International Journal of Manufacturing, Materials, and Mechanical Engineering
Volume 13 • Issue 1 • January-December 2024

Maintenance Resources Optimization Using Pareto Analysis:

Instrumentation Air Compressor in Oredo, Nigeria

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ABSTRACT

Managing resource allocation for optimum effectiveness at various levels of maintenance activities is always a challenging task. Optimizing maintenance resources enables an organization to set priorities towards achieving certain goals which are availability and reliability of the equipment for operational excellence. The purpose of this analysis is to determine the optimum resources allocation proportions among the failure modes and to identify the failure modes that have the greatest cumulative effect on the equipment's downtime. This paper presents a methodology using the Pareto analysis in conjunction with failure mode effect and criticality Analysis in maintenance resources optimization. The approach is based on ensuring all failure mode criticality number are considered to obtain the significant failures mode that you should focus on as a priority. The analysis shows that failure mode; FM5, FM 3, FM 2, FM 12, FM 7 and FM 13 are confirmation to the Pareto principle, identifying that most of the downtime of the Instrumentation Air Compressors originated from these failure modes.

KEYWORDS

Failure Mode, Pareto Analysis, Optimization, Maintenance, Resources, Availability, Reliability

1. INTRODUCTION

Maintenance resources optimization consists of the development and analysis of mathematical models aimed at improving or optimizing maintenance resources allocation. Resource allocation is a critical task in the oil and gas industries. Effectively allocating resources is critical to the success of any project or initiative. Resource allocation is the process of assigning and managing resources to meet equipment maintenance requirements and achieve organizational goals which is availability and reliability of these equipment. It involves balancing the needs and constraints of the project with

DOI: 10.4018/IJMMME.353392

the resources available. Resource allocation can be a complex task in maintenance activities, and organizations need to have a systematic approach to ensure that they allocate resources effectively.

There are several different approaches to resource allocation, each with its strengths and weaknesses. One approach that has gained popularity in recent years is Pareto analysis. Pareto analysis is a statistical technique in decision making that is used for the selection of a limited number of tasks that produce significant overall effect. The results of a Pareto analysis are typically represented through a Pareto cart. Talib et al. (2010) presented a study to identify and propose a list of "vital few" Total quality management (TQM) and critical success factors (CSFs) for the benefit of researchers and service industries practitioners, quality tool "Pareto analysis" was used to sort and arrange the CSFs according to the order of criticality. They concluded that top-management commitment was listed as the top CSFs with customer focus and satisfaction close behind. Pareto chart is a graphical tool that helps to break a big problem down into its parts and identify which parts are the most important (Talib et al., 2010). One key area in addressing inefficiencies is to find out where limited resources should be deployed to create maximum benefit. The Pareto analysis is also referred to as the 80-20 rule or the rule of the "vital few", holds that much of any given set of effects or outcomes (80%) can be attributed to result from a minority of causes (20%) (Joiner Associates, 1995). Pareto analysis is a problem-solving technique that involves identifying the 20% of factors that contribute to 80% of the results. In the context of resource allocation, Pareto analysis can be used to identify the resources that have the most significant impact on project outcomes. In the oil and gas industry the factors or events that contribute to the results (unreliability/downtime) are the failure mode of the equipment or components, hence we talk about failure mode effect analysis (FMEA). When extended by Criticality Analysis procedure (CA) for failure modes classification, it is known as Failure Mode Effects and Criticality Analysis (FMECA). Ora et al. (2017) discussed the failure mode effect analysis of various equipment used in ceramic industry and identify the hazards associated with all those critical equipment which may lead to life loss, property damage or may cause harm to environment also. A total of seven different equipment was considered so that based on risk priority number, Pareto chart was drafted and on the basis of their findings action plan can be suggested. Their results will provide significant insights for the management in dealing with the issues of numerous hazards which may lead to mishap, based on RPN and if it is significant then refer action plan to resolve it as per their need. Aziz et al. (2013) discussed the use of pareto analysis to determine the allocation proportions among these groups and to identify the faculties that have the greatest cumulative effect on the university budget allocation. From their analysis they identified the areas of highest financial operation management allocation that have the greatest cumulative effect on the university's overall budget. The study established that ten faculties have been identified as dominant faculties since they received high budget allocations in proportion to the total university's budget. These results will provide significant insights for the management in dealing with planning budget allocation. Khan et al. (2019) presented a methodology to analyse and improve the allocation of junior doctor resources through the study of pager calls using the Pareto principle. Their analysis of the pager frequency data showed confirmation to the Pareto principle, identifying that the majority of calls to the junior doctor/resident originate from a limited number of departments/locations. Such analysis has allowed a restructuring of resources, to better streamline departmental efficiency. De Castro, & Cavalca (2006) presented an availability optimization of an engineering system assembled in a series configuration, with redundancy of units and corrective maintenance resources as optimization parameters. His optimization method used a Genetic Algorithm based on biological concepts of species evolution. Their results indicated that the methodology is suitable to solve a wide range of engineering design problems involving allocation of redundancies and maintenance resources. The main contribution of their work is the availability optimization considering redundant components and maintenance resources. Schoenmakers, & Zeiler (2017) discussed the application of the Pareto Principle in the context of designing nearly Zero Energy Building (nZEB) hospitals. Braglia et al. (2003) presented an alternative multi-attribute decision-making approach for prioritizing failures in failure mode, effects and criticality analysis (FMECA). The approach is based on a fuzzy version of the "technique for order preference by similarity to ideal solution" (TOPSIS). They established that the sensitivity analysis of the fuzzy judgement weights confirmed that the proposed approach gives a reasonable and robust final priority ranking of the different causes of failure. Varzakas, & Arvanitoyannis (2007) applied FMEA model for the risk assessment of potato chips manufacturing. They also used Pareto diagrams for finding the optimized potential of FMEA. Nguyen, & Bagajewicz (2010) proposed a genetic algorithm to obtain an economically optimal preventive maintenance frequency for different equipment, the parts inventory policy (number and type of spare parts to keep in stock), and labour allocation in process plants was made.

Sepe et al. (2022) presented an overview of an analytics framework for predictive maintenance service boosted by Machine Learning and asset knowledge, applied to turbomachinery assets. Through their risk model an optimization of the maintenance scenario was performed that assesses online health status and probability of failure, by detecting functional anomalies or aging phenomena and evaluating their impact on the asset serviceability. Sally et al. (2024) presented Reliability Centered Maintenance (RCM) methodology to optimize maintenance activity in critical machines at the Sabiz 1 plant to minimize downtime, costs incurred for machine repairs, and production losses. By implementing their preventive maintenance, it was observed that it can reduce costs incurred compared to before optimization was carried out. The percentage of savings was expected to decrease by around 68% for high-pressure pumps and around 75% for conveyor base powder. Talib et al. (2010) proposed methodology for optimising system continuity by integrating Failure Modes and Effects Analysis (FMEA) and inventory preventive maintenance scheduling for designing a preventive maintenance schedule and spare parts inventory based on failure modes for complex systems with multiple components, and also to ensure the continuity of system outputs by modelling subsystems and components as parallel and series arrangements, and using a genetic algorithm to determine the optimal replacement intervals and spare parts inventory based on failure modes. Their model achieved the following key outcomes in developing an integrated methodology Firstly, the FMEA block model concept was realized to schedule preventive maintenance and ensure continuous production. Secondly, a complete mathematical formulation was created that incorporates the Weibull distribution and economic stock control theory using the FMEA block replacement concept. Lastly, the capability of the mathematical formulation to adapt the ordering strategy for spare parts based on the performance of suppliers. Optimal preventive maintenance intervals and necessary spare parts were determined for each block of the FMEA using a genetic algorithm. Prabhu et al. (2023) presented the use of genetic algorithms in maintenance optimization in Plate and coil mill plants. It is expected that by implementing the proposed remedial suggestion, the number of failures and the mean downtime can be effectively reduced. Ultimately, the uptime of the overall plant efficiency can be enhanced Novelty of the approach lies in developing a holistic preventive maintenance. Talib et al. (2010) has developed a failure mode-based PM scheduling method for complex engineering systems schedule using failure mode and effects analysis for a complete system. The approach did not only improve maintainability and reliability, lowers the cost of maintenance, but also keeps continuity of production. Okanminiwei et al. (2020) examined the behavior of selected maintenance downtime parameters of handling equipment in a container terminal and established the system's optimal parameters. Taguchi method, Taguchi–Pareto method, and Taguchi–ABC method was applied to analyze it. The methods were used to establish the effects of three downtime parameters, namely, downtime hours, probability density function on the responses. It was established that the model parameters are sensitive to changes in the conditions in the life phases of the container terminal. Yanjie et al. (2022) introduced the method of failure mode and effect analysis (FMEA) to study the maintenance scheme of electric drive compressor. It was established from their model that one can avoids excessive maintenance and under maintenance. Fu et al. (2024) conducted a comprehensive performance test and developed an integrated simulation model, using computational fluid dynamics (CFD) methods. From their study the isentropic efficiency and pressure ratio of the Max_σ solution were improved by 18.7% and 70.1%, while those of the Max_ηc solution were enhanced by 23.0% and 48.9%, respectively. After optimization, the gas experiences reduced shock loss, diminished entropy increase and enhanced flow stability.

Moreover, there are limitations inherent in this tool, highlighting its primary drawbacks. Pareto analysis does not consider the interdependencies between risks. For example, if two risks are ranked as being less critical individually, their combined impact may be greater than the one of a single, higher-ranked risk. Another important limitation of this tool is that Pareto analysis has a limited perspective on the problems as it only focuses on identifying the causes that contribute to most of the issues, without considering the underlying causes of problems, but simply identifying their symptoms. This means that without a root cause analysis, it is difficult to determine the most effective solutions for the problems identified in a Pareto Chart. Furthermore, based on extent review of literature failure mode effect analysis (FMEA) was used for optimization of the maintenance strategy and not capturing the limited resources that will be used in carrying out the maintenance Hence, it is against this background that the paper is presented to investigate these areas of concern. To overcome these limitations, this paper integrated other techniques, such as failure mode effect and criticality analysis in conjunction with Pareto Analysis in optimizing maintenance resources. A flow station is a gathering centre where primary separation/processing of the reservoir fluid takes place, these fluids are later transported to terminals for export or to the refinery, while the other products are either treated, flared or disposed (Devold, 2013). Operators of flow stations want to gain as much as possible profit with ensured safety and minimum environmental impact, also placing increased emphasis on the reliability of the flow station. Availability of flow station critical equipment such as Instrumentation Air Compressors, is the core term for maintenance activities in the flow station. Compressors are mechanical devices that are used to increase the pressure of compressible fluid such as gas or vapor and reduce the volume of the gas as it passes through it.

2. METHODOLOGY

Economic resources and available personnel are limited, prioritizing the maintenance resources helps to focus the efforts where they are the most necessary. Prioritization or risk ranking in this paper was done using Failure Mode Criticality analysis (FMECA) and Risk matrix. The analysis utilizes two tools, the Failure Mode Criticality analysis and Pareto analysis. The Failure Mode Criticality analysis was used to determine the failure mode criticality number, the values are determined using equation 1, find below attached table for calculation of failure mode criticality number and the item criticality number for the same. as shown in Table 3 on the other hand, the Pareto chart is used to identify the areas in highest failure mode that have the greatest cumulative effect on the equipment, and thus, screen out the less significant failure mode based on the analysis find below attached table for calculation of pareto analysis and the graph chart as show in Table 5 and Figure 1 respectively. The failure mode criticality number is integrated into the Pareto analysis to allocate our maintenance resources.

2.1 Severity Classification

We evaluate each item failure mode in terms of the worst potential consequences upon the system level which may result from equipment failure. We then assign a severity classification to each system level effect. These will provide a qualitative measure of the worst potential consequences resulting from an equipment failure (Obi, & Nwajana, 2022a, Rausand, 2004, Ebeling, 2019, Obi, & Nwajana, 2022b) as shown in Table 1.

2.1.1 Typical Failure Effect Probabilities (β)

The values are the conditional probability that the failure effect will result in the identified criticality classification, given that the failure mode occurs. The $\boldsymbol{\beta}$ values represent our judgment as

Table 1. Severity classification

Severity	Category	Definition
Catastrophic	I	A failure which may cause death or system loss, Major or total destruction to installation, exceed 90days of down time
Critical	II	A failure which may cause severe injury, occupational illness, major system damage, Major damage to installation, which will result in mission loss.10 to 90 days of down time
Marginal	III	A failure which may cause minor injury, minor occupational illness, minor system damage, or which will result in delay or loss of availability or mission degradation. Some structural and equipment damage 1 to 10 days of down time
Negligible	IV	A failure which may cause less than minor injury, occupational illness, or
		system loss, Minimum equipment damage with less property damage or system damage, but which will result in unscheduled maintenance or repair. and negligible downtime

to the conditional probability the loss will occur and would be quantified in this study in accordance with the following (MIL-STD-1629A, 1993), (Ebeling 2003):

Failure Effect (***β***) Value
Actual Loss 1.00
Probable Loss > 0.10 to < 1.00
Possible Loss > 0 to 0.10
No Effect 0

2.1.2 Failure Probability/Failure Rate (λ_p) Data Source

In this study we used the failure rate data from each failure mode of Instrumentation Air Compressor in Oredo flow station in the calculation of criticality numbers.

2.1.3 Failure Mode Ratio (α)

The failure mode ratio is the probability expressed as a decimal fraction that the part or item will fail in the identified mode. If all potential failure modes of a particular part or item are listed, the sum of the values for that part or item will equal one (1).

2.1.4 The failure mode criticality number $\boldsymbol{C_m}$

The value of the failure mode criticality number in this study is the portion of the criticality number for the item/component due to one of its failure modes under a particular severity classification. This was calculated using Equation (1).

$$C_m = (\beta * \alpha * \lambda_p * t_i) \tag{1}$$

where t_i = time to failure for the particular failure mode

α = Failure Mode Ratio

λ_p = Failure Rate

Table 2. Risk matrix

SEVERITY				
PROBABILITY/ CRITICALITY C_r/C_m	**IVNegligible**	**IIIMarginal**	**IICritical**	**ICatastrophic**
A) Frequent				
B) Probable				
C) Occasional				
D) Remote				
E) Improbable				

Red: Increased Risk – Dark Green: Severe risk – Yellow: Medium risk – Light Green: Low risk

The failure mode criticality number is then used to place the failure mode into a Risk matrix. As shown in Table 2.

2.1.5 The Item criticality number C_r

The value of the item criticality number of an item in this study is the number of system failures of a specific type of system failure expressed by severity classification for the item/component failure modes, for a particular severity classification and mission phase the Item criticality number C_r, is the sum of the failure mode criticality number C_m under the severity classification. This will be calculated using Equation (2).

$$C_r = \sum_{n=1}^{j} \left(\beta * \alpha * \lambda_p * t_i\right)_n \ , n = 1,2,3,4\ldots.j \tag{2}$$

C_r = Criticality number for the item.
n = The failure modes in the items that fall under a particular criticality classification.
j = Last failure mode in the item under the criticality classification.

Then the Criticality number for the item will be ranked and entered in the Risk matrix. The risk matrix used in this study is shown in Table 2.

The criticality matrix will provide us with a visual representation of the critical areas of a system. Items displayed in the upper right-hand corner of the matrix require the most immediate attention. These failures have a high probability of occurrence and a catastrophic effect on system operation or personnel safety. As you move diagonally towards the lower left-hand corner of the matrix, the criticality and severity of potential failures decreases. Furthermore, we used Pareto analysis as shown in Table 5 and Figure 1 with the failure mode and their respective criticality number showing the significant/vital few failures mode that fall under the green “80% cut off” line are also the failure mode whose severity category is high in the failure mode risk matrix to allocate our maintenance resources. Compressors of all types are used in every phase of the petrochemical industry, production, transportation and oil and gas industry. In recent years, many flow stations utilize advanced methods to enhance their knowledge and understanding about the Instrumentation Air compressors performance and its impact on process behavior to provide a practical and structured approach for a satisfactory maintenance strategy.

The purpose of this study is to use Pareto Analysis in conjunction with failure mode effect and criticality analysis method in optimization of maintenance resources. To achieve the objective, we used

Lognormal linear regression on the time to failure data obtained from the maintenance department of Oredo Flow Station. The data used in the study for Instrumentation Air Compressor (A) run on a 24/7 basis. Recording of data started 1200hrs on 16th Feb 2018 and recording stopped by 1300hrs on the 18th September 2020.

2.2. Abbreviation

λp: Failure rate
FM: Failure Mode
FMEA: Failure Mode Effects Analysis
CA: Criticality Analysis
FMECA: Failure Mode Effects and Criticality Analysis
TOPSIS: Technique for order preference by similarity to ideal solution
nZEB: nearly Zero Energy Building
CFD: Computational fluid dynamics
$\boldsymbol{\beta}$: Typical Failure Effect Probabilities
α: Failure Mode Ratio.
C_m: The failure mode criticality number
t_i: Time to failure for the particular failure mode
C_r: The Item criticality number
n: The failure modes in the items that fall under a particular criticality classification.
j: Last failure mode in the item under the criticality classification
LS: Lubricating System
HE: Heat Exchanger
SV: Solenoid Valve
R: Radiator
HE: Heat Exchanger
HiHi: High-High
Ops: Operations
IACA: Instrumentation Air Compressor (A)
TQM: Total quality management
CSFs: Critical success factors

3. RESULTS AND DISCUSSION

Evaluating the criticality number of all the failure modes using failure mode effect and criticality analysis method by considering all possible; Failure Effect ($\boldsymbol{\beta}$) Value, Failure Probability/Failure Rate $\left(\lambda_p\right)$, Failure Mode Ratio (α), and time to failure for the particular failure mode $\left(t_i\right)$, equation 1 and 2 was used in table 3 as show below to determine failure mode criticality number (C_m) and item criticality number (C_r).

The dots from the red cumulative Frequency % line that fall under the green “80% cut off” line relate to the failure mode; FM5, FM 3, FM 2, FM 12, FM 7 and FM 13 are causes that we should focus on as a priority when allocating resources. However, we can act on any of the causes particularly if they may be easy to address or of high risk. Failure modes: FM 5 (High temperature), correspond to component; Heat Exchanger (HE). Failure modes: FM 12 (Fail to Unload), correspond to component; Solenoid Valve (SV). Failure modes: FM 11 (High temperature), correspond to component; Heat Exchanger (HE). Are in severity class II hence needs migration from severity class II to IV. The largest contributing factor to the high criticality numbers of these devices is their

Table 3. Failure mode effect criticality analysis for instrumentation air compressor (A)

Identification number	Item/Functional Identification (Nomenclature)	Function	Failure Mode and causes	Potential Effect of Failure	Mission Phase/ Operational Mode	Severity Class	Failure Mode Probability (α)	Time To Failure (hrs)	Failure Effect Probability (β)	Failure rate λ_p	Failure mode criticality number (C_m)	Item Criticality Number $|(C_r) = \sum_{n-1}^{j} C_m$
FM 5	Heat Exchanger (HE)		High temperature	Shut Down	Ops	II	0.2500	24452.42	1	2.40229E-05	0.146854368	
FM 6			High temperature	Shut Down	Ops	IV	0.2500	218.58	0.3	0.000704913	0.011555988	
FM 11			High temperature	Shut Down	Ops	II	0.2500	372.74	1	0.000510327	0.04755482	
FM 13			High temperature	Shut Down	Ops	III	0.2500	2028.19	0.6	0.000162697	0.04949713	
												0.255462306
FM 2	Solenoid Valve(SV)		Debris on line	Shut Down	Ops	IV	0.5000	21464.85	0.3	3.89813E-05	0.125509055	
FM 12			Debris on line	Shut Down	Ops	II	0.5000	3285.18	0.9	5.63768E-05	0.083343508	
												0.208852564
FM 3	Lubricating System(LS)		HiHi oil Temperature	Shut Down	Ops	III	0.2000	22970.45	0.6	5.6273E-05	0.155114003	
FM 4			HiHi oil Temperature	Shut Down	Ops	IV	0.2000	412.9	0.3	0.000471876	0.011690247	
FM 8			HiHi oil Temperature	Shut Down	Ops	IV	0.2000	1356.83	0.3	0.000197233	0.016056703	
FM 9			HiHi oil Temperature	Shut Down	Ops	IV	0.2000	21.93	0.3	0.007153794	0.009412962	
FM 10			HiHi oil Temperature	Shut Down	Ops	III	0.2000	251.6	1	0.000711843	0.035819924	
												0.228093839
FM 1	Radiator(R)		High temperature	Shut Down	Ops	IV	0.5000	10011.7	0.3	2.12205E-05	0.031867974	
FM 7			High temperature	Shut Down	Ops	IV	0.5000	14663.72	0.5	2.05951E-05	0.075500086	
												0.10736806

Table 4. Failure mode criticality ranking instrumentation air compressor (A)

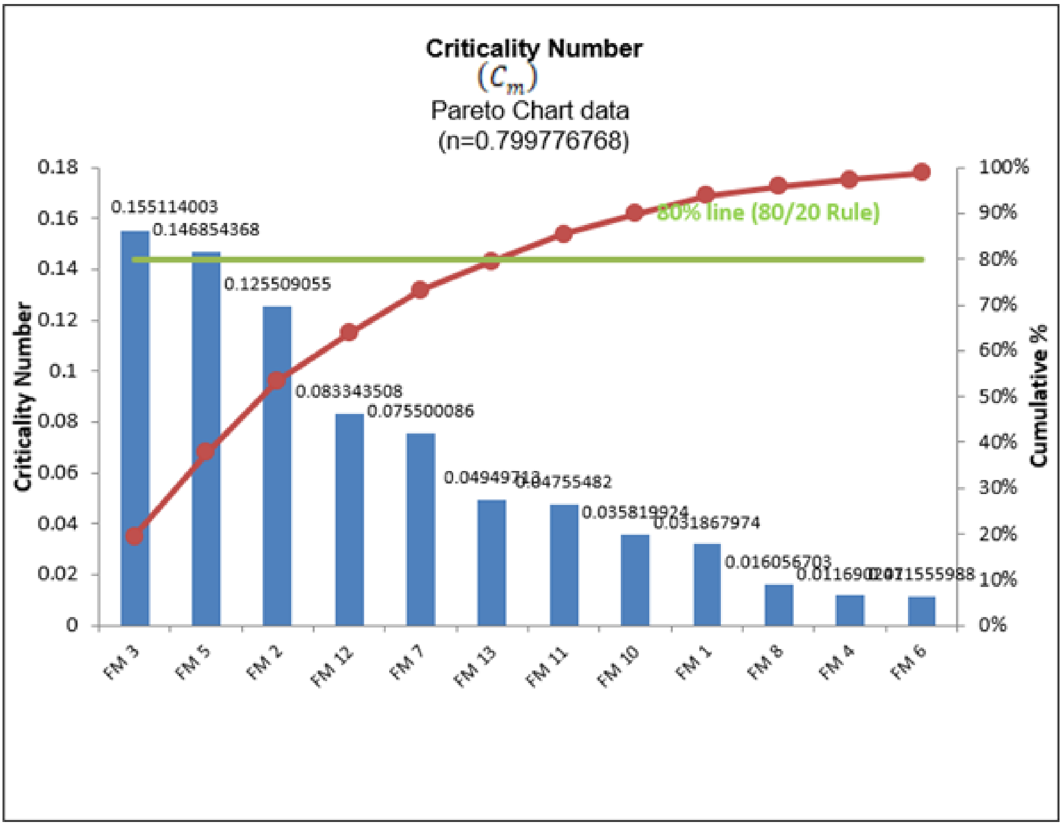
Identification number	**Failure mode Criticality Number (c_m)**	**Item/Functional Identification (Nomenclature)**
FM 3	0.155114003	Lubricating System (LS)
FM 5	0.146854368	Heat Exchanger (HE)
FM 2	0.125509055	Solenoid Valve (SV)
FM 12	0.083343508	Solenoid Valve (SV)
FM 7	0.075500086	Radiator (R)
FM 13	0.04949713	Heat Exchanger (HE)
FM 11	0.04755482	Heat Exchanger (HE)
FM 10	0.035819924	Lubricating System (LS)
FM 1	0.031867974	Radiator (R)
FM 8	0.016056703	Lubricating System (LS)
FM 4	0.011690247	Lubricating System (LS)
FM 6	0.011555988	Heat Exchanger (HE)
FM 9	0.009412962	Lubricating System (LS)

Table 5. Pareto chart for IACA criticality number

Failure Mode	**Criticality Number (C_m)**	**Cumulative Total**	**Cumulative %**	**80% (80/20 rule)**
FM 3	0.155114003	0.155114003	19%	80%
FM 5	0.146854368	0.301968371	38%	80%
FM 2	0.125509055	0.427477426	53%	80%
FM 12	0.083343508	0.510820934	64%	80%
FM 7	0.075500086	0.586321020	73%	80%
FM 13	0.04949713	0.635818150	79%	80%
FM 11	0.04755482	0.683372970	85%	80%
FM 10	0.035819924	0.719192894	90%	80%
FM 1	0.031867974	0.751060868	94%	80%
FM 8	0.016056703	0.767117571	96%	80%
FM 4	0.011690247	0.778807818	97%	80%
FM 6	0.011555988	0.790363806	99%	80%
FM 9	0.009412962	0.799776768	100%	80%
Total	**0.799776768**			

high Time-To- Repair with respect to the other devices in the Instrumentation Air Compressor (A) which contributed to high Failure Effect Probability (β) of 1, 0.9 and 1 respectively. Failure modes: FM 3 (HiHi oil Temperature), correspond to component; Lubricating System (LS). Failure modes: FM 13 (High temperature), correspond to component; Heat Exchanger (HE). Failure modes: FM 10 (HiHi oil Temperature), correspond to component; Lubricating System (LS). Are in severity class III hence needs migration from severity class III to IV The largest contributing factor to the high criticality numbers of these devices is their high Time-To- Repair with respect to the other devices

Figure 1. Pareto chart for IACA criticality number with cumulative line



in the Instrumentation Air Compressor (A) which contributed to high Failure Effect Probability (β) of 0.6, 0.6 and 1respectively. While other failure modes are in severity class IV hence, they do not need any migration as their risk is low.

Therefore, the results of the criticality analysis indicate that the components whose failure mode criticality number is high and of high risk has the worst failure consequences regarding aspects such as personnel health and safety, the environment, production, and cost. These were integrated into Pareto analysis as shown in Table 5 and Figure 1. with the failure mode and their respective criticality number showing the significant/vital few failure modes that fall under the green "80% cut off" line are also the failure mode whose severity category is high in the failure mode risk matrix. Further exploratory data analysis is to be carried out to determine the trend and root cause of the failure modes of these components of Instrumentation Air Compressor in the Flow Station.

4. CONCLUSIONS

Optimization of maintenance resources plays an important role in resource allocation in which it can be a tool for a structured approach for efficient utilization of resources in the oil and gas sector.

The following conclusion were drawn from the study:

i. The use of Pareto analysis in conjunction with failure mode effect and criticality analysis in optimizing maintenance resources of Oredo Flow station was established.

ii. The method was used to prioritize the failure mode that have the greatest impact on the equipment (Instrumentation Air Compressor) and gain a more comprehensive understanding of the issues and risks the flow station faced, leading to more efficient and effective decision-making.
iii. The study has established that; FM5, FM 3, FM 2, FM 12, FM 7 and FM 13 whose cumulative Frequency % line fall under the green "80% cut off" line are causes that we should focus on as a 'priority'. From the Pareto principle, roughly 80% of the equipment downtime came from 20% of these vitae few failure modes.
iv. The study has developed a valuable tool for the oil and gas industry that are seeking to optimize maintenance resources and improve their operational excellence with ensured safety and minimal environmental impact,

4.1. Contributions

This study tackles the critical limitation in the extant literature on optimization of maintenance strategy using failure mode effect analysis and other techniques, they did not capture the maintenance resources and how they could be optimized. To overcome these limitations, this paper has developed a mathematical model for optimizing maintenance resources of critical equipment such as Instrumentation Air Compressor in Oredo Flow station Nigeria.

Author contributions: All authors contributed, read, and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Competing interests: The authors declare no competing of interest.

Data availability statement: No additional data is applicable besides the data/information already included in the manuscript.

PROCESSING DATES

08, 2024

This manuscript was initially received for consideration for the journal on 06/15/2024, revisions were received for the manuscript following the double-anonymized peer review on 07/22/2024, the manuscript was formally accepted on 07/22/2024, and the manuscript was finalized for publication on 08/08/2024

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REFERENCES

Alamri, T. O., & Mo, J. P. (2022). Failure mode structured preventive maintenance scheduling with changing failure rates in industry 4.0 environment. *Frontiers in Manufacturing Technology*, *2*, 828986. DOI:10.3389/fmtec.2022.828986

Alamri, T. O., & Mo, J. P. (2023). Optimisation of Preventive Maintenance Regime and Spare Part Inventory based on Failure Mode System Modelling.

Aziz, R. W. A., Shuib, A., Aziz, W. N. H. W. A., Tawil, N. M., & Nawawi, A. H. M. (2013). Pareto analysis on budget allocation for different categories of faculties in higher education institution. *Procedia: Social and Behavioral Sciences*, *90*, 686–694. DOI:10.1016/j.sbspro.2013.07.141

Braglia, M., Frosolini, M., & Montanari, R. (2003). Fuzzy TOPSIS approach for failure mode, effects and criticality analysis. *Quality and Reliability Engineering International*, *19*(5), 425–443. DOI:10.1002/qre.528

Cahyati, S., Puspa, S. D., Himawan, R., Agtirey, N. R., & Leo, J. A. (2024, June). 2024 Optimization of preventive maintenance on critical machines at the Sabiz 1 plant using Reliability-Centered Maintenance method. *SINERGI*, *28*(2), 355–368. DOI:10.22441/sinergi.2024.2.015

De Castro, H. F., & Cavalca, K. L. (2006). Maintenance resources optimization applied to a manufacturing system. *Reliability Engineering & System Safety*, *91*(4), 413–420. DOI:10.1016/j.ress.2005.02.004

Devold, H. (2013). Oil and gas production handbook: an introduction to oil and gas production. Lulu. com.

Ebeling, C. E. (2019). *An introduction to reliability and maintainability engineering*. Waveland Press.

Fu, J., Wang, H., Sun, X., Bao, H., Wang, X., & Liu, J. (2024). Multi-objective optimization for impeller structure parameters of fuel cell air compressor using linear-based boosting model and reference vector guided evolutionary algorithm. *Applied Energy*, *363*, 123057. DOI:10.1016/j.apenergy.2024.123057

Joiner Associates. (1995). *Cause and Effect Diagrams: Plain and Simple* (*Vol. 1*). Oriel Incorporated.

Khan, A. S., Biggs, T. C., & Faoury, M. (2019). Improving the allocation of junior doctor resources using Pareto analysis of pager activity. *Int. J. Otorhinolaryngol. Head Neck Surg*, *5*(1), 1–4. DOI:10.18203/issn.2454-5929.ijohns20184676

Memon, S. A., Gohil, P. R., Purohit, H., & Achari, M. (2024). Maintenance Optimization in Process Plant Using Failure mode effect analysis. *Nirma University Journal of Engineering and Technology*, *1*(2), 21–30.

Nguyen, D., & Bagajewicz, M. (2010). Optimization of preventive maintenance in chemical process plants. *Industrial & Engineering Chemistry Research*, *49*(9), 4329–4339. DOI:10.1021/ie901433b

Obi, E. R., & Nwajana, A. O. (2022a). Modeling, Integration, and Automation of Degradation to Generate Asset Lifespan Analytics Using: AssessLIFE Software. [IJMMME]. *International Journal of Manufacturing, Materials, and Mechanical Engineering*, *12*(1), 1–40. DOI:10.4018/IJMMME.300828

Obi, E. R., & Nwajana, A. O. (2022b). *AssessLIFE software for automation of asset degradation to estimate Asset life and degradation drivers. In 5G Internet of Things and Changing Standards for Computing and Electronic Systems*. IGI Global.

Okanminiwei, L., & Oke, S. A. (2020). Optimization of maintenance downtime for handling equipment in a container terminal using Taguchi scheme, Taguchi-Pareto method and Taguchi-ABC method. *Indonesian Journal of Industrial Engineering & Management*, *1*(2), 69–90. DOI:10.22441/ijiem.v1i2.9912

Ora, A., Kumar, D., & Darade, N. (2017). Failure mode effect analysis with pareto chart for various critical equipment used in ceramic industry. *International Journal of Engineering Science and Computing*, *7*(4), 10168–10173.

Rausand, M. (2004). *System Analysis Failure Modes, Effects, and Criticality Analysis. System Reliability Theory* (2nd ed.). Wiley.

Schoenmakers, I., & Zeiler, W. (2017). Pareto analysis: a first step towards nZEB Hospitals.

Sepe, M., Ruggiero, G., Leto, A., Mordacci, G., & Agresta, A. (2022, March). Maintenance Scope Optimization, through a Real Time Prediction of Risk of Failure. In *Offshore Technology Conference Asia (p. D041S036R001)*. OTC. DOI:10.4043/31343-MS

Talib, F., Rahman, Z., & Qureshi, MN (2010), "Pareto analysis of total quality management factors critical to success for service industries", International Journal of Quality Research (IJQR), Center for Quality, University of Podgorica Montenegro and University of Kragujevac, Serbia, 4.

Varzakas, T. H., & Arvanitoyannis, I. S. (2007). Application of Failure Mode and Effect Analysis (FMEA), cause and effect analysis, and Pareto diagram in conjunction with HACCP to a corn curl manufacturing plant. *Critical Reviews in Food Science and Nutrition*, *47*(4), 363–387. DOI:10.1080/10408390600781316 PMID:17457722

Yanjie, J., Shiyu, G., Jun, L., Ying, S., Kaihong, L., Dongliang, Y., & Fei, X. (2022, November). An FMEA maintenance optimization method for electric drive compressor. In 2022 7th International Conference on Intelligent Informatics and Biomedical Science (ICIIBMS) (Vol. 7, pp. i-iv). IEEE. DOI:10.1109/ICIIBMS55689.2022.9971518

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