International Journal of Engineering, Technology and Natural Sciences
E-ISSN: 2685-3191 | P-ISSN: 2775-7706
Vol 6 No 2 (2024)

Innovations in Engineering for Safety: Risk Control and Occupational Health in Deep-Sea Sampling with Modified Research Equipment

Eli Nurlaela[*,a,1], **Danu Sudrajat**[a,2], **Erick Nugraha**[a,3], **Sakti Pandapotan Nababan**[a,4], **Hery Choerudin**[b,5], **Rafith**[a,6], **Nofendy Dwija Saktianto**[a,7], **Estefanus Gunawan Tampi**[a,8], **Mahardhika Derahmat**[a,9], **Sayuri Mantani**[c,10]
[a]Politeknik Ahli Usaha Perikanan, Jakarta, Indonesia
[b]Institut Pertanian Bogor, Bogor, Indonesia
[c]Marine Technical College, Hyogo, Japan

*Corresponding Author: elimumtaza@gmail.com

Abstract

Occupational Health and Safety (OHS) is vital in high-risk environments, especially on research vessels conducting deep-sea sampling operations. The increased risk of accidents in maritime research requires an urgent focus on implementing specialized OHS systems. This study aims to analyze the application of OHS during deep-sea sediment sampling on the KM Madidihang 03 vessel. The research employs a descriptive design using the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method. Data were collected through direct observation during operations, utilizing modified Box Core and Gravity Core equipment for sediment collection. The hydraulic crane and tension meter were used to ensure the safe operation of these instruments. Data were analyzed to identify hazards, assess risks, and implement appropriate control measures. The results indicate that equipment failure, such as crane malfunction and cable breakage, poses the highest risk, necessitating regular equipment maintenance and safety training. The study recommends enhancing OHS procedures, including stricter supervision and crew training, to mitigate accidents and improve safety on research vessels. Future studies should focus on developing advanced safety protocols tailored to modified deep-sea research operations.

Keywords: Deep-sea Sampling, Occupational Health and Safety, Risk Management

I. INTRODUCTION

Occupational Health and Safety (OHS) is essential for protecting workers in high-risk environments, particularly aboard scientific research vessels. Deep-sea sampling operations involve heavy machinery and extreme environmental conditions, such as high pressure and low temperatures, making robust OHS measures a necessity. The rising number of occupational accidents in the maritime sector, as reported by the Ministry of Manpower [1], [2], highlights the urgency of addressing these risks. Such incidents jeopardize worker safety, disrupt productivity, and increase costs, affecting operational efficiency. Proper OHS implementation not only reduces risks and safeguards workers but also enhances productivity and sustainability [3], [4]. A strong commitment to OHS fosters a safer, more efficient, and resilient maritime research environment, positioning it as both a legal responsibility and a strategic advantage for the sector.

From a literature perspective, existing studies have explored the impact of OHS on performance and risk management in maritime activities, focusing on the prevention of ergonomic, physical, and psychological hazards aboard ships [5], [6], [7], [8], [9]. These studies offer valuable frameworks and tactics for general safety management but often lack specificity when addressing the unique challenges posed by specialized deep-sea research equipment. Standard safety protocols designed for generic maritime operations are insufficient for handling the unique risks associated with equipment such as the Box Core and Gravity Core, which are integral to deep-sea sampling [10], [11], [15], [16], [17]. The research gap lies in the limited exploration of OHS strategies tailored specifically for deep-sea sampling operations using modified research equipment. The complex operational environments of deep-sea research—characterized by dynamic weather, extreme pressures, and high mechanical forces—necessitate a more targeted approach to safety management. Current literature does not adequately address the structural integrity of modified equipment, the operational challenges at sea, or the interplay of environmental and mechanical hazards.

To bridge this gap, the present study aims to develop a dedicated OHS framework tailored to deep-sea research operations. This framework incorporates innovative risk assessment methods, such as Failure Mode and Effect Analysis (FMEA) and risk matrices, to systematically evaluate hazards and prioritize control measures based on their severity and likelihood [12], [13], [14]. Furthermore, the study emphasizes the importance of crew training and supervision, which are critical for hazard identification, equipment usage, and emergency response. By integrating these elements, the study seeks to reduce hazards and improve safety outcomes for both researchers and equipment. The research assumes that a structured and specialized OHS framework can significantly enhance safety and operational efficiency in deep-sea research. It hypothesizes that tailored risk assessment techniques, combined with targeted training and adaptive safety strategies, can address the unique challenges of working with modified equipment in extreme environments. The study also posits that the implementation of such a framework will result in fewer accidents, improved equipment reliability, and better overall outcomes for deep-sea sampling operations.

Indeed, this study addresses critical questions surrounding the implementation of Occupational Health and Safety (OHS) protocols in the operation of adapted heavy equipment specifically designed for deep-sea sampling activities. It aims to thoroughly examine the existing practices to uncover potential gaps that may compromise safety and efficiency. By identifying these shortcomings, the research seeks to propose tailored training programs and procedural adjustments that align with the unique challenges of maritime research operations. Furthermore, it aspires to develop a robust and comprehensive safety framework that not only mitigates risks associated with heavy equipment usage but also enhances the overall safety standards aboard research vessels, such as KM Madidihang 03. In tackling these pressing issues, the study contributes significantly to the field of safety engineering within the maritime research sector. Beyond addressing immediate concerns, it lays the groundwork for ongoing improvements and future innovations in OHS practices, fostering a safer and more resilient environment for researchers and crew members engaged in the exploration of the ocean's depths.

II. METHOD

This study aimed to evaluate the application of occupational health and safety (OHS) during deep-sea sediment sampling activities on the research vessel KM Madidihang 03. Due to the high risks involved in operating heavy duty apparatus such as the Box Core and Gravity Core, both of which have been adapted for use in deep sea research, the story topic was chosen. This modified equipment introduces additional challenges for the crew in terms of risk control, which is why this study is of great urgency [18], [19], [20]. This research was a descriptive design by occupational health and safety Methods: HIRARC (Hazard Identification, Risk Assessment, and Risk Control). In addition to the cameras, data were collected through direct observations undertaken visually during the sampling operations, by using two main tools, the Box Core for shallow sediment sampling and the Gravity Core for more depth sampling. The instruments were chosen for deployment in a range of seabed conditions and depths [21], [22]. During the operation devices were lifted and lowered with the hydraulic crane [23].

Data was collected through direct observation of the operational processes and using a tension meter to monitor cable tension to maintain safety when using the equipment. A boat winch was used to lower and retrieve the sediment instruments in a controlled manner, ensuring smooth operation of the entire system. These data were analyzed using the HIRARC approach, which is a standard risk assessment tool used to evaluate the level of risk and necessary control actions to ensure workplace safety [12], [24], [25]. The risk management analysis started from hazard identification, identifying potential hazards related to equipment, materials or the work environment conditions. Next was risk assessment, which also included measuring the risk rating on hazards identified in the previous step. At this stage, two parameters were adopted, the probability that the hazard occurs and the severity of the consequences of risk occurrence. The risk levels of these parameters are given in Tables 1 and 2. The risks associated with these assessment results were further evaluated and shown in a risk matrix (as presented in Table 3). This work applies an evaluation method for risk matrix according to the AS/NZS 4360:2004 [19]. On the basis of the risk matrix results, the hazards that were rated the highest were dealt with first, followed by those that were rated low risk, be it extreme, high, moderate or low risk.

Table 1 Probability Scale

Level	Description	Explanation
1	Rare	Almost never occurs, very unlikely to happen
2	Unlikely	Infrequent, rarely occurs
3	Possible	Occasional, may happen from time to time
4	Likely	Frequent, likely to occur
5	Almost Certain	Very frequent; can happen at any time

Source: AS/NZS 4360:2004

The potential risks are assigned five levels of likelihood, based on the internationally recognised AS/NZS 4360:2004 risk management standard. The following type of scale where risk assessment can have rare (potential hazards) to almost certain (potential hazards). The “Rare” category describes scenarios where risks are very unlikely to occur (or require a very unique or extreme set of conditions). While rare, such risks can still have significant consequences and therefore warrant mitigation efforts, especially in systems that cannot tolerate failures. The “Unlikely” category covers risks that would be rare events but could happen under some circumstances. For instance, mechanical failure of equipment that is not exposed to high pressure is typically included in this category and regularly requires inspection to ensure adequate mitigation is in place. The Possible level of risk refers to risks that can happen at a certain time, mostly based on external factors or human error. Risk control in this category is mainly preventive: people (crew training) and equipment (equipment maintenance).

What we mean by “Likely” risks are those that happen regularly -- for example, equipment can break down because it literally gets used too much, without maintenance. Such risks require extensive monitoring and increased control efforts. At the highest level of risk, “Almost Certain,” risks can be expected to occur more often and at any point in time, often due to poor-maintained repairs or any major deviation in procedural protocol. That is level that is, which requires urgent action and overall mitigation to prevent disastrous scenarios. This table plays a pivotal function for the evaluation of hazards because it helps to give attention to hazard control activities. The risks can then be classified in a risk matrix, along with a severity scale that help in identifying the criticality of the risk; low, medium, high or extreme. Extreme risks—both likely and severe—must be acted on urgently.

Table 2 Severity Scale

Level	Description	Explanation
1	Insignificant	No injuries, minimal financial loss
2	Minor	Minor injuries, small financial loss
3	Moderate	Moderate injuries, medical attention required, significant financial loss
4	Major	Severe injuries affecting >1-person, major financial loss, production disruption
5	Catastrophic	Fatal injuries affecting >1 person, very large financial loss, widespread impact, complete operational shutdown

Source: AS/NZS 4360:2004

Table 2 shows the categorisation of risks on five levels, as per AS/NZS 4360:2004 standard. Therefore, this scale is used to measure the severity of the effect of the identified risks from “Insignificant” to “Catastrophic” in terms of potential harm to people, economic loss, and interruption in operations. At the first level, “Insignificant,” there are no injuries, and there is a negligible financial loss. Scenarios at that level might involve slight equipment failures that do not interrupt overall operations. Although this will not have much impact, it is still important to manage risks in this area so that it does not escalate in the future. The second tier is “Minor,” for relatively minor injuries and small money losses. These cases may need minor medical care and do not have a major operational impact. The severity is low, but risk management helps mitigate risks so that such low severity does not turn into any level of high severity (high or critical).

Inability to perform activities of daily living costs and requires medical treatment, specifically you fall into the “Moderate” category. Such as temporary operational disruptions or damages of equipment requiring repairs. Mitigation measures and corrective actions to mitigate potential future loss are necessary at this level of risk. The fourth category, “Major” has “Severe injuries—as a result of an accident—affecting more than one person and serious loss of money and loss of production.” These could be serious open-ended scenarios that can range from major equipment failures, which can lead to severe injuries and make processes come to a complete standstill or very slow. This level of risk management involves fast response and resource allocation to mitigate similar events in the future. The highest severity, “Catastic,” includes fatal injuries to multiple people, catastrohpic financial loss, widespread systemic effects, and complete operational shutdown. These may be large-scale disasters such as critical infrastructure collapse or cataclysmic equipment failure. Such high-level consequences require extensive backup systems and extensive monitoring to ensure this never happens again.

Table 3 Risk Matrix

Probability	Severity				
	1	2	3	4	5
5	M	H	H	E	E
4	L	M	H	E	E
3	L	M	M	H	E
2	L	L	M	M	H
1	L	L	L	M	M

Source: AS/NZS 4360:2004

Table 3 is the "Risk Matrix" expands Probability and Severity to assess whether and when to classify risk. This tool plays a crucial role in risk management as it encourages a structured methodology to prioritize threats and decide which of them needs immediate mitigation. The matrix employs five levels of probability and severity leading to a combination of individual points risk classified to four categories of risk, namely, Low (L), Moderate (M), High (H), and Extreme (E). These categories provide guidance on the appropriate control measures that may need to be implemented, commensurate with the severity of the risk. Low risks describes situations with low probability and low impact, like small wounds or very unlikely events. Most of these risks are handled through regular procedures without the need for major intervention. Moderate Risks — these are situations where risk factors either have a moderate probability of occurrence or a moderate impact for the organization, and require more active measures to manage, such as regular maintenance, crew training, procedural updates, and/or proper corrective actions from previous incidents. High risks are scenarios likely to occur with a high impact, like equipment failures that may cause operational delays or severe injuries. Top line details need urgently focus and resource allocation to mitigate probable consequences.

Extreme risks—the most devastating class—happen when both there is the highest probability and level of severity. Risks like catastrophic equipment failure or fatal accidents threaten safety and operations and will require urgent, broad-spectrum intervention. Under such scenarios, organizations will possibly want to induce rigorous contingency strategies, suspend operations, or exert close risk management until the threats are addressed successfully. Designed to inform decision making and resource allocation in risk mitigation strategies, the risk matrix helps in risk management strategies. Representing identified risks within the matrix allows organizations to evaluate their relative urgency and alignment. Extreme risks are actively monitored and immediate actions are taken to minimise their potential to cause catastrophic damage. Subsequently, high risks are picked, where, we will focus on making sure they occur less often or on reducing the impact of the risk event. Medium and low risks are generally phased into business as usual safety management processes and their control monitored for change.

III. RESULTS AND DISCUSSION

Risk identification is established on this essay to bolster the anti-workplace hazards as it is a core element in reducing workplace hazards, especially in high-risk environments like deep-sea research operations. Risk identification includes various systematic analytical methods (e.g., Failure Mode and Effect Analysis (FMEA) and risk matrices [14] used to assess potential hazards and may prioritize the control measures according to their likelihood and severity. These tools offer a systematic approach for assessing risks related to specialized equipment usage, environmental factors, and human influences. Quantifying risks with any of the above methods helps companies allocate their resources toward Hong Kong's most significant risks, which ultimately leads to a safer workplace. But recognizing risks is just the start; the success of hazard utility efforts also depends on a thorough case of crew training and ongoing supervision.

Following these preconditions, the process of implementing OHS systems in deep-sea research is a sequential process, starting with hazard identification. The first stage is dedicated to the process of identifying potential sources of risk like failure of mechanics, environmental influences, and the human factor. That is followed up with risk assessment, which involves strategically analyzing those hazards to ascertain the likelihood of their occurrence as well as the potential impact a hazard could have on crew safety and operational outcomes. Ultimately, they put in place risk control measures to treat the identified risk, utilizing a spectrum that ranges from that technical layer (like modifying equipment and doing maintenance) to that behavioral level (more training, stricter adherence to timing and protocols). This systematic methodology guarantees that hazards are recognized as well as prioritized, leading to safer and much more efficient research activities in the difficult atmosphere of deep-sea exploration.

A. *Hazard Identification*

Table 4 Hazard Identification

No	Hazard Identification	Risk
1	Crane failure during the lowering of the Gravity Core	Severe injury caused by falling equipment
2	Steel cable failure during the lowering of the Box Core	Serious injury due to the Box Core falling to the seabed
3	Injury due to winch operation	Hand or limb injury during operation
4	Slipping while working in wet areas	Minor injury caused by slipping or falling
5	Hazard related to equipment handling	Serious injury caused by improperly secured equipment

In the context of this type of operations, potential risks are accidental injuries from heavy machinery (e.g., cranes, lifting devices, etc.) which can cause serious injuries to the workers involved [26], [27]. Moreover, there are elements of the environment where adverse weather and high seas may increase the risk of accidents [28]. These hazards include failures of the crane to deploy the Gravity Core, hazards associated with transferring equipment, and the potential for the operator to drop the Gravity Core. Each hazard's risks can lead to severe injuries to workers. The first hazard is a crane failure, which can result in serious injuries from heavy equipment falling. This shows how essential it is to carry out regular crane maintenance and to have proper supervision during operation. Failures can be caused by component wear, operational error, or loads exceeding design capacity [29], [30]. Studies show that heavy machinery breaking down is often due to not being sufficiently maintained or having routine inspections [31]. These may result in dropping equipment, which can seriously injure or kill workers near the operation [32].

The second hazard, the break of steel cables that occurred when the Box Core was deployed, also presents a high risk, as serious injury could be caused if the equipment were to fall to the seabed. This hazard is why the steel cables undergo regular inspections to prevent these types of events. It takes skill and training to operate heavy equipment. We are training on data till October 2023, so any information after that is not available to us. Examples include inappropriate load management or equipment operation leading to serious accidents [33]. This makes thorough training of the heavy equipment operator essential to reducing risk. The third category of injury when operating a winch involves hand/limb injuries. Workers can get caught between the winch and surrounding equipment or work structures, which can result in crush injuries. This is especially true in compact workplaces where space is constrained [34]. A broken winch cable or contact made while the cable is in operation can lacerate workers. Abrasions can also be caused by handling rough cables or equipment [35]. This emphasizes the significance of operator training and the use of correct personal protective equipment (PPE).

T Even though slips and hazards involved in transfer of equipment represent lower risks in these types of environments, preventing measures should be in place. We will need to use non-slip mats and proper equipment securing procedures to minimize risk of injury. Transshipment of heavy machinery, whether onshore or at sea, can be a dangerous process. For instance, uncontrolled movement of equipment may trap or drop a worker [26], [27]. In addition, the additional tools for lifting equipment such as forklifts or cranes require a special level of attention when transferring equipment to ensure that the safety and protection measures are implemented according to safety procedures. Unstable environmental conditions such as high waves, strong winds, or rain can lead to a higher risk of accidents during sampling operations. Conditions in the deep sea are subject to unpredictable weather patters, including storms and currents. These extreme conditions can lead to major accidents such as damage to offshore facilities and operator injuries [31], according to research. Powerful waves can rattle large equipment and cause the loss of control [28]. Hence, keeping an eye on the weather is important, and if it is considered unsafe, delay operations. Workers may be exposed to dangerous chemicals by sediment sampling, representatively lead heavy metals contained in sediment. Study shows heavy metals can be mobilised into the ocean ecosystem and adversely affect human health and environments [36], [37], [38]. This exposure can result in short- and long-term health issues such as skin irritation or respiratory conditions [39]. Heavy machinery can create significant noise and vibration, negatively impacting workers' hearing health and general well-being. Persistent exposure to loud sounds can cause chronic health issues [40]. Consequently, mitigation measures must be taken, including sound absorbents and more recent machinery with covered cabins to decrease the noise exposure levels [40].

B. Risk Assessment

At this stage of risk assessment, the level of risk is determined based on the probability of occupational accidents and the severity of the associated hazards. The probability measurement parameter used in this study is the frequency of unsafe acts and unsafe conditions that have the potential to result in workplace accidents. The impact of the identified hazards from the previous stage is then analyzed using a risk matrix table to obtain a risk rating for each hazard, taking into account both its probability and severity.

Table 5 Risk Assessment

No	Hazard Identification	Risk	Risk Rating (Scale)	Risk Rating
1	Crane failure during the lowering of Gravity Core	Severe injury due to falling equipment	Probability: Frequent (4) Severity: Major (4)	High
2	Steel cable failure during the lowering of Box Core	Serious injury due to the Box Core falling to the seabed	Probability: Occasional (3) Severity: Major (4)	Moderate
3	Injury due to winch operation	Hand or body injury during operation	Probability: Frequent (4) Severity: Moderate (3)	High
4	Slipping while working in wet areas	Minor injury from falling or slipping	Probability: Frequent (4) Severity: Minor (2)	Moderate
5	Hazards related to equipment handling	Serious injury due to improper securing of equipment	Probability: Frequent (4) Severity: Major (4)	High

Heavy machinery operation in a maritime context risk assessment is depicted in Table 5. Each risk is classified according to the likelihood of an accident happening (probability) as well as the gravity of the injury (consequences) should the risk materialize. This evaluation differentiates risk management measures by their priority in preventing workplace fatalities. In this case, crane failure while lowering the Gravity Core, rated four for probability (frequent) and four for severity (severe) the risk is high. That is why control measures such as maintenance and training of operators are an absolute need. This is a major safety issue as the Gravity Core that fell can injure or kill any personnel in the area [28], [33]. Equipment malfunction may cause severe damage to the crane itself and other items used in the operation, resulting in expensive repairs and downtime of the equipment [39]. In addition, it is possible that the material in the Gravity Core is polluted, therefore, the failure could result in environmental pollution that tortures the severity of the accident [41].

The second risk — cable failure during the lowering of the Box Core — has a medium probability (3) but a severe impact (4), giving it a moderate risk rating. Inspections for the steel cable must be done routinely to help eliminate the chance for any injuries to occur. The risk of injury arising from the winch operation is also rated high based on a frequent (4) probability of occurrence with a moderate severity level (3). Emphasizing the requirement for proper training to operate the winch, which is why ROV Operators must be properly trained to operate a winch safely. Finally, the risks of slipping when walking on wet or damp surfaces and risks associated with the movement of equipment are assessed as moderate risks, as they have high likelihoods of occurring but tend to result in less severe injuries than the other risks. Yet, employing preventive measures like anti-slip mats and properly securing equipment is still vital for reducing potential injuries.

C. Risk Control

Risk control is implemented to minimize the level of risk from identified potential hazards. In this study, a comprehensive analysis was conducted on the risk assessment results, focusing on those with an extreme risk rating. The extreme risk levels were prioritized in the risk control measures, as they pose the greatest threat and should be addressed with utmost urgency (Table 6).

Table 6 Risk Control

No	Hazard Identification	Risk	Risk Rating	Risk Control
1	Crane failure during the lowering of Gravity Core	Severe injury due to falling equipment	High	Regular crane maintenance, cable inspections prior to operations, and crane operator training.
2	Steel cable failure during the lowering of Box Core	Serious injury due to the Box Core falling to the seabed	Moderate	Routine inspection of steel cables, ensuring the use of cables that meet safety standards.
3	Injury due to winch operation	Hand or body injury during operation	High	Use of personal protective equipment (PPE) such as gloves and helmets, along with operator training.

No	Hazard Identification	Risk	Risk Rating	Risk Control
4	Slipping while working in wet areas	Minor injury from falling or slipping	Moderate	Utilization of non-slip mats, ensuring that the work area is kept clean and dry at all times.
5	Hazards related to equipment handling	Serious injury due to improper securing of equipment	High	Properly secure equipment, utilizing cranes or other appropriate tools in accordance with safety standards.

Risk control is the implementation of measures to reduce the risk posed by potential hazards that have been identified. This study performed a detailed analysis of the risk assessment results, specifically among those classified as extreme, as these should be targeted for risk mitigation. Table 6 contains the risk control measures for potential hazard with extreme risk levels. For Gravity Core and Box Core sediment sampling operations, the prevailing hazards consistent with the activities include the collapse of heavy equipment, which includes cranes and steel cables that lower the equipment to the seafloor. If the steel cables snap or the crane malfunctions while in operation, the equipment can become dislodged and fall to the ground, resulting in serious injuries. Hence the proper crane maintenance along with the tension monitoring through a Tension Meter is the solution to risk control.

Risk management also involves the correct application of personal protective equipment (PPE), including helmets and protective gloves. Operator safety training is also needed to ensure that all procedures are done safely, especially with high-risk physical injury equipment like the Box Core and Gravity Core. Work means workers are close to heavy equipment when in operation. According to the statistics, a large number of accidents are attributed to many that occur when the workers are too close to the machinery during operation initiating “struck-by” incidents [42], [43]. Alerts and monitoring can help ensure that people are safely outside of the working envelope of heavy equipment. The interior of the vessel is wet, increasing the chances of manure slipping out of hand while going up to the laboratory with the sediment. In this instance, the non-slip mats as well as this cleanliness and dry environment are a top priority in minimizing the injuries inflicted in operations. Additionally, the dangers of securing equipment after use need close oversight to ensure that no equipment is hazardous during transfer.

Regular inspection or condition monitoring of essential components like cables, pulleys, and hydraulic systems could help to identify, troubleshoot and replace issues at an earlier stage before equipment is sent for repair [44], [45]. The Importance of Crane Operators Extensive Training Programs Also, operators should know safe operating procedures, emergency responses, and characteristics of the equipment. Operators should respond to the simulation of such failures as part of their training [31], [32]. However, there, through good risk assessment and proper protocols of operation considering environmental conditions, risk can be greatly mitigated. Severe equipment [37] For example, operations should be halted during severe weather or when the equipment is deemed unsafe. Additional protective measures can include the use of safety installations like load monitoring equipment and alarms. These systems will warn operators of possible overloads or mechanical problems before a failure occurs [36]. The deployment of this engineering innovation of brighter STROBE lights will ensure that when cranes and mechanical winches are used to operate modified equipment like the Box Core and Gravity Core (helping to meet occupational safety and health standards), they will operate without risk to the engineering crew working to ensure continued sustainable development of oceanic waters. For example, this system might include automatic load sensors to sense overloads on cranes during the lowering or lifting of heavy equipment. A control system would be integrated with the sensors, and if the load exceeds the safety limit, the operation will stop automatically, preventing equipment damage and operator injuries. Also the automatic stability mechanism should be part of the mechanical winch. The stabilization system ensures that such equipment as the Box Core and Gravity Core remains stable while being lifted and lowered, even in rough seas. This automatic stabilization system minimizes the possibility of uncontrolled swinging of equipment and thereby reduces the risk of injury to workers.

A further enhancement may relate to changing the auto-locks that are deployed to secure equipment when in use. Lifting could be made safer with the introduction of double-locking hooks, which would prevent equipment from accidentally coming off the hook. That’s important, because if the hook fails, the equipment could crash into the ocean, putting crew members’ lives at risk. Improvements are also needed in the early warning system.” Such a system might involve indicator lights and audible alarms to warn operators of possible equipment malfunctions or when equipment is nearing maximum load capacity. This new approach will ensure that the operation of modified heavy equipment for deep-sea research protects occupational safety and health to a greater extent compared to the current industry standards of minimizing accidents. The M.V. Madidihang 03, initially built as a fisheries training ship, has been entirely repurposed as a deep-sea research vessel for oceanographic surveys. Its systems for deployment and retrieval of sampling instruments (e.g., gravity corers, box corers) have undergone significant changes. These changes have allowed the ship to gather more intricate and complete subsurface information. It is a challenging task to analyze the operational characteristics of functional-modified research vessels, and the study plays an essential role in contributing to the development of functional-modified research vessel safety standards. These modifications often use heavy equipment and complicated operational procedures which creates potential safety problems for the crew. A common risk is having untrained personnel use survey equipment or make mistakes in load calculations. The findings of this study can reference for other research vessel operators seeking such modifications in future. Essentially, by grasping the pitfalls and hazards involving alterations to vessels, operators can take precautionary steps to guarantee the safety of crew members and the platform of survey execution.

IV. CONCLUSION

This study successfully identifies inherent risks related to deep-sea sediment sampling operations, and, in particular, to the use of heavy manned equipment as of modified Box Core and Gravity Core. Crane failure and steel cable breakage remains the most significant hazards that can link to serious injury to crew. Hence, regular equipment inspection, cable tension checks, and comprehensive safety training are critical measures to minimize the likelihood of incidents. Safety measures such as the use of PPE and working in a clean environment have prevented many small injuries, such as slipping in wet areas. Theoretically, this study is useful for the establishment of a more specific and structured OHS system control of deep-sea research activities. The methods used in this study enable better risk identification and implementation of pertinent and effective risk control measures. What is more, the study is limited to a lack of data from similar operations on other research vessels with modified deep-sea survey equipment. Future research should include more data from different deep-sea research operations to increase the generalizability of the results.

REFERENCES

[1] H. Nainggolan, “Evaluasi Penerapan Sistem Manajemen Keselamatan Dan Kesehatan Kerja (K3) Pada Industri Galangan Kapal Kecil Di Indonesia,” *Jurnal Kesehatan Tambusai*, vol. 4, no. 4, pp. 7129–7151, 2023, doi: 10.31004/jkt.v4i4.16083.

[2] H. Herlinawati and A. S. Zulfikar, “Analisis Penerapan Sistem Manajemen Keselamatan Dan Kesehatan Kerja (Smk3),” *Jurnal Kesehatan*, vol. 8, no. 1, pp. 895–906, 2020, doi: 10.38165/jk.v8i1.94.

[3] A. Askar, H. Hidayat, and A. Sani, “Hubungan Implementasi Program K3 Terhadap Produktivitas Kerja Pada Pekerja Di PT. Industri Kapal Indonesia,” *Window of Public Health Journal*, vol. 3, no. 4, pp. 680–689, 2022, doi: 10.33096/woph.v3i4.435.

[4] R. F. A. Rio, A. S. Batara, and N. U. Mahmud, “Penerapan Program Keselamatan Dan Kesehatan Kerja PT. Industri Kapal Indonesia,” *Window of Public Health Journal*, pp. 250–260, 2020, doi: 10.33096/woph.v1i3.115.

[5] S. Hasugian, A. A. I. S. Wahyuni, M. Rahmawati, and A. Arleiny, “Pemetaan Karakteristik Kecelakaan Kapal Di Perairan Indonesia Berdasarkan Investigasi KNKT,” *Warta Penelitian Perhubungan*, vol. 29, no. 2, pp. 229–240, 2018, doi: 10.25104/warlit.v29i2.521.

[6] A. S. C. Mappangara, “Analisis Risiko Kecelakaan Angkutan Pelayaran Rakyat Di Perairan Gugus Kepulauan Pangkep,” *BerkalaFSTPT*, vol. 1, no. 3, pp. 677–686, 2023, doi: 10.19184/berkalafstpt.v1i3.593.

[7] A. Khamid, Y. Mulyadi, and M. Mukhtasor, “Analisa Risiko Keselamatan Dan Kesehatan Kerja (K3) Terhadap Kecelakaan Kerja Serta Lingkungan Dengan Menggunakan Metode Hazard and Operability Study (HAZOP) Pada Proses Scrapping Kapal,” *Jurnal Teknik Its*, vol. 7, no. 2, 2019, doi: 10.12962/j23373539.v7i2.33216.

[8] A. Andriani, “Analisis Faktor Risiko Low Back Pain Pada Pekerja Industri,” *Comphi Journal Community Medicine and Public Health of Indonesia Journal*, vol. 4, no. 1, 2023, doi: 10.37148/comphijournal.v4i1.136.

[9] E. H. C. Sihombing, “Faktor Tingkat Risiko Ergonomi Terhadap Terjadinya Keluhan Muskuloskeletal Pada Penjahit Kota Denpasar,” *Majalah Ilmiah Fisioterapi Indonesia*, vol. 12, no. 2, p. 189, 2024, doi: 10.24843/mifi.2024.v12.i02.p12.

[10] N. A. N. Rahmat, “Analisis Risiko Pembangunan Kapal Menggunakan Teknik Matriks Konsekuensi-Probabilitas,” *Zona Laut Jurnal Inovasi Sains Dan Teknologi Kelautan*, pp. 86–91, 2021, doi: 10.62012/zl.v2i3.18678.

[11] A. Suryanto, “Pengukuran Risiko Ergonomi Pekerja Kantor Menggunakan Metode Rapid Office Strain Assessment(ROSA),” *Waktu Jurnal Teknik Unipa*, vol. 21, no. 02, 2023, doi: 10.36456/waktu.v21i02.7553.

[12] J. D. Fairussihan, “Analisis Risiko Keselamatan Dan Kesehatan Kerka (K3) Pada Proses Perbaikan Kapal Di Pt. Dock Dan Perkapalan Surabaya Menggunakan Metode Hirarc (Hazard Identification, Risk Assessment, and Risk Control),” *Zona Laut Jurnal Inovasi Sains Dan Teknologi Kelautan*, pp. 23–29, 2023, doi: 10.62012/zl.v4i1.18977.

[13] N. Andriany, “Optimalisasi Kesadaran Manajemen Sumber Daya Manusia Di Rumah Sakit Tentang Sistem Manajemenkeselamatan Dan Kesehatan Kerja (Smk3),” *Jurnal Ekonomi Trisakti*, vol. 3, no. 2, pp. 2545–2552, 2023, doi: 10.25105/jet.v3i2.17189.

[14] Y. R. Hanif and M. Basuki, “Penilaian Risiko K3 Pada Proses Pembangunan Kapal Bantu Rumah Sakit (BRS) Menggunakan Metode Failure Mode and Effect Analysis (FMEA) Dan Matrik Risiko,” *Jurnal Sumberdaya Bumi Berkelanjutan (Semitan)*, vol. 1, no. 1, pp. 280–288, 2022, doi: 10.31284/j.semitan.2022.3219.

[15] A. Hendrawan, “Program Kesehatan Dan Keselamatan Kerja Di Atas Kapal,” *Jurnal Sains Teknologi Transportasi Maritim*, vol. 2, no. 1, pp. 1–10, 2020, doi: 10.51578/j.sitektransmar.v2i1.12.

[16] Y. Megawati, “Konsep Kesehatan Dan Keselamatan Kerja Di Rumah Sakit,” 2020, doi: 10.31219/osf.io/d9s6v.

[17] A. PUTRI, A. Wahyu, and Y. Thamrin, “Penerapan Prosedur Dan Pengetahuan K3 Terhadap Kejadian Kecelakaan Kerja Pada Pekerja Pt. Industri Kapal Indonesia,” *Hasanuddin Journal of Public Health*, vol. 2, no. 2, pp. 138–149, 2021, doi: 10.30597/hjph.v2i2.13017.

[18] M. A. S. Billah, “Efforts to Control Work Accident Risks in Steel Construction Work Using the Job Safety Analysis (JSA) Method. (Case Study at PT. Xyz),” *Jurnal Sains Dan Teknologi Industri*, vol. 20, no. 2, p. 842, 2023, doi: 10.24014/sitekin.v20i2.22166.

[19] M. David and H. Irawan, “Analysis of Potential Hazards in the Palm Oil Processing Process at PT. Karya Tanah Subur Using Job Safety Analysis (JSA),” *Jurnal Inotera*, vol. 8, no. 1, pp. 20–26, 2023, doi: 10.31572/inotera.vol8.iss1.2023.id200.

[20] C. K. Hon, C. Sun, K. A. Way, N. L. Jimmieson, B. Xia, and H. C. Biggs, “Psychosocial Hazards Affecting Mental Health in the Construction Industry: A Qualitative Study in Australia,” *Engineering Construction & Architectural Management*, vol. 31, no. 8, pp. 3165–3192, 2023, doi: 10.1108/ecam-07-2022-0617.

[21] M. K. Umami, M. Arif, Z. Arifin, and I. Mu’arrifah, “Evaluasi Dan Rekomendasi Penerapan Keselamatan Dan Kesehatan Kerja Pada Industri Kecil Mebel (Studi Kasus Pada Industri Kecil Mebel Purnama Di Jombang),” *Jurnal Aplikasi Ilmu Teknik Industri (Japti)*, vol. 2, no. 1, p. 22, 2021, doi: 10.32585/japti.v2i1.1495.

[22] H. Sofyan and M. F. Maulana, “Analisis Bahaya Dan Risiko K3 Dengan Metode Hirarc Pada Area Dieshop Di Pt Xyz Plant 2,” *Sistemik Jurnal Ilmiah Nasional Bidang Ilmu Teknik*, vol. 10, no. 1, pp. 21–26, 2022, doi: 10.53580/sistemik.v10i1.66.

[23] T. J. Madarsara, S. Yari, and H. Saeidabadi, “Health and Safety Risk Assessment Using a Combined FMEA and JSA Method in a Manufacturing Company,” *Asian Pacific Journal of Environment and Cancer*, vol. 2, no. 1, pp. 63–68, 2019, doi: 10.31557/apjec.2019.2.1.63-68.

[24] S. A. Muhtia, S. A. Fachrin, and A. Baharuddin, “Analisis Risiko Keselamatan Dan Kesehatan Kerja Dengan Metode HIRARC (Hazard Identification, Risk Assesment, Risk Control) Pada Pekerja PT. Varia Usaha Beton Cabang Makassar,” *Window of Public Health Journal*, pp. 166–176, 2020, doi: 10.33096/woph.v1i3.29.

[25] A. M. Syabana and M. Basuki, “Analisis Risiko Keselamatan Dan Kesehatan Kerja (K3) Menggunakan Metode Hazard Identification, Risk Assessment and Risk Control (HIRARC) Di PT. Bintang Timur Samudera,” *Jurnal Sumberdaya Bumi Berkelanjutan (Semitan)*, vol. 1, no. 1, pp. 110–114, 2022, doi: 10.31284/j.semitan.2022.3230.

[26] R. D. Nurhayati, “Analisis Risiko K3 Dengan Metode HIRADC Pada Industri Pengolahan Makanan Laut Di Jawa Timur,” *Insologi Jurnal Sains Dan Teknologi*, vol. 2, no. 3, pp. 450–461, 2023, doi: 10.55123/insologi.v2i3.1883.

[27] M. Telaumbanua, C. Marbun, and B. A. H. Siboro, “Perancangan Sistem Manajemen Keselamatan Dan Kesehatan Kerja Pada Laboratorium Desain Produk Dan Inovasi,” *Jisi Jurnal Integrasi Sistem Industri*, vol. 9, no. 1, p. 47, 2022, doi: 10.24853/jisi.9.1.47-57.

[28] D. Komalasari and S. M. Nasri, “Penilaian Risiko Kesehatan Terkait Stresor Lingkungan Kerja Faktor Fisika, Kimia Dan Biologi Pada Petugas Pengambil Contoh Di Laboratorium Lingkungan Pt X,” *Jurnal Kesehatan Tambusai*, vol. 4, no. 2, pp. 1758–1766, 2023, doi: 10.31004/jkt.v4i2.16048.

[29] N. I. N. Ilmi, “Penggunaan Metode HIRARC Dan Diagram Fishbone Dalam Analisis Risiko K3 Pada Industri Baja Karbon,” *Waluyo Jatmiko Proceeding*, pp. 431–440, 2023, doi: 10.33005/wj.v16i1.65.

[30] M. Irfan and I. H. Susilowati, “Analisa Manajemen Risiko K3 Dalam Industri Manufaktur Di Indonesia: Literature Review,” *Prepotif Jurnal Kesehatan Masyarakat*, vol. 5, no. 1, pp. 335–343, 2021, doi: 10.31004/prepotif.v5i1.1635.

[31] G. Asuelimen, E. Blanco-Davis, J. Wang, Z. Yang, and D. B. Matellini, “Formal Safety Assessment of a Marine Seismic Survey Vessel Operation, Incorporating Risk Matrix and Fault Tree Analysis,” *Journal of Marine Science and Application*, vol. 19, no. 2, pp. 155–172, 2020, doi: 10.1007/s11804-020-00136-4.

[32] Y. Li and L. Yu, “Research Progress and Hotspot Analysis of Heavy Metal Pollution of Sediments in the Bohai Sea Based on CiteSpace Literature Metrology,” *E3s Web of Conferences*, vol. 393, p. 03016, 2023, doi: 10.1051/e3sconf/202339303016.

[33] A. H. Riandini, M. Sagaf, and A. Syakhroni, “Penerapan Majemen Risiko Keselamatan Dan Kesehatan Kerja Dengan Metode Hiradc Pada Pltgu Tambak Lorok Semarang,” *Jurnal Disprotek*, vol. 14, no. 1, pp. 11–18, 2023, doi: 10.34001/jdpt.v14i1.3657.

[34] F. Berendt, E. Tolosana, S. Hoffmann, P. Alonso, and J. Schweier, “Harvester Productivity in Inclined Terrain With Extended Machine Operating Trail Intervals: A German Case Study Comparison of Standing and Bunched Trees,” *Sustainability*, vol. 12, no. 21, p. 9168, 2020, doi: 10.3390/su12219168.

[35] J. Corniche, M. Pasquier, B. Yersin, C. Kern, and P. Schoettker, “Helicopter Rescue Involving the Winching of a Physician,” *Air Med J*, vol. 31, no. 2, pp. 87–91, 2012, doi: 10.1016/j.amj.2011.08.003.

[36] G. Zhang, L. Chen, H. Wu, L. Chen, and Q. Han, “Heavy Metal Contamination in the Marine Organisms in Yantai Coast, Northern Yellow Sea of China,” *Ecotoxicology*, vol. 21, no. 6, pp. 1726–1733, 2012, doi: 10.1007/s10646-012-0958-4.

[37] M. M. Khan, Md. R. Hasan, S. Aktar, and K. Fatema, “Distribution of Heavy Metals in Surface Sediments of the Bay of Bengal Coast,” *J Toxicol*, vol. 2017, pp. 1–7, 2017, doi: 10.1155/2017/9235764.

[38] D. Rumahlatu, E. K. Huliselan, and S. I. A. Salmanu, “Spatial and Seasonal Distribution of Cadmium and Lead in Sediment, Water and Its Response of Metal Transcription Factor-1 in Cardinal Fish Apogon Beauforti,” *Ilmu Kelaut*, vol. 23, no. 1, p. 45, 2018, doi: 10.14710/ik.ijms.23.1.45-54.

[39] S. C. Sudiantoro, “Analisis Pengendalian Risiko Kecelakaan Kerja Pada Proses Produksi Di PT. XYZ Menggunakan Metode Hazard Identification Risk Assessment and Risk Control,” *Jurnal Ilmiah Inovasi*, vol. 23, no. 1, pp. 27–33, 2023, doi: 10.25047/jii.v23i1.3829.

[40] S. K. Saleh, S. Woskie, and A. Bello, “The Use of Noise Dampening Mats to Reduce Heavy-Equipment Noise Exposures in Construction,” *Saf Health Work*, vol. 8, no. 2, pp. 226–230, 2017, doi: 10.1016/j.shaw.2016.09.006.

[41] F. Apriliani, “Analisis Potensi Bahaya Dan Penilaian Risiko Keselamatan Dan Kesehatan Kerja (K3) Pada Bengkel Motor Di Kota Bogor,” *Factory Jurnal Industri Manajemen Dan Rekayasa Sistem Industri*, vol. 2, no. 2, pp. 46–59, 2023, doi: 10.56211/factory.v2i2.420.

[42] F. Vahdatikhaki and A. Hammad, “Visibility and Proximity Based Risk Map of Earthwork Site Using Real-Time Simulation,” 2015, doi: 10.22260/isarc2015/0028.

[43] B.-W. Jo, Y. S. Lee, R. M. A. Khan, J.-H. Kim, and D.-K. Kim, “Robust Construction Safety System (RCSS) for Collision Accidents Prevention on Construction Sites,” *Sensors*, vol. 19, no. 4, p. 932, 2019, doi: 10.3390/s19040932.

[44] M. B. Anthony, “Identifikasi Dan Analisis Risiko Keselamatan Dan Kesehatan Kerja (K3) Pada Proses Instalasi Hydraulic System Menggunakan Metode HIRA (Hazard Identification and Risk Assesment) Di PT. HPP,” *Jurnal Media Teknik Dan Sistem Industri*, vol. 4, no. 2, p. 60, 2020, doi: 10.35194/jmtsi.v4i2.1030.

[45] M. I. Ramdani, “Analisis Implementasi Sistem Manajemen Kesehatan Dan Keselamatan Kerja (SMK3) Berdasarkan ISO 45001:2018 Di Bengkel Mitsubishi Dipo Internasional Pahala Otomotif Serang City,” *Jurnal Global Ilmiah*, vol. 1, no. 3, pp. 199–206, 2023, doi: 10.55324/jgi.v1i3.34.