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Shipbuilding Risk Assessment: Legal Frameworks and Practical Challenges in Indonesian Shipyards

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ABSTRACT

Ship accidents during the shipbuilding process, including construction, repair, and operation, remain frequent and unresolved, often leading to legal issues for ship owners and shipbuilding companies. This research aims to analyse the obstacles encountered during these stages and the associated accidents. We employed the Hazard and Operability Study (HAZOP) method to analyse the data. We collected primary data from 13 shipping companies located in six major cities in Indonesia. The findings indicate that problems such as rework at the erection and outfitting stage due to worker negligence, delays in contract schedules, and accidents due to worker's negligence frequently happen in the process of shipbuilding. Then, rework at the sub-assembly stage due to engine damage and repairs due to engine damage were the highest risks in ship repair, and collision accidents were the highest risk in ship operations. Current efforts to reduce ship accidents focus on continuous improvement strategies at both organizational and individual levels through the development of best shipbuilding practices.

1. INTRODUCTION

Ship collisions continue to disrupt the global shipping industry, encompassing incidents such as fires and explosions during construction, collisions and sinking during trial runs, and natural disasters like earthquakes. Contractual obligations require shipyards to safeguard their interests and those of their customers against these hazards. The shipbuilding sector, characterized by unique attributes and a complex economic environment, is considered a high-risk industry requiring meticulous management [1].

Shipbuilders typically face challenges in competing with other shipyards due to the lengthy construction processes required in national shipyards. We can divide the ship production process into three distinct phases: ship construction, ship maintenance, and ship operation. During the new shipbuilding process, it is critical to prioritize the timely completion of ship construction as specified in the contract [2]. Multiple factors have impacted recent shipbuilding endeavors, resulting in delays. The late arrival of imported ship materials is one significant issue causing delays. The shipyard industry should take proactive measures to anticipate the timely arrival of these supplies. To predict and mitigate delays in project completion, it is necessary to apply risk analysis and risk assessment [1].

Researchers used a variety of methodologies to detect potential dangers and conduct risk evaluations. In order to obtain the necessary data, they employed Failure Mode and Effects Analysis (FMEA) [3-6], HAZOP (Hazard and Operability Study) [7], HIRADC (Hazzard Identification, Risk Assessment And Determining Control) [8, 9], HIRARC (hazard identification, risk assessment, and risk control) [10, 11], HIRARC combined with SWOT (Strength, Weakness, Opportunity, Threat) analysis [12], JSA (Job Safety Analysis) [13], JSA combined with Bowtie analysis [14, 15], Interval type-2 Fuzzy expert system integrated with the dynamic Bayesian network and bow-tie model [16], Dynamic Multi-Attribute Decision-Making Method [17], and the rule-based Bayesian network (RBN) and utility function [18]. RBN technique excels at handling ambiguous and uncertain risk information.

The growing maritime activity is amplifying the potential hazards associated with oceanic operations, particularly the dangers faced by ships as the primary means of transportation. Hence, it is appropriate for the ship owner to obtain vessel insurance. Presidential Instruction No. 5/2005, which pertains to the empowerment of the national shipping industry, mandates that all ships owned and/or operated by national shipping companies, as well as used ships or newly constructed vessels that will be acquired domestically or internationally, must be insured, with a minimum coverage of Hull and Machinery [19]. Both parties must comprehend the provisions of the Marine Hull and Machinery Insurance Policy, which serves as a written record of the sea transportation agreement derived from the Marine Insurance Act of 1906 [20]. This understanding will enable each party to anticipate any potential legal hazards that may develop [21]. At present, the maritime sector receives satisfactory insurance service. The shipping customer satisfaction index at PT. Indonesian Service Insurance is 67.82%, indicating a satisfactory level of satisfaction [22].

Risk analysis studies related to shipping companies have employed various approaches and methodologies. For instance, using Failure Modes and Effects Analysis (FMEA), risk analysis on operational functions tries to keep companies from losing money by finding possible failures and offering ways to deal with the risks that come up [23]. The Warship Division of PT. PAL Indonesia adopted the House of Risk (HOR) model for their Risk Assessment and Risk Mitigation Program [24]. Louhenpessy and Febriansyah utilised a technological model to determine the technology contribution coefficient value at the shipyard, quantifying the overall contribution of technical components such as technological equipment, human resources, information systems, and organizational machinery [25]. This study examined the availability, development needs, and mapping of ship component product standards using descriptive and quantitative methods, literature review data, questionnaires, surveys, and interviews [26].

Qualitative and quantitative risk analyses, in particular, involve systematic evaluations of the potential impact and likelihood of identified risks. These methods prioritize risks based on their impact on project objectives. Asdi and Basuki define quantitative risk analysis as the process of numerically evaluating the likelihood and consequences of each risk for project objectives [27]. Qualitative analysis typically complements this by leveraging company resources, such as expenses, time, and performance, to execute the project. This work has the potential to significantly contribute to the development of improved risk models.

When discussing risk assessment, the government must take responsibility for improving safety in navigation-related areas. Whether handled by individuals or businesses, governments must prioritize the safety aspects of shipping. In order to reduce the frequency of maritime accidents, it is crucial for the government to effectively enforce laws and regulations.

In Indonesia, the need for maritime transportation remains significant due to the growing popularity of marine transport techniques. The legal ties that exist in maritime transport services are complex, involving both private and public law relations. The government must be present within the framework of public law relations to effectively carry out its duty as a guardian of the populace. Shipping Law No. 17 of 2008 governs the organisation and execution of both commodity and individual transportation.

Law enforcement must conduct their operations with proportionality and professionalism in order to guarantee safe and secure shipping and minimise incidents of violence at sea [28]. As a result, it is necessary to establish the state's accountability for preventing maritime vessel accidents in accordance with international regulations and incorporate them into Indonesian legislation [29].

Previous studies assessed the risk of ship accidents separately, namely at the shipbuilding stage, the repair stage, and the operational stage only. Furthermore, the research focuses on the technical aspects without touching on the legal aspects. This paper uses a legal study to develop a risk assessment for ship accidents in phases of inertia. The legal aspect will provide clear guidance on what shipowners and related agencies should do. Based on the above explanations, the paper will answer the following questions: a) What are the problems faced in the process of building, repairing, and operating ships?; b) What is the risk assessment in the process of building, repairing, and operating ships?

The study aims to evaluate risks in shipbuilding, repair, and ship accidents while operating under the risks covered by insurance. Additionally, the study evaluates the safety facilities at shipyards, standard operating procedures, and the types of insurance that the Directorate General of Sea Transportation can use to reduce the risk of losses during the construction of state ships. The benefits of the study are to provide input for decision-makers at the Directorate General of Sea Transportation, especially the Directorate of Traffic and Sea Transportation, and related parties in the construction of ships for sea transportation. Furthermore, the study's output will contribute to producing guidelines and policies as minimum requirements for ship construction insurance and as best practices for shipbuilding.

2. LITERATURE REVIEW

Significant work accident risks are associated with three key ship construction operations: plate pounding, welding, and lifting work [30]. The primary risks in shipbuilding projects include potential delays in material supply and the need for improvements due to changes in recommendations following work completion [3, 31]. Despite these risks, the application of risk analysis to various aspects of the shipbuilding production process remains insufficient [32-34]. Additional hazards that emerge include the occupational safety and health conditions of the workforce [7, 35]. Furthermore, the painting process, as well as the sandblasting and welding procedures, have inherent hazards [4]. The shipbuilding process is prone to significant risks, such as challenges in delivering ship materials and equipment, insufficient shipyard facilities, alterations in ship design, and suboptimal labor productivity [5].

Ship repair is the next stage in ship construction, typically conducted at offshore wind farms. Despite the fact that offshore wind facilities are often located far from commercial shipping routes, the rapidly growing demand for repair or replacement services drives a significant concentration of ship maintenance activities. Currently, there is insufficient attention to evaluating the likelihood of collisions between maintenance ships and offshore wind turbines. The risk of such collisions primarily arises during the maintenance of certain wind turbine components that require corrective repair or replacement [36]. Additional hazards or limitations associated with repair work can also emerge due to changes in ship owners' and classification societies' requirements [1].

The lifting process of moving blocks or goods using a crane, the cutting process of lifting materials and placing them on the cutting machine, the grinding process of lifting materials and placing them on the grinding place, the fitting and working at height process of installing plates, and the main engine overhaul process all involve high risk [8]. The repair procedure is at high risk due to unfinished work equipment, inefficient work planning, inadequate preparation for painting the ship's body, and incomplete production equipment [6]. Other high-risk situations include welding in enclosed areas, docking and undocking procedures, cutting metal plates, doing maintenance and repairs in electrical rooms, and being reckless when filling gas cylinders [10]. Additional high-risk concerns include the extended duration of approval for goods requests, delays in client payment processes, changing design specifications, the owner's decision-making process, the lengthy delivery process, inadequate material inventory, and insufficient stock material availability [37]. During the plate cutting process, there are significant issues with sandblasting hose leaks, which pose considerable hazards during the repair stage [9, 11, 13].

The next stage in the shipbuilding process involves the ship's operation, where conducting risk assessments is of utmost importance. A significant challenge in obtaining precise and dependable risk estimations is the lack of data and uncertainty surrounding the likelihood of collisions caused by human and organizational factors [38]. During ship operations, the risk of ship fires, in addition to ship-to-ship collisions, is a major concern. These fires can occur suddenly and escalate quickly, with even minor mistakes leading to severe consequences. The swift responses of both crew and passengers are primary factors in mitigating the severity of ship fire incidents [39]. The International Maritime Organization (IMO) has introduced the Formal Safety Assessment (FSA) to evaluate risks on board, but has not yet implemented a specific tool for analyzing the risks involved in ship operations [40].

During the operation phase, there is a significant risk of machinery operational failures, including main motor failure, propulsion system failure, and power system failure, all of which can potentially lead to accidents [16]. Failures are the primary factor contributing to the malfunction of the pod propulsion system on cruise ships. Other notable risks include inadequate management for the players involved in the logistics chain, human errors, restricted storage capacities, subpar warehouse conditions, and a lack of knowledge regarding proper handling techniques during loading and unloading operations [18]. Environmental safety and health are high-risk considerations at a shipyard [41-43]. This includes addressing potential environmental dangers [41], such as the inhalation of toxic air or gas by ship sailors during the inspection of the cofferdam tank [15]. Additionally, cost services related to delivery [35] and the safety of loading and unloading activities [12] are also taken into account. During the operation stage, significant risks arise from containers falling and ships colliding with container cranes [14]. Furthermore, people's mishandling of the process is the primary risk element that significantly impacts the safety of ship-to-ship LNG bunkering [44].

The Law of the Republic of Indonesia No. 17/2008 on Shipping, Chapter IX, Article 124, stipulates that all procurement, construction, and assembly of ships, including their equipment, as well as the operation of vessels in Indonesian waters, shall comply with the ship's safety requirements [45]. The safety requirements for ships encompass various aspects such as materials, construction, buildings, machinery and equipment, stability, equipment arrangement, including auxiliary and radio equipment, and ship electronics. Further, Article 125 specifies that before the ship's construction and assembly, including its equipment, the owner or shipbuilder is obliged to make calculations and drawings of the construction plan as well as its completion data. All of these rules are mandatory, as long as we try to comply with the ship's safety measures. According to Article 245, a ship accident is defined as any event that could jeopardize the ship's safety and/or human lives, including sinking, burning, colliding, and ship cladding. The owner or operator of a vessel of a specific type and size must insure their liability to meet the requirements of maritime liability [46].

In the implementation of new ship construction, there is always the potential for delayed completion of the ship. This is extremely detrimental to the ship-owner because of the vessel's inability to operate. Due to the ongoing use of the land for shipbuilding, the shipyard must incur higher expenses and a penalty for the delay, thereby hindering its ability to proceed with other shipbuilding projects. A variety of factors, such as contract terms and conditions, the preparedness of the basic design and key plan drawing of the ship, the clarity of ship information and specifications, the procurement of ship materials and equipment, the availability of manpower, facilities, and production processes, and the financing support from the banking sector, can cause delays in the completion of shipbuilding. We must identify the issues facing the national shipyard industry in building new vessels so we can determine the necessary actions to reduce the risk of shipbuilding delays that could harm ship-owners and shipyards. Increased self-navigation activity undoubtedly heightens the potential risks associated with these activities at sea, particularly for ships that serve as the primary means of transportation. Marine Hull and Machinery Insurance Product aims to provide comprehensive insurance protection for ships, ship engines, and parts of ship engines, i.e., connecting rods, cylinder blocks, cylinder liners, and rocker arm inlet valves.

Builder Risk Marine Insurance is one of the marine insurance products that guarantees all risk of loss or damage to the hull and machinery that may occur in connection with the ship's construction. This includes risk at the launching stage, during the sea trial, and during the surrender of the ship to the principal at the destination port (delivery voyage). When a ship is built, the shipbuilder and buyer enter into a shipbuilding contract that outlines the terms and conditions of the agreement. The contract positions the builder as the party responsible for the purchased ship throughout its construction and until it reaches the buyer's hands. When the damage occurs, the costs are enormous and can result in financial losses. Therefore, the builder is very much in need of builder risk marine insurance to cover such losses. In addition, marine insurance, also known as protection and indemnity (P&I), provides comprehensive protection for ships against the risk of accidents they may cause.

Marine Insurance Act 1906, Chapter 41, states that a marine insurance contract is an agreement in which the insurer agrees to compensate the insured for any losses related to marine activities [20]. This contract's purpose is to protect the insured against potential losses in inland waters or land-related risks that may arise from any sea voyage. The relevant provisions of this Act will apply, to the extent that they are applicable, if marine insurance covers a marine adventure. Nevertheless, this Act will not modify or impact any legal principle that is applicable to any insurance agreement, except for a specific type of insurance known as maritime insurance as described by this Act., except as provided in this section of marine insurance as defined by this Act.

The legal requirements cover a variety of topics, including shipping safety, ship dimensions, and specific standards that crews must adhere to. In order to ensure the safety requirements of shipping, the corporation must comply with the regulations pertaining to ship construction, ship maintenance, and ship operations. This stage is a crucial milestone in enhancing the security of navigation. The Safety of Life at Sea (SOLAS) convention governs maritime safety, specifically addressing requirements pertaining to navigation equipment, the integrity of the ship's watertight compartments, communication systems, construction standards, and other safety equipment. According to Article 1, Paragraph 34 of Act No. 17 of 2008 on shipping, a certificate obtained through inspection and testing serves as evidence of a ship's safety.

These vessels' safety regulations are relevant to ship construction, building, and maintenance, as well as their operation in Indonesian seas.

The government implements regulations that focus on the procedural process of establishing general and technical policies. This includes setting norms, standards, guidelines, criteria, planning, and procedures, as well as ensuring safety in shipping and licensing requirements. Just like in shipbuilding, the government oversees the procedural process by issuing instructions, advice, training, licenses, certifications, and providing technical support in the development and operation fields. The government monitors development, maintenance, and operation activities to ensure compliance with legislative requirements. This includes applying corrective actions and enforcing laws.

3. METHODOLOGY

This study uses a quantitative methodology, including a criterion scale, to analyse interview data and risk observations at each stage of shipbuilding. The work procedure begins with researchers conducting face-to-face interviews with workers and meticulously tracking the various stages of shipbuilding. We conduct interviews to identify potential hazards at each stage of ship construction. In addition, we employ the Hazard and Operability Study (HAZOP) method to analyse the data. HAZOP is a systematic and structured technique for identifying and reviewing hazards in a process or operation inside a system [47]. Identification is required to uncover potential issues that may disrupt the process and pose dangers to individuals, facilities, or the current system in the environment.

The primary survey or field survey was conducted at 13 companies spread across six significant regions in Indonesia, such as Medan, Jakarta, Surabaya, Makassar, Bitung, and Sorong. In Medan, there were two companies: PT. Waruna Shipyard Indonesia and PT. PELNI Branch Medan. At Makasar, there were two companies: PT. Industri Kapal Indonesia and PT. Pelni Branch Makasar. In Bitung, there were two companies: the PT. Industri Kapal Indonesia branch and the PT. PELNI branch. We conducted surveys on three companies in Surabaya: PT Dumas Tanjung Perak Shipyard, PT Adiluhung Saransegara, and the Pelni Branch of Surabaya. In Jakarta, we conducted surveys at PT. Proskuneo Kadarusman, PT. Daya Radar Utama, and PT. Pelayaran Nasional Indonesia. There was only one company in Sorong: the PT. PELNI branch. We conducted a survey on the inventories of state ships, the challenges encountered during their development, repair, and operation, and the insurance products utilized in this process.

The respondents are 40 males, with an average age of 44 years old; the youngest was 35 years old, while the oldest was 50 years old. The forty respondents included eight HRD managers, seven branch managers, six engineering managers, five commercial SPV directors, four masters, four production general managers, four site managers, one marketing chief, and one marketing manager.

Secondary data collection is required in the process of analysis and policy related to the requirements of state shipbuilding insurance, including the Marine Insurance Act 1906, Chapter 41; The Law of the Republic of Indonesia No. 17/2008 on Shipping, Chapter IX, Articles 124, 125, and 245; Government Decree No. 51 of 2002 on Shipping, Article 121, and Presidential Instruction No. 5/2005. Other supporting data are shipyard facility and production process data; shipbuilding construction data; ship machinery data used; certificate-ship excellence and safety data; policy documents; and past studies.

We used the Likert scale method, which uses a value on a Likert scale as an indicator to describe the variable under measurement. This value serves as a starting point for creating instruments that employ the Likert scale, which ranges from extremely positive to extremely negative. If we assign a value of 5 to an alternative answer, we then sum up its value into five weighting categories on the Likert scale. We can calculate the answer and present it as a table for average calculation. Sugiyono uses the Likert scale to gauge an individual's or a group's attitudes, opinions, and perceptions about social phenomena [48]. Each instrument item's answers on the Likert scale have a gradation from very positive to very negative. Therefore, the author formulated a question to gather data or information from expert staff members across all 13 companies. The author then weights the data processed from the questionnaire collection for each alternative answer.

Then we use descriptive analysis to process the data. We use descriptive statistical analysis to scrutinise the collected data and provide a detailed description. The statistics used in this study are the mean and standard deviation. The variables in this research are the likelihood risk and the risk impact that occur in shipbuilding, ship repair, and ship operation.

Risk assessment is the evaluation of events that threaten agencies' objectives and targets [49]. We use this type of assessment to identify situations, processes, and other hazardous activities. The risk assessment criteria include three things: the risk impact scale, the probability scale, and the risk scale. Five categories make up the risk impact scale: insignificant (score 1), minor (score 2), moderate (scale 3), major (score 4), and catastrophic (score 5). Table 1 displays the risk impact scale.

Table 1. The risk impact scale

Scale	Score	Description	Percentage
Insignificant	1	No cost overruns	0%
Minor	2	Low cost overruns	<5%
Moderate	3	Medium cost overruns	5%-10%
Major	4	High cost overruns	11%-20%
Catastrophic	5	Extreme cost overruns	>20%

The second criterion is a likelihood-risk scale. We divide this scale into five categories: rare (score 1), unlikely (score 2), possible (score 3), likely (score 4), and almost certain (scope 5). Rare (scale 1) means that the risk is unlikely to occur in extreme circumstances, whereas almost-certain (5 scores) means that this risk has occurred or is certain to occur more than once in a year. Table 2 displays the likelihood-risk scale.

Table 2. The likelihood risk scale

Scale	Score	Description	Percentage
Rare	1	Seldom occur	<20%
Unlikely	2	Rarely occur	20%-40%
Possible	3	Sometimes occur	41%-60%
Likely	4	Frequently occur	61%-80%
Almost certain	5	Certain to occur	>80%

Table 3. The risk scale

Likelihood	Consequences				
Probability/ frequency	What is the severity of financial impact if the risk actually occurs?				
How likely is the event at sometimes in the past	Insignificant (1) No cost overruns 0%	Minor (2) Low cost overruns <5%	Moderate (3) Medium cost overruns 5%-10%	Major (4) High cost overruns 11%-20%	Catastrophic (5) Extreme cost overruns >20%
Almost certain (5) Certain to occur >80%	M 5	H 10	H 15	E 20	E 25
Likely (4) Frequently occur 61%-80%	M 4	M 8	H 12	H 16	E 20
Possible (3) Sometimes occur 41%-60%	L 3	M 6	M 9	H 12	H 15
Unlikely (2) Rarely occur 20%-40%	L 2	M 4	M 6	M 8	H 10
Rare (1) Seldom occur <20%	L 1	L 2	L 3	M 4	M 5

The last criterion is the risk scale. We use the formula R=L×C to assess risk. R is risk, L is likelihood, and C is the value of consequences. In risk assessment, the risk matrix is 5×5. The classification of consequences values includes low (score 1), medium (score 2), high (score 3), and extreme (score 5). Low means that the impact is less than 5%; low means the impact caused is 5-10%. Medium is defined as 10-15%. High indicates an effect of 15-20%, while extreme indicates a cause of more than 20%. The following table provides a clearer understanding of the level of danger by classifying the risk value from the formula above. Table 3 displays the risk scale.

4. RESULTS AND DISCUSSION

4.1 Problems in the process of building, repairing, and operating ships

Before discussing the problems faced in the process of building, repairing, and operating ships, we need to know the activities that occurred in each phase. Based on the results of interviews with respondents, there are several stages of new shipbuilding, including planning, fabrication, sub-assembly, erection and outfitting, sea trials, and delivery.

4.1.1 Problems in ship-building phase

The first stage of shipbuilding is to develop the owner's requirements. Each customer utilizes their ship according to their specific needs. Understanding the ship owner's wishes leads to the creation of a preliminary or concept design. This stage is significant because approved designs will serve as the foundation for shipbuilding based on these approved designs. Fabrication is the next step. Fabrication is the initial stage in the shipbuilding process that involves producing its components. Fabrication consists of marking, cutting, and forming. The process of marking a plate begins with profiles and frames. A code that includes the ship number, block number, and marking position matches the name. Cutting a plate involves using a gas cutter or acetylene while considering the target plate's cutting angle, speed, and thickness. While forming involves transforming a plate from its original shape to the desired one, Rolling, bending, and pressing machines assist with plate formation. The next step is sub-assembly, which involves combining components from the fabrication process into smaller blocks. By merging small blocks, we can reduce the work of welding. The next step is to attach frames to the stomach skin. The process of merging several wrangs, as well as merging two blocks, involves combining part assemblies from the subassembly into a single block. We weight the built-in blocks based on the crane's capabilities.

Erection is the process of combining block structures to form the vessel's body. Erection is the last stage of the assembly process. This procedure entails merging blocks from the assembly process into a vessel. The erection process typically starts with the double bottom block, often in conjunction with the keel-laying process, and then progresses upwards to the superstructure part. Before the erection process starts, we will perform a block reversal. The direction block follows the block at the back, and the erection process takes place on two double-bottom blocks, which also serve as the vessel's keel-laying blocks. Outfitting is the process of assembling ship components, including hull outfitting, piping, accommodation, propulsion systems, and machinery outfitting. A sea trial is a test carried out by ship owners and shipbuilders. Tests include speed, maneuver, anchor drop and withdrawal, fire extinguishers, and others that cover the entire function of the equipment at the time the ship goes to sea. The last step in shipbuilding is the delivery of a ship from the shipyard to the ship owner.

Every stage of the shipbuilding process has the potential to suffer significant obstacles. For example, in the planning process, there is a possibility that the completion of shipbuilding takes longer than the agreed-upon contract schedule. This completion delay may be due to a delayed supply of spare parts, resulting in rework at the fabrication stage. Similarly, in the sub-assembly and outfitting phases, rework can occur due to both human and machine errors. To understand the specific issues that arose during the shipbuilding process, refer to Table 4, which displays the responses from respondents regarding the problems they encountered.

In this study, we decide using the perceptions of the respondents; thus, to do this, we use the weighted average value. To calculate the weighted average value, we simply sum up the mean values for the items, then divide by the total number of items. If an item's mean score is higher than the weighted score, the decision is highly probable to occur. On the other hand, if the item's mean is below the weighted score, the decision has a low probability of occurring.

Table 4. Responses on respondents' perceptions of problems occurred during ship building

Problems	Code	Mean	STD	Decision
Rework at the erection and outfitting stage due to worker negligence	SB1	4.33	1.23	High
Rework at the sub assembly stage due to engine damage	SB2	4.28	1.40	High
Rework at the sub assembly stage due to worker negligence	SB3	4.08	1.37	High
The ship's speed did not match the design	SB4	3.43	1.46	High
Delay in delivery	SB5	3.15	1.63	High
Engine failure during free trial	SB6	2.83	1.56	High
The ship sank during the free trial	SB7	2.73	1.66	High
Rework at the fabrication stage due to planning errors	SB8	2.63	1.79	Low
Delay in contract schedule	SB9	2.46	1.50	Low
Delay in supply of spare parts	SB10	2.33	1.46	Low
Delay in supply of plate material	SB11	2.30	1.56	Low
Rework at the erection and outfitting stages due to planning errors	SB12	2.25	1.56	Low
Rework at the sub assembly stage due to planning errors	SB13	2.20	1.49	Low
Engine failure in delivery	SB14	2.15	1.71	Low
Ship fire in delivery	SB15	2.15	1,46	Low
Rework at the fabrication stage due to worker negligence	SB16	2.13	1.54	Low
The ship sank in delivery	SB17	2.10	1.45	Low
Ship fire during free trial	SB18	2.03	1.8	Low
Rework at the fabrication stage due to engine damage.	SB19	2.00	1.45	Low
Rework at the erection and outfitting stages due to machine damage	SB20	1.88	1.39	Low

Note: N=40, Rare=1, Unlikely=2, Possible=3, Likely=4, Almost certain=5. Weighted average=53.49: 20=2.67

The table above indicates that certain problems have a high probability of arising during the shipbuilding process. We reworked the first three issues during the erection and outfitting stages, as well as the sub-assembly stage. During the free trial stage, the following high possibilities emerged: The highest possibility was that rework occurred at the erection and outfitting stages due to worker negligence, with a score of 4.33 out of 5. This means that there was a high frequency of human error in the process of erection and outfitting. The second-highest possibility (the score of 4.28) was that rework occurred at the sub-assembly stage due to engine damage. This implies that, in addition to human error, engine error also played a role. The next highest possibility was that rework occurred at the sub-assembly stage due to worker negligence, with a score of 4.08. These two possibilities suggest that human error played a significant role during the shipbuilding stage. The following high possibility occurred: the ship's speed did not match the design during the free trial, with a score of 3.43. Another issue was a delivery delay, with a score of 3.15. Not only did the engine failure occur during the sub-assembly stage, but it also occurred during the free trial, earning a score of 2.83. Furthermore, the ship that sank during the free trial had a high probability of occurring, with a score of 2.73.

4.1.2 Problems in ship-repair phase

A ship undergoes an integrated repair in the dockyard, adhering to the Bureau of Classification's requirements, where the ship undergoes withdrawal or docking prior to the repair. Every year, the dockyard performs an annual docking, a routine repair that encompasses the maintenance of machinery, armour, and other equipment. Special docking takes place every four years, usually during class updates, so the ship's condition must be perfect. Emergency docking refers to necessary repairs beyond the repair schedule, such as when a ship sustains damage from a collision. Human error and engine error can cause potential problems during the ship repair process. Table 5 specifically illustrates the problems encountered during ship repair.

The table indicates that a delay in the contract schedule, with a score of 2.6 out of 5.0, is the most likely event during ship repair. The next highest possibility, with a score of 2.5, was a delay in the supply of plate material and rework due to engine damage. Worker negligence was also highly likely to occur in ship repair, with a score of 2.4.

Table 5. Responses on respondents' perceptions of problems occurred during ship repair

Problems	Code	Mean	STD	Decision
Delay in contract schedule	SR1	2.6	1.72	High
Delay in supply of plate material	SR2	2.5	1.68	High
Rework due to engine damage	SR3	2.5	1.43	High
Rework due to worker negligence	SR4	2.4	1.78	High
Delay in supply of spare-parts	SR5	2.2	1.45	Low
Rework during ship repair.	SR6	2.0	1.37	Low

Note: N=40, Rare=1, Unlikely=2, Possible=3, Likely=4, Almost certain=5. Weighted average=14.19: 6=2.37.

4.1.3 Problems in ship-operation phase

Ship operation is the next stage. Before the ship can operate, it must complete several stages. Crews have to do pre-ship preparations, such as licensing documents, navigation, and route management. The unloading process begins once the ship arrives at the destination port. During the journey to the destination port, ships may encounter emergency situations, including collisions, fires, explosions, stones, leaks, sinking, people falling into the sea, pollution, reactions from hazardous cargo, shifting cargo, engine damage, severe weather, war, or piracy, among others. Human error is the cause of any interruption during sailing, but natural factors may also play a role. Any disruption at the time the ship sails is an emergency because it will delay the ship's arrival in time. An emergency is an out-of-normal condition that occurs on a ship and has a level of inclination that may endanger human life, property, and the environment in which the ship is located.

Ship operations are susceptible to human and engine errors, similar to shipbuilding and repair processes. Furthermore, adverse weather conditions can pose potential obstacles, leading to ship fires, accidents, sinking, vessel leaks, and other potential dangers. To find out what problems occurred during the ship operation process, see Table 6 below.

Table 6. Responses on respondents' perceptions of problems occurred during ship operation

Problems	Code	Mean	STD	Decision
Accident due to worker's negligence	SO1	3.0	1.69	High
Accident due to collision	SO2	3.0	1.88	High
Accident due to crashing the port	SO3	2.7	1.63	High
Leak in hull	SO4	2.7	1.82	High
Accident due to bad weather	SO5	2.6	1.81	High
Piracy	SO6	2.4	1.66	High
Accident due to collision with heavy equipment	SO7	2.2	1.60	High
Ship fire	SO8	2.1	1.46	Low
Engine explosion	SO9	2.0	1.45	Low
Problem with collision liability	SO10	2.0	1.49	Low
The ship sank.	SO11	1.8	1.28	Low
Accident due to collision with crane	SO12	1.8	1.27	Low
Jettison	SO13	1.7	1.19	Low
Problem with sue and labor	SO14	1.7	1.34	Low
Problem with pollution hazard.	SO15	1.7	1.02	Low
Accident due to pilot's negligence	SO16	1.7	1.12	Low
Problem with general average and salvage.	SO17	1.4	0.59	Low
Barratry	SO18	1.3	0.57	Low

Note: N=40. Rare = 1, Unlikely=2, Possible=3, Likely=4, Almost certain=5. Weighted average=37.75: 18=2.1.

The table above indicates that the most likely event during ship sailing on the sea was an accident due to worker negligence and collision, receiving a score of 3.00 out of 5. A port crash or a hull leak accounted for the next highest possibility, each receiving a similar score of 2.7. Accidents caused by severe weather also had a high probability, with a score of 2.6. With a score of 2.4, piracy had the potential to happen. A collision with heavy equipment caused an accident with a high probability and a score of 2.2.

4.2 The risk assessment in the process of building, repairing, and operating ships

The previous section explained that risk assessment evaluates events that pose a threat to agencies' purposes and targets [23]. We use this type of assessment to identify situations, processes, and other hazardous activities. The risk assessment criteria include three things: the risk impact scale, the probability scale, and the risk scale. We use the formula R=L×C for risk assessment. R is risk, L is likelihood, and C is the value of consequences. In risk assessment, the risk matrix is 5×5. The classification of consequences values includes low (score 1), medium (score 2), high (score 3), and extreme (score 5). Low means that the impact is less than 5%; low means the impact caused is 5-10%. Medium is defined as 10-15%. High indicates an effect of 15-20%, while extreme indicates a cause of more than 20%. The following table provides a clear classification of the risk value obtained from the formula above, allowing us to better understand the level of danger. Table 7 displays the risk assessment for shipbuilding.

4.2.1 Risk assessment in ship-building phase

The shipowner must produce an elaborate schematic for each construction or repair undertaken on the vessel. The ship's construction plans must undergo a thorough examination and secure permission from the Office of the Ship Safety Inspectorate, which functions under the Ministry of Transportations. According to the requirements stated in Article 4 of Government Regulation No. 51 of 2002, the entrepreneur, owner, or builder must perform calculations and produce drawings of the ship's design and completion data before starting construction or repair. Shipbuilding inspections are necessary to verify that ships meet safety regulations, comply with requirements, follow standardised practices, facilitate ship operation and maintenance, and make use of technology. These examinations should not just depend on the data provided by the shipowner.

Table 7. Risk assessment in ship building

Problems	Likelihood	Consequences	Risk	Decision	Rank
SB1	4.3	3.1	13.3	High Risk	3
SB2	4.3	3.9	16.8	High Risk	1
SB3	4.1	3.1	12.7	High Risk	4
SB4	3.4	1.8	6.1	Medium risk	20
SB5	3.2	4.3	13.8	High Risk	2
SB6	2.8	3.6	10.1	High Risk	8
SB7	2.7	4.4	11.9	High Risk	5
SB8	2.6	3.1	8.1	Medium Risk	15
SB9	2.5	4.1	10.3	High Risk	7
SB10	2.3	4.0	9.2	Medium Risk	13
SB11	2.3	4.0	9.2	Medium Risk	12
SB12	2.3	3.2	7.4	Medium risk	17
SB13	2.2	3.0	6.6	Medium Risk	19
SB14	2.2	3.5	7.7	Medium Risk	16
SB15	2.2	4.7	10.3	High Risk	6
SB16	2.1	3.2	6.7	Medium risk	18
SB17	2.1	4.6	9.7	Medium Risk	9
SB18	2.0	4.8	9.6	Medium Risk	10
SB19	2.0	4.6	9.2	Medium risk	11
SB20	2.0	4.5	9	Medium risk	14

Note: N=40. Risk=Likelihood × Consequences. Risk=1-3=Low. Risk=4-9=Medium. Risk=10-16=High. Risk=20-25=Extreme.

Table 7 shows that there are eight high-risk issues during shipbuilding development. The first issue required rework at the sub-assembly stage due to engine damage, resulting in a risk score of 16.8 out of 25. Rahmat's study, which shows that the sub-assembly process, including the plating and welding procedures, is prone to high-risk situations [30], directly relates to this problem. At this point, it is crucial to use further caution. Before initiating the ship's plate replating procedure, we must inspect and thoroughly clean the tanks, paying special attention to the fuel and chemical tanks to ensure they are gas-free. Prior to cutting, it is imperative that the ship's condition is thoroughly devoid of gas, as the plate's pores typically retain gas that is highly susceptible to expansion and combustion. The ship's body building section performs the replating welding procedure to join previously severed construction parts and install other components, prioritising ship construction.

The next high risk was a delay in ship delivery to the ship owner, with a risk score of 13.8. This finding correlates to previous studies [32-34], which found that various aspects of the shipbuilding production process are still inadequate. This causes delays in ship deliveries to their owners. The contract stipulates the location for the ship's handover. The work schedule (time schedule) outlines a plan for the handover, with a maximum duration of 450 calendar days. The shipyard is responsible for the ship's mobilization to the handover site.

Then, during the erection and outfitting stages, rework occurred due to worker negligence, with a risk score of 13.3. In addition to the erection and outfitting stages, rework also occurred in the sub-assembly stage due to worker negligence, with a risk score of 12.7. The issue of worker negligence is of utmost importance. Prior studies have identified personnel mishandling as the primary influencing element contributing to risk [18, 39]. Several variables influence employee performance. They possess distinct personalities and capabilities. The task may necessitate exceptional aptitude. If this is the case, identify the right person or team to carry out the task and decide on the best way to complete it. Specialized training or guidance may be required. The assignment may present a potential hazard to individuals with physical or cognitive impairments, as well as to inexperienced and youthful employees.

In the free trial, sinking, fire, and engine failure had a high risk score of 11.9, 10.3, and 10.1. Machinery operational failures, such as Main motor failure, propulsion system, and power system failure can cause accidents [16, 18]. Failures are the primary reason pod propulsion systems malfunction on ships. Engine failure refers to a situation in which the engine functions in a condition that deviates from typical conditions. An abnormal condition can arise due to a malfunction in the full-authority digital engine control system, which can cause an abnormal state. The engine has neither direct pilot control nor a manual control mode. In the event of a malfunction in the control system, the engine will cease to function.

A delay in the contract schedule was also high-risk, with a score of 10.3. This finding is consistent with previous studies showing that delays in material supply, ship materials delivery, and equipment delivery can cause delays in the contract schedule. High-risk factors that caused delays in the contract schedule include potential delays in material supply, the need for improvements due to changes in recommendations following work completion [3, 31], the delivery of ship materials and equipment, insufficient shipyard facilities, alterations in ship design, and suboptimal labour productivity [5].

4.2.2 Risk-assessment in ship-repair phase

This section will show the high risks that occur during the ship repair process. The provisions of the set contract agreement must guide the implementation of ship repairs. Problems that may arise in the implementation of ship repairs are delays in contract schedules, delays in supply of plate materials, rework due to engine damage, rework due to worker negligence, delays in supply of spare parts, and rework during ship repair.

A ship must function with absolute safety. Therefore, it is imperative to enforce safety protocols during the repair phase, irrespective of the frequency or severity of incidents. To put it otherwise, it would be inconceivable to disregard a risk that has an extremely low occurrence rate on the ship. The personnel, in their role as technicians, were not aware that they would be required to accept the risk prioritization described earlier. Based on this awareness and concept, the ship management business receives the results of the vessel's risk assessment.

According to Table 8, there are three high-risk activities in the ship repair stage. Rework due to engine damage posed the highest risk, scoring 11.5 out of 25. This finding aligns with a previous study, which discovered that engine damage led to accidents during the lifting process of moving blocks or goods using a crane, during the cutting process of lifting materials and placing them on the cutting machine, during the grinding process of lifting components and placing them on the grinding machine, during the fitting and working at height process of installing plates, and during the main engine overhaul process, all of which carry a high risk [8].

Table 8. Risk score in ship repair

Problems	Likelihood	Consequences	Risk	Decision	Rank
SR1	2.6	3.9	10.1	High Risk	2
SR2	2.5	4.0	10	High Risk	3
SR3	2.5	4.6	11.5	High Risk	1
SR4	2.4	3.2	7.7	Medium Risk	5
SR5	2.2	4.1	9.0	Medium Risk	4
SR6	2.0	3.4	6.8	Medium Risk	6

Note: N=40. Risk=Likelihood × Consequences. Risk=1-3=Low. Risk=4-9=Medium. Risk=10-16=High. Risk=20-25=Extreme.

Other high-risk issues include a delay in the contract schedule, which had a high risk (a score of 10.1), and a delay in supplying plate material, which also had a high risk (a score of 10). These findings supported the previous study that potential delays occurred due to unfinished work equipment, inefficient work planning, inadequate preparation for painting the ship's body, and incomplete production equipment [6]. Delay also occurred due to the long approval for goods requests, delays in client payment processes, changing design specifications, the owner's decision-making process, the lengthy delivery process, inadequate material inventory, and insufficient stock material availability [37]. The next significant risk is the possibility of reworking due to worker negligence. The high risk of worker negligence correlates to the process, which includes welding in enclosed areas, docking and undocking procedures, cutting metal plates, doing maintenance and repairs in electrical rooms, and being reckless when filling gas cylinders [10].

4.2.3 Risk-assessment in ship-operation phase

High-risk in ship operation refers to a situation where there is a significant likelihood of safety and life risks owing to factors such as war, military tension, conflicts, pirate activities, and other events that pose an immediate threat to visiting warships and their crews. The operational risks faced during maritime transportation include crashes, fires, terrorist operations, adverse weather conditions, and cargo system malfunctions. The primary objective of risk assessment is to mitigate the occurrence of accidents by facilitating the exchange of information regarding potential hazards, such as blind spots and uncharted areas, among crew members and between the vessel and shore-based management entities, such as the shipowner and ship management company. This is particularly important when undertaking high-risk operations. Therefore, it is crucial to include all individuals involved in the operation in the briefing and to communicate the outcomes to both the crew and shore management, rather than relying solely on the Master/Chief Engineer or Chief Officer/First Engineer at a desk.

Table 9 reveals that a collision accident, with a score of 14.7 out of 25, posed the highest risk in ship operations.

This finding aligns with a previous study that identified the lack of data and uncertainty surrounding the likelihood of collisions caused by human and organizational factors as a significant challenge in obtaining precise and dependable risk estimations [38]. During ship operations, the risk of ship fires, in addition to ship-to-ship collisions, is a major concern. These fires can occur suddenly and escalate quickly, with even minor mistakes leading to severe consequences. The rapid responses of both crew and passengers are the primary factor in mitigating the severity of ship fire incidents [39]. The next high risk factor involved accidents caused by severe weather, with a score of 11.2. During the operation phase, there is a significant risk of severe weather, which can lead to machinery operational failures and potentially cause accidents [16]. Failures are the primary factor contributing to the malfunction of the pod propulsion system on ships. Worker negligence (score of 10.2), which includes inadequate management for the logistics chain players, human errors, and a lack of knowledge regarding proper handling techniques during loading and unloading operations [18], constitutes high-risk issues in ship operations. Port crashes are the next highest risk (a score of 10). During the operation stage, significant risks arise from containers falling and ships colliding with container cranes [14]. A leakage hull, with a score of 10.5, was another high risk. Environmental safety and health are high-risk considerations at a shipyard [41-43]. This includes addressing potential environmental dangers [41], such as the inhalation of toxic air or gas by ship sailors during the inspection of the cofferdam tank [15]. During the plate cutting process, there are significant issues with sandblasting hose leaks, which pose considerable hazards during the repair stage [9, 11, 13].

Table 9. The risk score in ship operation

Problems	Likelihood	Consequences	Risk	Decision	Rank
SO1	3.0	3.4	10.2	High Risk	5
SO2	3.0	4.9	14.7	High Risk	1
SO3	2.7	3.7	10.0	High Risk	6
SO4	2.7	3.9	10.5	High Risk	4
SO5	2.6	4.3	11.2	High Risk	3
SO6	2.4	4.8	11.5	High Risk	2
SO7	2.2	3.2	7.0	Medium Risk	9
SO8	2.1	3.9	8.2	Medium Risk	8
SO9	2.0	3.1	6.2	Medium Risk	13
SO10	2.0	3.5	7.0	Medium Risk	10
SO11	1.8	5.0	9.0	Medium Risk	7
SO12	1.8	3.4	6.1	Medium Risk	14
SO13	1.7	3.7	6.3	Medium Risk	12
SO14	1.7	1.1	1.9	Low Risk	18
SO15	1.7	3.9	6.6	Medium Risk	11
SO16	1.7	3.2	5.4	Medium Risk	15
SO17	1.3	2.1	2.7	Low Risk	17
SO18	1.3	3.5	4.6	Medium Risk	16

Note: N=40. Risk=Likelihood × Consequences. Risk=1-3=Low. Risk=4-9=Medium. Risk=10-16=High. Risk=20-25=Extreme.

5. CONCLUSIONS

This research provides a comprehensive analysis of accident risks associated with the processes of ship construction, repair, and operation in Indonesian shipyards. The findings indicate that the construction phase faces the highest risk during sub-assembly due to machine damage, while the repair phase is most at risk due to rework caused by machinery damage. During the operational phase, collision accidents pose the highest risk. This study highlights the importance of implementing continuous improvement strategies at both organizational and individual levels to mitigate ship accident risks.

The key findings of this research include the identification of frequent issues in ship construction and repair processes, such as worker negligence leading to rework and contract schedule delays. Additionally, accidents caused by worker negligence are common. The study also reveals that machine damage is the most significant risk during the construction and repair phases, whereas collision accidents are the main risk during ship operation. These findings underscore the need for improved shipbuilding practices to reduce accident risks.

Limitations of this research include: the data collection, which was conducted at only 13 shipping companies in six major cities in Indonesia, potentially not fully representing national conditions. Additionally, the research focuses more on technical and operational aspects without deeply examining management and safety culture in shipyards.

Future research could focus on developing a more comprehensive risk model by considering management and safety culture aspects in shipyards. Moreover, further studies are needed to explore the impact of government regulations and policies on risk management in the shipyard industry. Longitudinal research involving more companies and regions can provide a more representative and in-depth picture of risk dynamics in ship construction, repair, and operation in Indonesia. Consequently, the results of this research can contribute to improving safety and efficiency in the national shipyard industry.

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