Factors Affecting Integrating Human Factors into Condition Monitoring for Improvement of Availability Performance in Marine Engine Room.

A case of Marine Engine Rooms, Dar es Salaam Port

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1.0 ABSTRACT:

The paper focused on integration of human factors into condition monitoring practices to enhance availability performance in marine engine rooms. However, the effectiveness of condition monitoring in improving availability performance is not solely dependent on technology. The integration of human factors was sought to be important.
Through questionnaires and structured interviews, key determinants such as Crew Competence, Communication Effectiveness, and Human-Machine Interface were identified as the most critical, with Relative Importance Index (RII) values of 0.907, 0.897, and 0.877respectively as well as Fatigue Management, Safety Culture, Maintenance Strategy, Workload Management were identified also as the most critical factors, with Relative Importance Index (RII) values of 0.860,0.857, 0.857, 0.827 respectively.

An integrated regression model was developed, exhibiting a strong correlation (R = 0.937) and supporting the creation of the Marine Engine Room Availability Performance Calculator. This tool predicts availability levels up to 86.89%, providing practical value for planning and evaluation. Additionally, a comprehensive Maintenance Management System was designed, embedding human-centred design principles and condition-based maintenance strategies to directly address identified human factors.

Recommendations for the maritime industry include enhanced crew training, standardised communication protocols, user-focused system design, and increased integration of advanced technologies.

Suggestions for future research include longitudinal validation of the model, exploration of human factor interactions, cultural influences, and the application of emerging technologies. The findings provide a foundational framework for improving operational performance, safety, and reliability through human-centric engineering practices in marine settings.

Key words: Engine room, Human factors, Maintenance system and Regression equations

2.0 INTRODUCTION:

In the context of Tanzania, the Tanzania Port Authority (TPA) is responsible for managing and operating the country's ports, including the maintenance of marine engine rooms. Improving the availability performance of marine engine room systems is crucial for the efficient operation of Tanzania's ports and the country's overall maritime industry. However, there is limited research and practical implementation of integrating human factors into condition monitoring in the Tanzanian maritime context.

Marine engine rooms play a crucial role in the operation and performance of ships. The availability and reliability of the machinery and systems in the engine room directly impact the overall efficiency and safety of the vessel. However, maintaining optimal performance in marine engine rooms is a complex task that involves various factors, including human factors and condition monitoring techniques.

Human factors, such as operator skills, training, and situational awareness, significantly influence the performance and reliability of marine engine room systems (J. Zhang et al., 2023). Integrating human factors into condition monitoring systems can help improve the availability and performance of these systems. (Gualeni & Vairo, 2023; Tawiah et al., 2018) Condition monitoring involves the continuous or periodic measurement and interpretation of data to assess the health and performance of machinery and systems (Seguin et al., 2023; P. Zhang et al., 2022).

Despite the potential benefits of integrating human factors into condition monitoring, there are several challenges and factors that affect its implementation in marine engine rooms. (Han et al., 2024; Morariu et al., 2022) These factors include technological limitations, data quality and interpretation, organisational culture, and the need for specialised training and expertise (Michailidis et al., 2019).
The main problem is the lack of a comprehensive framework or model that effectively incorporates human factors into condition monitoring processes. Existing condition monitoring systems often focus primarily on technical aspects, such as sensor data and machine learning algorithms, while neglecting the role of human operators and their interactions with the systems (Ao et al., 2022; Kudelina et al., 2021).

3.0 RESEARCH ELABORATIONS:

The study aims to develop a maintenance management system for integrating human factors into condition monitoring for Improvement of availability performance in the marine engine room.

Methodology Matrix
Table 2. Methodology Matrix:

Research Objective	Data Collection Method	Data Analysis Technique	Output
To identify maintenance factors affecting Integrating human factors into condition monitoring for Improvement of availability performance in marine engine room	- Questionnaires - Semi-structured interviews - Document analysis	- Descriptive statistics - Thematic analysis RII relative Importance Index	factors affecting Integrating human factors into condition monitoring for Improvement of availability performance in marine engine room
To develop a maintenance management model for integrating human factors into condition monitoring for Improvement of availability performance in marine engine rooms	From objective (i)	- Inferential statistics (e.g., regression analysis) - Thematic analysis	maintenance management model for Integrating human factors into condition monitoring for Improvement of availability performance in marine engine room
To integrate human factors into condition monitoring for Improvement of availability performance in marine engine rooms.	- Semi-structured interviews - Document analysis - Observations	- Thematic analysis - Content analysis	Integrating human factors into condition monitoring for Improvement of availability performance in marine engine room.

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3.1 Conceptual framework

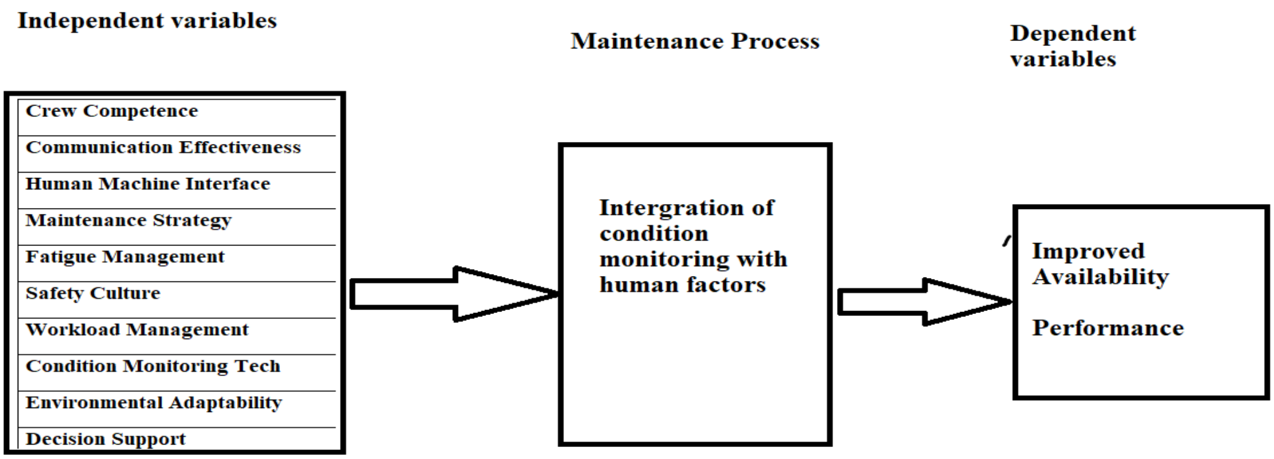

Figure 1. Conceptual framework for integrating human factors into condition monitoring (Source Researcher)

3.2 Adopted Methodology

The adopted methodology was identification of factors for integrating human factors into condition monitoring, whereby questionnaires and observations were done and analysed by using RII. Thereafter, the identified factors were used to develop a multiple regression model. Furthermore, the factors and model were used to develop a maintenance management system.

3.3 Sample Size

The sample size for the qualitative component was determined by the principle of data saturation, where data collection continues until no new themes or insights emerge. However, a minimum of 20 participants were targeted for ensuring a diverse range of perspectives and experiences were captured.
For the quantitative component, the sample size was determined using the Yamane formula (Chanuan Uakarn, 2021)

$$n = N / (1 + Ne^2)$$

Where: n = sample size N = population size (70) e = margin of error (set at 0.05)
Plugging in the values, we get:

$$n = \frac{70}{(1 + 70 \times 0.05^2)\ n} = \frac{70}{(1 + 0.175)\ n} = \frac{70}{1.175\ n} \approx 60$$

Therefore, the sample size for the quantitative component was 60 participants.

3.4 Table 1 Sample Size Distribution:

Participant Category	Sampling Technique	Sample Size	Data Collection Method
Marine Engineers	Purposive sampling	15	- Semi-structured interviews - Questionnaires
Maintenance Technicians	Stratified random sampling	20	- Questionnaires - Observations
Condition Monitoring Specialists	Purposive sampling	10	- Semi-structured interviews - Questionnaires
Maintenance Managers	Purposive sampling	10	- Semi-structured interviews - Questionnaires
Document Custodians	Purposive sampling	5	- Document analysis
Total		60	

4.0 RESULTS AND FINDINGS

The Demographic data gave the participants' backgrounds, including their years of experience, qualifications, areas of specialisation, involvement in maintenance and condition monitoring, use of maintenance systems, familiarity with human factors, and preferred communication methods. The analysis aimed at providing insights into the characteristics of the study population and their relevance to the research objectives as shown in Table 3.

Table 3 Demographic Information:

Category	Subcategory	Frequency	Percent
Years Experience	Less than 5 years	17	28.3%
	5-10 years	18	30.0%
	11-20 years	8	13.3%
	More than 20 years	17	28.3%
Highest Qualification	Diploma	11	18.3%
	Bachelor's Degree	20	33.3%
	Master's Degree	13	21.7%
	PhD	16	26.7%
Area of Specialisation	Maintenance	21	35.0%
	Propulsion	23	38.3%
	Electrical	16	26.7%
Maintenance Frequency	Daily	11	18.3%
	Weekly	11	18.3%
	Monthly	9	15.0%
	Quarterly	11	18.3%
	Annually	10	16.7%
	Never	8	13.3%
Condition Monitoring Involvement	Responsible for daily/routine	22	36.7%
	Involved in periodic	21	35.0%
	Not involved	17	28.3%
Use of Maintenance Systems	Yes, daily	13	21.7%
	Yes, occasionally	18	30.0%
	No, but interested	15	25.0%
	No, not interested	14	23.3%
Familiarity with Human Factors	Very familiar	19	31.7%
	Somewhat familiar	11	18.3%
	Not very familiar	16	26.7%
	Not familiar at all	14	23.3%
Preferred Communication	Email	22	36.7%
	Phone	38	63.3%

4.1 Factors identification:

The data were analysed using mean score ranking technique to identify the boundary of different levels of factors. Further, an investigation was done using Kendall’s concordance analysis that helped to measure the agreement of different respondents on their ranking of factors. In the Mean Score Ranking technique (MSR), a four-point Likert scale (1- strongly disagree, 2-disagree, 3- agree, and 4 -strongly agree) was used. The MSR for each factor was computed by equation (2)

$$MSR = \frac{\sum(f \times s)}{N}, (1 \leq \text{MSR} \leq 5)$$

Where:
s = score given to each defect by respondents, ranging from 1 to 5.f = frequency of each rating (1-5) for each defect
N total number of respondents, and Table 2: Factors Identification early deterioration by using Kendall's Mean Ranking and RII Technique, as shown in Tables 3 and 4

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Table 4: Guide to degree of significance:

Degree of significance	Rating
Most significant	0.76 -Above.
Significant	0.67-0.75
Less significant	0.45-0.67
Not significant	0.44 -Below.

Source: (Vanduhe, 2012).

The study identified seven significant factors that contribute to the deterioration of the **Availability Performance in Marine Engine Room**: crew competence, Communication Effectiveness, Human Machine Interface, Maintenance Strategy, Fatigue Management, Safety Culture, Workload Management, Condition Monitoring Tech, Environmental Adaptability and Decision Support

Table 5. Ranking table using only RII values and significance remarks:

Rank	Factor	RII	Significance
1	Crew Competence	0.907	Most Significant
2	Communication Effectiveness	0.897	Most Significant
3	Human Machine Interface	0.877	Most Significant
4	Maintenance Strategy	0.857	Most Significant
5	Fatigue Management	0.860	Most Significant
6	Safety Culture	0.857	Most Significant
7	Workload Management	0.827	Most Significant
8	Condition Monitoring Tech	0.323	Not Significant
9	Environmental Adaptability	0.333	Not Significant
10	Decision Support	0.327	Not Significant

4.2 Model Development

The model was developed using the identified seven most significant factors. The factors were: crew competence as X1, communication effectiveness as X2, Human Machine Interface Human Machine Interface HMI as X3, maintenance strategies as X4, Fatigue maintenance as X5, safety culture as X6 and workload management as X7. This is shown in Table 6

Table 6. Coefficient: Regression Equation for Marine Engine Room Availability Performance

	Coefficients[a]							
S/NO	**CONSTANT**	**B**	**STD Error**	**Beta**			**Tolerance**	**VIF**
		-.414	3.461		-.120	907		
1	crew competence X1	.435	.295	.396	1.473	.169	.687	1.455
2	communication effectiveness X2	.299	.386	-.226	-.775	.454	.585	1.709
3	Human Machine Interface X3	.407	.266	.368	1.531	.154	.860	1.163
4	maintenance strategies X4	.101	.136	.196	.741	.474	.716	1.396
5	Fatigue maintenance X5	.596	.250	.652	2.381	.036	.665	1.504
6	safety culture X6	.014	.203	.017	.070	.946	.839	1.193
7	workload management X7	-.267	.316	-.204	-.845	.416	.856	1.168
	Dependent Variable: Availability performance							

4.3 Dependent Variable: Availability performance

Based on the coefficients provided in the multiple linear regression analysis, the equation for predicting availability performance in marine engine rooms is:

$$Y = -0.414 + 0.435X_1 + 0.299X_2 + 0.407X_3 + 0.101X_4 + 0.596X_5 + 0.014X_6 - 0.267X_7$$

Where: Y = Availability performance in marine engine rooms X_1 = Crew Competence X_2 = Human Machine Interface X_3 = Fatigue Management X_4 = Communication Effectiveness X_5 = Safety Culture X_6 = Maintenance Strategy X_7 = Workload Management

This equation represents the linear relationship between the predictor variables (human factors) and the dependent variable (availability performance). The constant term (-.414) represents the baseline performance when all other factors are zero, though this has limited practical interpretation in this context.

. This system's design philosophy effectively combines human factors principles with condition-based maintenance strategies, offering a framework for significant improvements in maintenance effectiveness, safety, and reliability in marine engineering operations. The system's emphasis on user-friendly interfaces and standardized procedures aligns with our findings on the importance of

Human Machine Interface and Crew Competence, while its integrated approach to data presentation and work management addresses the critical need for effective communication and workload management in marine engine rooms.

5.0 CONCLUSION AND RECOMMENDATION

The most significant factors emerged as Crew Competence, Communication Effectiveness, and Human-Machine Interface were identified as the most critical, with Relative Importance Index (RII) values of 0.907, 0.897, and 0.877 respectively as well as Fatigue Management, Safety Culture, Maintenance Strategy, Workload Management were identified also as the most critical factors, with Relative Importance Index (RII) values of 0.860,0.857, 0.857, 0.827 respectively. These findings underscore the paramount importance of human-centred elements in marine operations, particularly the need for well-trained crew members, effective communication systems, and user-friendly interfaces.

The model was developed; it represents a significant step forward in quantifying the impact of human factors on availability performance in marine engine rooms. Our regression model, with a strong correlation coefficient (R = 0.937) and an R-squared value of 0.191, demonstrates a robust relationship between the identified human factors and availability performance. The Marine Engine Room Availability Performance Calculator, derived from this model, provides a practical tool for predicting performance levels, estimating an impressive 86.89% availability (equivalent to 625.57 uptime hours out of 720) when all factors are optimised. This calculator offers tangible metrics for operational planning and performance evaluation, bridging the gap between theoretical understanding and practical application in the field.

The developed maintenance management system represents a holistic approach to integrating human factors into condition monitoring practices. By incorporating elements such as a human-centred user interface, an integrated condition monitoring dashboard, comprehensive inspection checklists, and features for technical team and work order management, the system directly addresses the key factors identified in our study.

Recommendation

The following were recommendations for the integration of human factors into condition monitoring practices to enhance availability performance in marine engine rooms:

a) Prioritise investment in comprehensive crew training programs that focus not only on technical skills but also on effective communication and human-machine interaction.
b) Develop and implement user-centred design principles in the creation and upgrade of marine engine room interfaces and monitoring systems.
c) Establish clear, standardised communication protocols and systems within marine engine rooms to enhance information flow and decision-making processes.
d) Integrate advanced condition monitoring technologies and decision support systems more effectively into daily operations, accompanied by thorough training and change management processes.
e) Implement regular assessments of human factors in marine engine room operations, using tools like the Marine Engine Room Availability Performance Calculator for benchmarking and improvement tracking.

f) Foster a culture of continuous improvement and learning in marine engineering teams, encouraging feedback and suggestions from crew members at all levels.
g) Develop and maintain comprehensive, user-friendly documentation and procedural guides that incorporate human factors principles.
h) Establish cross-functional teams that bring together expertise in marine engineering, human factors, and technology integration to drive holistic improvements in shipboard operations.(chanuan & kajohnsak, 2021)

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