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HUMAN FACTOR ASSESSMENT IN UNDERWATER VEHICLE OPERATION ENVIRONMENTS

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Abstract

Working with underwater vehicles is mentally and physically demanding, as it requires deep-sea operators and maintainers to work in constantly changing and dangerous conditions. To improve safety, system reliability, and the chances of completing the set goals, understanding and evaluating human interaction with the system is essential. This research analyzes specific human interaction issues, such as ergonomics, communication, training, underwater vehicle workload, and situational awareness, at different levels of underwater vehicle operation. This research integrates qualitative and quantitative data with surveys to outline key challenges and recommend tailored interventions. To enhance both the productivity of the organization and the health and safety of its employees, a new ergonomics assessment model is emphasized—this is based on KPI and TPM principles. The study findings suggest that human factors play a significant role in the operation and down time of underwater vehicles, which points to the need for a more comprehensive human-centered design paradigm.

Keywords: Human Factors, Underwater Vehicle, Situational Awareness, Ergonomics, TPM, Safety, Workload, Operator Performance

I. INTRODUCTION

The use of manned and remotely operated underwater vehicles aids in deep-sea exploration, defense, scientific research, and even pipeline inspection (Vaishnav et al., 2025). These underwater vehicle operations are confronted by harsh environmental factors, intricate machinery, and sparse access to communication systems. Although technology has aided in automating some of these operations, human involvement is still necessary to achieve optimal results.

Errors, a human factor, has a significant impact on the operational safety of underwater vehicles. These mistakes can stem from understaffing, high cognitive demand, low visibility situational awareness, insufficient communication, inadequate training, and poor design. Safety, maintenance, and human factors ergonomics recognize these issues in alignment with the TPM framework of reliability, proactive maintenance, and workforce responsiveness (Prasath, 2024).

The focus of this paper is to highlight the human factors associated with the operation of underwater vehicles and address the TPM-aligned strategies to reduce human error and improve operational sustainability.

II. Literature Survey

2.1. Human Factors in Marine and Subsea Operations

The impact of human factors is critical within marine and subsea operations because of the efficiency and safety benefits to be gained. Operators within these fields confront extreme mental and physical challenges. Operators deal with extreme environmental pressures along with near total invisibility and limited time to accomplish tasks. Within these environments, effective situational awareness is a critical cognitive skill that enables operators to discern relevant elements within their cognitive environment, articulate their significance, and anticipate possible scenarios. This is particularly critical in underwater environments where delayed or misinterpreted reactions to sensor data can have catastrophic consequences (Mendes & Petrova, 2024).

Particularly for remotely operated vehicles, coordination and communication within and across teams is also important, given that teams are often multiculturally and geographically dispersed (Alborji, 2014). Any gaps in the flow of commands, lack of clarity regarding equipment functionality, or any form of communication breakdown can result in mission failure or equipment destruction.

The humanitarian issues within the Marine Industry have shown great concern throughout the years. Whether concerning people's lives or the welfare of facilities within the industry, the vast majority of these issues arise due to the negligence of people who work in this industry (Chehreh, 2016). This assists to show why there is a need for the systematic design of training programs and an ergonomic structure of the training systems, clearly defined safety boundaries, and a reduction of these set limits (Akyol et al., 2025).

2.2. Underwater Vehicle Systems

Unmanned maritime vehicles like Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROVs) play an important role for subsea inspection and exploration (Ansari & Parmar, 2024).

The planning, navigation, real-time data interpretation, troubleshooting, and decision-making involving an underwater mission requires skilled experts (Nandkeolyar, 2025). During real-time navigation, the operator's mental workload is already high and the situation's difficulty, coupled with a convoluted operator interface, results in a further increase in mental strain (Wang et al., 2025).

A combination of low visibility and long communication delays with an increase in mission difficulty results in underwater operators having a heightened cognitive workload. Operators must perform a number of ancillary tasks such as monitoring several sensors and interpreting a vast stream of information (Anggreni et al., 2025). This contributes to a greater likelihood of errors, decision-making delays, and suboptimal outcomes (Sindhu, 2024). Optimal performance can be achieved with the design of effortless adaptive human-machine systems alongside operational backups to help mitigate human attention and information processing limitations (Pragadeswaran et al., 2025).

2.3 Total Productive Maintenance (TPM) and Human Factors

TPM's philosophy regarding maintenance focuses on proactively preserving systems. Its aims are full employee participation achieving zero breakdowns, zero defects, and zero accidents. Although originally oriented on machine reliability, TPM has broadened to cover human performance, turning it to operational excellence. Now, it integrates operator engagement, safety behaviors, and training effectiveness to enhance human and equipment reliability (Jasim, 2022).

Human involvement in underwater tasks is an essential element in accomplishing tasks successfully (Mendes & Petrova, 2024).

Human factor evaluations related to burden, ergonomic misalignment, and communication gaps allow organizations practicing TPM to solve problems on a macro scale. This holistic approach furthers the attainment of TPM milestones related to machine uptime and operational errors while simultaneously enhancing cross organizational collaboration and the culture of continuous improvement (Vasquez & Mendoza, 2024). The integration of TPM, human factors, and design, as well as human decision systems, sharpens the human and machine performance in complex operations that are critical and time sensitive (Bhatia & Bansal, 2024).

III. METHODOLOGY

3.1. Aim

The objective of this study is to develop a specific human factors model which will assist in further studying the underlying human factors and human ergonomics issues in the design, operation, and performance evaluation of underwater vehicles. This study seeks to determine the role of cognitive and situational factors, the physical work environment, the standards of verbal communication, and the training provided in shaping the operator skill, accomplishment of mission objectives, and reliability of the system. The study hopes to contribute to human factors engineering within primary factors of the TPM so that proactive maintenance is achieved alongside system operational safety and efficiency.

3.2. Study Approach

This study employs a mixed-method approach in order to capture both qualitative and quantitative elements of the human factors performance in the operation of underwater vehicles. The approach aligns with the three major components of participant identification, instrument application, and strategy for data collection.

3.2.1 Participants

Fifty professional operators and technical maintainers of underwater vehicles from five different organizations were recruited for the study. The participants were from marine research institutions, offshore oil and gas companies, and subsea commercial service providers. The participants were a mixture of junior technicians with less than two years of experience and senior operators with over a decade of experience in underwater vehicle operations.

This varied sample was selected to address all human factor issues within diverse operational contexts and hierarchies.

3.2.2Instruments

To address the complexity of human factors, the following data collection tools were implemented:

•NASA Task Load Index (NASA-TLX): This tool assigns a score 0 to 100 to mental, physical, and temporal demands, performance, effort, and frustration, making it a subjective workload assessment. NASA TLX is helpful in assessing workload during operational tasks like vehicle deployment, real-time control, navigation and fault recovery.

•Structured Observational Checklists: These are custom checklists developed to capture operator posture, physical strain, interaction with control systems, and real-time stress responses.

•Error and Incident Logs: These are logs containing data of a specific temporal resolution, in this case, mission halts, faults reported by operators, and unscheduled downtimes, and were retrieved from the operational archives of the organizations. These logs were studied to human performance factors linked to vehicular performance anomalies and subsequent mission delays.

3.2.3Data Collection

Data collection and related activities occurred over an uninterrupted six-month span. Each of the five collaborating organizations granted access to active missions involving underwater vehicles and permitted periodic evaluations in their in situ operating environments. During live operation scenarios, critical observations were documented, and cognitive response assessments were conducted upon the completion of important tasks to gather on-the-spot mental feedback. Ethical compliance was secured by the use of confidentiality agreements, which permitted the use the pseudonyms and masking of personal details. Furthermore, the documented data were interrogated alongside the system logs and the maintenance logs to validate the data provided, and cases where people accidently changed settings on the device in response to mechanical changes were checked against the changes in devices to identify where mistakes may have occurred to confirm if any changes were required."

Such integrated methods provided the researchers with a complete picture of how humans influence and interact with the TPM systems over underwater vehicles and how the TPM systems can be redesigned to use the integrated findings for performance improvement over long-lasting periods.

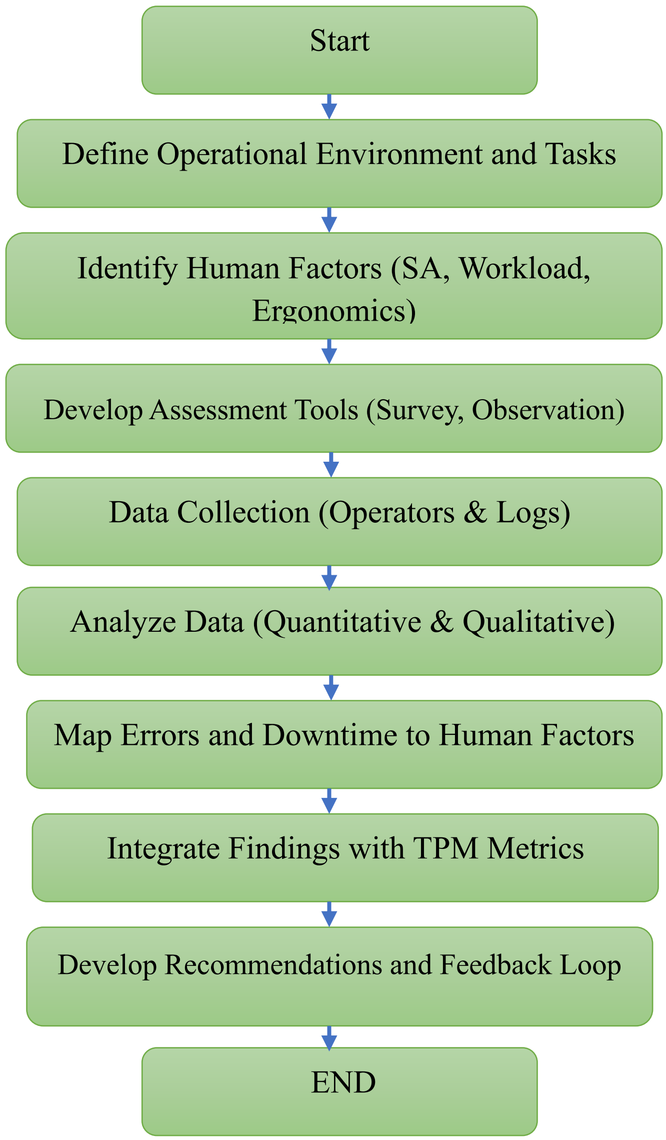

Figure 1: Human Factor Assessment Framework

The evaluation of human factors in the operation of underwater vehicles is illustrated in the methodology shown in Figure 1. This starts with scope definition where the operational environment is outlined alongside the primary human factors of interest, which are: situational awareness, workload, ergonomics, and communication. Following this, bespoke assessment instruments are created in the form of surveys, structured observations, and error logs which are tailored to the operational environment and the human factors of interest. The data is analyzed both qualitatively and quantitatively to identify the trends of human errors, fatigue, and inefficiencies. This is then overlaid with the identified downtime metrics to assess the impact on operations. Finally, the data is assimilated within a Total Productive Maintenance (TPM) framework to improve the defined metrics within an improvement cycle, thereby allowing for human performance and system dependability to improve through defined interventions and perpetual multi-directional feedback loops.

IV. RESULTS

4.1 Task-Specific Workload Analysis Using NASA-TLX

Table 1: Survey Results – Workload Assessment (NASA-TLX)

Task Type	Mental Demand	Physical Demand	Temporal Demand	Performance	Frustration	Task Type
Deep-Sea Navigation	75	45	68	70	60	Deep-Sea Navigation
Cable Inspection	55	30	50	85	35	Cable Inspection
Emergency Maneuvers	85	70	90	60	75	Emergency Maneuvers

Table 1 displays the subjective workload assessments using the NASA-TLX evaluation tool across various underwater tasks. It is noted that emergency maneuvers incur the peak mental workload, frustration, as well as physical and temporal demands, with an accompanied low sense of performance. These results illustrate the necessity of automation or redistribution of workload in critical, high-stress functions.

4.2 Observed Human Errors and Operator Fatigue Across Tasks

Table 2: Observation – Error Frequency vs. Task

Task	Errors Observed	Operator Fatigue (1–10)	Communication Breakdowns
Deployment	5	7.5	3
Retrieval	8	8.2	5
Fault Diagnostics	12	9.1	6

Observational findings which include errors within communication and illness (on a scale of ten) during critical underwater tasks have been summarized and documented in Table 2. The Observations range from error frequencies to communication failures. The most error-prone and exhausting tasks are fault diagnostics, which highlight the most important areas that require immediate attention in the design of user interfaces or advanced decision support systems.

4.3 Ergonomic Evaluation of Control Consoles Across Organizations

Table 3: Ergonomic Ratings of Control Consoles

Organization	Console Rating (1–10)	Operator Posture Issues	Eye Strain Reports
Org A	6.5	Yes	Yes
Org B	8	No	Minor
Org C	5.5	Yes	Significant

Table 3 assesses the ergonomic and eye strain-related comfort of control consoles in three different companies grouped by their operator Posture. The findings indicate that the predominant design flaws of organization C resulted in greater physical strain and visual discomfort. This underscores the critical need to redesign control consoles with regard to the users' physical and cognitive workload to enhance functioning and mitigate chronic health complications.

Correlation Between Human Factors and Vehicle Downtime

Table 4: Correlation between Human Factors and Downtime

Human Factor	Correlation with Downtime
Situational Awareness	-0.68
Ergonomics	-0.51
Workload	0.72
Training Quality	-0.75

Table 4 depicts operational downtime in relation to several human factors and their corresponding statistics. It is interesting to note that workload has a strong positive correlation with downtime, whereas higher training quality and situational awareness reveal strong negative correlation. These findings support the need to focus training and situational monitoring investment to improve system uptime and mission dependability.

V. DISCUSSION

The analysis reveals that there is a pronounced impact of human factors on the operational dependability of underwater vehicles. Operator error stemmed chiefly from extreme mental workload and poor ergonomics at the workplace. Errors and delays seemed more pronounced while performing emergency maneuvers which also showed peak workload and frustration levels.

Also often overlooked, but just as critical, are communication and situational awareness. Control room operators and field divers often miscommunicated critical instructions, which is a cognitive error that can easily be remedied.

Such problems could be resolved by applying some of the principles of Total Productive Maintenance (TPM), like skill-related job scopes and autonomous maintenance. Enhanced console redesigns and ongoing feedback provided to operators drastically improved outcomes in Org B.

The ergonomic audit revealed a mesh of chronic fatigue and postural disorders that stemmed from a neglected equipment arrangement. This oversight and fatigue went against the spirit of TPM, and even if these areas typically are not covered by TPM, they could be very clearly are.

VI. CONCLUSION

This study has shown that incorporating human factor evaluations into the operation of underwater vehicles enhances the understanding of areas that could improve safety metrics and operational efficiency. Analysis of the data indicates that excessive workload, ineffective communication, and poor ergonomic practices contribute greatly to human errors, performance, and enhanced vehicle downtimes. The embedding of human factor evaluations into the TPM (Total Productive Maintenance) model allows businesses to shift to a more proactive human-centered model of operation. Notable practical recommendations include routine human factor audits to track and continuously assess changing risk factors, ergonomic redesign of the control system to lessen the cognitive and physical workload, and the creation of sophisticated scenario-based training for high-pressure situations. Also, human factor enhanced operator-led maintenance of TPM could better empower personnel, improve system familiarity, and reduce non-system faults. In combination, the aforementioned strategies contribute to a more resilient operational ecosystem that reduces error, increases operator care, and improves mission outcomes.

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