Open Journal of Safety Science and Technology, 2026, 16(2), 99-114
https://www.scirp.org/journal/ojsst
ISSN Online: 2162-6006
ISSN Print: 2162-5999

Human-HAZOP Approach for Identifying Hazards and Evaluating Risks in Ship Recycling Activities in Bangladesh

Arun Kr Dev[1], Mst. Zebun Nahar Eti Moni[2], Md. Imran Uddin[3], Zobair Ibn Awal[2], N. M. Golam Zakaria[2], Shaumik Sharif Dipto[4]

[1]Naval Architecture and Maritime Engineering, Newcastle University in Singapore (NUiS), c/o-NewRIIS, Singapore
[2]Department of Naval Architecture and Marine Engineering, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh
[3]Accident Research Institute, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh
[4]Japan International Cooperation Agency (JICA), Dhaka, Bangladesh
Email: a.k.dev@newcastle.ac.uk

How to cite this paper: Dev, A.K., Moni, M.Z.N.E., Uddin, M.I., Awal, Z.I., Zakaria, N.M.G. and Dipto, S.S. (2026) Human-HAZOP Approach for Identifying Hazards and Evaluating Risks in Ship Recycling Activities in Bangladesh. *Open Journal of Safety Science and Technology*, **16**, 99-114.
https://doi.org/10.4236/ojsst.2026.162007

Received: April 21, 2026
Accepted: June 15, 2026
Published: June 18, 2026

Abstract

The ship recycling sector in Bangladesh plays a pivotal role in the national economy, primarily through the recovery of reusable materials and employment generation. However, it grapples with substantial challenges related to worker safety and operational hazards. This study applies the Human-Hazard and Operability Study (Human-HAZOP) method to identify hazards and assess risks in the ship dismantling yards of Bangladesh. The primary reason for selecting this method is its strong ability to identify hazardous activities performed by shipbreaking workers, which involve complex human behaviour and decision-making processes. A comprehensive questionnaire survey was conducted across 18 ship dismantling yards, identifying 14 worker groups and gathering insights from workers, supervisors and safety experts. The survey responses were aggregated in a Human-HAZOP analysis, revealing that the cutter group was exposed to the highest number of hazards, while the wire group, the cutter group, and the oil and barge handler group are at higher risk in their fieldwork. In the end, several pragmatic safety measures are proposed to create a safer work environment in the ship recycling yards in Bangladesh.

Keywords

Human-HAZOP, Ship Recycling, Bangladesh

1. Introduction

For over four decades, Bangladesh has been internationally recognized as one of the major centres for ship recycling. Recently, Bangladesh has reaffirmed its position as the leading ship recycling nation, with more than half of the world's ships recycled there [1]. This success is mainly attributed to its lower labour costs and strategic geographic location. Moreover, this industry plays a vital role as the primary source of steel for Bangladesh, contributing approximately US$ 770 million annually to the national economy [2]. However, negligence toward safety has led to significant health and safety challenges for ship recycling workers in the country. Most recycling yards operate with outdated machinery and inadequate safety measures, leading to frequent accidents and environmental pollution. At present, most of the shipbreaking yards of the nation do not comply with the Hong Kong Convention guidelines [3].

Bangladesh has yet to achieve global recognition for its safe and environmentally friendly ship recycling practices. Several studies have highlighted the worker safety issues and environmental concerns associated with ship recycling activities in the country. Hossain *et al.* [4] identified exposure to hazardous substances in the ship recycling yards of the country, and emphasised improved safety regulations, proper use of Personal Protective Equipment (PPE), and health screenings. Moreover, Pasha *et al.* [5] reported unsafe working conditions and inadequate protective gear and proposed the use of advanced technologies and comprehensive training for shipbreaking workers. Haque [6] investigated the occupational hazards in the shipbuilding industry and stressed the need for mandatory safety training, proper handling of hazardous materials, and cooperation between international organizations, the government, and communities. Besides, Rabbi and Rahman [7] investigated workplace injuries and fire incidents in ship dismantling yards, attributing them to poor safety measures. However, Patwary and Bartlett [8] emphasized combined health, safety, and environmental hazards, suggesting cleaner technologies and stronger government oversight to improve safety standards in those yards. Gunbeyaz *et al.* [9] pointed out that the lack of occupational training is the predominant cause of increased exposure to workplace hazards and injuries. Moreover, Ahamad *et al.* [10] found that poor use of PPE is the primary cause of increased health risks in recycling yards in Bangladesh. Uddin [11] recommended regular training on safety and environmental regulations and, more vigorous enforcement of international standards to improve working conditions. Mehtaj *et al.* [12] identified physical hazards due to a lack of proper safety measures and training, and recommended, for cost-effective mechanisation, the use of appropriate PPE and regular safety audits. Additionally, Tanha *et al.* [13] emphasised the Hong Kong Convention (HKC) certification, infrastructure investment, proper training, and inculcation of safety culture to reduce injuries and fatalities in the shipbreaking yards. Islam *et al.* [14] suggested enhanced occupational health and safety through standard training, accident reporting, safety audits, and sufficient investment to ensure worker safety. Besides, Abdullah *et al.* [15] emphasised the need to strengthen shipbreaking infrastructure, ensure legal compliance, prioritise worker safety, and foster government-private sector collaboration to promote sustainable practices. Recently, Mehtaj *et al.* [16] conducted a risk assessment based on a questionnaire survey to present the health impacts under two categories: long-term and short-term. It was revealed that many workers lacked formal education and awareness, which contributed to a poor understanding of accident consequences and increased exposure to workplace hazards. Finally, it was emphasised that promoting eco-friendly recycling methods and investing in advanced technology could significantly improve worker safety. However, a major limitation of the study was the failure to perform a risk assessment of the specific activities performed by each worker group.

This study employs the Human-HAZOP methodology to create a comprehensive map of critical weaknesses in the ship recycling industry, identifying hazards and assessing associated risks. To better comprehend the extent of the challenges within Bangladesh's ship recycling yards, a detailed questionnaire survey was conducted. Based on the survey responses, the Human-HAZOP analysis thoroughly assessed each phase of the recycling operation, identifying potential worker-safety issues and operational flaws. The findings of this analysis suggested several necessary safety measures to mitigate risks and enhance safety practices in Bangladesh's ship recycling yards.

2. Methodology

2.1. Questionnaire Survey for Human-HAZOP Analysis

To conduct the Human-HAZOP analysis, an extensive questionnaire survey was conducted in 18 shipbreaking yards in the Chattogram district, the core hub of ship recycling in Bangladesh. With support from the Ministry of Industries of the Government of the People's Republic of Bangladesh, and the Bangladesh Ship Breakers and Recyclers Association (BSBRA), this survey was conducted from August to October 2022, and a total of 1074 respondents participated. The survey was conducted to collect responses from workers and supervisors across 14 groups, gathering their opinions on existing safety practices and potential hazards associated with ship dismantling procedures and activities. It should be emphasized here that there was no specific sampling procedure for the study. All the workers and supervisors of the 18 yards participated in the questionnaire survey. It is worth mentioning that some worker groups have a higher number of workers than the other groups depending on the nature and scope of work in the yards. **Table 1** presents the number of participants in each worker group and the corresponding role.

The questionnaire was developed focusing on the activities performed by the worker groups, each having different sets of questions based on the nature of their respective work. In addition, some information from the questionnaire survey conducted by Mehtaj *et al.* [16], which focused on investigating only the health impacts of workers in ship dismantling yards in Bangladesh, aided in developing the questions of this questionnaire survey. Besides, some expert opinions were also taken to improve the questionnaire before field use. Furthermore, the survey also included valuable insights from experts in both industry and academia, which helped to propose necessary safety measures to mitigate the identified risks. This way, the present study has been able to perform a comprehensive Human-HAZOP analysis, identifying potential hazards for each worker group and proposing required safety measures to improve the overall safety of shipbreaking and ship recycling activities in Bangladesh. The surveyed area is illustrated in Figure 1.

Table 1. Distribution of the number of workers based on groups and corresponding key roles.

Name of Group	No. of Participants	Key Roles in Yards
Inspection team	15	Assess ship's readiness for dismantling operation at the outer anchorage before beaching
Beaching group	86	To Beach or lay the ship at ashore
Loader group	44	Create openings in the forward and bow sections of the ship to facilitate further operations
HAZMAT handler group	88	Conduct a pre-inspection to identify and safely dispose of insulating and hazardous materials
Vendors and contractors	44	Inspect the ship before beginning of gas cutting operation
Mud group	81	Remove mud and relevant wastes from the vessel
Wire group	91	Transport ropes and wires, and connect those to winches or various parts of the ship
Oil and bilge handler group	42	Drain and clean oil and fuel tanks
Cylinder handler group	77	Remove used or partially used cylinders from the ship
Cutter group	185	Cut different parts of the ship
Fitter group	113	Remove reusable mechanical and electrical machinery items from the ship
Welder group	44	Create platforms and modify passageways for access to various locations through welding
Electrical group	40	Disconnect electrical cables inside the ship
Mechanical group	124	Transfer steel plates from one location to another within the yard using mechanical means or vehicles

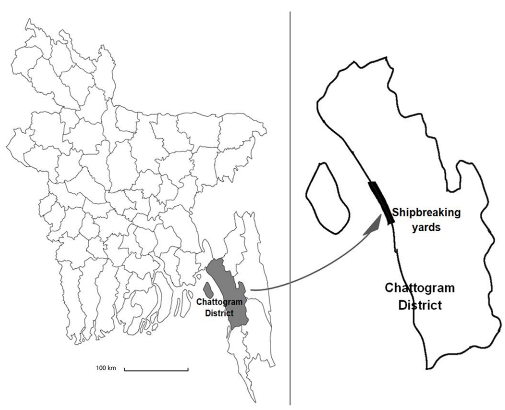

Figure 1. Location of surveyed shipbreaking yards in Bangladesh.

2.2. Human-HAZOP Method

The Hazard and Operability Study (HAZOP) is a method used to identify and evaluate hazards and operational issues within a system. This process is systematic, organised, and thorough, allowing for a detailed hazard identification assessment of a particular system. By applying this method, organisations can enhance safety protocols and create a safer working environment for individuals [17]. Since human operators and workers mainly perform activities in ship recycling yards in Bangladesh, it is necessary to select a HAZOP method that addresses the hazards associated with those activities. In this context, the Human-HAZOP technique is selected, which addresses the human factors [18]. Many hazards that remain unidentified in traditional HAZOP analyses can be identified by the Human-HAZOP [19]. It should be emphasised that, unlike the conventional HAZOP, which addresses technical risks primarily and system-related risks, the Human-HAZOP focuses on identifying and mitigating risks by analysing human behaviour, decision-making processes, and interactions within a given environment. It is helpful to conduct the Human-HAZOP analysis using the typical HAZOP worksheet provided by Ericson [17]. However, to address human factors, the guidewords used differ from the conventional HAZOP Guidewords. A list of some guidewords used in the Human-HAZOP analysis is shown in **Table 2**.

Table 2. Guide words used by the Human-HAZOP method [19].

Guide Words	Meaning
Not done	Action was not carried out
Repeated	Action was carried out more times
Less	Action was carried out with a lower effect
More	Action was carried out with a bigger effect
Earlier	Action was carried out earlier
Later	Action was carried out later
And also	Another action was also carried out
Reversed	A sequence of actions was breached
Other than	Different action was carried out
Part	Only a part of the action was carried out

2.3. Risk Evaluation

A risk is the likelihood or probability that a hazard will cause harm, taking into account both the severity of the potential damage and the likelihood of exposure to the hazard. Probability refers to the likelihood of a hazard occurring, while severity reflects the potential consequences or harm that the hazard may cause. The risk value for each hazard is obtained by combining its severity and probability. The severity and probability are primarily expressed in terms of corresponding levels. For severity, the levels typically range from high to low, with four categories like 'catastrophic', 'critical', 'marginal', and 'negligible'. **Table 3** presents the description of the severity levels used in the survey. Likewise, for probability, the qualitative values also range from high to low, with five categories like 'Frequent', 'Probable', 'Occasional', and 'Improbable' denoting the likelihood of an event. **Table 4** presents the description of the probability levels used in the survey.

Table 3. Description of severity levels.

Severity Levels	Description
Catastrophic (1)	Fatality or permanent total disability of the victim
Critical (2)	Hospitalization of at least 3 persons due to severe injury, permanent partial disability, or occupational illness
Marginal (3)	Loss of one or more working days due to moderate injury or occupational illness
Negligible (4)	No loss of working days; however, minor treatment is required for simple injury or occupational illness

Table 4. Description of probability levels.

Probability Levels	Description
Frequent (A)	Likely to occur once in a week
Probable (B)	Have the potential to occur once in a month
Occasional (C)	Likely to occur for a few times in a year
Remote (D)	Have the possibility to occur once in a year
Improbable (E)	Very unlikely to occur

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low

Figure 2. Risk assessment matrix [20].

The risk matrix is an effective way to demonstrate risks, outlining them as a combination of severity and probability. The matrix is prepared in accordance with the well-established system safety standard proposed by the United States

Department of Defence [20]. The matrix, as illustrated in **Figure 2**, uses a gradient colour scheme to represent varying levels of risk based on the combination of severity and probability. Several boxes in the top-left corner of the matrix are shaded red, indicating high-risk levels where both severity and probability are substantial. The boxes of the orange zone indicate serious risk, the yellow areas specify medium risk, and the green areas at the bottom-right indicate low risk. The identified risks will be examined to propose recommendations for mitigating the hazards effectively.

The responses obtained from the participants had a discrete value for severity and probability. However, each value of severity and probability for a particular question is averaged to obtain their overall view of perception towards safety. In that case, the averaged value becomes fractional in most cases, which is a standard procedure followed in several previous studies [21]-[23]. Eventually, the risk assessment matrix is obtained that depicts the overall scenario of risks as per the perception among the workers of ship dismantling yards in Bangladesh.

3. Results and Discussion

3.1. Identification of Hazards Involving the Ship Recycling Activities

In the Human-HAZOP analysis, worksheets are prepared for each group based on a questionnaire survey to thoroughly identify potential hazards, taking into account the nature and scope of the activities performed. To prepare the worksheet, firstly focus is given to the items whose absence or improper use could be hazardous. Then the deviation or pattern of probable unsafe actions by the use of that item or not using that item is identified. Later, the potential causes of that deviation are listed, and relevant hazards are identified. The identified hazards are then used to assess the corresponding risk level. Finally, several recommended measures are proposed to mitigate those deviations and hazards. Therefore, all the items used by a particular group are investigated to identify the relevant potential hazards. In this way, the Human-HAZOP worksheet is prepared based on the responses of the participants. It should be noted that, no disagreement rule was used in this questionnaire survey, and all types of respondents were weighted equally. For brevity, the worksheet for only one group, *i.e.*, the wire group, will be presented here. The workers of this group are tasked with transporting wires and ropes and connecting them to winches or various parts of the ship. During these operations, they are prone to experiencing muscle pain, cuts, fractures, amputations, and even death. The Human-HAZOP analysis will analyse all those potential hazards and propose several mitigation measures. The worksheet of the wire group is presented in **Table 5**.

The overall Human-HAZOP analysis covering 14 worker groups has identified 105 discrete hazards associated with ship recycling activities. The number of hazards per worker group is presented in **Figure 3**. It is evident that the ‘cutter group’ is most vulnerable to hazards, with 17 identified cases due to the extensive nature of their work. On the other hand, 14 hazards are assigned to the ‘HAZMAT handlers group'. Furthermore, both the 'Fitter group' and the 'Oil and Bilge Handler group' are associated with 12 hazards each, whereas the 'Beaching group' is prone to face 11 hazards. The remaining groups are exposed to fewer hazards by comparison. However, the hazards and risks associated with any worker group's activities must not be overlooked. It should be noted that all worker groups work in the same area, and hazards in one group can affect workers in another.

Table 5. Human-HAZOP worksheet of the wire group.

ID	Item	Deviation	Cause	Hazard	Recommendations
R1	Safety shoes	Not wearing safety shoes on muddy surfaces while carrying rope wires	Lack of PPE, negligence, complacency, and lack of supervision	Sustaining a severe foot injury from a sharp object or slipping down	Ensure availability of safety shoes, proper supervision, arrange training program, and toolbox meeting
R2	Safety shoes	Not wearing safety shoes while transporting ropes/wires to connect those with winches or ship parts	Lack of PPE, negligence, complacency, and lack of supervision	Leg injury	Ensuring proper supervision, availability of safety shoes, arrange training program, and toolbox meeting
R3	Winch-connected wires and chain ropes	Perform the dismantling operation involving winch-connected wires and chain ropes other than following the safe procedure	Lack of adequate facility, negligence, Lack of situational awareness, lack of supervision	Several types of injury	Ensure the availability of proper functioning tools, proper supervision, arrange training program
R4	Wires and chain ropes	Not performing the maintenance works of wires and chain ropes regularly	Lack of scheduled maintenance activity, lack of directives by supervisor	Several types of injury	Pre-inspection of operating wires and chain ropes, Proper maintenance by following checklist, proper supervision
R5	Shoulder pads	Not wearing proper shoulder pads while carrying rope wires and small metal plates	Lack of adequate facility, ignorance or negligence, lack of directives of supervisor	Injury on shoulder and neck	Ensuring availability of shoulder pads, proper supervision, arrange training program
R6	Wires and heavy machineries	Perform the transporting operation of wires and heavy machineries other than following the safe procedure	Lack of adequate facility and supervision, Ignorance or negligence, and complacency	Several types of injury	Proper supervision, ensuring availability and safe use of standard carriers for carrying wires and heavy machineries
R7	Wires and chain ropes	Attach wires and chain ropes with block section, anchor, winch and so on other than following the safe procedure	Lack of situational awareness, Ignorance or negligence, complacency, and lack of supervision	Several types of injury	Proper supervision, arrange training program, toolbox meeting

The dismantling operation of a ship is completed in several zones. The worker groups participate in their respective activities in those zones. The zones are termed as the outer anchorage zone, the intertidal zone, the primary cutting zone, the secondary cutting zone, the tertiary cutting zone, the inside yard facility, the storage area, and the disposal zone. It should be noted that a particular worker group may be involved in performing activities at different zones based on the nature and type of dismantling operation. For instance, the wire group is engaged in carrying wires and ropes to the primary cutting zone. After completing their tasks at the primary cutting zone, they proceed to the secondary and tertiary cutting zones. That is, the activities in the yards usually follow a sequential schedule of activities. Hence, there is rarely a possibility that those workers will remain in more than one zone at a time. Therefore, it did not create any problem in classifying workers during the hazard counting. **Figure 4** illustrates the zones and the percentages of hazards for different worker groups in each zone.

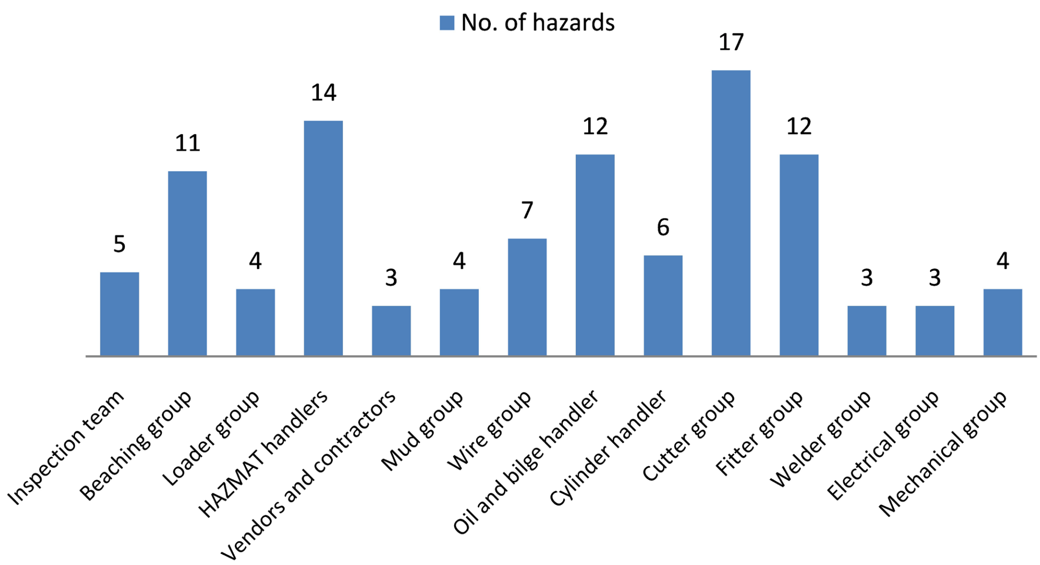

Figure 3. Distribution of the number of hazards based on worker groups.

The hazard ultimately has an impact on the human body, causing injury and even death. A depiction of the affected areas of the human body can help illustrate the hazards workers face. An illustration of the human body, depicting the total number of potential effects by hazards on particular parts, is shown in **Figure 5**. The total number of hazards is shown in two categories: specific hazards and common hazards, drawn from a pool of 105 main hazards associated with different body regions. The specific hazards affect only a particular part of the human body. However, implications for common hazards are those that affect multiple body parts and are counted based on the impact caused by each part of the body, due to their widespread effects. For instance, a worker who falls from a height is at risk of injuries throughout the body. Therefore, each part of the body is assigned to a single hazard within the common hazards category.

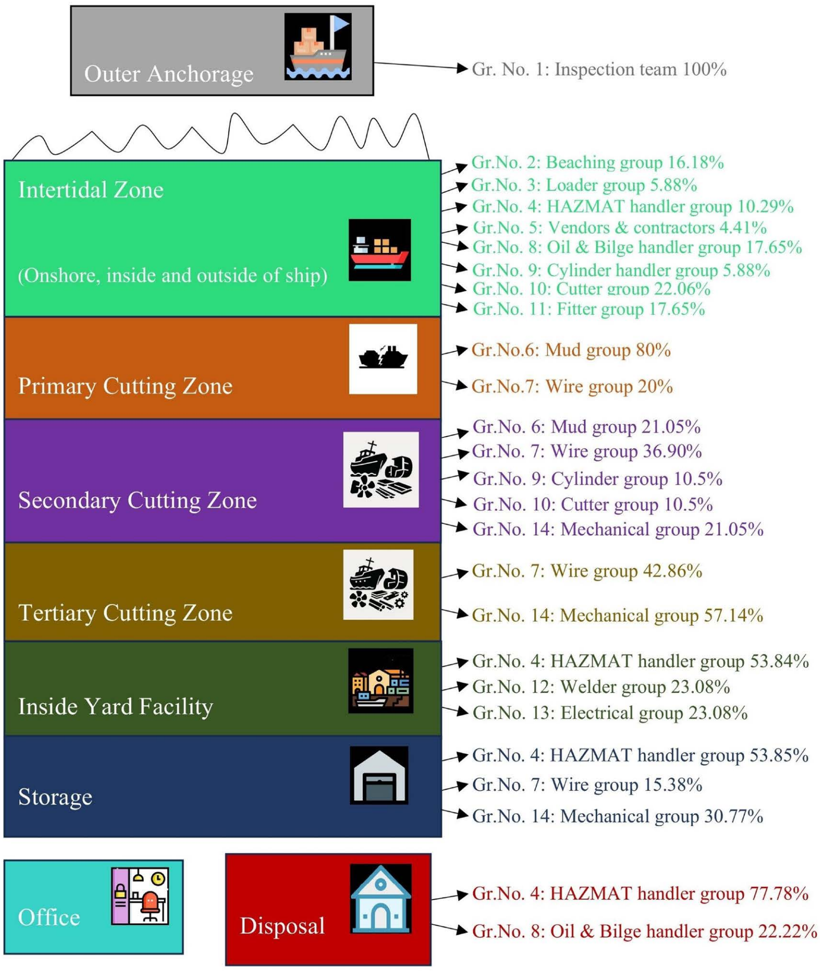

Figure 4. Zone-wise percentage of hazards for different worker groups.

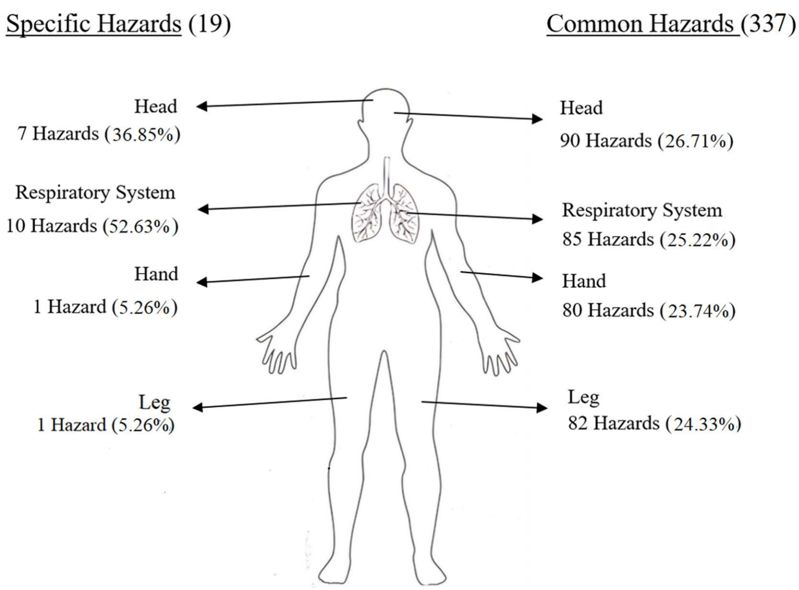

Figure 5. Illustration of different parts of the human body based on potential impacts by hazards.

Regarding specific hazards, the respiratory system is primarily at risk, with 10 hazards. The head area is susceptible to 7 hazards. Furthermore, both hands and legs are individually prone to encountering one hazard. Among common hazards, the head area stands out with 90 identified hazards, indicating significant risks to the eyes, ears, and head, primarily due to exposure to fumes, sparks, loud noise, impact from hitting an object on the head, and so on. Additionally, the respiratory system is associated with 85 hazards, highlighting moderate risks to respiratory health from gases, dust, and other harmful airborne particles. Furthermore, the hands are prone to 82 hazards such as cuts from sharp metals, burns, etc. Additionally, the legs are linked to 80 hazards, underscoring concerns about slips, cuts from sharp metal, injuries to the lower limbs, and more.

3.2. Risk Evaluation and Recommendations

After identifying hazards, it is essential to assess the associated risks. Although the values are obtained as whole numbers from each respondent, in the risk matrix, they are presented as fractional values obtained by averaging the summed values over the total number of respondents. The risk assessment matrix for the wire group is illustrated in **Figure 6**. The hazards identified by the Human-HAZOP analysis, as shown in **Table 3**, are used to generate the matrix based on participants' responses. In this matrix, the risk R1, which involves carrying ropes over muddy surfaces without safety shoes, is considered serious and placed in the orange zone. It falls into the probability category of 'remote'; however, it has a severity category of 'catastrophic'. Similarly, the risks ranging from R2 to R6 are placed in the yellow zone due to their medium risk. However, the risk R7 remains in the green zone, indicating a low level of risk, with a probability in the 'occasional' category and a severity in the 'negligible' category.

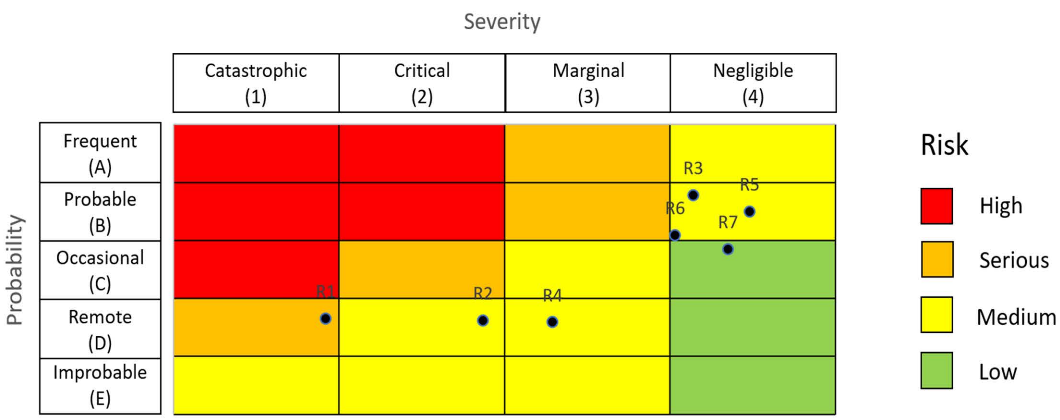

Figure 6. Risk assessment matrix for the wire group.

Figure 7 illustrates the risk levels associated with all 105 identified risks, categorised by different worker groups. It is evident that the highest number of data points is clustered in the yellow zone, indicating a medium level of risk. Additionally, the green zone, which means a low level of risk, has fewer data points than the yellow zone. However, only four points fall in the orange zone, which is considered a serious risk. It is worth mentioning that no risk is found in the red zone, indicating that potential incidents of high severity and probability are absent. It must be emphasized here that, the data of the study were collected from the perception-based responses of the participants involved in ship-recycling activities. There could be two potential reasons for the absence of hazards in the high-risk zone. Firstly, the participants could have the perception that the ship-recycling activities are free from high-risk zone hazards. Secondly, there would be a lack of a proper concept of safety among the workers due to the absence of proper training, and the existence of a poor form of safety culture in the ship dismantling yards. However, a general relationship as evident from the figure is that as probability increases, severity tends to decrease, and vice versa. Specifically, the wire group, cutter group, and oil and barge handler group are higher-risk groups compared to other worker groups.

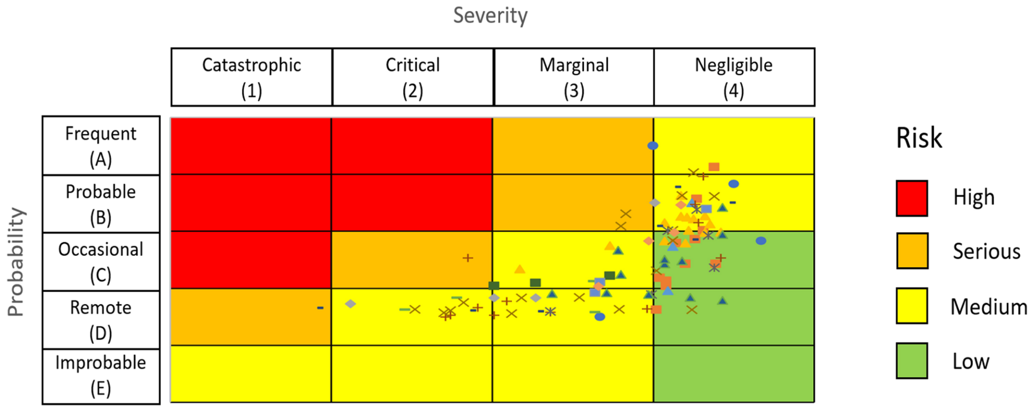

Figure 7. Risk assessment matrix for all groups.

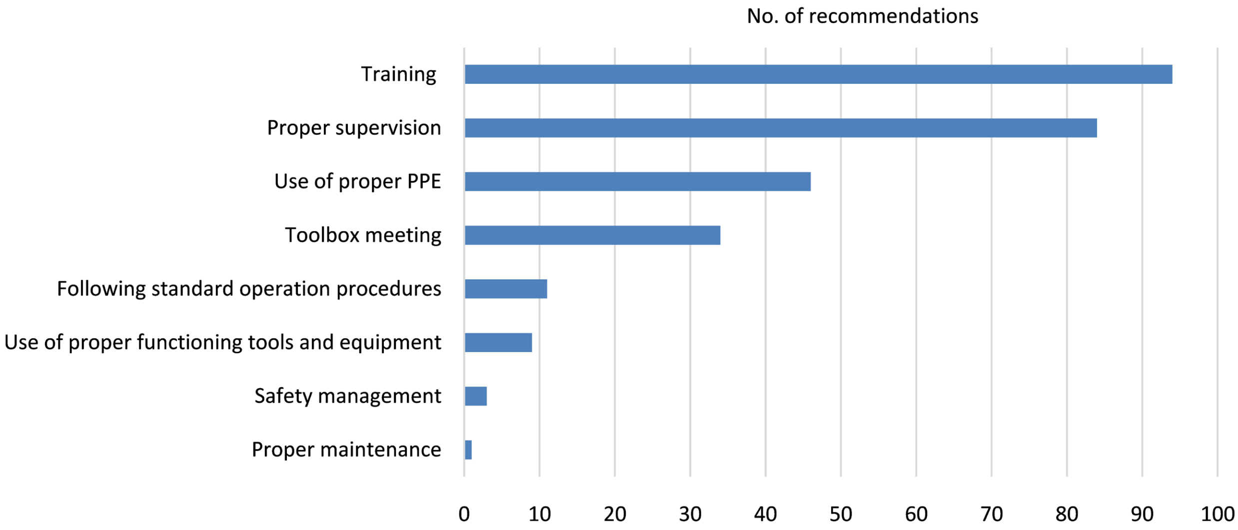

Figure 8. Distribution of the number of recommendations based on categories.

Figure 8 illustrates the number of recommendations categorised by their type, as elicited from the Human-HAZOP analysis. These recommendations will help mitigate the identified risks. It is evident that training and proper supervision are the two predominant categories of recommendations. Additionally, the use of appropriate PPE and toolbox meetings is another notable category. Furthermore, following standard operating procedures, using adequate, functioning tools and equipment, safety management, and proper maintenance are all minor recommendations.

4. Recommendations and Conclusions

4.1. Recommendations

This section highlights several key recommendations to enhance overall safety in Bangladesh's ship recycling yards. Furthermore, the limitations of the present study and the scope of future work have also been highlighted. It is highly anticipated that these recommendations, if implemented successfully, will improve working conditions and promote long-term sustainability in Bangladesh's ship dismantling operations.

The Human-HAZOP worksheet for each worker group should be distributed to the respective group to ensure that they comprehend the nature of potential hazards and risks. Additionally, structured training programs, interactive workshops, and knowledge-sharing seminars should be organised to facilitate discussions on potential hazards and associated risks. These initiatives will significantly enhance safety awareness among workers, supervisors, and management personnel. Moreover, such discussions would create an open platform for workers, supervisors, and safety experts to share their experiences, observations, and concerns, thereby identifying previously unidentified hazards. In addition, the five worker groups—the cutter group, the HAZMAT handler group, the oil and barge handler group, the fitter group, and the beaching group—should be given high consideration due to their potential to experience a higher number of hazards. On the other hand, the wire group, the cutter group, and the oil and barge handler group are higher-risk groups compared to other worker groups. However, it is crucial to highlight that prioritising the workers of these groups does not imply neglecting other groups. It must be emphasised that all worker groups work in the same area, and the hazards of one group also have the potential to affect the workers of another group. Therefore, ensuring a comprehensive safety framework for all worker groups is crucial to maintaining a safer work environment.

The Human-HAZOP analysis has proposed several recommendations to mitigate the impacts of each identified hazard. Most of the recommendations have addressed arranging proper training programs, ensuring adequate supervision, providing sufficient PPE, and holding toolbox meetings. However, to implement these recommendations, the Government of Bangladesh must impose strict guidelines on all shipyards. Additionally, the shipyard authorities must allocate sufficient budgets to implement these safety measures, ensuring a safer working environment and minimising the risks associated with hazardous tasks in ship recycling. Moreover, to facilitate the successful implementation of these safety measures, a comprehensive checklist should be developed based on the Human-HAZOP worksheet. This checklist will serve as a structured guideline to ensure all necessary precautions are followed to mitigate risks. Regular inspections and adherence to the checklist will contribute to a more organised and secure working environment in the shipyard.

A thorough investigation of accidents and incidents is crucial for taking precautionary measures to prevent similar events in the future. However, no such database was found during this study. Therefore, the government should mandate that each ship recycling yard authority maintain a standardised database that includes a comprehensive description of each accident and incident. Additionally, to minimise workers' health hazards, the Government of Bangladesh should explore replacing human labour with automated machinery in select cases where the potential for severe health hazards is high. In this regard, a comprehensive discussion with stakeholders and the adoption of best global practices are essential.

It must be emphasised that the questionnaire survey was conducted among workers at 18 ship recycling facilities. However, conducting the study across all ship recycling yards in the country to perform a comprehensive Human-HAZOP analysis, resulting in more extensive feedback from workers, supervisors, and safety experts, would yield a more thorough safety assessment. Additionally, other standard hazard analysis methods can be applied to identify hazards related to ship dismantling operations. Some of these techniques include Systems Theoretic Process Analysis (STPA), Failure Mode and Effects Analysis (FMEA), Event Tree Analysis (ETA), and others. Comparing these techniques' outputs would also help identify previously unidentified hazards in shipbreaking yards. However, these matters may be the subject of future research.

4.2. Conclusions

The ship recycling industry in Bangladesh faces significant challenges stemming from inadequate safety measures for the workers. Despite its considerable importance to the national economy, the sector operates with minimal safety standards, resulting in frequent casualties and long-term health issues. The primary objective of this study is to identify the hazards associated with ship recycling activities by analysing the activities of different worker groups and to assess the corresponding risk values using the Human-HAZOP method. As a novel application, it is expected that workers and stakeholders will be able to comprehend the underlying hazards and their potential impacts. Besides, the risk matrix would provide profound insight into the severity and probability of those hazards, helping them understand their nature and probable effects.

In summary, the findings of this study are expected to be highly beneficial, guiding the development of safety standards by reducing potential safety hazards across all shipbreaking yards in Bangladesh. Therefore, the outcomes of this analysis will play a pivotal role in fostering a safer, more sustainable, and environmentally friendly ship recycling industry in Bangladesh.

Acknowledgements

The authors express their sincere gratitude to Engineering X, an international collaboration established by the Royal Academy of Engineering and the Lloyd's Register Foundation, for funding, which enabled the completion of the study. They also acknowledge the support from the Ministry of Industries (MoI) of the Government of the People's Republic of Bangladesh and the cooperation from the Bangladesh Ship Breakers and Recyclers Association (BSBRA).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Ali, M. (2022) Bangladesh Top in Global Ship Recycling Again. https://www.tbsnews.net/economy/industry/bangladesh-top-global-ship-recycling-again-541874

[2] Ahammad, H. and Sujauddin, M. (2017) Contributions of Ship Recycling in Bangladesh: An Economic Assessment. IMO-NORAD SENSREC Project Report, London.

[3] Islam, S.M.M.U. (2025) Upcoming Challenges of the Ship Recycling Industry in Bangladesh. The Daily Star. https://www.thedailystar.net/law-our-rights/news/upcoming-challenges-the-ship-recycling-industry-bangladesh-3863051

[4] Hossain, M.S., Chowdhury, S.R., Jabbar, S.A., Saifullah S.M. and Rahman, M.A. (2008) Occupational Health Hazards of Ship Scrapping Workers at Chittagong Coastal Zone, Bangladesh. *Chiang Mai Journal of Science*, **35**, 370-381.

[5] Pasha, M., Mahmood, A.H., Rahman, I. and Hasnat, A. (2012) Assessment of Ship Breaking and Recycling Industries in Bangladesh—An Effective Step towards the Achievement of Environmental Sustainability. 2012 *International Conference on Agricultural, Environment and Biological Sciences*, Phuket, 26-27 May 2012, 43-47.

[6] Haque, M. (2017) Occupational Health and Safety in the Ship-Breaking Industries of Bangladesh. In: Basu, R. and Rahman, M.S., *Governance in South Asia*, Routledge, 157-177.

[7] Rabbi, H.R. and Rahman, A. (2017) Ship Breaking and Recycling Industry of Bangladesh; Issues and Challenges. *Procedia Engineering*, **194**, 254-259. https://doi.org/10.1016/j.proeng.2017.08.143

[8] Patwary, M.S.H. and Bartlett, D. (2019) Impacts of Shipbreaking Industry in Bangladesh: Search for a Sustainable Solution. *European Journal of Engineering and Technology*, **7**, 64-79.

[9] Gunbeyaz, S.A., Kurt, R.E. and Baumler, R. (2019) A Study on Evaluating the Status of Current Occupational Training in the Ship Recycling Industry in Bangladesh. *WMU Journal of Maritime Affairs*, **18**, 41-59. https://doi.org/10.1007/s13437-019-00164-0

[10] Ahamad, A.F., Schneider, P., Khanum, R., Mozumder, M.M.H., Mitu, S.J. and Shamsuzzaman, M.M. (2021) Livelihood Assessment and Occupational Health Hazard of the Ship-Breaking Industry Workers at Chattogram, Bangladesh. *Journal of Marine Science and Engineering*, **9**, Article 718. https://doi.org/10.3390/jmse9070718

[11] Uddin, M.M. (2021) Impact of International Standard System Application: In the Context of Ship Recycling Industry of Bangladesh. *Journal of International Maritime Safety, Environmental Affairs, and Shipping*, **5**, 120-131. https://doi.org/10.1080/25725084.2021.1917829

[12] Mehtaj, N., Dipto, S.S., Zakaria, N.M.G., Awal, Z.I., Hannan, M.A. and Dev, A.K. (2021) A Techno-Economic Study on Ship Recycling Practices in Bangladesh: From Safety Perspective. *Proceedings of the* 3*rd International Conference on the Decommissioning of Offshore & Subsea Structures*, Aberdeen, 29-30 March 2021, 52-63.

[13] Tanha, M., Michelson, G., Chowdhury, M. and Castka, P. (2022) Shipbreaking in Bangladesh: Organizational Responses, Ethics, and Varieties of Employee Safety. *Journal of Safety Research*, **80**, 14-26. https://doi.org/10.1016/j.jsr.2021.09.006

[14] Islam, M.S., Awal, Z.I., Alamgir, M.Z., Adib, S.H. and Jerin, F.T. (2022) A Survey on Occupational Health and Safety in the Ship Recycling Industries of Bangladesh. *Proceedings of the* 13th *International Conference on Marine Technology*, Dhaka, 21-22 December 2022, 541-547.

[15] Abdullah, A., Awal, Z.I., Alamgir, M.Z., Mia, M.J., Mim, F. and Dhar, U.K. (2023) A Review on Ship Recycling Industry in Bangladesh from Global Perspective. *Journal of Ocean and Coastal Economics*, **10**, Article 4. https://doi.org/10.15351/2373-8456.1165

[16] Mehtaj, N., Zakaria, N.M.G., Awal, Z.I., Dipto, S.S., Hannan, M.A., Dev, A.K., *et al.* (2024) Ship Recycling Process in Bangladesh and a Survey-Based Risk Assessment with Mitigation Proposal. *Heliyon*, **10**, e39344. https://doi.org/10.1016/j.heliyon.2024.e39344

[17] Ericson, C.A. (2005) Hazard Analysis Techniques for System Safety. Wiley. https://doi.org/10.1002/0471739421

[18] Jacinto, C. and Marques, P.H. (2016) Human-HAZOP Studies in the Risk Management of Major Accidents. *International Symposium on Occupational Safety and Hygiene*, Guimarães, 12-13 February 2016, 146-148.

[19] Vechgama, W., Silva, K., Pechrak, A. and Wetchagarun, S. (2021) Application of Hazard and Operability Technique to Level 1 Probabilistic Safety Assessment of Thai Research Reactor-1/Modification 1: Internal Events and Human Errors. *Progress in Nuclear Energy*, **138**, Article 103838. https://doi.org/10.1016/j.pnucene.2021.103838

[20] United States of America (2012) Department of Defense, Standard Practice: System Safety. https://safety.army.mil/Portals/0/Documents/ON-DUTY/SYSTEMSAFETY/Standard/MIL-STD-882E-change-1.pdf

[21] Spasenic, Z., Makajic-Nikolic, D. and Benkovic, S. (2022) Integrated FTA-Risk Matrix Model for Risk Analysis of a Mini Hydropower Plant's Project Finance. *Energy for Sustainable Development*, **70**, 511-523. https://doi.org/10.1016/j.esd.2022.08.024

[22] Komendantova, N., Mrzyglocki, R., Mignan, A., Khazai, B., Wenzel, F., Patt, A., *et al.* (2014) Multi-Hazard and Multi-Risk Decision-Support Tools as a Part of Participatory Risk Governance: Feedback from Civil Protection Stakeholders. *International Journal of Disaster Risk Reduction*, **8**, 50-67. https://doi.org/10.1016/j.ijdrr.2013.12.006

[23] Cruz, C.O., Soares, H.N. and de Lima, H.M. (2024) Tailings Dams' Classification Based on Risk Using Data from SIGBM. *Caderno Pedagógico*, **21**, e3359. https://doi.org/10.54033/cadpedv21n3-164