A Techno-Economic Study On Ship Recycling Practices In Bangladesh: From Safety Perspective

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Abstract: Shipbreaking in Bangladesh plays a pivotal role in providing scrap steel and other reusable materials for construction and reselling. Due to steady and cyclical steel supply-demand, this industry has attained global attention as a leading sector for the economy of Bangladesh. On one hand, this industry holds a significant aspect from the economic perspective but on the contrary, poses certain risks associated with environmental and occupational health and safety. This paper discusses the problems of existing ship recycling practices for most yards in terms of cutting technology and material handling. Information about the current cutting and material handling methods followed by non-compliant recycling yards and the risks and accidents involved has been obtained from outcome-based FGD findings. The nature of the existing occupational hazards associated with the current practices from the data of 2014-2018 has been evaluated with reasoning. Also, the advantages and drawbacks of the existing cutting and material handling methods have been identified. Based on the findings, this paper recommends cost-effective mechanization for improving the cutting technology and material handling systems for the recycling facilities with the determination to enable safe, and sustainable ship recycling in Bangladesh.

Keywords: *Obsolete vessels, Ship recycling, Cutting technology, Material handling system, Economy.*

1. Introduction:

Ship recycling can be acknowledged as a "Green Industry," because the various materials obtained from obsolete vessels, such as steel and other metal components, machinery and electrical equipment, and wooden furniture, can all be reused in a variety of ways, resulting in the availability of scrap steel for re-rolling steel plants and other construction purposes as a by-product. The ship-recycling sector is a major supplier of raw materials for local steel manufacturers, accounting for over 60% of all raw materials [1]. According to World Bank studies and YPSA, about 25,000 to 50,000 workers are employed at ship breaking yards in Bangladesh directly whereas the number is around 100,000 to 200,000 indirectly [2,3]. This relatively condensed labor market has been possible due to cheap labor which makes the ship recycling industry a profitable business entity for the yard owners within this region. The ship-breaking sector thus contributes to the labor market both directly and indirectly, not only in terms of providing a source of income but also in terms of connecting distinct kinds of vendors who help to keep the economy stable. The ship recycling industry generates scrap materials primarily steel, wood, and electrical components. Out of these, the most significant output is the availability of scrap metals, which are used for construction and are referred to as 'rebar' (re-reinforcement steel). Bangladesh, being a small country with no iron ore mines has no alternative but to rely on scrap steel for construction purposes. Thus, ship recycling is important for the economy, since it can reduce the pressure on iron-ore mining for raw steel and primary rebar production and can also minimize the environmental impacts or emissions of the iron-ore mining process. As per the life cycle assessment methodology for steel, it has been found that secondary rebar produced from the scrap metals obtained from recycling can save up to 16.5 GJ (Gigajoules) of primary energy per ton of rebar and about 1965 kg (kilograms) of CO_2 eq greenhouse gas emissions per ton of rebar when compared to primary rebar obtained via iron-ore mining [4].

However, the aforementioned conveniences cannot conceal the underlying difficulties of the ship recycling industry. One of the general problems existing within the industry lies in the non-compliance with occupational health and safety management. In the last 2 to 3 decades, a considerable number of workers have been injured and in some cases, also lost their lives. Several types of accidents are reported in the ship recycling yards during that period. Major accidents happen because of the explosion of leftover or unidentified gas and fumes within the tanks. Falling from high heights while carrying out block-cutting operations and skin burns while gas cutting, and welding are other major accident cases. Due to the lack of adequate safety measures, for example, not using safety suits or personal protective equipment (PPE) and self-contained breathing apparatus (SCBA), and other essential safety kits, serious accidents occur while working in confined spaces. Also, minor & major accidents which include bruises, broken bones while carrying heavy metals and falling off metal plates on the workers, cuts due to sharp edges, and tripping over metal plates often occur. On the organizational side, the absence of proper fire-fighting systems, and non-responsive emergency evacuation plans are reasons behind the mismanagement of occupational safety maintenance within the yards. Moreover, the lack of proper basic training before hot-working and heavy lifting operations, lack of awareness development, and lack of following standardized block cutting and gas cutting sequences are other key issues associated with workplace safety within the ship recycling yards [5].

When a particle has characteristics such as ignitability, corrosivity, reactivity, and toxicity, one of them can be considered waste [6]. The hazards linked to shipbreaking broadly fall into two categories: intoxication by dangerous substances, and accidents on the plots. In a ship recycling yard, most hazardous material can be referred to as toxic or flammable. Asbestos was hugely used in the old ship, as an insulator in the piping systems, bulkheads, glands, and gaskets of valves and in winches as friction material which is considered a lethal substance. In the case of separating these particles during the recycling of a particular ship, workers without proper safety gear may come in direct contact with asbestos. As such, they are prone to suffering from serious diseases.

POPs (Persistent Organic Pollutants) are a group of very toxic chemicals that include PCB, dioxin, mirex, furan, and others that are used as fire-retardants. These are also present in electrical transformers and capacitors, as well as being used as ship paint additives and coatings [7]. Direct exposure to POPs can cause short or long-term health problems [2]. In a research paper by Therese H. Nøst et al, it has been shown that the concentration of PCBs in the air in the Chittagong ship-breaking zone is approximately 100 pg/m3 [8].

Other than that scrapped ships discharge a variety of waste and disposable materials in the form of solids and fluids such as ammonia, burnt oil leakage, floatable grease and lubricants, metal rust (iron), and other trash or reject materials, which often mix with the beach soil and neighboring waters. These can cause metal shards and rust (especially iron) in the soil, fumes, haze, and oil deposits, hampering marine biodiversity, and increasing shore erosion and turbidity of seawater [9].

Due to geological limits, obsolete vessels in Bangladesh are rarely able to be beached at the shore. As a result, ships get stranded in the intertidal zone, where the cutting procedure begins. The gravity rule or free-falling, which is generally called an uncontrolled demolition approach, is now the practicing process. As a result, many particles, including big blocks fall into the intertidal zone which may cause damage to the intertidal zone's seafloor [10].

Many researchers are striving to solve all these problems in this sector. For example, Fariya et al. and Chowdhury et al. examined the options to accept material handling systems to be implemented for green recycling yards utilizing three types of cranes: fixed cranes, mobile cranes, and crawler cranes. However, the scope of their research was limited to the application of these cranes in terms of crane features only. The study does not go into detail on the specific types of cranes that should be employed or their operating zones [11,12]. In the case of handling waste materials like asbestos, POPs, and others, Zakaria et al. have proposed some alternative processes that appear to be effective in terms of handling HAZMATs in an environmentally friendly and safe manner, but the recommendations are not detailed. They have also mentioned using high-temperature incineration to handle HAZMATs such as ODS (Ozone Depleting Substances) or paint and coatings, but this type of incinerator facility is not available in the majority of ship recycling facilities in Bangladesh [13].

As fire hazards, explosions, and toxic fumes are another primary concern, researchers are trying to solve the relevant problems by improving the cutting technology and searching out better alternate approaches. For example, Choubey et al. have suggested using laser system cutting but they recommended it only for the thickness of the plates within the range of 4 to 20mm [14]. The abrasive water jet method was briefly explored by Hongshen et al in their study work, and according to Gunbeyaj and Daniel, the abrasive water jet method is one of the most efficient and environmentally friendly cutting procedures that can be used in this industry. However, given Bangladesh's economic circumstances, it is unlikely that this cutting procedure will be used in this industry as of now because it is too expensive [15,16].

According to the reviews, increased capital and operating costs, along with the lack of clear analysis of the overall recycling process following ship-specific recycling plans are the most frequent reasons for not adopting mechanization or automated technology to improve the situation. Hence, this paper introduces some of the cost-effective alternatives in the context of Bangladesh, along with a detailed breakdown of the process and a delineated explanation of how these new procedures can bring effectiveness to the workplace while not costing a lot if considered a long-term investment. However, because recycling an outdated vessel is a lengthy procedure involving multiple activities, this study focuses on the cutting technology and material handling system, which are two major segments of the ship recycling process.

2. Methodology:

2.1 Overall view of ship recycling process:

To initiate the recycling of the obsolete vessel, an expert beaching master and the captain of the obsolete vessel work together to perform the intertidal landing. The ship has now arrived at the shore facilities and is ready to be demolished. The navigational equipment such as radar, GPS, Auto-pilot system, speed log, compass, electronic chart, echo sounder, transponder, and other components of the LRIT and AIS system is removed at the start of the dismantling process by the Navy. After that, the ballast and bilge water are discharged. The concentration of organic components in the ballast and bilge water is checked in the first step. Before discharge, the chromium pollutant concentration is also tested.

Following the separation of the ballast and bilge waters from the ship, the leftover oily particles or oily substances are gradually eliminated. In two stages, the waste oil particles can be eliminated. The first step is to transfer and remove the ship's fuel tanks and bunkers, as well as any other areas or passageways where oily particles may be present. This is accomplished through bunkering, which involves loading the majority of the oil onto medium or small oil tankers and oil tanker barges. The remaining oil is then moved to storage places such as oil drums using equipment such as pipes, valves, gauges, compressors, and regulators. Pipelines are used to accomplish this on the beach. It is necessary to ensure that no oil spills during this operation, thus yards utilize oily-water separator trays or impermeable flooring within onshore plant locations. After the initial checking and cleaning, the vessel is ready to be dismantled. It is cut in different stages according to the cutting plan, and the blocks are transferred based on the requirements and plan. The blocks are detached from the vessel utilizing the gravity fall method after the primary cutting takes place in the intertidal zone. The block is then moved to the secondary cutting zone with the help of a winch and rope. Following secondary cutting, the metals are either delivered to the tertiary cutting area or sold directly to the vendors, depending on demand and supply.

2.2 Data Collection:

FGD (Focused Group Discussion) - a qualitative approach designed for the specific examination of the subject of interest - was employed in this study. First and foremost, the goal has been set to develop an appropriate solution for the cutting and material handling sections, as it has been established that the risk of accidents related to cutting and material handling systems is unquestionably significant. This involves suggesting the use of mechanical material handling and cutting equipment as part of infrastructure development for the non-compliant ship recycling yard's long-term viability. The participants were chosen with this in mind to achieve a workable solution in this situation. People who are directly involved in the sector have been contacted for suggestions on how to mitigate often occurring incidents practically. In this case, the discussion was carried out with the following personnel:

(a) Facility Coordinator
(b) HSE Executive
(c) Safety Officer
(d) Security In-charge
(e) An engineer from the Civil construction dept.
(f) Paramedics Officer
(g) Yard Supervisor

A questionnaire based on the relevant literature reviews had been designed to conduct the discussion session. However, because ship recycling is a large, production-oriented sector, the questionnaire was restricted to questions about infrastructure, organizational compliance for occupational health and safety, and financial restraints.
Both offline and online interactions were used to conduct the conversation. From September 2021 to December 2021, field inspections at recycling yards at Sitakunda, Chattogram, were done. Due to the pandemic, some industrial visits were compromised, and discussions were conducted remotely.

An outcome-based evaluation process was used to assess the collected data. Recommendations on certain segments have been offered based on the information on existing field practice gained from the discussions, which may be found in sections 3.1, 3.2, 3.3, and 3.4.

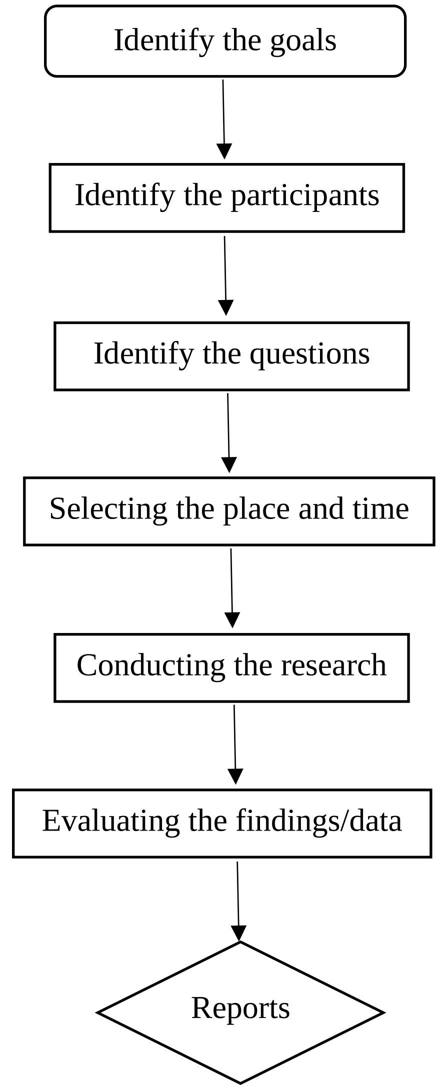

Fig 1: Flowchart of FGD Process

2.3 Data Analysis

2.3.1 Pattern of Hazards:

This paper discusses a few key areas of the overall ship recycling process where hazards are most likely to occur. Kundu has revealed a fatality trend of workers from the years 2014 to 2018 in his thesis. According to him, 28 workers succumbed to their injuries between 2014 and 2018. 4% died from suffocation, 25% died from falling off heavy plates, 14% died from being struck by heavy plates, 11% died from falling from great heights, 11% died from fire burns, and 21% died from explosions and 4% died as a result of toxic gases contamination, and the cause of the other 11% deaths is yet unknown [17].

2.3.2 Cutting Process:

(a) Primary Cutting:

The vessel's cutting commences in the intertidal zone. Because the Sitakunda coast's shoreline hinders the vessels from being entirely lifted along the shore facility, there are no other options for doing primary block cutting at the facility sites. As a result, the cutter foremen are obliged to carry out the cutting operation within the intertidal zone. The foremen must reach the vessel via boat or by walking along geo-bags. As such, they carry all essential cutting and safety devices while ascending to the vessel's decks. As a result, using portable and easy-to-carry equipment is a simple way to begin primary cutting. Precision and accuracy are less important during main block cutting. The primary goal is to cut down blocks quickly and efficiently as possible. For primary cutting, Oxy-LPG is generally used which offers the following benefits:

(i) When compared to other fuels such as LNG, acetylene, MAPP, and others, LPG has a greater BTU (British Thermal Unit), which is roughly 2500 BTU/ft3. As a result, it produces total heat combustion more than others.
(ii) Oxy-LPG is relatively inexpensive and easy to store in cylinders. In Bangladesh, portable LPG cylinders weighing 12 to 18 kg are commonly available.
(iii) When LPG is burned, it produces less carbon.

However, LPG has the following drawbacks:

(i) Propane has a lower explosive limit of 2.1%, but methane has a lower explosive limit of 4.4%, which implies that if the volume of propane gas in an enclosed space equals or exceeds 2.1 % of that enclosed space, there is a high risk of explosion. Furthermore, because LPG has a specific gravity of 1.52, making it heavier than air, there are higher chances for the gas to get entrapped in that location. This is a tricky problem to resolve since it is practically tough to replace LPG while retaining the same efficiency and cost.
(ii) Breathing propane gas is hazardous because it depletes the lungs' oxygen supply and makes breathing difficult. When a person with respiratory disorders like asthma, bronchitis, or a pulmonary ailment comes in contact with LPG, it is extremely harmful.

(b) Secondary Cutting:

The primary cut blocks are stacked in the secondary cutting zone of the onshore recycling facilities. Large blocks are cut into smaller sections during this phase. The blocks are cut using the conventional oxyfuel cutting technique. However, during secondary cutting, there are certain concerns with material quality and the formation of harmful fumes and vapors. Another difficulty that arises during flame cutting is the risk of fire. The following suggestions may be proposed to solve the problems connected with secondary cutting. However, there are significant concerns about the quality of the material and the formation of harmful fumes and vapors during secondary cutting, as detailed below:

Disadvantages:

(i) When it comes to the demand and supply of raw scrap steel, the quality of the final steel product is vital. The inconsistency of the heat produced by the Oxy-LPG gas cutting method compromises this quality. A decarburized layer of solidified steel may form on the material edges as a result of the high temperature, which must be removed after cutting. In addition, the material's heat-affected zone hardens, and cracks may emerge.
(ii) There is no surface cleaning procedure in place prior to the cutting. As a result, the number of poisonous vapors, predominantly carcinogenic gases, is unusually high, and the number of carbon particles in the air is also high due to the use of LPG gas in cutting.

2.3.2 Material Handling System:

A ship is a sophisticated construction made up of steel plates that are stiffened. A ship's lightweight consists of wood and outfitters, machinery and equipment, and navigational system components, in addition to steel. The ship's components are separated into three categories of materials once they arrive at their destination for being dismantled. These materials are currently handled in a variety of ways, and the processes can be found in this section.

(a) Scrapped Metal Handling:

Steel is the primary attraction of this industry; approximately more than half of the steel used in Bangladesh comes from this recycling industry. Around 85% of this steel is used in rerolling mills, while the remaining 15% is used in melting scrap material mills [3]. These material quality and management are a major concern. In many practicing yards, this material handling system presently relies heavily on manual functions, which sometimes leads to large-scale accidents or risks and consumes considerable time and manpower. As a result, mechanization is inevitable to improve the effectiveness and safety of this sector.

(i) Primary cutting and block handling:

The primary cutting takes place at the intertidal zone, and the blocks are the largest in comparison to the other parts. Gravity fall is a commonly used handling system that is highly disregarded in Europe and other nations. Metal chips and small bits become embedded in the soil, eventually being washed away into the coastal seas during high tides. This contaminates the nearby coastal water with heavy metals if not handled properly.

In terms of health and safety, the unregulated fall of a large section of the metal poses the potential for serious harm or numerous accidents. Several incidences of worker fatalities have been documented in ship recycling yards, with the primary cause of death being metal chunks falling on the workers. Currently, the blocks are hauled towards the beach with the use of winches or cable ropes after free-falling. Due to the elevated continental shelf in Bangladesh, the vessel cannot be towed toward the land. Between the beach and the intertidal zone, where the vessel is moored, there is over a 500–1000 meter gap. As a result, the recycling yards have no alternative except to commence the cutting within the intertidal zone.

(ii) Onshore to the secondary cutting zone:

Secondary cutting takes place within the facility area. After the primary blocks have been transported to the shore, the blocks are generally transported using a winch and ropes to the secondary cutting zone. The state of these types of equipment may not always be up to the standard either due to heavy long-term usage or wearing out due to load-lifting over the safety margins which causes serious accidents. Also, this particular practice may lead to tremendous stress for the laborers engaged.

(b) Hazardous materials handling:

Hazardous materials management is the most difficult material handling task. When it comes to the safe management of HAZMATs, such as asbestos, PCBs, and ODS, every step is critical, from collection to transfer, storage, and disposal. Currently, asbestos is treated in recycling facilities by wet methods or solidification. Most of the yards have certified asbestos handlers to treat the asbestos. A special negative pressure facility and HEPA filters are included in the asbestos storage compartment for handling the asbestos. Electronic debris containing PCBs is similarly handled by skilled personnel and transported from the vessel to storage sites in double-wrapped bags. Concerned HAZMATs containing ODS are likewise dealt with in the same way. A few high-performing recycling facilities have designated buildings for the storage of HAZMATs after collection. Unfortunately, there is no TSDF (Treatment, Storage, and Disposal Facility) for ship recycling facilities in Bangladesh, leaving no choice but to temporarily store hazardous materials within the site areas.

(c) Reusable and Recoverable Materials Handling:

The reusable elements obtained from the dismantled vessels can be further segregated into the following entities:

(i) The reusable materials include wooden furnishing materials and outfitting, as well as a variety of household items, machinery, and electrical and heating equipment. All these components are transported ashore from the vessels via chain or ropeway cables. Developed yards with barges can haul or transfer these materials to the shore by barges. Other yards rely on boat chains or ropes fitted as harnesses or sliding pathways to shift them from the vessels to the shore facility. They are then cleaned and stored in different storage locations before being sold to traders at profitable prices. Generally, no reusable component goes to waste, and almost all of them can be reused in some capacity.

(ii) Reusable oil particles which contain engine oil, bilge oil, lubricants, hydraulic oil, residual oil, and grease-like floatable substances make up about 0.05 percent of the overall materials recovered [18]. Often, following the primary cutting if individual blocks that may contain traces of oil are permitted to fall freely on the intertidal zone, there is the chance that the oil gets mixed with the coastal water, inflicting a threat to marine biodiversity as well as impacting the seabed. The current processes for the collection and storage of oily particles along with the risks of oil spillage have already been stated in section 2.1.

(iii) Paint and other coating materials may contain lead, cadmium, chromium, zinc, tin, and arsenic, as well as TBT (tributyltin) compounds. The intact paints are sold to suppliers immediately once recovered, while the others are examined for TBTs and heavy metals. Scrubbing is used to remove these, and sometimes slag catchers are used to collecting the residual paint chips. The majority of these are either dumped or incinerated. In case, haphazard landfills may contaminate the soil and groundwater. On the other hand, the lack of a suitable incineration system to handle a large number of wastages may produce toxic chemicals and pollutants.

3. Discussion and Proposals:

3.1 Primary Cutting

The primary cutting process as currently practiced in the recycling yards poses certain drawbacks connected to the use of Oxy-LPG-based cutting, particularly in enclosed spaces, and the issue of health hazards associated with it. Recycling yards must address the critical demand of reducing the occupational risks as well as optimizing the primary cutting techniques more efficiently.

The following alternative measures should be enforced during primary cutting:

(a) It is recommended for the cutter foremen to create proper ventilation in the bottom side of the enclosed spaces prior to using LPG for cutting.

(b) Sufficient time gaps should be allowed while block cutting using LPG to provide ample time for the gas to dissipate.

(c) P2 or P3 type respirators must be used while cutting to avoid inhaling unwanted gases.

3.2 Secondary Cutting

Surface cleaning of the blocks or cutting sections is usually not carried out across the yards prior to secondary cutting, as per current industrial practice. Before making secondary cuts, the blocks should be cleaned or prepared on the surface. This must be done to ensure that no harmful fumes are produced, as well as to ensure that the plates produced have a smoother finish and better material quality after secondary cutting. It is suggested that two types of surface cleaning approaches can be used in this case. Wet sandblasting is one option, while solvent cleaning with chemicals like soaps and detergents is the other. The repair and maintenance shipyards in Bangladesh are already using the sand-blasting surface cleaning technique, so this method can be adopted by the recycling yards as well. The main advantages of wet sandblasting include dust reduction and the ability to work in an open atmosphere, both of which will be beneficial in the case of secondary cutting. Furthermore, since water is used as a hydrostatic force, less abrasive or sand particles will be required. It is quick and simple to use and is also inexpensive. Most importantly, abrasive or dry sandblasting may generate sparks that can result in explosions, whereas wet blasting produces no such sparks and there are no risks of explosion.

This research recommends two alternatives for Oxy-LPG cutting during secondary cutting. The first is the use of Oxygen and Methane (Natural Gas) in combination with a booster for cutting, and the second is plasma arc cutting.

(a) LNG with Booster

The supply of methane is not a concern because secondary cutting takes place within the onshore site facilities and can be easily transferred via pipelines. Methane is also relatively cheap, and by using it, the oxygen supply will also be limited. As a result, overall costs will be reduced. According to Mishra et al.[19], cutting using methane produces lower carbon concentrations than cutting with propane. Furthermore, using natural gas as a flame-cutting fuel may mitigate the consequences of LPG's high temperature and unsteady flame. Because methane is lighter than air and takes less time to dissipate, it decreases the chances of ignition and fire threats.

When compared to propane (2510 BTU), methane has a BTU (British Thermal Units) value of 1030 units at a standard nozzle pressure of 15 psi (pounds per square inch), which is optimal. However, enabling a portable torch booster to raise the nozzle pressure to 25 psi, the BTU of methane will eventually rise to around 1717 BTU, which is satisfactory for secondary cutting.

(b) Plasma arc cutting:

Plasma arc cutting can be an excellent secondary cutting alternative to flame cutting because it ensures high precision for cutting at substantially high cutting speeds while also producing improved material quality. The plasma arc creates tiny heat-affected zones within the material, which improves the sheet metal cut edges. Apart from steel, a vessel's superstructure is made of aluminum and other materials. Plasma cutting can also be a viable option in this instance because it can cut through a wide range of materials and has minimal consumable costs while operating in the open air. However, plasma arc cutting has some disadvantages. When cutting thick sections, fumes are created, noise can be heard, and arc glare can be seen while operating in the air. However, these issues can be prevented if workers take necessary precautions, such as using P2 or P3 respirators, wearing safety goggles, and ear muffins. Above all, as compared to other cutting processes such as abrasive water jets and laser beam cutting, plasma arc cutting's net operating costs are still low [16].

3.3 Material Handling System:

3.3.1 Scrapped Metal Handling

Instead of using winches with manual force to drag the large blocks to the shore, block lifting using a barge-mounted crane is recommended, which will reduce the reliance on human force and make the method less time-consuming and smooth, with no environmental or health risks. The yard can also deploy a tower crane if the vessel is already hauled towards the shore away from the watery surface and the proximity range is 70 meters or less, as the latest cranes have a maximum outer range of 70 meters. A barge-mounted crane or tower crane may appear to be an expensive one-time investment for a yard, but it would be valuable and cost-effective in the long run.

To transfer the blocks and metal pieces throughout the facility, a crawler crane, pick and carry cranes, or magnetic cranes can be used to avoid the casualties mentioned in section 2.3.3.

3.3.2 HAZMATs Handling

The following improved methods can be strictly adopted in the recycling yards for optimal management of HAZMATs:

(a) It is necessary to ensure that all categories of recycling yards hire enough certified asbestos handlers.
(b) Materials identified with the dangers of PCBs and ODS should be handed over to the approved vendors. In Bangladesh, the number of authorized vendors is minimal, and as a result, some yards adopt the process of landfills which is not done by maintaining a proper plan. As a result, increasing the number of certified vendors is strongly advised until the TSDF is activated.

3.3.3 Other Reusable Materials Handling:

Wooden consumables, resalable machinery, and household items retrieved from obsolete vessels must be safely removed, handled, and cleaned before being stored, as there may be trace amounts of asbestos or pathogens. In case of handling heavy machinery, a barge-mounted crane should be used.

And the engine and other gears should be thoroughly checked as they are prone to explosive gases and materials before removing from the obsolete vessel.

The existing procedure of recovering residual oil and fuel can result in spillage, as outlined in section 2.3.3. The following recommendations to avoid spilling can be adopted:

(a) It is necessary to ensure that the blocks are clean and free of any remaining oil particles. Prior to contemplating gravity falls, solvent cleaning of any blocks that may have traces of oily substances must be performed.
(b) The authorities must closely monitor the transportation of oil and traces of residual oil towards the shore to ensure that no oil spills occur during the transfer. In this case, it is proposed that drums and fuel tanks are moved using on-site mobile plants to minimize the risk of oil spills.
(c)Yards must install and operate an oily water separator tray to ensure that water and oil do not mix in any way.

The indicated concerns surrounding the paint and coating removal process outlined in section 2.3.3 can be alleviated in the following ways:

(a) Instead of piling up or storing paint chips, adhesives, or other unusable debris, the yard authority can designate a specific area inside the site for landfilling maintaining appropriate safety and environmental protocols. To minimize landfills, double-layered non-porous materials like clay or high-density polyethylene resin (HDPE) can be utilized. To ensure caution for the onsite employees, the dumpsite or area should be cordoned off with warning signs and arrows. Contamination from a health standpoint can thus be avoided.
(b) Using high-efficiency particulate air (HEPA) vacuums to keep the surrounding air free from harmful paint particles.

3.4 Economic Viewpoint:

It has been reported that the majority of Bangladesh's underdeveloped ship recycling yards are reluctant to install adequate mechanization for recycling operations. The following are the main reasons why such yards are lagging:

(a) The majority of the proprietors are primarily concerned with making profits at the lowest possible operational costs. Their perception lacks the willingness or mindset to change. As a result, they are unwilling to comply with the standards set by the Bangladesh government and other top-tier yards in the industry.
(b) Because the owners are oblivious to the expensive capital and machinery expenditures, these yards lack the proper infrastructure. They are also apathetic about the environment and the workers' safety.

The biggest hurdle they face is when an unfortunate mishap happens. They are under great pressure from the workers union and the concerned ministry to temporarily halt all operations since they are unable to offer emergency safety responses. A single accident can result in the shutdown of an industry and the termination of employees. This shutdown, which lasts for about months, has a significant impact on the yard's business operations and profitability. Furthermore, foreign cash buyers are unwilling to sell other ships to these yards for another 3-6 months, causing the yards to come to a standstill.

Based on the foregoing considerations and our recommendations, the non-compliant medium and low tier yards can undoubtedly improve their quality of work and status with some investment and well-planned management. Though these yards' initial capital expenses may result in a lower profit margin, for the time being, one thing that will keep them optimistic is their desire to provide a safe and effective working environment for their workforce. Short-term capital investment will cater toward long-term and sustainable business growth. From Table 1, it can be stated that interim short-term capital investments may seem to be a burden for the substandard non-compliant recycling facilities. But its long-term benefits surely do pay off when it comes to comparing the factors of working efficacies and safety standards for these recycling yards. The unwanted issues associated with the detrimental effects on the recycling business for these yards as stated above could be mitigated if these yards show the willingness to improve their infrastructure and equip just the right mechanized setups. The long-term benefits for these yards can be reflected in the following ways:

Table 1: Comparison of Work Efficiency and Safety Aspects for Current and Recommended Practices in terms of Capital and Operating Infrastructural Expenses

Installation Cost Parameters (Infrastructure)	Current Practice		Recommended Practice		Current Practice		Recommended Practice	
Stages Of Ship Recycling	Capital Expenses	Operating Expenses	Capital Expenses	Operating Expenses	Working Efficiency	Safety Aspect	Working Efficiency	Safety Aspect
Primary Cutting	Low	Low	Comparatively Higher	Slightly Higher Than Usual	Time-consuming	High Casualties And Accidents	Faster Cutting	Lower Risk Of Accidents
Secondary Cutting	Low	Comparatively Higher	Slightly Higher	Lower Than Usual	Time-consuming	Casualties During Plate Carrying	Faster And Precise Cutting	Lower Risk Of Accidents
Metal Handling	Low	Low	Comparatively Higher	Comparatively Higher	Poor	High Casualties And Accidents	Faster And Organized	Lower Risk Of Accidents

(a) The production process will be more efficient, and the demand-driven steel supply chain will be better integrated.
(b) These yards will produce high-quality metals for sale as a result of their precision cutting and production processes.
(c) The yards will be eligible to seek international compliance from the international authorities (HKC and EU) and will have greater opportunities for obtaining foreign subsidies to promote green recycling methods.
(d) Yard owners will get access to a plethora of other cash buyers who are currently refusing to sell obsolete vessels to yards except for those with green yard facilities. In the long run, this would increase their profitability and allow them to expand their business.
(e) Most importantly, the development of infrastructure will assure mechanization and a reduction in direct labor involvement, greatly minimizing the odds of any occupational risks occurring within their yards. As a result, their commercial image as an industry contributor will be enhanced. The safety standards will be higher than they were previously.
(f) Today's short-term investments will cater to safe, sustainable, and long-term profit margins, rebranding these sinking yards as green and compliant if they can display the determination and integrity to foster change for the betterment of their future.

4. Limitations:

This research was limited to FGD based qualitative findings. The second wave of the Covid pandemic, which began in 2021, has impeded research efforts in data-driven methodological and experimental studies. In addition, the authors were also unable to visit a wide range of ship recycling yards thus the study was based on limited data.

5. Conclusion:

Ship recycling in Bangladesh is unquestionably a promising profitable business that is helping to balance the country's tight economy by considerably contributing to the local steel demand and fueling the labor market. However, this industry is prone to dangerous and poorly managed working conditions. In Bangladesh, inadequate safety requirements and non-mechanized recycling operations are frequent. This study suggests commendable mechanization and cost-effective techniques that all non-compliant ship recycling facilities can formulate and execute to achieve long-term lucrative business growth while also improving their safety compliance and commercial goodwill.

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