

Applying the Analytic Hierarchy Process (AHP) to Evaluate Safety and Hazard-Related Objectives in Bangladesh's Ship Recycling Industry

Nayma Hassan Emu¹, Zobair Ibn Awal¹, Arun Kr Dev²

¹Department of Naval Architecture and Marine Engineering, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh

²Naval Architecture and Maritime Engineering, Newcastle University in Singapore (NUIs), c/o-NewRIIS, Singapore
Email: a.k.dev@newcastle.ac.uk

How to cite this paper: Emu, N.H., Awal, Z.I. and Dev, A.K. (2025) Applying the Analytic Hierarchy Process (AHP) to Evaluate Safety and Hazard-Related Objectives in Bangladesh's Ship Recycling Industry. *Open Journal of Safety Science and Technology*, 15, 282-299.

<https://doi.org/10.4236/ojsst.2025.153015>

Received: July 20, 2025

Accepted: September 16, 2025

Published: September 19, 2025

Copyright © 2025 by author(s) and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution-NonCommercial International License (CC BY-NC 4.0).

<http://creativecommons.org/licenses/by-nc/4.0/>



Open Access

Abstract

As Bangladesh's entry into force of the Hong Kong Convention approaches, the demand for safe and environmentally sustainable ship recycling practices has intensified. Despite Bangladesh and South Asia holding the largest share of the ship recycling industry, Bangladesh has faced criticism for inadequate safety measures, training, and tools, leading to accidents and unsafe working conditions. Thus, to prioritise safety measures and training, key recycling activities that require attention to personnel safety, environmental hazards, and regulatory compliance must be identified. This study aims to determine the most crucial activity, taking into account safety and hazard management in the Bangladesh ship recycling industry, using the Analytic Hierarchy Process (AHP) analysis. The objective focuses the industry on high-priority activities requiring immediate attention to ensure safer, more sustainable ship recycling practices. Six criteria are defined based on safety and hazards in the ship recycling industry. The AHP analysis has been conducted considering six ship recycling activity groups (alternatives), amongst which the most crucial one would be identified. This study conducted six expert surveys to create the pairwise comparison matrix (PWCM), gaining insights into evaluating criteria and alternatives. The results of the AHP analysis highlight that Personnel Safety (PS) is the most significant criterion in ship recycling, with Inspection Activities being the most critical activity (30.83%). Operational Risk Complexity, Safety Training, and Regulatory Compliance also play significant roles. Environmental and waste management concerns are comparatively less prioritised due to their long-term rather than immediate risks. According to the

results, some recommendations have been suggested to ensure safe and hazard-free ship recycling. Recommendations include emphasising rigorous pre- and post-inspection protocols, providing proper training and safety equipment for workers, increasing regulatory oversight, and implementing effective waste management strategies to ensure compliance with safety standards and prevent incidents.

Keywords

Ship Recycling, Analytic Hierarchy Process (AHP), Safety and Hazard Management, Multi-Criteria Decision Analysis (MCDA), Risk Assessment

1. Introduction

After reaching service life, ships are sailed or towed to ship recycling yards for recycling. Although recycling a ship after its end of life can produce a considerable amount of hazardous waste, it is considered the best means of disposing of a vessel at the end of her operational life.

Bangladesh holds the largest share of the industry worldwide, and South Asia is the global centre for shipbreaking and recycling of End-of-Life (EOL) ships. Although Bangladesh and South Asia have the largest share of the ship recycling industry, they have been criticised for their unsafe working conditions and environmental practices. Accidents often occur due to inadequate safety precautions, insufficient training, and inadequate tools.

1.1. Background

Bangladesh ratified the Hong Kong Convention for the Safe and Environmentally Sound Recycling of Ships in June 2023, allowing the Convention to enter into force on 26 June 2025. As a result, the demand for safe and environmentally sustainable ship recycling practices has intensified. The complexities of balancing economic benefits with safety and environmental responsibilities make it imperative to explore innovative solutions. Chowdhury *et al.* [1] conducted a descriptive and conceptual study in 2020 to identify the impact of the working environment in the Bangladesh ship-breaking industry on the health & safety conditions of its workers. In 2022, Islam *et al.* [2] surveyed occupational health and safety issues in ship recycling yards in Bangladesh, suggesting areas for improvement in occupational health and safety for workers, including updated training programs, accident reporting systems, safety audits, and sufficient investment. In 2024, Misaala *et al.* [3] identified and addressed the challenges hindering Bangladeshi ship recycling yards from achieving compliance with the convention. The study's findings encompass tailored recommendations, including the implementation of continuous monitoring for effective job scope management and transparent financial backing for yard enhancements. Again, in 2024, Nafisa *et al.* [4] examined the risk patterns in the ship recycling industry by conducting field surveys across 18 ship

recycling yards in Bangladesh. They provided practical recommendations to minimise these risks.

Therefore, the recycling activities that require the most attention must be identified, considering personal safety, environmental hazards, and regulatory compliance, so efforts can be prioritised to increase safety measures and training. In this study, the most critical ship recycling activity will be discovered, taking into account safety and hazard management in the Bangladeshi ship recycling industry. A multi-criteria decision analysis (MCDA) method, specifically the Analytic Hierarchy Process (AHP), will be applied to achieve this objective. This method has been applied in various fields to address complex decision-making problems.

1.2. Aim and Objectives

This research aims to identify and prioritise the ship recycling activities that have the most significant impact on safety and hazard management. Greater priority is given to activities that significantly prevent accidents, minimise health risks, ensure regulatory compliance, and effectively manage environmental hazards.

The main objectives are as follows:

- 1) To determine which activities pose the most significant risk to personnel and the environment.
- 2) To identify activities crucial for reducing or preventing accidents, environmental damage, and failures in hazardous waste management.
- 3) To prioritise efforts to enhance safety measures, training, and compliance for activities that currently lack adequate safety and hazard management.
- 4) To ensure that the selected activities comply with international and national safety standards, helping the industry avoid legal and regulatory violations.

Ultimately, the objective helps the industry focus on high-priority activities that require immediate attention and improvement to ensure safer, more sustainable, and compliant ship recycling practices.

2. Literature Review

Decision-making methods, such as AHP, have been utilised in the shipping industry, particularly in the ship recycling sector, as they simplify complex decision-making by structuring problems into a hierarchy of goals, criteria, and alternatives. In 2019, Dev and Shao'En [5] conducted a critical analysis of different ballast water treatment systems using AHP that aided ship owners in selecting the most suitable system for their vessels. In the same year, Hossain [6] created an assessment model using the Analytic Hierarchy Process (AHP) to evaluate and rank 13 local ship recycling yards in Bangladesh based on six criteria, including sustainability and operational efficiency. The study suggested that if proper guidance and professionalism can be enforced, the local recycling industry of Bangladesh will be sustainable in the future. It was also recommended that the ship recycling industry requires continuous monitoring, leadership, financing, guidance, motivation, and support from the government and the international community.

In 2023, Baihaqi *et al.* [7] applied the novel Integrated Value Engineering and Risk Assessment (IVENRA) framework for measuring shipyard performance, combining the Fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL) and Analytic Hierarchy Process (AHP) tools. A shipyard case study in Indonesia was used to apply the proposed framework, showing that the shipyard with a high personnel safety group is more critical than the environmental impact. Waste management was found to be the most impactful attribute amongst the criteria group, while the HSE (Health, Safety and Environment) department was the most critical criterion.

In 2024, Saraswati *et al.* [8] formulated alternative strategies and priorities for maritime environmental protection in the Silugonggo River channel employing the analytical hierarchy process (AHP). The results recommended prioritising several maritime environment management and protection strategies, including the development of policies related to the maritime environment and the construction of anchor pools and supporting infrastructure.

That year, Celik *et al.* [9] utilised a combined SWOT-TOWS-ANP triangle method to identify the best possible strategy for the Aliaga ship recycling facility, explicitly focusing on the environmental implications. The analysis results are expected to guide industry stakeholders in establishing a safe, reliable, cleaner, and more sustainable ship recycling industry.

This study aims to employ the analytical hierarchy process (AHP) based on expert judgments to identify the criteria and activities crucial for safety and hazard management in the Bangladeshi ship recycling industry.

3. Methodology

AHP is particularly suited for the ship recycling industry compared to other MCDA methods, as it allows experts to systematically compare safety and hazard management activities through pairwise comparisons, ensuring a structured, reliable decision-making process. Thomas L. Saaty [10] developed the Analytical Hierarchy Process (AHP), a multi-criteria decision analysis that uses human judgments to rank the alternatives to make a decision. The AHP analysis consists of multiple steps, and the procedure flowchart is shown in **Figure 1**.

The first step of the Analytic Hierarchy Process (AHP) is to define the goal, which is to select the ship recycling activity that is most critical in terms of safety and hazard management. The second step involves identifying the criteria and structuring the hierarchy. In this case, six criteria were used to evaluate the most crucial activity among the six activity groups.

Next, questionnaires need to be developed for expert opinion surveys. Based on the survey responses, a Pairwise Comparison Matrix (PWCM) is constructed for both the criteria and the alternatives. Each PWCM is then normalised, and the criteria weights are calculated.

An essential step of AHP is checking the consistency of the PWCM. If the PWCM is consistent, the final weight calculations can proceed, and a decision can

be made. However, if it is inconsistent, the PWCM must be revised, and the process will be repeated until consistency is achieved.

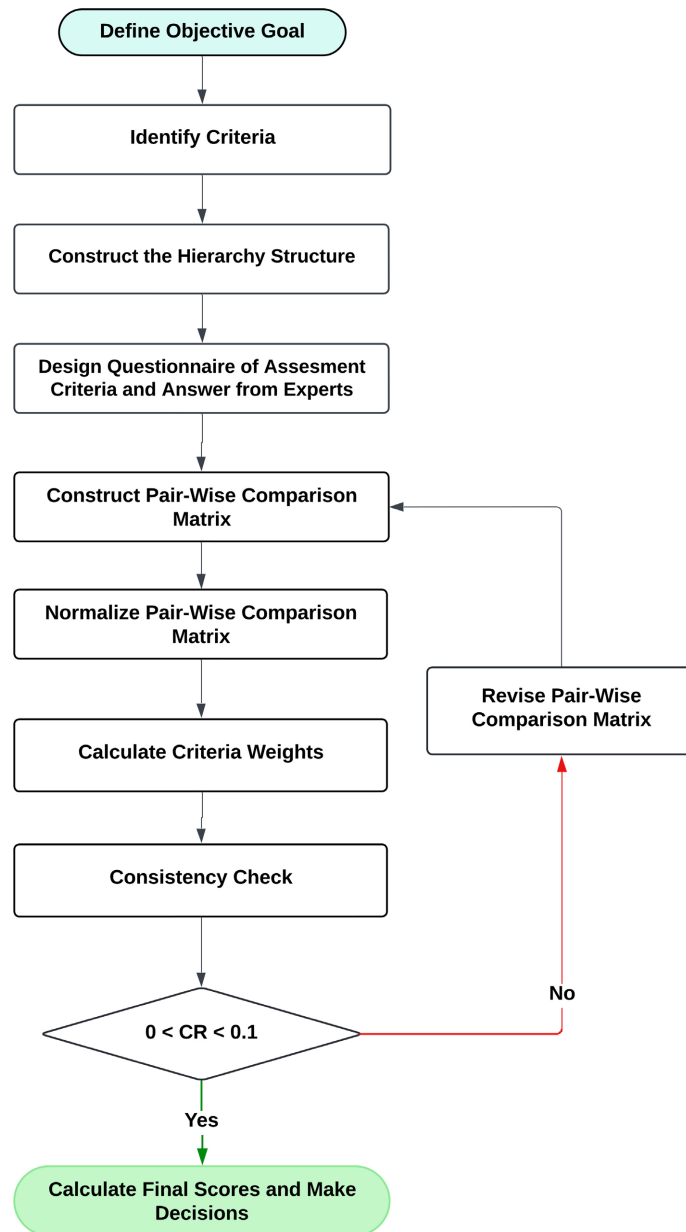


Figure 1. Flowchart of AHP analysis.

Detailed Procedure of AHP Calculation

The step-by-step procedure of AHP calculation is given below:

- 1) Definition of Objective Goal.
- 2) Structure the hierarchy with the decision goal at level 1, the list of criteria at level 2, and then the list of alternatives at level 3.
- 3) Construct a set of PWCM of size $(n \times n)$ for each element of level 2 and level 3. Each component of an upper level (j) is used to compare the elements with the

level directly below (*j*) concerning it, using the Saaty comparison scale [10] in **Table 1**. To elaborate, the criteria are compared in terms of the higher goal, and alternatives are compared concerning each criterion.

Table 1. Saaty comparison scale.

Linguistic Scale	Rating	Reciprocal Rating
Equally Important	1	1
Equally to Moderately Important	2	1/2
Moderately Important	3	1/3
Moderately to Strongly Important	4	1/4
Strongly Important	5	1/5
Strongly to Very Strongly Important	6	1/6
Very Strongly Important	7	1/7
Very Strongly to Extremely Important	8	1/8
Extremely Important	9	1/9

4) There are $(n(n - 1))/2$ decisions that are to be compared for each PWCM in step 3. In each pairwise comparison, reciprocals are automatically assigned, and the diagonal values are always one. Then, the elements of the columns are summed.

5) The PWCM is normalised by dividing each element of the column by the total sum of that column calculated in the previous step. The Criteria weight vector [*W*] is calculated by averaging the total row of each element. The sum of the column of each element should be equal to one.

6) Then, a consistency check must be done to ensure the consistency ratio (CR) is less than 0.1. If it is greater than or equal to 0.1, it indicates that rankings are not being made appropriately, and the PWCM must be revised.

Procedure to check consistency:

1) Calculate weight sum vector, [*Ws*]

Let, original PWCM = [*C*], Criteria weight vector = [*W*]

$$[Ws] = [C] \times [W]$$

2) Calculate the Consistency vector, [λ] = [*Ws*] \times 1/[*W*]

3) The sum of each element of the Consistency vector is equal to λ .

4) Calculate the Consistency index (CI), $CI = ((\lambda - n))/((n - 1))$ where, *n* = matrix size.

5) Determine the consistency ratio (CR), $CR = CI/RI$

6) RI = Random Index is a standardised value presented in **Table 2**.

Table 2. Value of random index.

Matrix Size	<i>n</i>	3	4	5	6	7	8	9
Random Index	RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45

4. Analytic Hierarchy Process Structure

This project aims to perform an AHP analysis for safety and hazard-related goals in Bangladesh Ship Recycling Industries to select the most critical Ship Recycling activity. In order to perform an AHP analysis, the hierarchy must be structured. This hierarchy structure has multiple levels; the first level defines the goal of the decision. The second level involves identifying the criteria that matter while evaluating the alternatives for achieving the goal, and the third level involves those alternatives. In this study, six alternatives will be assessed to identify the most critical ship recycling activity concerning six criteria related to safety and hazards in the ship recycling industry. The AHP structure is shown in **Figure 2** and described below:

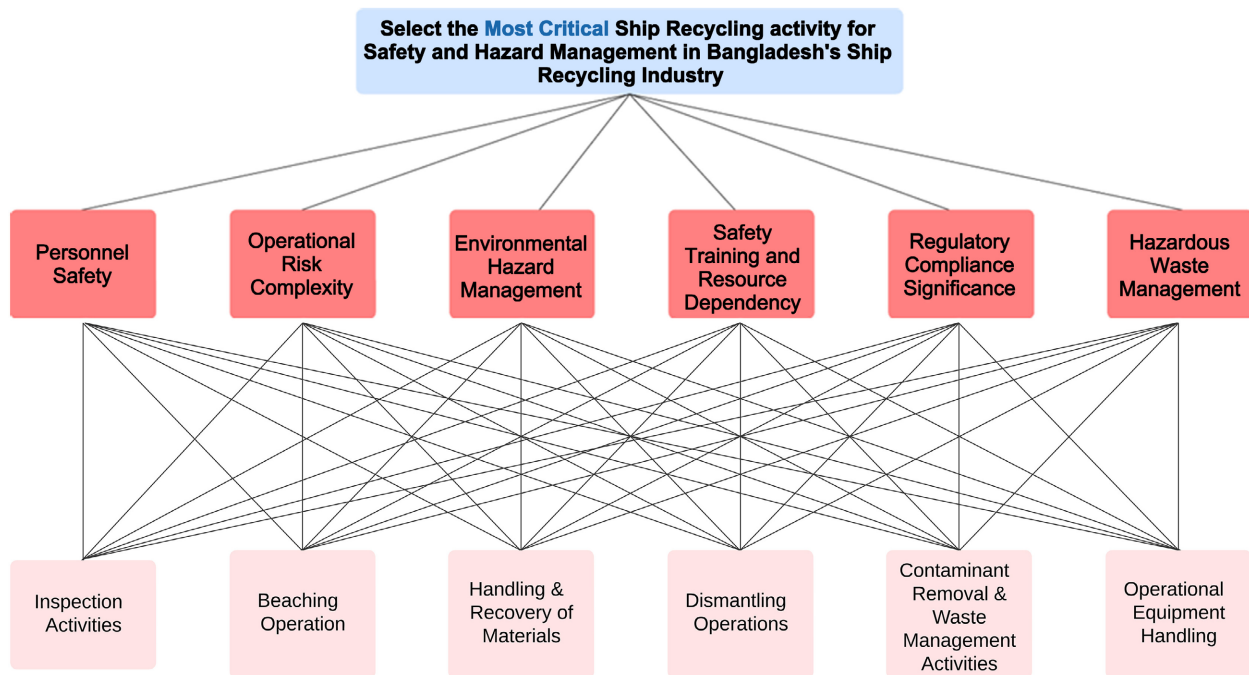


Figure 2. AHP structure diagram.

Level 1-Goal:

The goal of the AHP analysis is to find out the most critical Ship Recycling activity for Safety and Hazard Management in Bangladesh's Ship Recycling Industry.

Level 2-Criteria:

Criteria are set to rank the alternatives to the decision. In the AHP analysis, the requirements are evaluated in terms of the higher goal, and alternatives are evaluated with respect to each criterion.

In this case, six criteria are defined based on safety and hazards in the ship recycling industry. Each criterion prioritises activities based on how well risks can be identified, managed, and mitigated. The selection and definition of each criterion focus on prioritising activities with higher inherent risks because activities posing greater risks require more robust management of hazards to ensure safety.

This approach helps identify activities that pose greater risks to personnel, the environment, or overall safety, making them more crucial for safety and hazard management in the ship recycling industry. The criteria are described below:

1) Personnel Safety (PS)

Definition: This criterion assesses the potential risks to workers' physical health and safety during the activity, including the likelihood of long-term health issues (e.g., respiratory problems, burns, and cancers) and severe injuries (e.g., equipment malfunctions, accidents, fires, and exposure to toxic substances). Activities that pose a higher risk of such incidents or have a higher probability of causing severe outcomes are prioritised as critical.

2) Operational Risk Complexity (ORC)

Definition: This measures the complexity involved in the activity, e.g., the complexity of safety procedures, specialised tools, or advanced risk management strategies. Activities that require advanced safety measures or intricate tools are considered more critical.

3) Environmental Hazard Management (EHM)

Definition: This evaluates the activity's potential to harm the environment. This includes the risk of spills, pollution, or improper disposal of hazardous materials. Considering the likelihood and the severity of environmental hazards, activities that contribute to significant environmental damage or require complex mitigation efforts to control such risks are prioritised as critical.

4) Safety Training and Resource Dependency (ST-RD)

Definition: This assesses the level of dependency on safety training, equipment, and worker competency. Activities that require specialised training, advanced safety protocols, or substantial resources (e.g., safety equipment) to mitigate risks are considered more critical.

5) Regulatory Compliance Significance (RCS)

Definition: This evaluates the importance of the activity in adhering to relevant national and international safety and environmental regulations (e.g., Hong Kong Convention, EU-SRR regulations, Basel Convention, Ship Recycling Rule - 2018). Activities that are essential in ensuring compliance with such regulations are prioritised as more crucial for managing safety and hazards.

6) Hazardous Waste Management (HWM)

Definition: This criterion assesses the effectiveness of handling hazardous materials (HAZMAT) in ship recycling. It covers the identification, safe handling, storage, and disposal of toxic substances, including fuel, oil, asbestos, and heavy metals. Activities directly involving hazardous waste or requiring extensive measures to mitigate environmental and health risks are deemed more critical.

Level 3-Alternatives:

These alternatives represent the activities that are under consideration. Each activity will be evaluated based on the criteria defined above. Previously, ship recycling processes were divided into 15 activities for risk assessment of the ship recycling process [4]. The activities are listed below in **Table 3**.

Table 3. List of activities for risk assessment.

Activity No.	Description
A1	Inspection at the Outer Anchorage
A2	Beaching
A3	Lohari Group (Iron Works)
A4	Pre-inspection immediately after beaching to identify and dispose of insulating and hazardous materials
A5	Inspection by Vendors and Contractors before Gas Cutting
A6	Removal of Mud & Other Contaminants
A7	Wire Group
A8	Draining & Cleaning of Oil and Fuel Tanks and Disconnecting Fuel Oil, Furnace Oil & Lubrication Oil Lines (Oil & Bilge Workers)
A9	Cylinder Handlers
A10	Cutters/Cutting Works
A11	Recovering Unused and Partially Spent Materials - Fitters and Associated Others
A12	Recovery and Decommissioning of Reusable and Recoverable Objects (Electrical, Electronic, Mechanical Machinery/Equipment) - Fitters
A13	Electrical Works
A14	Welding Group
A15	Rotational and Linear Movement of Equipment & Vehicles (Winch, Crane, Excavator & Trucks)

Table 4. List of alternatives for AHP analysis.

Alternative No.	Title	Recycling Activities Included
R1	Inspection Activities	A1
R2	Beaching Operation	A2
R3	Handling & Recovery of Materials	A3, A5, A7, A9, A11, A12
R4	Dismantling Operations	A7, A10, A13, A14
R5	Contaminant Removal & Waste Management Activities	A4, A6, A8
R6	Operational Equipment Handling/Material Transfer	A15

After analysing the ship recycling survey [4], 15 alternatives were identified for assessment. However, due to time constraints, conducting analyses on these many activities would be challenging. Therefore, the activities are grouped into broader categories to reduce the number of alternatives. In **Table 4**, the activities are grouped into six categories based on their similar characteristics and operational flow. It should be noted that activity A7, listed under both R3 and R4, represents tasks that are involved in both material handling and dismantling operations, which is why it is included in both groups. An AHP (Analytic Hierarchy Process)

analysis will then be performed on these categories, treating them as alternatives.

The alternatives for the AHP analysis of safety and hazard-related goals in Bangladesh's ship recycling industry are listed below in **Table 4**.

Therefore, the AHP analysis has been conducted considering these six activity groups, amongst which the most crucial one would be identified.

5. Expert Survey Conducted

The Analytic Hierarchy Process (AHP) involves creating pairwise comparisons for various criteria and alternatives, which depend on experts' judgments to establish priority scales. All survey participants are actively involved in the Ship Recycling project at the Department of Naval Architecture and Marine Engineering, BUET, Bangladesh. When selecting participants, it was ensured that each had at least a BSc degree in Naval Architecture and Marine Engineering, providing them with a strong foundation in the subject. The participants included professors, current and former research assistants, and technical support staff of this project, all of whom possess substantial experience and expertise in the ship recycling industry of Bangladesh.

During the survey, participants are briefed on the objective and structure of the analysis, and an instruction file is provided. They are also instructed on how to rank criteria and alternatives using the Saaty scale (**Table 1**). The survey was conducted online via a Zoom meeting, and the data collection medium used was Microsoft Excel.

Finally, a survey for AHP analysis was conducted, gathering input from six experts. However, expert knowledge and advice have been utilised throughout all stages of the methodology, including data collection in this study. The expert profile is shown in **Table 5**.

Table 5. Expert profiles.

Serial No.	Name of the Expert	Profession	Education
1	Arun Kr Dev	Reader in Naval Architecture and Maritime Engineering/Associate Professor, Newcastle University in Singapore	PhD
2	Zobair Ibn Awal	Professor, Department of Naval Architecture and Marine Engineering, Bangladesh University of Engineering & Technology	PhD
3	Md. Imran Uddin	Assistant Professor, Accident Research Institute (ARI), Bangladesh University of Engineering and Technology	PhD
4	H.M. Sabbir Hossen	Technical Support Staff, Department of Naval Architecture and Marine Engineering, Bangladesh University of Engineering & Technology	BSc
5	Mst. Zebun Nahar Eti Moni	Technical Support Staff, Department of Naval Architecture and Marine Engineering, Bangladesh University of Engineering & Technology	BSc
6	Shaumik Sharif Dipto	Consultant, JICA Bangladesh Ship Recycling Technical Cooperation Project. Former Research Assistant, Department of Naval Architecture and Marine Engineering, Bangladesh University of Engineering & Technology	MSc

6. Results and Discussion

In this study, the arithmetic mean was used to aggregate expert judgments due to its simplicity and ease of interpretation. The arithmetic mean allows for a straightforward calculation of the average judgment across multiple experts, providing a clear representation of the consensus view. **Table 6** shows the overall pairwise comparison matrix for criteria and **Table 7** shows the normalised pairwise matrix for the criteria.

Table 6. Pairwise comparison matrix for criteria.

Criteria	PS	ORC	EHM	ST-RD	RCS	HWM
PS	1	4	5	2	3	3
ORC	1/4	1	2	1	1	2
EHM	1/5	1/2	1	1	1	1
ST-RD	1/2	1	1	1	2	1
RCS	1/3	1	1	1/2	1	2
HWM	1/3	1/2	1	1	1/2	1

Table 7. Normalised pairwise matrix for criteria.

Criteria	PS	ORC	EHM	ST-RD	RCS	HWM	Criteria Weight	In percentage
PS	0.382	0.500	0.455	0.308	0.353	0.300	0.383	38.29
ORC	0.096	0.125	0.182	0.154	0.118	0.200	0.146	14.56
EHM	0.076	0.063	0.091	0.154	0.118	0.100	0.100	10.02
ST-RD	0.191	0.125	0.091	0.154	0.235	0.100	0.149	14.94
RCS	0.127	0.125	0.091	0.077	0.118	0.200	0.123	12.30
HWM	0.127	0.063	0.091	0.154	0.059	0.100	0.099	9.89
Sum	1	1	1	1	1	1	1	100.00

Figure 3 shows the priority weights of the criteria with respect to the goal. Key observations are given below:

- 1) Firstly, Personnel Safety (PS) is given the highest priority, with 38.29% weight. This means worker safety should be the primary concern in ship recycling.
- 2) Secondly, Operational Risk Complexity (ORC) and Safety Training & Resource Dependency (ST-RD) are moderately significant, with 14.56% and 14.96% weight, respectively. These factors highlight the importance of complexity in risk management and the necessity of proper training and resources in ship recycling.
- 3) Thirdly, the significance of Regulatory Compliance Significance (RCS) is considered relevant but not dominant, with a weight of 12.30%. While compliance with national and international regulations (e.g., the Basel Convention, the Hong Kong Convention) is essential, it is not as critical as ensuring personnel safety and mitigating operational risk.

4) Lastly, Environmental Hazard Management (EHM) and Hazardous Waste Management (HWM) are regarded as the least prioritised, with respective weights of 10.02% and 9.89%. Despite the environmental impact of shipbreaking, these aspects seem to have lower importance than direct worker safety and operational risk. This could be due to the immediate life-threatening nature of safety hazards, whereas environmental damage has long-term consequences.

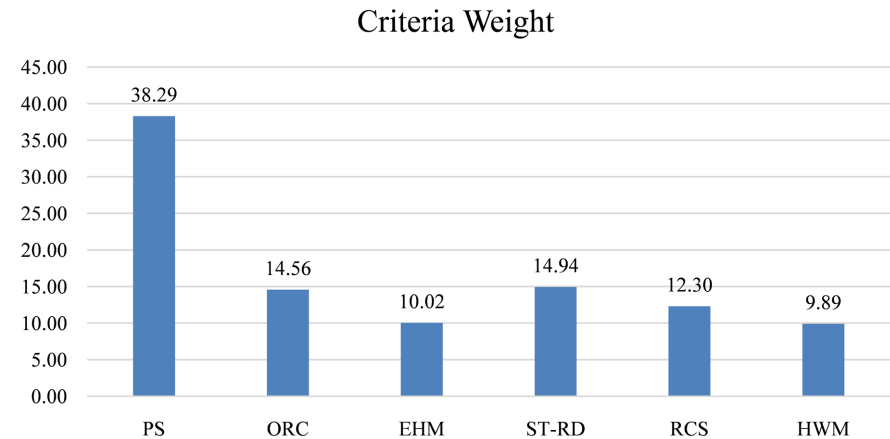


Figure 3. Criteria weight.

Tables 8-13 respectively represent the PWCM for Personnel Safety, Operational Risk Complexity, Environmental Hazard Management, Safety Training & Resource Dependency, Regulatory Compliance Significance, and Hazardous Waste Management.

Table 8. Pairwise comparison matrix for personnel safety.

PS	R1	R2	R3	R4	R5	R6
R1	1	3	3	3	3	2
R2	1/3	1	1	1	1	1
R3	1/3	1	1	1	2	2
R4	1/3	1	1	1	2	2
R5	1/3	1	1/2	1/2	1	1
R6	1/2	1	1/2	1/2	1	1

Table 9. Pairwise comparison matrix for operational risk complexity.

ORC	R1	R2	R3	R4	R5	R6
R1	1	3	2	3	3	3
R2	1/3	1	2	3	3	3
R3	1/2	1/2	1	2	3	3
R4	1/3	1/3	1/2	1	2	1
R5	1/3	1/3	1/3	1/2	1	2
R6	1/3	1/3	1/3	1	1/2	1

Table 10. Pairwise comparison matrix for environmental hazard management.

EHM	R1	R2	R3	R4	R5	R6
R1	1	3	2	2	3	2
R2	1/3	1	1/3	1/3	1/3	1/2
R3	1/2	3	1	1	2	1
R4	1/2	3	1	1	2	2
R5	1/3	3	1/2	1/2	1	4
R6	1/2	2	1	1/2	1/4	1

Table 11. Pairwise comparison matrix for safety training & resource dependency.

ST-RD	R1	R2	R3	R4	R5	R6
R1	1	3	2	2	2	2
R2	1/3	1	1	1	1/2	1/3
R3	1/2	1	1	1	1	1
R4	1/2	1	1	1	2	1
R5	1/2	2	1	1/2	1	1
R6	1/2	3	1	1	1	1

Table 12. Pairwise comparison matrix for regulatory compliance significance.

RCS	R1	R2	R3	R4	R5	R6
R1	1	3	1	1	2	1
R2	1/3	1	1/2	1/3	2	1/3
R3	1	2	1	1	2	1
R4	1	3	1	1	2	1
R5	1/2	1/2	1/2	1/2	1	2
R6	1	3	1	1	1/2	1

Table 13. Pairwise comparison matrix for hazardous waste management.

HWM	R1	R2	R3	R4	R5	R6
R1	1	3	2	2	2	2
R2	1/3	1	1/2	1/2	1/2	1/3
R3	1/2	2	1	2	1	2
R4	1/2	2	1/2	1	2	2
R5	1/2	2	1	1/2	1	4
R6	1/2	3	1/2	1/2	1/4	1

The overall priority matrix for the most critical ship recycling activity is shown in **Table 14**.

Table 14. Overall priority matrix for most critical ship recycling activity.

Criteria/ Alternative	PS	ORC	EHM	ST-RD	RCS	HWM	Overall Priority Weight	In percentage
R1	0.351	0.330	0.296	0.291	0.204	0.279	0.308	30.83
R2	0.123	0.230	0.063	0.101	0.097	0.075	0.121	12.14
R3	0.158	0.182	0.174	0.138	0.190	0.186	0.167	16.71
R4	0.158	0.099	0.190	0.160	0.204	0.170	0.160	15.99
R5	0.099	0.086	0.164	0.140	0.128	0.177	0.121	12.12
R6	0.109	0.074	0.113	0.168	0.177	0.112	0.122	12.21
							1.000	100.00

Figure 4 shows the overall priority weights of ship recycling activities. Key observations are given below:

1) Inspection Activities (R1) is considered the most critical ship recycling activity, receiving the highest priority weight of 30.83%. This indicates that thorough inspections before and during shipbreaking operations ensure worker safety, reduce operational risks, and minimise environmental hazards.

R1 scores high in key criteria—Personnel Safety (PS: 0.351), Operational Risk Complexity (ORC: 0.330), and Environmental Hazard Management (EHM: 0.296). This highlights the importance of inspections in preventing severe accidents, ensuring safe dismantling processes, and managing hazardous conditions.

2) Handling & Recovery (R3) and Dismantling Operations (R4) are considered moderately critical activities, with 16.71% and 15.99% respective priority weights. These activities are crucial due to their involvement in high-risk tasks such as material handling, welding, and cutting, which require strict adherence to safety measures. R4 is particularly critical in terms of hazardous material exposure and regulatory compliance.

R3 has balanced importance across all criteria, whereas R4 is critical in terms of Environmental Hazard Management (EHM 0.190) and Regulatory Compliance Significance (RCS 0.204), indicating concerns about hazardous material exposure and regulatory compliance.

3) Beaching (R2), Contaminant Removal & Waste Management (R5), and Operational Equipment Handling (R6) are regarded as less critical activities, each with approximately a 12% priority weight. These activities are essential but pose fewer immediate risks to workers compared to direct dismantling. Their lower complexity and safety impact have resulted in lower priority weights.

Despite the valuable insights provided by this study, several limitations may be considered when interpreting the findings. Firstly, the study is conducted with the opinion of six experts. Although the experts are knowledgeable, in the context of AHP analysis, this sample size can be considered small and may limit the generalizability and robustness of the findings. Secondly, although the selected experts

have substantial experience, their personal biases and individual perspectives could influence the results. Thirdly, the paper groups 15 detailed activities into six broader categories (R1 - R6) for the AHP analysis. This simplification of activities may result in the loss of differences between individual activities, potentially affecting the accuracy of the prioritisation of activities. Lastly, the AHP analysis is conducted, focusing on the ship recycling industry in Bangladesh. Therefore, while the findings are important for local contexts, they may not be directly applicable to ship recycling industries in other countries with different safety standards, regulatory frameworks, or operational conditions.

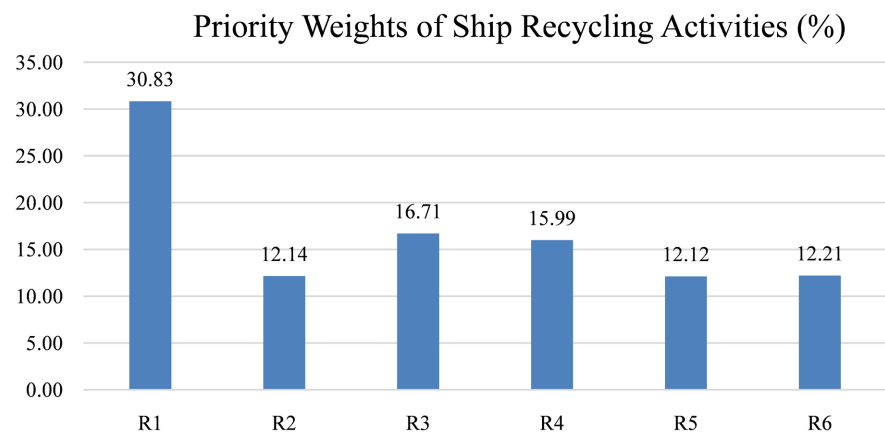


Figure 4. Overall priority weights of ship recycling activities.

7. Recommendations

The following recommendations can be drawn up based on AHP analysis results.

7.1. Inspection Protocols and Regulatory Oversight

Inspection activities gaining more than 30% weightage indicate that thorough inspection is essential to ensure personnel safety. Moreover, other activities, such as handling & recovery of materials, dismantling, and contaminant removal & waste management, depend on inspection activities for their proper and safe execution. A thorough inspection should be conducted to identify the inventory of hazardous materials, assess the structural and mechanical systems, and safely shut down energy sources. Additionally, regulatory oversight should be increased during inspections to enhance compliance with national and international standards. Rigorous pre- and post-beaching inspections should be implemented to identify potential hazards early.

7.2. Ensuring Inspector Safety and Preparedness

Accidents may occur during inspection activities. Therefore, inspectors should ensure that proper safety protocols are followed. This should include protective gear such as helmets, gloves, and safety boots. Additionally, adequate hazard assessment training should be provided, ensuring that inspectors can identify po-

tential risks and hazardous materials.

7.3. Mitigating High-Risk Operational Hazards

Activities such as ironworking, cylinder handling, cutting, and welding are prone to fatal accidents and can cause long-term injuries. Therefore, safety measures, including proper training and the use of safety equipment, should be emphasised during handling, recovery, and dismantling operations. There should be strict enforcement of protocols for gas cutting, welding, and dismantling activities to prevent fires, explosions, and injuries to workers.

7.4. Prioritising Safe Dismantling Procedures

Dismantling operations are crucial for managing environmental hazards and ensuring compliance with relevant regulations. Consequently, the safe disposal of hazardous materials and adherence to regulations must be prioritised during dismantling operations. Moreover, continuous monitoring and the implementation of advanced safety measures should be carried out throughout the dismantling process to mitigate environmental impacts and protect worker health and public safety.

7.5. Advanced Safety Equipment and Waste Management Strategies

Implementing advanced safety equipment (e.g., gas detectors, protective suits) for workers dealing with hazardous materials should be ensured. Additionally, developing efficient waste management strategies should be prioritised to safely segregate, store, and dispose of hazardous residues and contaminants.

These recommendations provide a strategic framework for addressing the critical safety and environmental challenges of Bangladesh's ship recycling industry.

8. Conclusions

Despite South Asia dominating the ship recycling industry, Bangladesh faces criticism for poor safety measures, inadequate training, and lack of proper tools, resulting in accidents and unsafe conditions. As Bangladesh prepares to implement the Hong Kong Convention, the demand for safe and sustainable ship recycling practices has increased.

In this study, an AHP analysis was conducted to assess safety and hazard-related goals in Bangladesh's ship recycling industry, to identify the most critical ship recycling activity. Six expert opinions were gathered to create the pairwise comparison matrices for the analysis.

The results show that Personnel Safety is the most significant criterion among the six in terms of safety and hazard management. Meanwhile, Inspection Activities were identified as the most critical activity. It can be explained that adherence to regulatory standards, identification of hazardous materials, and implementation of safety protocols cannot be achieved without proper inspection, making it

the most crucial among others. Handling & Recovery and Dismantling Operations were considered moderately significant due to their high-risk nature, requiring strict safety measures.

The study successfully addressed the objective of identifying activities that pose the greatest risks to personnel and the environment. It identified key activities—such as inspection, handling & recovery, and dismantling operations—that are crucial for reducing accidents, environmental damage, and failures in hazardous waste management.

In conclusion, the analysis emphasises efforts to improve safety measures, training, and compliance, ensuring that these high-risk activities adhere to international and national safety standards. The activities deemed critical require immediate attention and should be prioritised in safety and hazard management initiatives.

Acknowledgements

This work was conducted as part of the collaborative project “Safety Envelope for Ship Recycling Practices in Bangladesh: Hazard Identification and Risk Evaluation” funded by the Royal Academy of Engineering (RAEng) and Lloyd’s Register Foundation (LRF) under Engineering X. The authors thank all project partners for their contributions. We extend our deepest gratitude to these esteemed institutions for recognising the importance of this project and for their commitment to advancing safety, hazard, sustainability, and innovation in the global ship recycling industry. We have made every effort to acknowledge all sources used in the preparation of this article. However, some references may have been inadvertently missed. We sincerely apologise for any such oversight and gratefully acknowledge the contributions of all whose work has informed this article.

Conflicts of Interest

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

References

- [1] Chowdhury, M.M.I., Othman, K., Khan, M.A. and Sulaiman, I.F. (2020) Working Environment and Its Impact on Health & Safety of Bangladesh Ship-Breaking Industry Workers. *ICELMGE 2020 Conference Proceedings*, Malaysia, 19-20 December 2020, 144-146.
- [2] 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. *SSRN Electronic Journal*.
- [3] Misaal, M., Wan Abdullah, W.M., Kasypi, M., Abu Bakar, A., Mhd Ruslan, S.M., Chuah, L.F., Bokhari, S., Kafi, A. and Mahmud, S.M. (2024) Assessing Bangladesh’s Ship Recycling Journey through the Hong Kong Convention: A Review. *Chemical Engineering Transactions*, **110**, 361-366.
- [4] 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>
- [5] Dev, A.K. and Shao' En, L. (2018) Critical Analyses of Ballast Water Treatment Technologies. *SNAMES 38th Annual Journal*, 40-50.
- [6] Hossain, A. (2019) Development of an Assessment Model for the Ship Recycling Industry in Bangladesh. *Proceedings of the 2nd International Conference on Industrial and Mechanical Engineering and Operations Management*, Dhaka, 12-13 December 2019, 279-285.
- [7] Baihaqi, I., Lazakis, I. and Supomo, H. (2023) Integrated Value Engineering and Risk Assessment Performance Measurement Framework in Ship-Manufacturing Industry Towards Net Zero Emissions Using Fuzzy DEMATEL-AHP. *Machines*, **11**, Article 799. <https://doi.org/10.3390/machines11080799>
- [8] Saraswati, I., Anggoro, S., Wijayanto, D. and Prasetiawan, A. (2024) Analytical Hierarchy Process (AHP) Analysis of Maritime Environmental Protection Strategies and Priorities in Silugonggo River Channel, Indonesia. *Aquaculture, Aquarium, Conservation & Legislation*, **17**, 1103-1111.
- [9] Celik, M.S., Akyar, D.A. and Ceylan, B.O. (2024) Navigating Environmental Sustainability in Ship Recycling Industry: Integrated SWOT-TOWS-ANP Approach. *Ocean Engineering*, **295**, Article 116906. <https://doi.org/10.1016/j.oceaneng.2024.116906>
- [10] Saaty, T.L. (2008) Decision Making with the Analytic Hierarchy Process. *International Journal of Services Sciences*, **1**, 83-98. <https://doi.org/10.1504/ijssci.2008.017590>