Improving the Operational Output of Marine Vessel Main Engine System through Cost Reduction using Reliability Technique

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DOI: 10.56201/ijemt.v8.no2.2022.pg36.52

ABSTRACT
This research seeks to use reliability technique to improve operational output through cost reduction of the main engine system of a ship. The various subsystems of the marine vessel main engine were identified. The failure mode effect and criticality index of the engine system and their root causes were analyzed. The reliability of the main engine system was analyzed using exponential reliability model and a maintenance task that reduces the operational cost of main engine system was generated thereby improving output. The reliability centred maintenance technique identified all the perspectives of failures in the ship main engine systems and employed the appropriate maintenance approach for each failure respectively. The results of the reliability analysis performed on the main engine systems generated the proposed preventive maintenance (PM) tasks and plan. Decrease in the rate of Run-To-Failure (RTF) data remains inevitable and programmed performance of condition based, task demand and fault finding (CD, TD and FF) was recommended. The projected work program if implemented will decrease labour cost from ₦177, 600,000.00/year to ₦100, 800,000.00/year (approximately 43.24% of the total annual labour expenditure). The projected PM scheduling outcomes showed a 44.64% saving in the total cost of maintenance when compared with the existing RTF practice. The main engine systems reliability increases with decreased labour cost. The proposed spare parts plan for the main engine systems was generated and the results showed that approximately 55.42% of the yearly costs of spare parts are saved when projected PM scheduling is adopted.

Keywords: *criticality index, Ship main Engine, Maintenance Technique, Reliability*

1. INTRODUCTION

The demand for large capacity marine carriers in business-related transportation has increased over the past years. These big vessels are actuated by strong maritime diesel engines, which must have high reliability for safe and sound operation. Due to the high costs involved in operations and maintenance in the shipping business, many service companies and marine vessel owners are increasingly directing attention on improving operational output through reducing costs of service and maintenance. Conversely, continuous development nowadays is inevitable in marine trade to ensure survival in competitive marine market. Uninterrupted advancement must be well thought-out and implemented with respect to safety, excellence and reliability in order for operational cost to reduce.

Reliability is defined as the probability that a component or system will perform its required function for a given period of time operating under certain specified conditions (Ali, 2010). The reliability of a marine vessel's main engine is dependent on a number of essential sub systems, including fuel oil system, lubricating oil system, cooling water system and scavenges air system (Anantharaman *et al.*, 2018; Nnaji *et al.*, 2020). Every one of these subsystems has it personal components; the dependability of their own individual system components would dictate the reliability of the corresponding subsystem, and the overall reliability of the main engine (EPSMA 2005; Nitonye, 2017). The degree of capability with which a system, an equipment or component is capable of being reinstated or retained in serviceable operation refers to maintainability. Time is a key feature, determining the value of the technical system. Reduced downtime translates to increase in functioning readiness or availability of the system, increasing the potential to maximize operational gains. Preventive replacements or repair of parts is implemented when the mechanical system and its parts display increasing rate of failures (Ali, 2010). Using this maintenance system in the event of regular failures, would influence the safety of the achieved reliability but with increase cost.

To address the concern above, an important process which has to be subject of upgrading is the maintenance technique. The cost of maintenance forms a considerable part of the general working costs in vessel operations. Maintenance clearly affects engine parts and coordination reliability, but if much is not done, it may give rise to an extreme numeral of expensive failures and low quality engine performance which for that reason reduces the engine system's reliability (Iselin, 2015). And when maintenance is done too often on the main engine, reliability possibly will perk up, but the cost of maintenance will abruptly swell. For a cost-efficient system, both expenditures have to be balanced. Reliability modeling technique presents a reliability centred maintenance (RCM) framework that compares various alternative maintenance methods and selects the most cost-effective maintenance method that will sustain the equipment's reliability (Xing & Robidoux 2009). Preventive maintenance strategies are optimized with RCM as it ensures that maintenance tasks are performed in an efficient, cost-effective, safe and reliable manner.

Failures in engine system raise the likelihood of having a disastrous environmental mishap and the likelihood of safety compromised accidents. The consequences of failures in marine vessel main engine system and subsystems, which leads to immobilisation of the engine, catastrophic environmental and safety-related accidents is a major concern of this research work as it affects ship operation in terms of cost and time. Therefore, using reliability technique to reduce the operational cost of the main engine of a marine vessel is the motivation for this research work. Identification of the basic subsystems of the marine vessel main engine, failure causes, and analyses of the failure mode effect and criticality index of the engine system, the use of exponential reliability model and parameters to determine the reliability of the identified main engine system aimed at developing a maintenance task that will improve the operational output of the main engine system by reducing cost of operation were the objectives of this study.

Recent research works reveals that good number of attempts has been made to the system of using reliability modeling to reduce operational cost of the main engine system of a marine vessel. These studies and more, however, addressed the problem of using reliability modeling to improve performance of ship main engine system operation, but in a restricted manner.

Nnaji *et al.* (2020) evaluated the dependability of the maritime diesel engine via the Weibull distribution. The dependability analysis of Model 38 FBM maritime vessel engine, with the application of Weibull distribution was conducted in this research. The Weibull parameters, Probability Density Function (PDF), Mean Time Between Failure (MTBF) and Cumulative Distribution Function (CDF) of the damaged components of the diesel engine were analyzed and reliability of the structure was ascertained. The information provided shows that the reliability of the maritime diesel engine varies inversely to the operational time and made available a stand for developing a Weibull set for marine engine components targeted at arming practitioners with the tool for failure pattern study for an enhanced maintenance culture.

Tran *et al.* (2017) studied marine propulsion structure dependability via fault tree analysis. The study investigated the reliability to guarantee the safe operation of the transport facilities as this issue remains a reoccurring decimal in transportation business. Their study offered an insight into a number of researches that employed Fault Tree Analysis technique (FTA) to model the assessment/analysis of marine propulsion system's reliability.

Rodrigo (2007) employed FTA and FMEA analysis for application of the reliability centered maintenance system: case study on hydraulic turbines. His research objective focused on evaluation of the impact of RCM technique on a power generating system. He asserted that RCM demands considerable development in the role played by maintenance, including an improvement in reliability and availability of equipment.

Dario and Luka (2011) studied the dependability of a light high pace maritime diesel engine. The empirical reliability functions $R(t)$, failure rate $\lambda(t)$ and the density of failures fe(t) of the main maritime diesel engine were ascertained by means of an experimental data on failures. Observation proved that the Weibull distribution with parameters $\eta=400$ and $\beta=2.613$ approximated fine the reliability of a light high pace maritime diesel engine. Successive reliability formation of the marine diesel engine component was investigated and the failure frequencies together with the values of the failure rate by components were ascertained.

Anantharaman *et al.* (2019) carried out records assessment to investigative the reliability of a main diesel engine. They asserted that marine transportation business is vital to the upgrade experienced in the international financial system and currently nearly majority of the world's trade occurs through marine transportation involving over fifty thousand merchant vessels. These vessels trading globally transport diverse goods, manned by several million mariners around the world. Yet the transport business continues to witness array of accidents resulting from failure of the main engine on transit, the major cause traceable to inappropriate maintenance strategy. As it stands the main engine onboard ship make do with a Planned Maintenance System (PMS), intended to suffice for maximum safety and operational handling by the ship management handlers, taking into consideration, advice of the OEM and/or ship's main engineers and masters. The data generated and model developed in their study was valuable to analyse the reliability of maritime engines and to map the maintenance strategy onboard the vessel.

2. MATERIALS AND METHODS:

Failure data was collected from the Nigerian Ports Authority (NPA) Marine Vessel-MT Otuoke to analyze the reliability of the main engines onboard the vessel for its operational cost reduction. One of the many agencies of the Federal Government of Nigeria is the Nigerian Ports Authority (NPA). The Agency presides over and operates Nigerian Ports. Nigerian's main Ports include: The Calabar port complex located in Cross River State, Tin Can Island port complex and the Lagos port complex both located in Lagos State, Rivers port complex and Onne port complex both located in Rivers State and the Delta ports located in Warri, Delta State. (NPA, 2021).

The coastal region of Rivers State plays host to the Rivers port complex, which plays a Mother-Port role to a number of jetties around her location as satellites unit via the provision of towage and pilotage services using three (3) tug boats at her quays. These boats are MT Otuoke, MT Balasa, and PC Hinna.

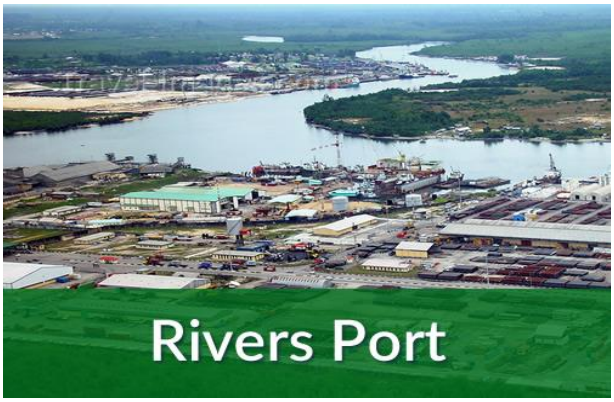

Plate 1: Nigerian Port Authority (NPA): Rivers Port (NPA, 2021)

2.1 Materials

Failure data from Marine Vessel-MT Otuoke, Failure Mode Effect and Criticality Analysis (FMECA), Root Cause Failure Analysis (RCFA), the SPSS Software and MATLAB Computer Program were employed in the analyses of the reliability parameters of the ship main engine system components.

2.2. Method

The main engine system was studied considering the smallest constituent of the system using materials and tools mentioned in section 2.1. The reliability-centred maintenance plan that was generated uses a predictive and preventive maintenance strategy (not just the corrective maintenance strategy as generally used onboard the vessel) for the engine system that reduces the downtime in the engine system's operation, consequently reducing the running cost and thereby improving the system performance. Result of the analysis was used to generate a maintenance plan, centred on the analyzed reliability, which reduces the operational cost of the diesel engine onboard ship-MT Otuoke thereby improving operational output.

2.3 Parts of Marine Diesel Engine

The description of individual parts of the marine diesel engine is categorized into moving or fixed parts. Moving parts includes the following: – the fuel pump, the camshaft, the crankshaft the piston rings, skirt and the piston, exhaust gas valve, inlet valve fuel injectors, turbo blowers, connecting rod and crank pin, rocker arm and push rod the air start valve, fuel valve and the crosshead .

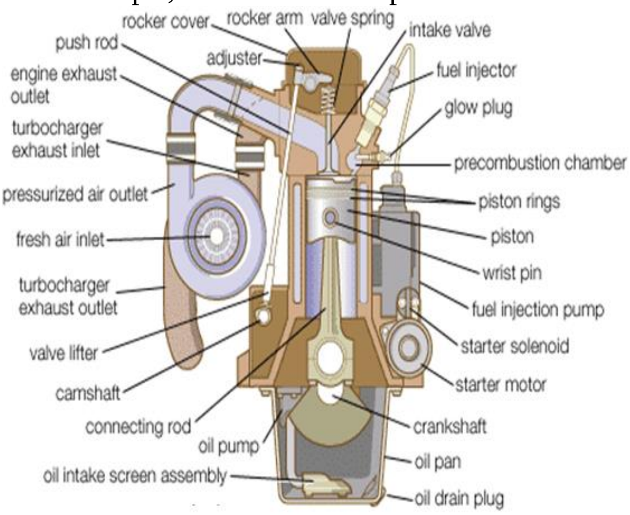

Figure 1: Moving Parts of Marine Diesel Engine (Retrieved from http://www.ystinjectors.com/html_news/?15-Major-Types-Of-Diesel-Engines-15.html)

A number of parts made up the fixed section, most of them are listed as follows: the cylinder head, bedplate, the stern tube, the thrust block, the cylinder liner etc. The cylinder block accommodates some of the engine components like pistons, pistons rings, crankshafts, oil pump and cylinders.

2.4 Mechanism of the Marine Diesel Engine System

Mechanism of the diesel engine comprises of various subsystems namely: combustion unit, emission unit, lubrication unit, and injection unit etc. The marine diesel engine block is made up cast iron cylinder, a single inspection access door per cylinder for ease of access to housed components like the connecting rod cap, liners, replaceable valves guides, valve seats camshaft with polynomial profile, separate cast iron head made up of four valves, toughened steel forged crankshaft with induction worked on journals, distribution units, hardened and grinded helicoidally gears, piston rings, lube oil cooled light alloy piston noted for high output and chromium – molybdenum steel conrods.

The temperature reducing (cooling) system is made up of raw fresh/salt water heat exchanger that incorporates thermostatic valves, expansion tanks and pumps. The anti-friction fluid system is made up replaceable cartridge lube oil cleanser, full flow screwable oil filters and fresh water cooler. This unit is made up of flange mechanical governor attached to the inline injection pump. Dual wall injection bundle attached with leakage collector and replaceable duplex fuel filters.

2.5 Exponential Reliability Model

The PDF of the Weibull distribution as given by (Ebeling, 2007):

$$f(t;\beta;\theta) = \frac{\beta}{\theta}.\left(\frac{t}{\theta}\right)^{\beta-1}.\exp\left[-\left(\frac{t}{\theta}\right)^{\beta}\right] \qquad (1)$$

where

t = hours of operation/ up time
θ = Weibull scale paramter
β = Shape parameter.

Equation 1 formed the exponential reliability technique applied. Reliability therefore

$$R(t) = e^{-\lambda t} \qquad (2)$$

2.6 Mean Time between Failures (MTBF)

$$MTBF = \frac{\sum t_I}{n} \qquad (3)$$

Where: $\sum t_I$ = the summation of running time in operation of the main engine system within an investigation period for both failed and non-failed items.
n = number of failures or breakdowns of main engine system or its components occurring during a certain investigation period.

2.7 Mean Time to Repair (MTTR)

MTTR represents the essential statistical assessment of maintainability of a reparable component or structure.

$$MTTR = \frac{Total\ Maintenance\ time}{Total\ number\ of\ repairs}$$

$$MTTR = \frac{\sum t_i}{n} \qquad (4)$$

Where: t_1 = total accumulative time of the main engine system to repair or maintain in statistical time.
n = number of repair actions in the population of the main engine system during the specified investigation time period.

2.8 Failure Rate (λ)

Failure rate represents the possibility of failure per unit time. It is the overall sum of failures divided by the overall collective time in working state, mathematically λ equals to MTBF /MTTF function.

$$\lambda = \frac{1}{MTBF} = \frac{n}{\sum t_1} \qquad (5)$$

where: $\sum t_I$ = the summation of running time in operation of the main engine system within an investigation period for both failed and non-failed items.
n = number of breakdowns or failures of main engine system or its components happening during a certain investigation period.

2.9 Repair Rate

Repair rate stands for the possibility, the chances of repair per unit time. It is the frequency of incidence of repairs, utilized where a system has reparable components.

$$\mu = \frac{1}{MTTR} \qquad (6)$$

Where: MTTR = Mean time to repair

2.11 Availability

Availability of a system or vessel engine simply refers to the ratio of the time the vessel engine is functioning to the cumulative time the vessel engine does not function including maintenance and repair time.

$$A = \frac{MTBF}{(MTBF + MTTR)} \quad (7) \quad \text{Or } A = \frac{T_O}{T_O + T_1} \quad (8)$$

Where: T_0 = Time that main engine system works.
T_1 = Time that main engine system do not work, include repair and maintenance time.

2.12 Analysis of Criticality.

Analyzing Criticality is effective way to appraise the manner equipment failure effects organizational output in a bid to methodically prioritize machinery physical material in maintenance scheduling. It is quantified using the values ranging from 1.0 through to 3 depending.

3. RESULTS AND DISCUSSION:

Grouping the criteria assessment into A, B, C, D, the criticality levels for the ship main engine system's failure mode group A, B, C, and D depending on the criticality index are as shown in Table 1. This table shows the probability that the occurrence of the established failure lies is on the critical path of the machinery network. Maximum negative effect is given A while minimum effect bears D, determined by: $\text{Equipment Criticality (EC)} = 40\% S + 40\% P + 20\% C$ (9)

The safety, Production and the cost connected impacts takes the value of 40%, 40%, and 20% respectively.

Table 1: Criticality Group, Index, Level and Effects

Group	Criticality Index	Criticality Level	Effects
A	3.0 - 2.5	High	High
B	2.5 – 2.0	Medium-High	Moderately high
C	2.0 - 1.5	Medium-Low	Moderately low
D	1.5 – 1.0	Low	Low

The results show that, out of the seven (7) systems that make the main engine system onboard the vessel, the engine cooling water system (CWS) has the highest MTBF with 19923.10 hours while the engine main system/diesel engine (EMS) has the lowest MTBF with 1191.70 hours within the study period.

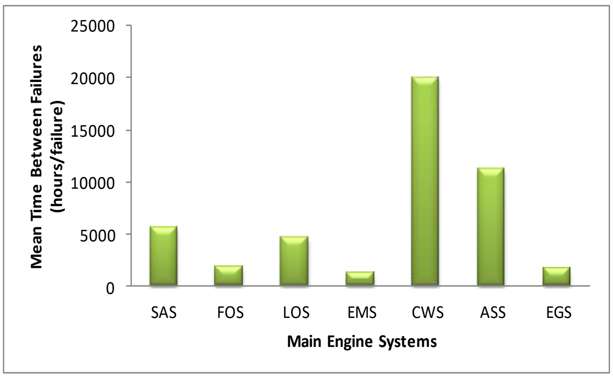

Figure 3: Ship Engine Systems' Mean Time between Failures (MTBF)

The mean time to repair (MTTR) of the main engine systems onboard Nigerian Ports Authority ship MT Otuoke for the ten (10) years period from 2010 to 2020 is represented in Figure 4. The results show that, out of the seven (7) systems that make the main engine system onboard the vessel, the engine main system/diesel engine (EMS) has the highest MTTR with 54.24 hours while the fuel oil system (FOS) has the lowest MTTR with 33.57 hours.

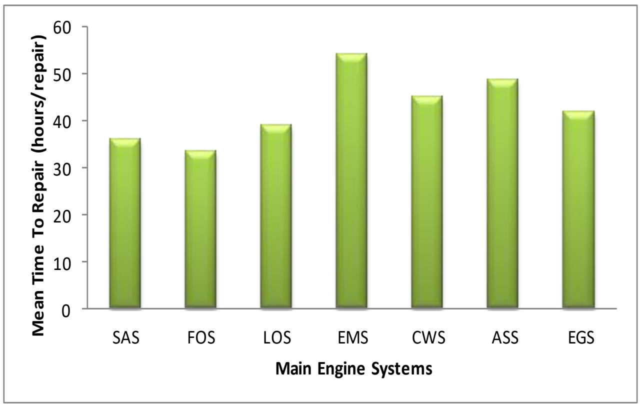

Figure 4: Ship Engine Systems' Mean Time to Repair (MTTR)

Figure 5 shows that out of the seven (7) systems that make the main engine system onboard the vessel, the engine main system/diesel engine (EMS) has the highest failure rate at 0.0008391failure/hr while the cooling water system (CWS) has the lowest failure rate with 0.00005019failure/hr within the study period.

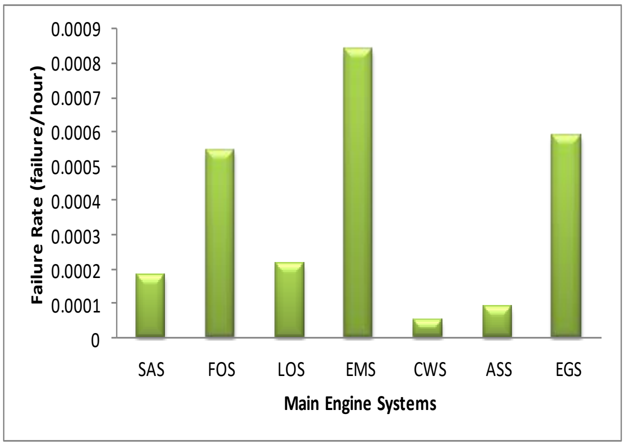

Figure 5: Ship Engine Systems' Failure Rate

The results as presented in figure 6 show that, out of the seven (7) systems that make the main engine system onboard the vessel, the starting air system/diesel engine (SAS) has the highest repair rate at 0.02769repair/hr while the engine main system/diesel engine (EMS) has the lowest repair rate with

0.01844repair/hr.

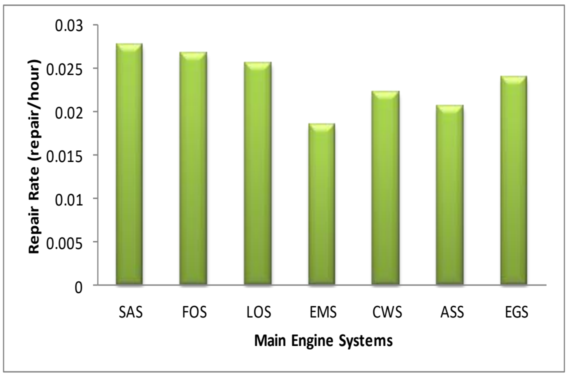

Figure 6: Ship Engine Systems' Repair Rate

The results of the Availability presented in figure 7 show that, out of the seven (7) systems that make the main engine system, the cooling water system (CWS) has the highest availability with 99.78% while starting air system (SAS) has the lowest availability with 94.35%.

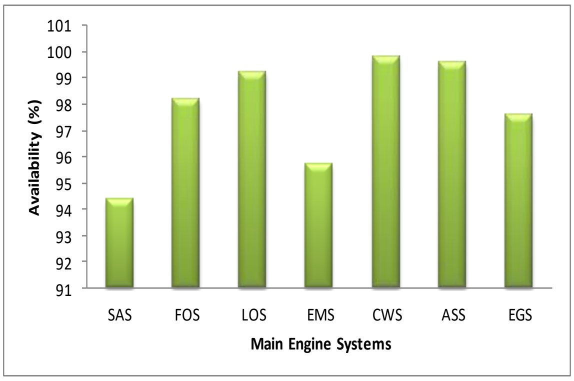

Figure 7: Ship Engine Systems' Availability

Out of the seven (7) systems that make the main engine system onboard the vessel, the cooling water system (CWS) has the highest reliability with 97.99% while the engine main system/diesel engine (EMS) has the lowest reliability with 3.77% as shown in figure 8.

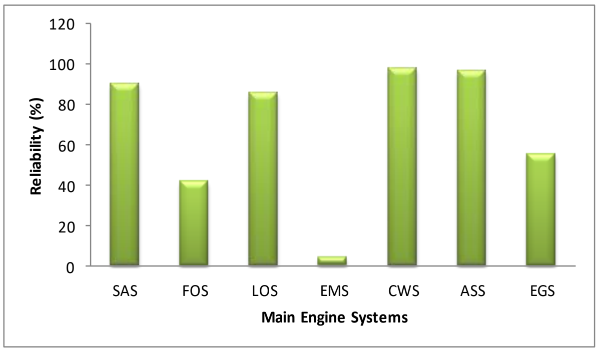

Figure 8: Ship Engine Systems' Reliability (R)

3.1: Reliability state of the Ship-MT Otuoke's Main Engine Systems

The ship engine systems' failure rates against operating time from figure 9 show that failure rate for starting air system (SAS) is 0.0001795failure/hour running for 89134.10 failures/hours, 0.0005448failure/hour for fuel oil system (FOS)running for 88100.70failures/hours, 0.0002135failure/hour for lubricating oil system (LOS)running for 88971.20failures/hours, 0.0008391failure/hour for engine main system/diesel engine (EMS) which has the highest failure rate running for 85806.60hours, 0.00008956failure/hour for air-charge/scavenge system (ASS) running for 89322.80hours and 0.0005895failure/hour for exhaust gas system (EGS) running for 88711.50hours. From Figure 10, the reliability of the cooling water system (CWS) has the highest reliability with 97.99% while the engine main system/diesel engine (EMS) has the lowest reliability with 3.77%.

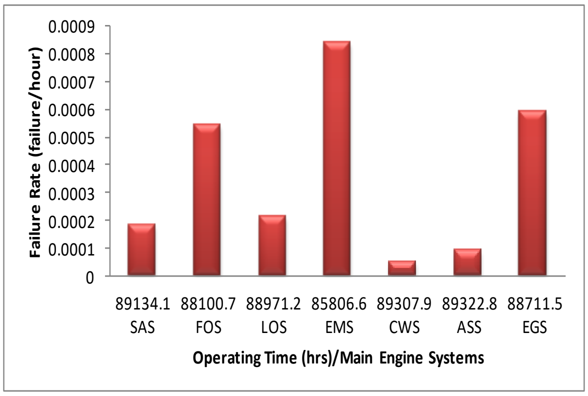

Figure 9: Ship Engine Systems' Failure Rate against its Operating Time

The maintenance strategy should be directed towards the item which is major contributor to the system failures which is the engine main system/diesel engine (EMS) as the reliability analysis reveals. After operating for 89307.90hours, the EMS shows the least reliability at 3.77% and highest failure rate at 0.0008391failures/hr due to worn piston ring, cracked cylinder liner, faulty governor, cracked engine block, broken crank pin, cracked cylinder head, misalignment, burred piston, shaft deforming, leaking valves, and broken bearing and coupling.

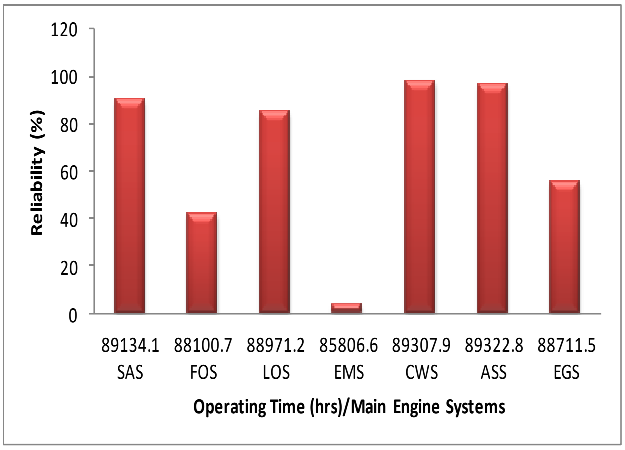

Figure 10: Ship Engine Systems' Reliability against its Operating Time

3.2 Engine Main System (EMS)/Diesel Engine System Root Cause Failure Analysis (RCFA)

As shown in Table 2, root cause failure analysis for the engine main system (EMS) is presented. The cause analysis (failure mode, reason and root cause) for the most critical system which is the EMS is determined as tabulated.

Table 2: Diesel Engine System Root Cause Failure Analysis

Failure Mode	Mechanism	Reason	Root Cause
Fuel Injector Failure	Injectors	Low injection pressure Accumulated Carbon	Faulty fuel injection pump & valve,
Piston Failure & Piston Rings	Piston Piston rings	Poor clearance Operation condition	Cracked piston Broken piston rings
Cylinder Block Failure	Vibration	Operation condition Poor cooling Bearing	Damaged bearing connecting rod Insufficient cooling
Crank-shaft Connecting rod Failure	Vibration Oil mist	Operation condition Journal pin Bearing	Cracked crankshaft Damaged crosshead & crankshaft bearing Crankshaft Mis-alignment Poor lubrication

3.3: Failure Mode and Effect Analysis (FMEA) of the Engine Main System (EMS)/Diesel Engine System

Failure mode and effect analysis is a tool that examines potential product or process failures, evaluates risk priorities, and helps determine remedial actions to avoid identified problems.

Table 3: Diesel Engine System Failure Mode Effect Analysis.

Item	Failure Mode	Effect			LTA
		Local	System	Plant	
Piston ring	Cracked and broken	Reduced engine power	Engine efficiency	Low efficiency	Y

	piston ring	Excessive exhaust emission Axial and radial wear			
Cy-linder head	Cracked and broken cylinder liner	Low compression Poor performance Leakages & excessive exhaust emission	Low per-formance	Low performance	Y
Governor	Faulty governor	Poor fuel consumption	Engine efficiency	Low performance	Y
Engine block	Crack & broken cylinder block		Engine efficiency	Low per formance	N
Crankshaft	Crank case explosion Damaged bearings, journals &journal pins	Excessive damage Shutdown	System shutdown	Engine shutdown	Y
Cy-linder liner	Cracked and broken	Excessive coolant loss Overheating	Poor performan ce	Poor performance	Y
Con-necting rod	Cracked or broken	Knocking noise Excessive oil consumption Low oil pressure	Low efficiency	Low efficiency	Y
Crank pin	Cracked or broken crank pin	Vibration Coupling failure Oil leakage Radial and axial wear	Poor performan ce	Poor performance	Y
Piston	Cracked or broken piston	Excessive oil consumption Loss of compression	Low performan ce	Low performance	Y

Blow by

Table 4: Criticality Analysis of the Diesel Engine System

Equipment	**Failure Mode**	**Failure cause**	**Criticality analysis**			**Criticality index**	**Group/ level**
			S	**P**	**C**		
Diesel engine	Injector failure	Poor fuel quality, Crack injector body	2	3	2	2.4	B Medium -High
	Piston & piston ring failure	Inadequate cooling & lubrication Improper fit of piston, Corrosion & Over-heating	3	3	3	3.0	A High
	Cylinder block failure	Impurities Insufficient cooling Piston failure Piston rod-connecting rod failure	2	2	3	2.2	B Medium -High
	Crankshaft & connecting rod failure	High stress concentration Misalignment faulty journal & main bearing	3	3	2	2.8	A High

3.4: Task Selection for the Diesel Engine System

The maintenance task for the diesel engine system is illustrated in Table 5. The table reveals that for injector failure mode which was analyzed with medium-high criticality level (criticality group B); the maintenance task prescribed is the condition-directed (CD) maintenance by monthly checking against contaminated fuel, fuel quality, inspecting and replacing crack & broken injector as it has a moderately high effect on the system. For piston & piston ring failure which were all analyzed with high criticality level (criticality group A), the maintenance task prescribed for all the failure causes are: the condition-

directed (CD) maintenance tasked with adequate cooling, sufficient lubrication, proper fit of piston, monthly, as the failure caused has a high effect on the system.
For Cylinder block failure mode which was analyzed with high criticality level (criticality group A), the maintenance task prescribed is condition-directed (CD and fault finding (FF), maintenance tasked against contaminants, sufficient cooling, replace faulty piston, piston rod-connecting rod failure alternately monthly and weekly, as the failure caused has a high effect on the system Finally, for failure mode crankshaft and connecting rod failure which was analyzed with high criticality level (group A), the maintenance task prescribed is the condition-directed (CD) and fault finding (FF) maintenance, tasked with adequate lubrication, checking against misalignment, replacing faulty journal and bearing monthly, and as it has a maximal effect on the system.

Table 5: Diesel Engine System Maintenance Task.

Failure Mode	Failure cause	Group /level	Task	Description	Frequency
Injector failure	Contaminated or Poor fuel quality Crack broken injector body	B (Medium-&High)	CD	Check fuel quality, Inspect, replace crack & broken injector	Monthly
Piston & piston ring failure	Faulty cooling & lubrication, Improper Piston fit Corrosion & Overheating	A (High)	CD	Check cooling System and lubrication, fit of piston	Alternate Monthly and weekly
Cylinder block failure	Contaminant, Insufficient cooling, Piston, Piston rod-connecting rod failure	B (Medium-High)	CD FF TD	Check Contaminants, cooling, Check/replace Piston, Piston rod-connecting rod failure	Monthly
Crankshaft & connecting rod failure	High stress concentration Misalignment faulty journal & main bearing	A (High)	CD FF	Adequate lubrication, misalignment, replace faulty main journal & main bearing	Alternate Monthly and weekly

3.4: Maintenance Labour Force for the Diesel Engine System
The maintenance labour or man hours required as shown in Table 7 indicates the maintenance labour

force calculations for the PM levels (six monthly, monthly and weekly). Tasks prescribed to be carried out every six month will be done twice (2) annually with 3 maintenance personnel working 21 hours on each schedule, totalling 126 (2 x 21 x 3) man-hour per PM level; same goes for monthly (10 x 5 x 2) and weekly (50 x 6.5 x 1, totalling 325) man-hours per PM level respectively.

Table 7: Annual Maintenance Labour Force Size for the Diesel Engine System.

PM Level	Frequency	Duration (Hours)	No. of Workers	Man-hour per PM level
Six months	2	21	3	126
Months	10	5	2	100
Weekly	50	6.5	1	325

The annual labour saving cost presented in Table 8 proves that the proposed annual labour cost (₦100, 800,000.00/year) decreased with respect to the current values (₦177, 600,000.00/year) by 43.24% savings.

Table 8: Annual Labour Saving Cost for the Diesel Engine System.

Item (and Estimated cost)	Labour Type	Current labours Per day	proposed labours Per day
Engineer Officers (₦ 1,000, 000.00/month)	Mechanical	4	2
	Electrical	4	2
	Control	2	2
Ratings (₦ 400, 000.00/month)	Mechanical	6	3
	Electrical	6	3
Total cost (Naira/year)		**177, 600, 000**	**100, 800, 000**
Saving cost (%) = 43.24			

3.5: Spare Parts Program for the Diesel Engine System

The proposed spare parts program is shown in Table 8. This table shows that the spare parts for the diesel engine main component. Proposed spare parts program results indicated a saving of about 55.42% of the spare parts total cost as compared with that of the current maintenance.

Table 8: Diesel Engine System Proposed Spare Parts Plan (Yearly).

Equipment	Spare part	Quantity Current	Cost Estimated current ₦ /year	Quantity Propose	Cost Proposed ₦ /year
Diesel Engine System	Valves	8	2,400,000	4	1,200, 000
	Piston	8	8,160,000	3	3,060, 000

	Piston rings	8	3,200,000	4	1,600,000
	Bearings Main and crosshead	8	4,900,000	4	2,450,000
	Gaskets	8	1,800,000	3	675, 000
	Fuel filters	8	2,500,000	4	1, 250, 000
Total cost ₦/year			**22,960, 000**		**10,235, 000**
Saving cost %				**55.42%**	

4. CONCLUSION

This study applied reliability analysis to improve the operational output through reduction of the operational cost of the main engine system of a marine vessel. Various subsystems of the marine vessel main engine, was determined, failure mode effect and criticality index of the engine system and their root causes was analysed. Applying exponential reliability technique, the reliability of the main engine system was established and a maintenance task that reduces the operational cost of main engine system developed.

Failure data collected were used to analyze the reliability of the most important engine systems onboard the vessel for its operational cost reduction. The SPSS Software and MATLAB Computer Program was employed to analyze the reliability parameters of the components of the ship main engine systems and to generate a maintenance plan, centred on the analyzed reliability of the engine systems, which improves its operational output by reducing the operational cost of the engine

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