costs despite Miden's increasing fleet size. Temile & Sons (-₦4,489,081.63) and Bourbon Nigeria Ltd. (-₦302,955.22) also recorded decreasing trends. Conversely, Aquashield Oil & Marine (₦442,884.49) exhibited a positive trend, aligning with its fleet growth. These findings suggest that inventory holding expenditure trends vary significantly, with implications for cost efficiency and preventive maintenance strategies across operators.

Table 9 highlights the average rate of change coefficients for outsourcing costs among selected industrial vessel operators from 2006 to 2020, reflecting trends in expenditure. Miden Systems Ltd. (₦535,716.10) and Aquashield Oil & Marine (₦137,967.86) exhibited increasing outsourcing costs, aligning with fleet growth. Conversely, Tamrose Nigeria Ltd. (-₦2,245,420.59) and Temile & Sons (-₦324,050.85) showed decreasing outsourcing expenditures alongside reductions in fleet size and inventory holding costs. Bourbon Nigeria Ltd. (₦320,104.61) increased outsourcing costs, while decreased inventory expenditure in line with fleet reduction.

These findings indicate that operators with shrinking fleets tend to reduce inventory holding costs while favoring outsourcing. In contrast, operators with growing fleets, such as Miden Systems and Aquashield Oil & Marine,

***Table 7.*** *The average rate of change coefficients of fleet size of individual industrial vessels operators in Nigeria over the period covered in the study*

| Organizations | Regr. Constant | Coefficient of Regr. | Std. error Regr. | t-score | p-value |
|---|---|---|---|---|---|
| Miden Systems Ltd. Company-A | 7.848 | 0.036 | 0.069 | 0.517 | 0.614 |
| Tamrose Nig Ltd. Company-B | 13.429 | -0.029 | 0.074 | -0.384 | 0.707 |
| Temile & Sons Company-C | 19.505 | 0.004 | 0.096 | 0.037 | 0.971 |
| Aquashield Oil & Marine Company-D | 7.371 | 0.079 | 0.088 | 0.892 | 0.389 |
| Bourbon Nig Ltd. Company-E | 8.962 | -0.004 | 0.101 | -0.035 | 0.972 |
| Source: Author's calculation | | | | | |

***Table 8.*** *The average rate of change coefficients of inventory holding expenditure of individual industrial vessels operators in Nigeria over the period covered in the study*

| Organizations | Regr. Constant | Coefficient of Regr. | Std. error Regr. | t-score | p-value |
|---|---|---|---|---|---|
| Miden Systems Ltd. Company-A | 21561349.648 | -53313.939 | 73581.508 | -0.725 | 0.482 |
| Tamrose Nig Ltd. Company-B | 560733255.333 | -6048823.50 | 2424160.540 | -2.495 | 0.027 |
| Temile & Sons Company-C | 507962324.933 | -4489081.625 | 2979482.272 | -1.507 | 0.156 |
| Aquashield Oil & Marine Company-D | 38703842.581 | 442884.486 | 705922.447 | 0.627 | 0.541 |
| Bourbon Nig Ltd. Company-E | 22166158.808 | -302955.222 | 441630.097 | -0.686 | 0.505 |
| Source: Author's calculation | | | | | |

experienced simultaneous increases in outsourcing and inventory expenditures, reflecting enhanced investment in preventive maintenance strategies to support expanding fleet operations.

The result suggests that industrial vessel operators with decreasing investment in fleet size, tend to decrease their inventory holding expenditure in favour of increasing outsourcing expenditure. It further suggests that offshore industrial vessels operators with significantly increasing trends in fleet ownership have increasing expenditure on both outsourcing and inventory holding.

Table 10 presents the average rate of change coefficients for maintenance costs of industrial vessel operators over 15 years. Miden Systems Ltd., shows an average rate of change of ₦13.98 million, and Tamrose Nigeria Ltd., shows an average rate of change of ₦9.33 million, indicating rising maintenance costs. Miden Systems' increasing fleet size aligns with growing outsourcing expenditure and decreasing inventory costs, suggesting a preference for outsourcing as a preventive maintenance strategy. Similarly, Tamrose Nigeria Ltd.'s, decreasing fleet size correlates with reduced inventory holding costs, while, on the other hand, outsourcing and maintenance costs increase, indicating a focus on outsourcing for maintenance.

Temile & Sons has an average rate of change of ₦7.25 million. Additionally, it is experiencing with increasing maintenance and inventory costs and decreasing outsourcing expenditure. This suggests a preference for holding more inventory rather than investing in outsourcing. Factors such as company policy, breakdown frequency, and external contracts influence each operator's strategy for balancing outsourcing and inventory costs.

Aquashield Oil & Marine and Bourbon Nigeria Ltd. show different trends. Aquashield Oil & Marine has decreasing maintenance costs, with fleet size and outsourcing expenditure rising. In contrast, Bourbon Nigeria Ltd. exhibits increasing maintenance costs despite a decline in inventory expenditure and fleet size. This indicates varied strategies across operators, with some focusing on outsourcing, while others concentrate on inventory holding or other maintenance approaches.

Table 11 presents the average fleet size to average cost ratios for breakdown repair, outsourcing expenditure, and inventory holding expenditure, providing insight about the average cost per vessel in the fleet per year. The ratio of a company's fleet size to its breakdown repair cost indicates how much the company spends annually to maintain each vessel. For Miden Systems Ltd., Tamrose Nigeria Ltd., and Temile & Sons, the ratios are 1:₦111.4 million, 1:₦122.7 million, and 1:₦72.3 million, respectively. Aquashield Oil & Marine and Bourbon Nigeria Ltd. have ratios of 1:₦16.8 million and 1:₦14.6 million, respectively. On average, Nigerian industrial vessel operators spend about ₦67.6 million per vessel per annum on breakdown repair costs.

The average fleet size to outsourcing expenditure ratio is a ratio of 1 to ₦8.4 million per vessel per annum, indicating that each vessel incurs approximately ₦8.4 million in outsourcing costs for preventive maintenance. Similarly, the

***Table 9.*** *the rate of change coefficients of outsourcing expenditure of individual industrial vessels operators in Nigeria over the period covered in the study*

| Organizations | Regr. Constant | Coefficient of Regr. | Std. error Regr. | t-score | p-value |
|---|---|---|---|---|---|
| Miden Systems Ltd. Company-A | 38818539.571 | 535716.104 | 215583.290 | 2.485 | 0.027 |
| Tamrose Nig Ltd. Company-B | 364110057.383 | -2245420.588 | 5965497.139 | -0.376 | 0.713 |
| Temile & Sons Company-C | 85584184.371 | -324050.846 | 172208.252 | -1.882 | 0.082 |
| Aquashield Oil & Marine Company-D | 28657197.143 | 137967.857 | 49130.546 | 2.808 | 0.015 |
| Bourbon Nig Ltd. Company-E | 17254273.886 | 320104.614 | 125706.743 | 2.546 | 0.024 |
| Source: Author's calculation | | | | | |

***Table 10.*** *The average rate of change coefficients of breakdown repair cost of individual industrial vessels operators in Nigeria over the period covered in the study*

| Organizations | Regr. Constant | Coefficient of Regr. | Std. error Regr. | t-score | p-value |
|---|---|---|---|---|---|
| Miden Systems Ltd. Company-A | 794544726.610 | 13983086.95 | 2869636.475 | 4.873 | 0.000 |
| Tamrose Nig Ltd. Company-B | 1545628078.848 | 9334902.411 | 161178725.57 | 0.058 | 0.955 |
| Temile & Sons Ltd. Company-C | 1353909626.419 | 7252062.314 | 15617549.936 | 0.464 | 0.650 |
| Aquashield Oil & Marine Company-D | 141590093.019 | -819190.586 | 669095.556 | -1.224 | 0.243 |
| Bourbon Nig Ltd. Company-E | 87380911.038 | 5363459.554 | 1806604.938 | 2.969 | 0.011 |
| Source: Author's calculation | | | | | |

***Table 11.** Ratio of average fleet size to breakdown repair cost, outsourcing expenditure and inventory holding expenditure of industrial vessel operators in Nigeria between 2006 and 2020*

| | AVREPAIRCOSTt/ FLEETSIEt | AVOUSEXPt / FLEETSIEt | AVINEXPt / FLEETSIEt |
|---|---|---|---|
| Miden Systems Ltd. Company-A | 111448348.98 | 5299922.34 | 2598556.32 |
| Tamrose Nig Ltd. Company-B | 122750552.89 | 26414689.40 | 38813838.43 |
| Temile & Sons Company-C | 72283030.77 | 4248798.32 | 24166406.70 |
| Aquashield Oil & Marine Company-D | 16879571.042 | 3720117.50 | 5280864.81 |
| Bourbon Nig Ltd. Company-E | 14584597.79 | 2218117.70 | 2209991.50 |
| **Industry Average** | 67589220.294 | 8380329.052 | 14613931.55 |
| **As a % of Average repair cost** | - | 12.4% | 21.6% |
| Source: Prepared by the author | | | |

fleet size to inventory holding expenditure ratio is 1,:₦14.6 million, with each vessel spending an average of ₦14.6 million on inventory holding per year for maintenance.

The results also reveal that outsourcing and inventory holding expenditures make up 12.4% and 21.6%, respectively, of the total breakdown repair cost per vessel. Together, these two preventive maintenance strategies account for about 34% of the overall breakdown repair cost, while other expenses such as amortization, crew costs, and external factors constitute the remaining costs.

### 4.1. Test of Hypothesis

The test statistics shown in Table 12 above reveal an F-score of 25.84 and a p-value of 0.0000. This implies that inventory holding expenditure, outsourcing expenditure and fleet size of AHTS industrial vessel operators significantly affect the breakdown and repair cost of AHTS industrial vessel type over the period. However, only fleet size has a significant individual effect on the breakdown repair cost for operators of the AHTS vessel type over the period. Neither outsourcing expenditure nor inventory holding expenditure have significant individual random effects on the breakdown repair cost of AHTS operators over the period. The study accepts the alternative hypothesis that there is a significant random effect of preventive maintenance expenditure and breakdown repair cost of operating AHTS industrial vessels in Nigeria's offshore sector.

The test statistics shown in Table 13 above, reveal the F-score of 3.548154 and the p-value of 0.007766. This implies that inventory holding expenditure, outsourcing expenditure, and fleet size of SEV industrial vessel operators significantly affect the breakdown and repair cost of SEV industrial vessel type over the period. Similarly, only fleet size has a significant individual random effect on the breakdown repair cost of operators of the SEV vessel type over the period. Neither outsourcing expenditure nor inventory holding expenditure has a significant individual random effect on the breakdown repair cost of SEV operators over the period. We thus reject the null hypothesis $H_{01b}$ to conclude that there is a significant random effect of both the preventive maintenance expenditure and the breakdown repair cost of operating SEV industrial vessels in Nigeria's offshore sector.

## 5. Discussion of Results and Policy Implications

The study's findings are significant for developing efficient preventive maintenance strategies for industrial vessel operations in Nigeria. The commitment to outsourcing and inventory holding expenditures as preventive practices influences the frequency of vessel breakdowns and overall maintenance costs.

***Table 12.** Test of hypothesis $H_{01a}$: Hypothesis $H^{01a}$: There is no significant influence of inventory holding expenditure, outsourcing expenditure cum fleet size of OSV operators on the breakdown and repair cost of operators AHTS industrial vessel type over the period*

| Hypotheses | F-cal. | p-value/sig. | Decision |
|---|---|---|---|
| $H_{01a}$ | 25.84247 | 0.000000 | Reject $\mathbf{H_{01a}}$ |
| **Variable** | **t-cal.** | **p-value/sig.** | **Decision** |
| FLEETSIZE | 3.502746 | 0.0011 | Significant |
| INVEXP | -0.341592 | 0.7344 | Not significant |
| OUSEXP | -0.871627 | 0.3885 | Not significant |
| *Reject null hypotheses if F-cal > f-critical; Accept null hypotheses if F-cal.< F-critical* <br> *Source: Authors calculation* | | | |

***Table 13.** Test of hypothesis $H_{01b}$: There is significant effects of inventory holding expenditure, outsourcing expenditure cum fleet size of OSV operators on the breakdown repair cost of SEV industrial vessel types*

| Hypotheses | F-cal. | p-value/sig. | Decision |
|---|---|---|---|
| $H_{01b}$ | 3.548154 | 0.0077668 | Reject $H_{01b}$ |
| **Variable** | **t-cal.** | **p-value/sig.** | **Decision** |
| FLEETSIZ | 1.909630 | 0.0673 | Significant |
| INEXP | -1.408354 | 0.1709 | Not significant |
| OUSEXP | 1.593574 | 0.1231 | Not significant |
| Reject null hypotheses if F-cal > f-critical; Accept null hypotheses if F-cal.< F-critical | | | |
| Source: Authors calculation | | | |

### 5.1. Outsourcing vs. Inventory Expenditures and Maintenance Productivity

The panel analysis revealed a nuanced trade-off between outsourcing and inventory holding in preventive maintenance. Higher spending on outsourced maintenance can bring specialized expertise but also introduces coordination overhead and reduced internal control. In our data, increased outsourcing did not linearly translate into higher productivity; in fact, excessive outsourcing expenditure sometimes coincided with marginal or even negative productivity gains. This suggests inefficiencies or misaligned incentives: for example, outsourcing firms may be paid for availability rather than uptime. Conversely, maintaining a large spare-part inventory improves parts availability and reduces unplanned downtime, but at the cost of tying up capital (a classic form of waste in lean terms) [23]. Notably, a similar study found that vessels "with full inventory" saw reduced maintenance expenditures over time, indicating that the right level of inventory can preempt costly breakdowns [22,24]. However, beyond a critical point, lean philosophy warns that excess stock yields diminishing returns.

Our model $R^2$, explained only a portion of productivity variance, implying that other factors, such as (e.g. crew skill, equipment condition), play roles. The modest $R^2$ underscores the need for integrated strategies, it suggests that simply shifting budgets between outsourcing and inventory will not fully resolve productivity shortfalls. In practice, we observed that as fleets grew, the cost-to-fleet-size ratio rose steadily. In other words, preventive maintenance costs were increasing faster than the number of vessels, signaling efficiency losses. This trend implies that without changes, expanding the fleet could amplify maintenance burdens. From a productivity standpoint, lean management would advocate for balancing outsourcing with in-house capabilities and using JIT stocking; too much outsourcing or bloated inventories represent forms of waste that ultimately dilute maintenance productivity. This corroborates the findings of references [22-24].

### 5.2. Lean Maintenance and BIM-Informed Decision Making

Lean maintenance principles offer a clear framework to interpret these findings. At its core, lean focuses on eliminating waste and optimizing processes [19]. In maintenance, this means shifting from reactive repairs to proactive, preventive scheduling. For Nigerian vessel operators, applying lean means critically evaluating every naira spent: large inventory holdings should be justified by demonstrable reduction, in downtime, and outsourcing contracts should be streamlined to add value. Lean tools like 5S and standardized work (implemented on board) can reduce the hidden costs of maintenance tasks (e.g, search time, errors).

BIM (or, in the maritime context, a digital twin of the vessel) complements lean thinking by improving decision-making. A BIM-like system aggregates asset information (maintenance history, parts data, sensor readings) to support JIT interventions. As reference [23] theorizes, the synergy of BIM and lean "through waste reduction" has a "positive impact on productivity performance". In other words, using rich digital models helps identify and eliminate waste (e.g., excessive inventory, unnecessary inspections) and to align maintenance activities with actual need. The conceptual model from reference [23] confirms that BIM capabilities and lean methods reinforce each other, and BIM has a "positive influence on productivity performance," with [lean] methods serving as an intermediary. In our context, a BIM-informed maintenance system could automatically trigger spare parts orders exactly when needed, schedule service windows during low-demand periods, and visualize bottlenecks – all consistent with lean's goal of continuous improvement.

The results also revealed that outsourcing expenditure per vessel and inventory holding expenditure per vessel represent 12.4% and 21.6% of the breakdown repair costs, respectively. This provides a basis for optimizing maintenance costs and improving preventive maintenance policies. The study found significant relationships between preventive maintenance expenditures and breakdown/repair costs for both AHTS and SEV vessels. The industry averages for breakdown repair cost, outsourcing expenditure, and inventory holding expenditure per vessel were found to be ₦67.6 million, ₦8.4 million, and ₦14.6 million, respectively. These results highlight the importance of effective maintenance strategies for cost optimization.

### 5.3. Integrated Lean/BIM Models for Maintenance Optimization

Taken together, the evidence suggests that an integrated lean/BIM approach can substantially optimize preventive maintenance planning. For example, a digital maintenance dashboard (analogous to BIM) can flag aging components before failure, allowing planning staff to apply lean "pull" (JIT) replenishment of parts. This avoids both emergency downtime and excessive inventory. Similarly, lean scheduling methods (like leveling and batch planning) can be encoded into digital workflows so that each vessel's preventive maintenance is harmonized with port schedules and weather windows. In practice, we envision a model where predictive analytics (the BIM component) uses real-time sensor data to forecast maintenance needs, while lean methods standardize and optimize the actual maintenance workflow. This dual strategy has been shown to cut cycle times and waste in construction projects cycle times and waste in construction projects (e.g., reducing "batch size" and variability) when BIM and lean are combined [23,24]. By analogy, offshore vessels can benefit from a "4-dimensional schedule" of maintenance tasks and a visual management system for inventory, ensuring that every maintenance action adds value and is completed promptly.

Importantly, our empirical trends support this integrated view. The panel results showed that increasing inventory investment without digital coordination yields limited productivity gains, and that ramping up outsourcing alone may even erode routine efficiency. An integrated lean/BIM model would instead use data to target inventory where it counts (high-criticality parts) and outsource only truly non-core tasks. For instance, a robust predictive model could signal exactly when a key generator needs servicing, a lean process would then procure parts and manpower just in time, and a digital platform would track the work. The policy of "full inventory on all vessels" observed in the data is thus refined to "intelligent inventory" and "selective outsourcing" guided by lean/BIM principles.

### 5.4. Policy Implications

The findings of the study suggest the need to emphasize lean maintenance training. Stakeholders (shipping companies, regulators, training institutes) should promote lean maintenance concepts. Practical training on total productive maintenance and inventory optimization can help maintenance crews reduce non-value-adding activities. Lean audits could identify waste (for example, calculating how excess inventory drives up the cost-to-fleet-size ratio) and set targets for continuous improvement.

The results and findings also suggest the need for offshore industrial vessel operators to invest in digital maintenance systems. Therefore, policymakers and firms should incentivize the adoption of BIM-like asset management platforms. Digital twins and sensor networks can provide the real-time data needed for lean decision-making. As reference [24] notes, BIM and lean together improve productivity; in policy terms, this means supporting technology deployment (perhaps through subsidies or partnerships) that enables predictive maintenance scheduling. For example, guidelines or grants for installing shipboard monitoring systems would allow Nigerian operators to forecast breakdowns and optimize spare-part orders.

The need for policy to optimize outsourcing strategy is also evident. The mixed effects of outsourcing expenditures suggest a need for strategic oversight. Rather than blanket outsourcing, policy should encourage hybrid models: core maintenance skills should be retained in-house, while highly specialized or episodic tasks can be contracted. Regulators could require performance-based contracting (e.g., linking payments to uptime), aligning third-party incentives with productivity. This addresses the finding that outsourcing alone does not automatically raise productivity and, as our trends showed, can in some cases decrease breakdowns only when coupled with proper IM.

Policies should be developed to encourage the use of cost ratios for benchmarking fleet maintenance costs. The cost-to-fleet-size ratio and related metrics (maintenance spend per vessel) should be tracked by industry bodies. High ratios or upward trends should trigger investigation; if a ratio is rising, operators need to identify waste or inefficiency. Benchmarking these ratios across companies or over time provides a transparent indicator for policy. For instance, a national maritime authority could publish average preventive maintenance costs per vessel in the fleet; companies exceeding this average would be encouraged—or required—to explain their maintenance strategy, potentially adopting lean/BIM methods.

Lastly, maintenance policies should be developed to encourage integration of Lean/BIM. Standards and regulations should explicitly recognize the value of integrated lean and digital approaches. For example, guidelines on maritime maintenance could reference the benefits of waste reduction and information management, endorsing frameworks like those in reference [23]. By framing maintenance requirements in terms of performance (e.g., availability targets) rather than inputs, regulators push operators toward lean/BIM solutions. This aligns with our analysis: since our panel model's modest $R^2$ suggests many unmeasured influences on productivity, a goal-based policy encourages companies to innovate, (via lean and BIM) to meet targets rather than just increasing budgets.

The findings imply that Nigerian offshore vessel stakeholders should move beyond descriptive budgeting of maintenance (outsourcing vs. inventory) and adopt a productivity mindset informed by lean principles and digital tools. Implementing integrated lean/BIM models – as theoretically supported by reference [23] – will optimize preventive maintenance planning, ensuring each naira spent tangibly improves fleet productivity and cost efficiency.

## 6. Recommendations

It is recommended that:

(1) Industrial vessel operators in the Nigerian offshore sector should ensure that models of empirical relationships between fleet size, preventive maintenance expenditure, and breakdown repair costs form the basis for developing policies for industrial vessel operations. This will guarantee that breakdown repair cost and the overall maintenance cost of industrial vessels do not escalate to levels where profitability of operations is endangered or negatively affected.

(2) The prevailing industry average of industrial vessel breakdown repair cost, outsourcing expenditure, and inventory holding expenditure per vessel should be used by industrial vessel operators as a benchmark to guide against non-optimal expenditure. This is particularly important for operators facing excessive vessel repair/maintenance costs, outsourcing expenditure, and inventory holding expenditure.

(3) The outsourcing expenditure per vessel and inventory holding expenditure per vessel in the fleet of industrial vessel operators in Nigeria as a percentage of the breakdown repair cost are about 12.4% and 21.6%, respectively. The optimization of the breakdown repair cost of industrial vessels in the Nigeria maritime and offshore sector should be based on the 12.4% and 21.6% industry average benchmark for outsourcing expenditure and inventory holding expenditure respectively

7. Suggestions for Further Studies

Further studies need to be conducted to ascertain the determinant factors that influence industrial vessels' breakdown incident rates and repair costs in the Nigerian offshore sector.

### Authorship Contributions

Concept design: C. O. Anyadiegwu, and O. C. Ndikom, Data Collection or Processing: C. O. Anyadiegwu, T. C. Nwokedi, and N. C. Ezeanya, Analysis or Interpretation: C. O. Anyadiegwu, T. C. Nwokedi, and D. E. Onwuegbuchunam, Literature Review: C. O. Anyadiegwu, O. C. Ndiom, and N. C. Ezeanya, Writing, Reviewing and Editing: C. O Anyadiegwu, and D. E. Onwuegbuchunam.

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