ROTTERDAM MAINPORT INSTITUTE

Inventory of Hazardous Materials (IHM): Robust Compliance

Research Proposal

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Preface

The research case project is part of the Master Shipping and Transport programme. These would develop our new knowledge, allow us to apply knowledge, make informed judgements, and improve our communication and research skills. Furthermore, the empirical research experience of the block 2 research case is indispensable to escalate the ability on conclude the literature review, gaps and needs, data collection methods, and data analysis methods. The research will address five competencies of the Master Shipping and Transport: analyzing, managing, influencing, and improving communication and research skills. We conduct a comprehensive report, data collection, and create a scientific-based analysis using tools to analyze a data set. The research case focusing on the Inventory of Hazardous Material (IHM): Robust Compliance.

The maritime industry, a significant contributor to the global economy, also poses potential environmental and human health risks due to the presence and handling of hazardous materials on board ships. The IHM serves as a critical tool for ship owners, detailing the types, quantities, and locations of these materials. The IHM is not merely a list; it is a comprehensive report of every hazardous material on board, from the engine room to deck paint. It signifies a commitment to safety, environmental excellence, and regulatory compliance. However, achieving and maintaining IHM compliance is a challenging task, with obstacles ranging from the sheer number of materials to be inventoried to the complexity of the regulations governing their use and disposal.

Our research provides a comprehensive understanding of the current state of IHM compliance. We will delve into the regulatory frameworks governing IHM, including the EU Ship Recycling Regulation (EU-SRR) and the Hong Kong Convention to explore and evaluate the potential of blockchain technology in enhancing the robustness of the Inventory of Hazardous Materials (IHM) compliance in the maritime shipping industry.

Many people have been important in our academic and personal growth, and we are grateful for their unwavering support and advice, which helped us finish this study project. We are very thankful to Paulo J. Marques Morgado, who oversaw our study case plan, and to Frederik de Wit, Jeroen Pruyn, Peter Troxler, and Josanne Heeroma-ten Katen, who generously sponsored our work. Their knowledge, advice, and help have been helpful throughout this project. Their unwavering faith in our abilities and desire to give us helpful feedback have impacted the direction and quality of this study.

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CHM	Containing Hazardous Material
DDoS	Distributed Denial of Service
DLT	Distributed Ledger Technology
DoS	Denial of Service
EU	European Union
GT	Gross Tonnage
HAZMAT	Hazardous Material
HBCDD	Hexabromocyclododecane
HKC	Hong Kong Convention
IHM	Inventory of Hazardous Materials
IMO	International Maritime Organization
IoT	Internet of Things
MDs	Material Declarations
MPEC	Marine Environment Protection Committee
PCHM	Potentially Containing Hazardous Material
PFOS	Perfluoro Octane Sulfonic Acid
SDOC	Suppliers Declaration of Conformity
SRF	Ship Recycling Facility
SRP	Ship Recycling Plan
SRP	Ship Recycling Plan
SSR	Ship Recycling Regulation

Research Summary

The research focuses on the Inventory of Hazardous Material (IHM), a critical tool for ship owners that details the types, quantities, and locations of hazardous materials on board ships. The maritime industry, a significant contributor to the global economy, also poses potential environmental and human health risks due to the presence and handling of hazardous materials on board ships. The research aims to explore and evaluate the potential of blockchain technology in enhancing the robustness of the Inventory of Hazardous Materials (IHM) compliance in the maritime shipping industry.

The research identifies the challenges in managing the Inventory of Hazardous Materials (IHM) in the maritime shipping industry. It explores how blockchain technology could be used to verify the authenticity and up-to-datedness of the IHM on a ship. The research also identifies potential barriers to implementing blockchain technology in the maritime shipping industry and strategies for overcoming them.

The research provides a theoretical framework that includes an overview of IHM and the importance of accuracy and security. It delves into the regulatory frameworks governing IHM, including the EU Ship Recycling Regulation (EU-SRR) and the Hong Kong Convention. It also reviews the current IHM systems and challenges, such as manual IHM processes and human errors, centralized databases vulnerable to cyber threats, and difficulty tracking changes and ensuring integrity. The research discusses the potential benefits of Blockchain for IHM, such as automating processes through smart contracts, maintaining a tamper-proof record of hazardous materials, and enabling supply chain transparency from manufacturer to recycling. The methodology includes data collection methods.

The research also discusses the key considerations and limitations when implementing Blockchain IHM. These include technology integration with legacy systems and industry-wide standardization and adoption challenges. The research also provides a detailed understanding of blockchain technology and its potential to address challenges in the maritime sector.

1 Introduction

1.1 Problem Description

The Alang Ship Breaking Yard in Bangladesh used to seem like a honeycomb of enormous ocean liners and crude carriers. The work was done by hundreds of manual laborers who buzzed around the ships, deconstructing them, rescuing what they could, and turning the remainder of the vessel into scrap (Mehta, 2008). However, the well-being of those employed at the Alang shipbreaking yard continues to be a matter of concern. A "dusty, murky pipe dream" is how worker safety and benefits have been described when referring to the yard in question. There have also been suggestions for increased safety measures to be implemented at the yard (Goyal, 2016).

In response to growing international criticism of the shipping industry's ship-scrapping practices, the International Maritime Organization (IMO) adopted The Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships (Hong Kong Convention/HKC) on May 2009 (IMO, 2009). The conference aimed to improve the health and safety of current shipbreaking practices, considered to be among the most dangerous of occupations. Following the ratification of the convention, it was determined that in order to ensure the safe operation of boats with a gross tonnage of more than 500 GT both during their active service and after they have been decommissioned, an inventory of hazardous materials (IHM) must be produced and approved. Alongside the Hong Kong Convention, the EU Ship Recycling Regulation (EU 1257/2013) has been implemented for EU-flagged vessels and vessel calling at an EU port or anchorage. The EU Ship Recycling Regulation is focused on implementing the choices reached at the Hong Kong Convention by adding extra safety and environmental standards to ensure compliance and better protect the environment and the seas (The Editorial Team, 2020).

1.2 Stakeholder Analysis

To get a general understanding of the issue at hand and of the stakeholders involved in this, the creation of a basic stakeholder map is the first step. This stakeholder map gives us a more clear and simplified view of the stakeholders involved. Stakeholders are often classified into two distinct categories: external and internal. Internal stakeholders are those that are part of the port authority organisation and are primarily focused on maximising return on investment, enhancing shareholder value, and generating wealth. Additionally, external stakeholders may be classified into four distinct groups: economic/contractual, public policy, community/environmental, and academic/research (Wendler-Bosco & Nicholson, 2020). Upon further inspection, the existence of different dynamics, interest and levels of influence leads us to the creation of an internal – external stakeholder map and an interest – influence graph. According to This leads to some deductions:

Ship Owner: The individual with the highest amount of interest and influence. They’ re an internal stakeholder that is directly connected to the shipping company as its owner. They are the parties with the most responsibilities. All decisions must be taken or approved by them, and all consequences fall to them, respectively. For those reasons, reasonable that this is a stakeholder that should be managed closely.

Shipping Company: The shipping company is an internal stakeholder with a direct connection to the ship owner, as it reports all progress and possible issues to them and carefully analyse the situations and advise the ship owner for the best possible

course of action, giving it a lot of influence. Its smooth operation is its biggest goal. For that reason, it is a stakeholder with a high amount of interest, and it should be managed closely.

Crew: An internal stakeholder with a small amount of interest. The ship's crew main job is the normal operation of the vessel. Unless an IHM list is present on the vessel it is not considered seaworthy. With that in mind we can understand that it has some significance for the crew, as it is part of their duties. The crew's influence is not extremely high as other than making sure an IHM list exists on vessel, there aren't more ways they can be involved with the issue at hand. That is why they should be kept informed.

Ship Management: An internal stakeholder sharing the responsibilities of the crew when it comes to IHM lists. The ship management team is responsible for the smooth operation of the vessel as well. They have a higher responsibility than the crew when it comes to the permits and paperwork required for a ship to be considered seaworthy and they have the ability to cope with issues that might arise from that. For this reason, their influence is high, and they should be managed closely.

Insurance Companies: External stakeholders with a medium level of interest and a low level of influence. Issues can be caused by insurance companies in case the ship retirement does not happen according to guidelines and insurance companies can make claims against the shipping company and the ship owner. For this reason, they should be monitored.

Port Authorities: External stakeholders with a medium to high amount of interest and influence. Flag state administrations, Port state authorities and local authorities are some of them and they could have some effect on the vessel and its retirement procedure. Surveys are performed on vessels by said organizations to confirm the state of the ships. Part of those surveys has to do with IHM lists on vessels, and failure to comply with the standards of those organizations leads to consequences, fines, and worst-case scenario, forbidding the ship from moving. For this reason, they should be kept satisfied.

Ship Recycling Facilities: This external stakeholder is crucial for the correct retirement of the ship. They are directly involved with this procedure and if the correct regulations are not followed, a variety of issues can occur. From worker accidents to environmental hazards meaning consequences of financial kind or other for the ship owner. That is why interest and influence are medium to high and they should be managed closely.

Environmental Organizations: Due to the significant impact that incorrect ship recycling has on the environment, naturally some Environmental Organizations are focused on the issue. One of them is NGO Ship Breaking Platform, actively taking a stance against said activities leading to a bad overall public image for the shipping companies involved in bad ship recycling practices, legal claims against them and big fines for not following the respected guidelines. Environmental Organizations are external stakeholders with a medium to high amount of interest and influence and they should be kept satisfied.

Ship Brokers: Brokers are external stakeholders that take a regularly active role in ship exchange. The description of their work is the acquirement and resale of marine vessels. The amount of interest they have is medium and their influence is medium as well. Usually choosing the most cost effective and fast way to finish a transaction, they tend to overlook important documents and surveys that need to be done for the proper exchange of vessels. So, brokers are partially responsible for loss of data during a ship exchange.

Global Organizations: Global Organizations are external stakeholders with a medium to high interest and influence. They include Classification Societies and IMO to name a few. The guidelines for proper ship recycling and for acquiring an IHM list certificate are issued by said organizations through inspections approved by them. Sea worthiness of ships is categorized by classes, and failure to comply with the

standards of Global Organizations can lead to big fines and halts to the ship's operations. For those reasons they should be kept satisfied.

Software Companies: Software companies have high importance as stakeholders. They are the external stakeholders that are responsible for the creation of a software program using blockchain technology, organizing and properly displaying IHM lists to the respective persons or organizations of interest. This requires arduous research and work, but the result could revolutionize the way ships are categorized and viewed. Holding a medium amount of interest as a business and a small amount of influence since they do not directly affect an aspect of this case. At this point they should be monitored.

Figure 1 Stakeholder Map

Internal Stakeholders	**External Stakeholders**
Ship Owner	Global Organizations
Ship Crew	Port Authority
Ship Management	Insurance Companies
Shipping Company	Software Companies
	Environmental Organizations
	Classification Societies
	Ship Recycling Facilities
	Ship Brokers

Table 1 Internal-External Stakeholder Board

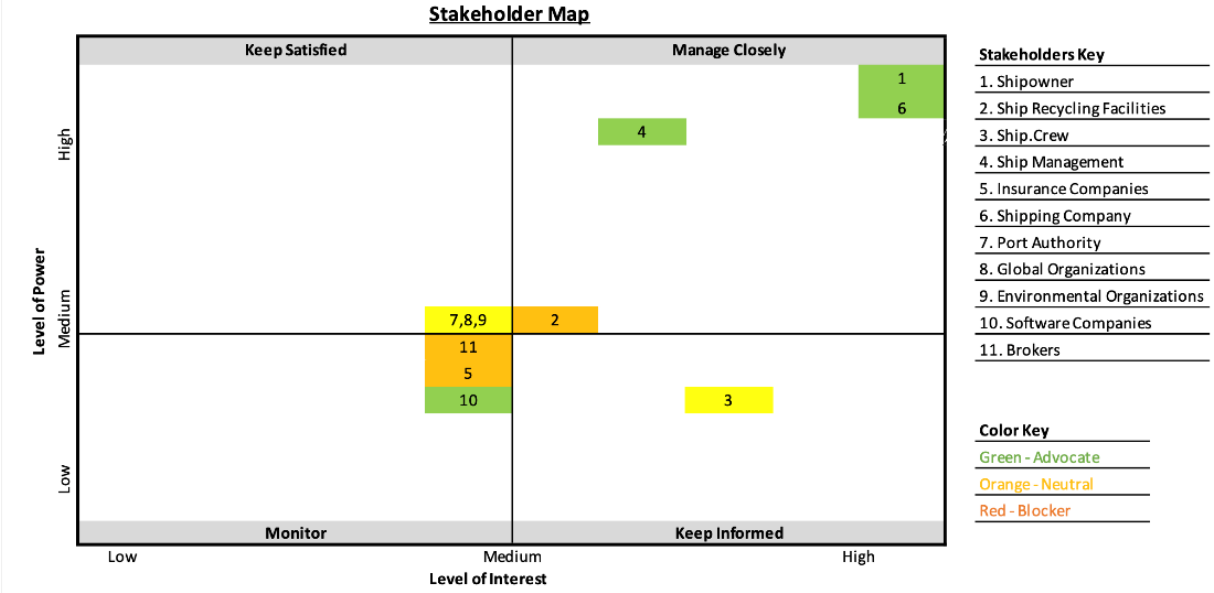

Table 2 Influence-Interest Stakeholder Map, Source Author

1.3 Problem Statement

Inventory Hazardous Materials (IHM) is a mandatory document for large vessels that contains valuable information about potentially toxic substances. The reliability of IHM is a significant issue in the maritime shipping industry. However, there is currently no reliable method to verify the authenticity and currency of IHM on ships. The problem is compounded by unclear records of changes made to ships during their lifetime and poor management of the transfer of IHM during changes in ship ownership. This lack of reliability poses potential risks to the environment and human health. Despite increased penalties for non-compliance, the current system is inadequate, necessitating a more reliable system.

1.4 Research Questions

The main question of this research proposal is presented below. We also include the following sub questions to introduce systematic steps that we want to do in this research to answer the main question. These research questions are created based on the previously stated problem statement.

Main Question:
"How could blockchain technology be practically implemented to improve the robustness of the Inventory of Hazardous Materials (IHM) in the maritime shipping industry?"

Sub-research questions:

1. What are the current challenges in managing the Inventory of Hazardous Materials (IHM) in the maritime shipping industry?
2. How could blockchain technology be used to verify the authenticity and up-to-datedness of the IHM on a ship?
3. What are the potential barriers to implementing blockchain technology in the Inventory of Hazardous Materials (IHM) in the maritime shipping industry?

1.5 Research Objective

The objective of this research is to explore and evaluate the potential of blockchain technology in enhancing the robustness of the Inventory of Hazardous Materials (IHM) compliance in the maritime shipping industry. The research aims to identify the current challenges in managing IHM, investigate how blockchain technology could be used to verify the authenticity and up-to-datedness of the IHM on a ship, and understand the potential barriers to implementing blockchain technology in the maritime shipping industry. The goal is to propose a practical, efficient, and secure system for IHM compliance that mitigates the risks associated with manual processes, human errors, and cyber threats.

1.6 Research Scope

This research will focus more on ships with EU flags, since those are the ones that can be affected by the regulations set by EU for ship exchange and recycling. The fact that those regulations are placed and that vessels with EU flags are forced to comply assists with pinpointing the exact life cycle of said vessels, helping with setting the groundwork for the creation of a database framework.
The provided text outlines three distinct approaches for a research project related to the maritime industry, specifically focusing on the use of blockchain technology in the context of Inventory of Hazardous Materials (IHM) lists, certificates, and ship retirement processes. Here is a summary of each approach:
Processing Procedure Approach:

- Objective: To research and analyse the definition of an IHM, and rules and guidelines that have been given.
- Method: Conduct thorough research and analysis of IHM definitions, and related regulations.
- Outcome: A comprehensive understanding of IHM including the potential consequences of not following them.

Technological Approach:

- Objective: To explore blockchain technology, including its definition, types, and main characteristics, and evaluate its potential as a solution in the maritime industry.
- Method: Conduct research on blockchain technology, its several types, and its key features. Evaluate its applicability in the maritime field.
- Outcome: A detailed understanding of blockchain technology and its potential to address challenges in the maritime sector.

Data Manipulation Approach:

- Objective: To investigate the applications of blockchain technology in the maritime industry, with a focus on IHM lists, and certificates.
- Method: Explore how blockchain can be used in managing IHM data and certificates. Refer to any ongoing development plans by companies and organizations.
- Outcome: Insights into the practical implementation of blockchain technology in managing IHM data and certificates in the maritime sector.

These three approaches together form a holistic research strategy that involves understanding the existing processes, exploring a potential technological solution

(blockchain), and delving into the practical applications of this technology in the maritime industry.
Robust compliance is a necessity for the solution to this problem. Development of a system to accurately identify, organize and file this vast amount of data is something incredibly complicated. The rise of Blockchain technology created an opportunity for it to be used to simplify the process of development for it to be achieved. Using a system like that, the maritime industry could be modernized. The applications range from shipping companies and classification societies to ship retiring facilities and more. The development of software for use in the maritime field using blockchain technology has already made progress, with some companies and organizations taking part in it. Some examples include IBM, who is the biggest investor in blockchain technology at this moment, Maersk, DNV GL and more. [OBJ]

2 Theoretical Framework

2.1 Overview

2.1.1 Background on IHM and importance of accuracy and security

The Inventory of Hazardous Material (IHM) is a crucial component in the maritime industry, particularly in the context of ship recycling. It provides a detailed account of hazardous materials present on a ship, which is essential for ensuring safety, environmental protection, and compliance with international regulations such as the Hong Kong Convention and the EU Ship Recycling Regulation (Ren Di & Lougridis, 2021).

Accuracy in IHM is of paramount importance. An inaccurate IHM can lead to safety risks, environmental harm, and non-compliance with regulations, which can be costly (Alhouli, 2011). For instance, if a hazardous material is not correctly identified and documented, it could be improperly handled during ship recycling, potentially causing harm to workers and the environment (Vivek et al., 2019).

Security, on the other hand, pertains to the protection of the data within the IHM. Given the sensitive nature of the information, it is crucial to ensure that it is securely stored and accessed only by authorized personnel. Unauthorized access or manipulation of the IHM data could lead to incorrect handling of hazardous materials, with potential safety and environmental implications

The application of blockchain technology could potentially enhance both the accuracy and security of the IHM. Blockchain, with its decentralized and immutable nature, can provide a secure platform for storing and sharing IHM data. It can ensure data integrity, prevent unauthorized access, and provide a transparent and traceable record of all transactions related to the IHM.

However, there seems to be a gap in the existing literature regarding the practical application of blockchain technology in the IHM context. While the potential benefits are evident, empirical studies demonstrating these benefits in real-world settings appear to be lacking. This gap presents an opportunity for further research to explore and validate the practical benefits of applying blockchain technology to the IHM in the shipping industry.

2.1.2 Guidelines For IHM Part I Maintenance: Revision-Processing-Preparation-Assessment-Collection

Hazardous Material Definition: Any substance that can pose a risk to the Health and Safety of the people or to the environment as identified and listed in Hong Kong Convention, 2009 and European Union Ship Recycling Regulation 1257/2013.

Figure 2 Process of implementing IHM, retirement process, DNV-GL, n.d.

What does inventory mean?

A document specific to each vessel, which gives an information on all the hazardous materials present on board, their location and approximate quantity in accordance with the Resolution MEPC.269(68) as mentioned in "Guidelines for the development of the inventory of hazardous materials". (MEPC.269(68), 2015)

HKC 2009

The Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, 2009, also known as the Hong Kong Convention (HKC), is a significant international agreement that aims to regulate ship recycling to protect human health and the environment. The HKC is designed to ensure that ships, when being recycled after reaching the end of their operational lives, do not pose any unnecessary risks to human health, safety, and the environment. The main information regarding HKC is mentioned as follows:

- All new and existing ships ≥ 500 GT Inventory of Hazardous Materials (IHM)
- Table A and Table B of Hazardous Materials (HM)
- To be ratified in 2025
- Total of 13 HM to monitor
- Alignment with EU Regulation (EU SRR 1257/2013)

EU SRR 1257/2013

The EU Ship Recycling Regulation (EU 1257/2013) is a comprehensive set of rules aimed at reducing the negative impacts associated with ship recycling. The regulation aims to prevent, reduce, and minimize accidents, injuries, and other negative effects on human health and the environment during ship recycling. The main information regarding EU SRR 1257/2013 is mentioned as follows:

- Ships ≥ 500 GT flying flag of a Member State Ships calling at a port or anchorage of a Member State
- Inventory of Hazardous Materials (IHM). Entered into force from 31st Dec 2020.
- Two Extra hazardous material (PFOS & HBCDD) in Annex I & Annex II
- Exception: Navy ships and domestic ships are excluded from the scope of the regulation.

Scope of IHM With Examples from a Vessel IHM List

Hazmat overview of a ship:

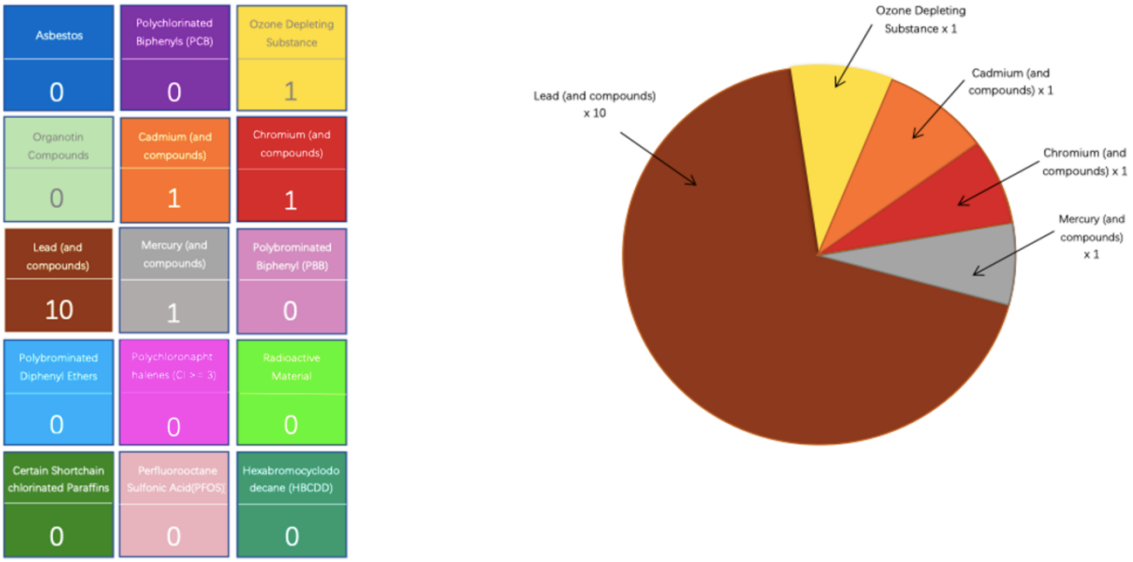

Figure 3 HAZMAT Overview of a Ship (source: Vertex Infosoft Solutions Pvt. Ltd. © 2023)

<u>Part I – Hazardous Materials inherent in the ship's structure and fitted equipment:</u>

To be maintained and updated throughout the operational life of a ship. Below is example of Part I document.

Part I Materials contained in ship structure or equipment

I-1 Paints and coating systems

No.	Created At	Name of Paint	Location	Material (classification in Appendix 1)	Apprx. Quantity	Parts where used	Remarks	PCHM/CHM
1	04/05/2020	CHUGOKU Marine Paints Ltd.	Throughout the Vessel	Lead and Lead Compounds	400 kg	Paints & Coatings /Signs	Sample 228.034 Yellow Colour Lead: 13620mg/Kg	CHM
2	04/05/2020	CHUGOKU Marine Paints Ltd.	Throughout the Vessel	Chromium VI and Chromium VI Compounds	400 kg	Paints & Coatings /Signs	Sample 228.034 Yellow Colour Chromium VI: 2226mg/kg	CHM
3	04/05/2020	CHUGOKU Marine Paints Ltd.	Exposed Steel Deck	Lead and Lead Compounds	3600 kg	Paints & Coatings / Wall & Ceiling Paint	Sample 228.007 White Colour Lead: 1947mg/Kg	CHM
4	04/05/2020	CHUGOKU Marine Paints Ltd.	Throughout the Vessel	Lead and Lead Compounds	699 kg	Paints & Coatings / Deck Paint	Sample 228.016 Pink Colour Lead: 3478mg/Kg	CHM
5	04/05/2020	CHUGOKU Marine Paints Ltd.	Throughout the Vessel	Lead and Lead Compounds	636 kg	Paints & Coatings / Wall & Ceiling Paint	Sample 228.015 White Colour Lead: 1222mg/Kg	CHM
6	04/05/2020	CHUGOKU Marine Paints Ltd.	Engine Room Extended	Lead and Lead Compounds	9030 kg	Paints & Coatings / Wall & Ceiling Paint	Sample 228.058 White Colour Lead: 1218mg/Kg	CHM
7	04/05/2020	CHUGOKU Marine Paints Ltd.	Funnel (Outside)	Lead and Lead Compounds	1040 kg	Paints & Coatings	Sample 228.042 Yellow Colour Lead: 11250mg/Kg	CHM

Figure 4 PART 1 of IHM (Vertex Infosoft Solutions Pvt. Ltd. © 2023.)

Part II – Operationally Generated Wastes:

Only when going recycling.

Part III – Stores:

Only when going recycling.

I-2 Equipment and machinery

No.	Created At	Name	Location	Material (classification in Appendix 1)	Apprx. Quantity	Parts where used	Remarks	Status
1	04/05/2020	Gyro Compass	Nav. Bridge Deck / Wheelhouse	Mercury and Mercury Compounds	<0.01 kg	Internal Fluid	-	CHM
2	04/05/2020	Batteries	Wheelhouse, Battery Room, Engine Room, Emergency Generator Room	Lead and Lead Compounds	700 kg	Metal Plates	28 PCS	CHM
3	04/05/2020	Secondary Piston	3rd Deck / Engine Room	Lead and Lead Compounds	1.2 kg	Metal Sheet for Lashing	Sample 228.070 Lead: > 900000 mg/kg	CHM
4	04/05/2020	Secondary Cylinder Liner	B Deck, EM'CY GEN. Room	Lead and Lead Compounds	2.4 kg	Metal Sheet for Lashing	Based on Sample 228.070	CHM
5	04/05/2020	Electrical / Electronic Equipment	All Decks	Lead and Lead Compounds	-	Printed Circuits Boards	Quantity does not need to be reported according to paragraph 3.3.2 of MEPC.269(68)	PCHM
6	04/05/2020	Electrical / Electronic Equipment	All Decks	Cadmium and Cadmium Compounds	-	Printed Circuits Boards	Quantity does not need to be reported according to paragraph 3.3.2 of MEPC.269(68)	PCHM

I-3 Structure and hull

Part II Operationally generated wastes

No.	Created At	Name	Location	Material (classification in Appendix 1)	Apprx. Quantity	Parts where used	Remarks	Status
1	04/05/2020	Ceiling, Wall and Floor panel	A Deck / Cold Provision Store	Ozone Depleting Substances	476 kg	Panel's Insulation	Sample 228.021 ODS: > 1077.7 mg/kg	CHM

Part III Stores

None of the relevant materials have been identified onboard

Figure 5 PARTS 2 and 3 of IHM (Vertex Infosoft Solutions Pvt. Ltd. © 2023.)

Guidelines for the development of the inventory of the IHM:

Materials to be listed in the inventory are:

1. Tables A and B correspond to Part I of the inventory. Table C corresponds to Parts II and III and Table D corresponds to Part III.
2. For loosely fitted equipment, there is no need to list this in Part I of the inventory. Such equipment which remains on board when the ship is recycled should be listed in Part III.
3. Those batteries containing lead acid or other hazardous materials fixed in place should be listed in Part I of the inventory. Batteries that are loosely fitted, which includes consumer batteries and batteries in stores, should be listed in Part III of the inventory.
4. Maintaining and updating Part I of the inventory during operations.
5. Any spare parts containing materials listed in Table A and Table B must be listed in Part III of the inventory.
6. Updating of Part I of the inventory in the event of new installation.

2.1.3 Brief Overview of Blockchain Technology and Relevant Capabilities

The best way to consolidate the compliance of IHM lists during the change of ownership or retirement of vessels would be the use of a reliable database, so the IHM lists are always available. To achieve that, blockchain technology would be a valuable tool. Blockchain is a technology that rose from the creation of Bitcoin, a "peer-to-peer electronic cash system". Blockchain technology is a distributed ledger system. That system is decentralized and in it, transactions are recorded with the use of computers. Those transactions are unchangeable, completely transparent, and secure. Said transactions are categorized chronologically as "blocks", forming a "chain" of linked data. According to Stephen & Alex (2018) Its main characteristics are as follows:

1. Immutability: Data that is entered into the chain is unchangeable, ensuring that the transaction is trustworthy.
2. Transparency: While the transactions in the chain are public and visible, the identities of the parties involved and the crucial information is encrypted, achieving transparency.
3. Decentralization: While ordinary databases need a central unit, blockchains are operated by a network of nodes, solving the biggest vulnerability of database.
4. Distributed ledger technology: All participants in a transaction of a blockchain network are provided with a copy of the ledger. So, the truth about the transaction is known only by the participants, with proof of it being the copy.
5. Consensus Mechanisms: Any transaction must be agreed upon by all parties and must follow the rules before linked to the chain.
6. Smart Contacts: Automatically executed tasks triggered by information contained in the blockchain. This provides a level of automation in the chain, further simplifying the transactions.

There are 3 types of blockchain according to Zhuang et al. (2021), mentioned below:

Public Blockchains: As the name implies, those blockchains operate publicly, giving access to everyone and have no central authority. Usually, no permissions are required to join those blockchains. Examples of public blockchains are most crypto currencies like Bitcoin and Ethereum.

Private or Consortium Blockchains: Private blockchains only grant limited access to participants in transactions and they are usually used by a company or an organization, or a consortium of them.

Hybrid Blockchains: Any mix of public and private blockchain technology produces hybrid networks, being both partly public and private.

Due to the nature of the shipping industry, the best approach in the use of blockchain technology would be a private blockchain.

2.2 Review of Current IHM Systems and Challenges

2.2.1 Manual IHM processes and human errors

The manual inventory of hazardous materials is a critical process in various industries, including shipping and transport. It involves the tracking and management

of hazardous substances to ensure safety and compliance with regulations. However, this process is prone to human errors, which can lead to profound consequences such as accidents, environmental damage, and regulatory violations.

According (Li et al., 2020), there are 4 types of human errors tracking and management of hazardous substances:

1. **Documentation Errors**: Occur when there are inaccuracies in the recording or reporting of information related to hazardous materials. This can lead to mismanagement of these materials, potentially resulting in accidents or regulatory non-compliance.
2. **Communication Errors**: Involve the miscommunication or lack of communication of valuable information about hazardous materials. This can result in misunderstandings or lack of awareness, which can lead to mishandling of these materials.
3. **Procedural Errors**: Occur when established procedures for handling hazardous materials are not followed correctly. This can result in unsafe conditions and potential accidents.
4. **Cognitive Errors**: Involve errors in decision-making, perception, or memory related to the handling of hazardous materials. These can lead to incorrect actions being taken, potentially resulting in accidents or other negative outcomes.

Human errors in the manual inventory of hazardous materials can be caused by several factors, including lack of training, fatigue, distraction, and lack of proper tools or equipment (Eckhoff, 2016). Additionally, complex, or unclear procedures can also contribute to human errors.

The impact of human errors in the manual inventory of hazardous materials can be severe. These errors can lead to accidents, such as fires or explosions, which can result in injuries or fatalities. They can also cause environmental damage and lead to regulatory violations, which can result in fines or other penalties (Mutschler, 2015).

Preventing and mitigating human errors in the manual inventory of hazardous materials involves several strategies. These include providing adequate training to ensure that workers understand how to handle hazardous materials safely and correctly, implementing clear and simple procedures, using proper tools and equipment, and promoting effective communication (Bouchard, 2007). Additionally, regular inspections and audits can help identify and correct potential issues before they lead to errors.

While there is substantial research on human errors in the manual inventory of hazardous materials, there appears to be a gap in the literature regarding the development of a comprehensive model that integrates all aspects of this issue. Such a model could help in understanding the interrelationships between several types of errors, their causes, and their impacts, and in developing more effective strategies for prevention and mitigation.

2.2.2 Centralized databases vulnerable to cyber threats

Centralized databases, which store data in a specific location, are vulnerable to several types of cyber threats. These threats can have significant impacts on different industries, including the maritime shipping industry, particularly in the context of

inventory management of hazardous materials. Preventive measures are crucial to mitigate these threats and protect sensitive data.

Centralized databases are systems where all data is stored and managed in a specific location. According to (Khalil et al., 2022) this centralization can make the system vulnerable to cyber threats, as a single breach can compromise the entire database.

Cyber threats refer to potential attacks or breaches that can compromise the security of a system, leading to unauthorized access, data theft, or system disruption. These threats can take various forms, including Denial of Service (DoS) or Distributed Denial of Service (DDoS) attacks, information gathering, man-in-the-middle attacks, injection attacks, and malware attacks (Douligeris & Mitrokotsa, 2003).

The maritime shipping industry, particularly in the context of managing inventories of hazardous materials, is increasingly reliant on digital systems and centralized databases. According to Erstad et al. (2022) this reliance makes the industry vulnerable to cyber threats. For instance, if the navigational systems on a ship fail due to a cyber incident, it could lead to significant safety risks for the crew, the vessel, and the environment.

The types of cyber threats that centralized databases face are diverse. For instance, a study identified five major threats, including DoS/DDoS attacks, information gathering, man-in-the-middle attacks, injection attacks, and malware attacks (Douligeris & Mitrokotsa, 2003). These threats can have significant impacts on various industries, including the maritime shipping industry.

While there is substantial research on the vulnerability of centralized databases to cyber threats, there is a gap in the literature regarding the specific impacts of these threats on the maritime shipping industry, particularly in the context of managing inventories of hazardous materials.

Moreover, while preventive measures against cyber threats are well-documented in the literature, there is a need for more industry-specific strategies. For instance, according to Erstad et al. (2022) the maritime shipping industry could benefit from strategies tailored to its unique operational and regulatory environment.

2.2.3 Difficulty tracking changes and ensuring integrity

The topic of tracking changes and ensuring integrity in the inventory of hazardous materials within the shipping and transport industry is a complex one, with several key concepts and findings from scientific literature that can be synthesized to identify gaps and suggest future research directions.

Data integration, according to Lenzerini (2002), a foundational element in managing the integrity of hazardous materials inventory. It involves the consolidation of data from various sources to provide a unified view of the inventory. This process is crucial in making informed decisions regarding the handling and transportation of hazardous materials.

Several studies have highlighted the challenges in tracking changes and ensuring integrity in the inventory of hazardous materials. According to Vanessa Munoz Macas et al. (2021), these challenges include the lack of advanced inventory management and control systems, biases in inventory decisions, and the need for risk management strategies.

The use of technology, such as machine learning, has been suggested as a potential solution to these challenges. According to Wu et al. (2021), machine learning can complement environmental investigations and quantify the risk of finding hazardous materials in buildings. However, the adoption of these technologies in the field of hazardous materials inventory management is still limited.

Despite the importance of tracking changes and ensuring integrity in the inventory of hazardous materials, there is a lack of comprehensive studies on the effective implementation of advanced inventory management systems in the shipping and transport industry. Future research could focus on exploring the potential of technologies like machine learning in enhancing inventory management practices (Wu et al., 2021).

Moreover, there is a need for more research on the biases in inventory decisions and how they can be mitigated. Understanding these biases could lead to the development of more effective inventory management strategies.

Lastly, while risk management strategies are crucial in managing hazardous materials inventory, there is a need for more research on how these strategies can be effectively implemented in different contexts. This could involve exploring the role of regulations, organizational practices, and technological innovations in risk management.

2.3 Potential Benefits of Blockchain for IHM

Blockchain technology has the potential to significantly improve the inventory management of hazardous materials in several ways, including enhancing safety and compliance, also increasing efficiency and transparency.

Blockchain technology can enhance safety and compliance in hazardous material inventory management by providing a secure, immutable record of all transactions and interactions with these materials. This can help organizations comply with regulations and policies related to hazardous materials. According to Deng et al. (2019), blockchain can also help protect the privacy and security of the donation process through zero-knowledge proof.

Blockchain can improve the efficiency and transparency of hazardous material inventory management by providing a decentralized, transparent record of all transactions. Blockchain can help improve inventory cost control, which is an essential factor in supply chain management. A study on the retail industry in the UAE found a significant positive impact of blockchain and smart inventory systems on supply chain performance (Kurdi et al., 2022).

While the potential benefits of blockchain for hazardous material inventory management are clear, there is a gap in the existing literature regarding the specific application of blockchain technology in this context.

2.3.1 Automate processes through smart contracts

Smart contracts, a product of blockchain technology, have the potential to automate processes in the inventory of hazardous materials, addressing aspects of risk management, supply chain, and compliance.

According to (Liu & Liu, 2019), smart contracts are self-executing contracts with the terms of the agreement directly written into code. They are stored and replicated on the system, supervised by the network of computers that run the blockchain. This

technology ensures transparency, security, and efficiency, reducing the need for intermediaries and enabling automation of processes.

Hazardous materials pose significant risks, and their management is crucial. Traditional environmental investigations are costly and time-consuming, leading to limited adoption. A data-driven approach can help assess the risk of encountering hazardous materials, mitigating unexpected costs and delays due to acute abatement. According to Shahzad et al. (2021), smart contracts could automate this process, using registered records as input data to manage hazardous materials at a large scale.

According to Shahzad et al. (2021), in the context of supply chain management, smart contracts can facilitate inventory sharing among stakeholders, increasing transparency, trust, and security of transactions. For instance, a blockchain-based inventory sharing approach using smart contracts on a private Ethereum network can link suppliers and retailers, improving information sharing and reducing inefficiencies. This approach could be particularly beneficial for managing the inventory of hazardous materials, ensuring real-time tracking and secure data exchange.

Compliance is a critical aspect of managing hazardous materials, given the potential risks involved. Streamlining the identification and inventory process of hazardous materials can enhance regulatory compliance reporting. According to Shahzad et al. (2021), smart contracts can automate this process, ensuring adherence to regulations and providing a transparent, auditable trail of compliance.

While the potential of smart contracts in managing hazardous materials inventory is evident, there is a gap in the literature regarding the practical implementation of this technology in this context.

2.3.2 Maintain tamper-proof record of hazardous materials

Maintaining tamper-proof records of hazardous materials is a complex task that involves various aspects such as technologies and challenges.

Blockchain technology has emerged as a promising solution for maintaining tamper-proof records. It provides immutable write action and distributed storage, which can be leveraged to develop a secure log system for hazardous materials. Distributed Ledger Technology (DLT), according to Sunyaev (2020), another technology that helps maintain and distribute information in a decentralized manner, creating transaction records that are hard to tamper with.

However, according to Ouaili et al. (2022), there are challenges in ensuring the consistency of distributed records, especially in the presence of multiple writers and potential malicious parties.

Despite the advancements in technologies and regulations, there are still gaps in the existing literature, particularly in terms of the practical implementation of these technologies and its effectiveness.

2.3.3 Enable supply chain transparency from manufacturer to recycling

Supply chain transparency from manufacturer to recycling involves several key concepts, including information sharing and traceability. These concepts are crucial in ensuring that all stages of the supply chain are accountable and sustainable.

Information sharing is a critical aspect of supply chain transparency. According to Tang et al. (2022), it refers to the exchange and delivery of data between different organizations in the transaction or cooperation process. Blockchain technology has been identified as a powerful tool to resolve information asymmetry, with its advantages in decentralization, transparency, traceability, confidentiality, and immutability. It can solve long-standing contradictions between data privacy and sharing, eliminating worries of related parties in data sharing. However, data stored publicly in the blockchain are still threatened by privacy leakage. Therefore, a fine-grained access control is needed to improve the security of data.

Traceability is the ability to verify the history, location, or application of an item by means of documented recorded identification. It is crucial in supply chains to ensure the authenticity and quality of products. However, traceability in supply chains, particularly in the cocoa industry, is still a challenge. According to Wang et al. (2019) blockchain technology can improve traceability by providing a transparent and immutable record of transactions.

The main challenges in enabling supply chain transparency from manufacturer to recycling include data privacy concerns, lack of fine-grained access control in blockchain, and the difficulty in tracing products back to their origin.

Future research could focus on developing more secure and privacy-preserving blockchain systems for supply chain management. Additionally, more effective traceability systems could be developed to improve the tracking of products from their origin to the end consumer. Lastly, research could also focus on how to effectively implement ethical and sustainable practices in supply chains.

2.4 Key Considerations and Limitations When Implementing Blockchain IHM

Blockchain technology has the potential to revolutionize the inventory management of hazardous materials, offering benefits in terms of safety, regulatory compliance, and efficiency. However, there are several key considerations and limitations that need to be addressed for successful implementation.

Blockchain can enhance safety by providing a transparent and immutable record of hazardous materials throughout their lifecycle, from production to disposal. This can help in identifying and tracking such materials, ensuring their safe handling, and systematic disposal to prevent environmental pollution. However, according to Ahmadjee et al. (2022), the safety of blockchain-based systems themselves is a concern. They must be designed to be resilient against cyber-attacks and data breaches, which could compromise the integrity of the inventory data.

Regulatory compliance is a critical aspect of hazardous materials management. Blockchain can help meet regulatory requirements by providing a verifiable record of compliance activities. However, the use of blockchain for this purpose, according to Barati et al. (2019), must itself comply with data protection and privacy regulations, which can vary across jurisdictions.

Blockchain can improve efficiency by automating inventory management processes, reducing paperwork, and enabling real-time tracking of hazardous materials. However, the implementation of blockchain technology can be complex and costly, requiring significant technical expertise and infrastructure (Barati et al., 2019).

Despite its potential, the use of blockchain for hazardous materials inventory management is still in its initial stages, and there are several limitations and gaps in the existing literature. For instance, there is a lack of empirical studies demonstrating the practical implementation and benefits of blockchain in this context. Moreover, the integration of blockchain with other technologies, such as Internet of Things (IoT) and machine learning, for hazardous materials management is an area that warrants further research.

2.4.1 Technology integration with legacy systems

Blockchain technology, with its decentralized, transparent, and secure nature, has the potential to revolutionize the inventory management of hazardous materials. According to Kumar & Abhishek (2021), it can address key challenges such as data security, supply chain transparency, and the implementation of smart contracts, which are particularly relevant in the context of hazardous materials inventory.

Blockchain technology can enhance data security by providing a decentralized and immutable ledger of transactions. This feature is crucial for the inventory of hazardous materials, where the integrity and authenticity of data are paramount. The decentralized nature of blockchain reduces the risk of a single point of failure and ensures that no single entity has control over the data. According to Stephen & Alex (2018), this can significantly enhance the security and reliability of inventory data.

Blockchain can also improve supply chain transparency. It allows for the traceability of materials from their origin to their destination, which is particularly important for hazardous materials due to the potential risks they pose. By providing a transparent and immutable record of transactions, according to Wang et al. (2019), blockchain can help ensure that all parties in the supply chain have access to the same information, reducing the likelihood of disputes and enhancing overall supply chain efficiency.

Smart contracts, which are self-executing contracts with the terms of the agreement directly written into code, can automate many processes in the supply chain. For instance, according to Kurdi et al. (2022), they can be used to automate the replenishment of inventory based on predefined conditions, reducing the need for manual intervention, and increasing efficiency.

Integrating blockchain technology with legacy systems of hazardous materials inventory presents several challenges. These include issues related to system interoperability, the quality and confidentiality of information, and the need for trust among all parties involved. However, these challenges, according to Sahai et al. (2020), can be addressed using private blockchain networks, which can link suppliers and retailers in a secure and efficient manner.

Despite the potential benefits of blockchain technology for the inventory of hazardous materials, there is a lack of comprehensive research on this topic. Specifically, there is a need for more studies on the practical implementation of blockchain technology in this context, including the development of specific algorithms for smart contracts and the integration of blockchain with existing inventory management systems.

2.4.2 Industry-wide standardization and adoption challenges

The adoption of blockchain technology in the maritime industry, particularly for verifying the authenticity and currency of the Inventory of Hazardous Materials (IHM), faces several challenges related to industry-wide standardization and

adoption. These challenges can be categorized into three primary areas: technological barriers, operational challenges, and regulatory barriers.

Blockchain technology, while promising, is still relatively new and complex. This complexity can lead to a lack of understanding and familiarity with the technology, which can hinder its adoption. The selection of the optimal consensus algorithm, an essential component of every blockchain application, is a critical decision that requires careful consideration. Furthermore, according to Barati et al. (2019), the high energy consumption associated with blockchain technology can also be a significant barrier.

Operational challenges include the cost of implementation, the lack of experienced partners, and the fear of transitioning to a new operating structure. The maritime sector has traditionally been conservative in adopting innovative technologies, which can lead to complications in the application of blockchain technology. Additionally, according to Mathivathanan et al. (2021), the lack of business awareness about what blockchain technology can deliver for future supply chains is a significant barrier.

Regulatory barriers can also impede the adoption of blockchain technology in the maritime industry. These can include issues related to data privacy and the need for regulatory frameworks that support the use of blockchain technology (Zhou et al., 2020).

While the existing literature provides valuable insights into the challenges of adopting blockchain technology in the maritime industry, there is a gap in research specifically related to the use of blockchain for verifying the authenticity and currency of IHM on ships, considering the identified technological, operational, and regulatory barriers. This could involve exploring potential solutions to these barriers, such as developing educational programs to increase understanding of blockchain technology, identifying strategies to reduce implementation costs, and advocating for regulatory changes to support the use of blockchain technology in the maritime industry.

3 Conceptual Model

Figure is a conceptual model that shows the variables that influence each other in the relationship between documentation of IHM and IHM robustness. The dependent variable is the IHM robustness that are influenced by the independent variable, the implementation of block chain technology as a moderator variable, could enhance the robustness of IHM documentation.

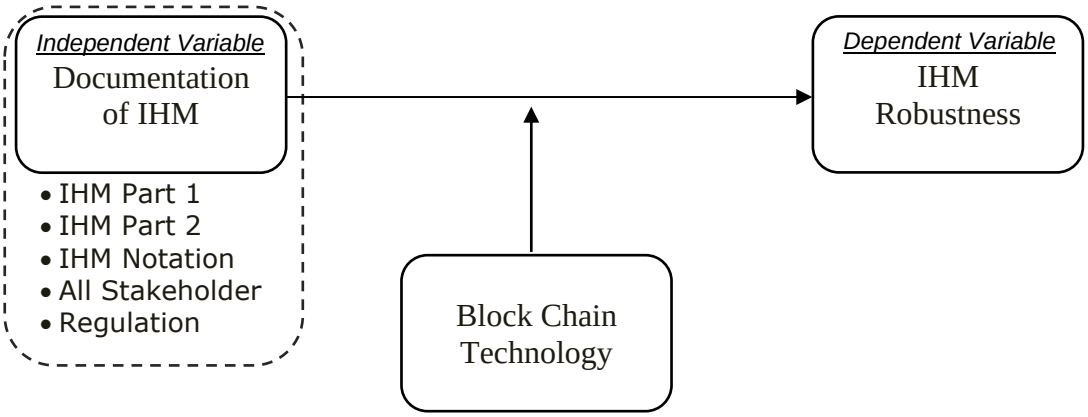

Figure 6 Conceptual model

3.1 Research Design

To answer the main research question "How could blockchain technology be practically implemented to improve the robustness of the Inventory of Hazardous Materials (IHM) in the maritime shipping industry?", sub research question is conduct as follows:

3.1.1 Sub-question 1: What are the current challenges in managing the Inventory of Hazardous Materials (IHM) in the maritime shipping industry?

Conduct literature on studies about the obstacles and barriers to implementing IHM in general. Interviewing classification bureaus to find out the obstacles faced during the process of issuing IHM Notation for ships, and interviewing shipping companies to find out the obstacles faced by ship operators in administering IHM Part 1, Part 2, and Part 3.

3.1.2 Sub-question 2: How could blockchain technology be used to verify the authenticity and up-to-date ness of the IHM on a ship?

Conduct a literature review to get an overview of the blockchain working system as a digital ledger to maintain the reliability of the data stored in it. Interviewing the port authority to find out the expected IHM standards.

3.1.3 Sub-question 3: What are the potential barriers to implementing blockchain technology in the Inventory of Hazardous Materials (IHM) in the maritime shipping industry?

Conduct a literature review related to the role of each stakeholder in IHM administration to determine the limitations of their authority and responsibility in managing IHM. Interviewing the shipping company, classification bureau, and port authority to obtain the information regarding

the limitations of authority and responsibility of each stakeholder related to the information recorded in IHM.

3.2 Methodology

Qualitative method will provide a comprehensive understanding of the IHM compliance perspective, the issue faced by the stakeholders and the strategies used to ensure compliance. It also can be useful for a better comprehending the practices, obstacles, and factors that influence conformity with hazardous material inventory standards.

3.2.1 Data Collection

There is a wide variety of qualitative data collection methods, each of which can be adapted to meet the requirements of the research, such as:

1. Interview
   This method involves one-on-one conversations with stakeholder of IHM compliance. Interviews can provide in-depth insights into their experiences, beliefs, and motivations that might be useful for the research objectives.

2. Observation
   This method involves observing and documenting naturally occurring behaviours in the context of IHM compliance. Observing the process of IHM preparation and maintenance can provide valuable insights.

3. Document analysis
   This method involves analysing relevant documents, such as Material Declarations (MDs) and Suppliers Declaration of Conformity (SDOC), IHM preparation and maintenance reports, and compliance audit reports.

4 Discussion

In this section, information to answer the sub-research question will be discussed. The information obtained through the literature review process and interviews with several stakeholders is presented in the form of paragraphs and figures.

4.1 The current challenges in managing the Inventory of Hazardous Materials (IHM) in the maritime shipping industry

In this section, the first sub-question raised will be answered which is; What are the current challenges in managing the Inventory of Hazardous Materials (IHM) in the maritime shipping industry?

To answer this sub-question, three stakeholders were interviewed using atlas.ti to explore the challenges of managing IHM. While several factors were identified, this report specifically focuses on those that were mentioned more than once during the interviews.

When analysing the interviews, keywords that were frequently used by the interviewees were identified. Subsequently, these repeated keywords were used to generate codes for aspects of IHM management challenges. The keyword network is illustrated in Figure 7 Network of codes for current challenges below.

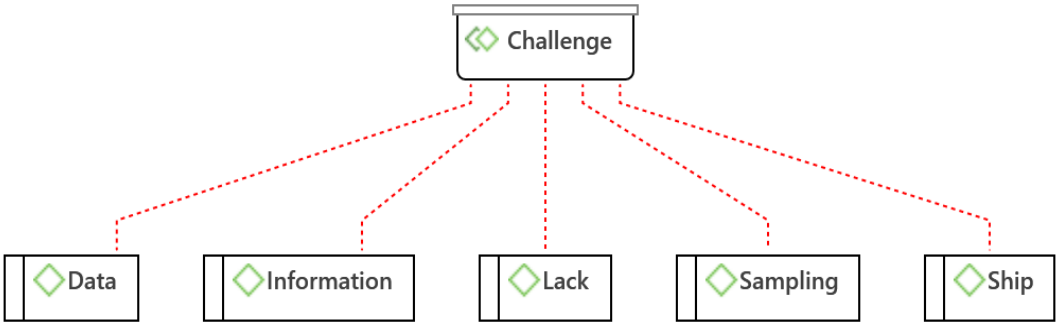

Figure 7 Network of codes for current challenges

The hazardous materials inventory process is prone to human error, which can lead to adverse consequences, such as breaking regulations. Based on the results of the interviews and literature review, several factors were found that resulted in the challenges arising.
Several factors make managing IHM challenging:

i. Data
The accuracy and completeness of data are crucial for managing IHM. Inadequate data can lead to incorrect assessments of hazardous materials present on a ship. The risk of human error in data collection and entry can result in non-compliance with regulations and standards, such as the Hong Kong Convention for the Safe and Environmentally Sound Recycling of Ships.

ii. Information
Information management is another challenge. The IHM process requires the collection, storage, and retrieval of vast amounts of information. Any mismanagement in this area can lead to errors in the inventory, potentially causing regulatory breaches and safety risks.

iii. Lack
A lack of resources, including trained personnel, can obstruct the effective management of IHM. This can lead to oversights and mistakes in identifying and documenting hazardous materials.

iv. Sampling
Sampling is a critical part of the IHM process, as it involves testing materials to confirm the presence of hazardous substances. Inaccurate sampling methods or human error during sampling can result in unreliable data, which can have profound consequences for ship recycling and environmental safety.

v. Ship
The complexity of ships themselves poses a challenge. Each vessel has a unique structure and history, which can make the identification and documentation of hazardous materials difficult. Also, ship operations' dynamic nature can lead to changes in the inventory of hazardous materials over time.

4.2 How blockchain technology be used to verify the authenticity and up-to-datedness of the IHM on a ship.

In general, the process of issuing hazardous materials inventory certificates for new and existing ships is obtained through literature reviews and interviews with stakeholders. The series of IHM issuance processes, combined with the implementation of blockchain technology. The whole concept is outlined in the form of a flowchart (see Figure 8)

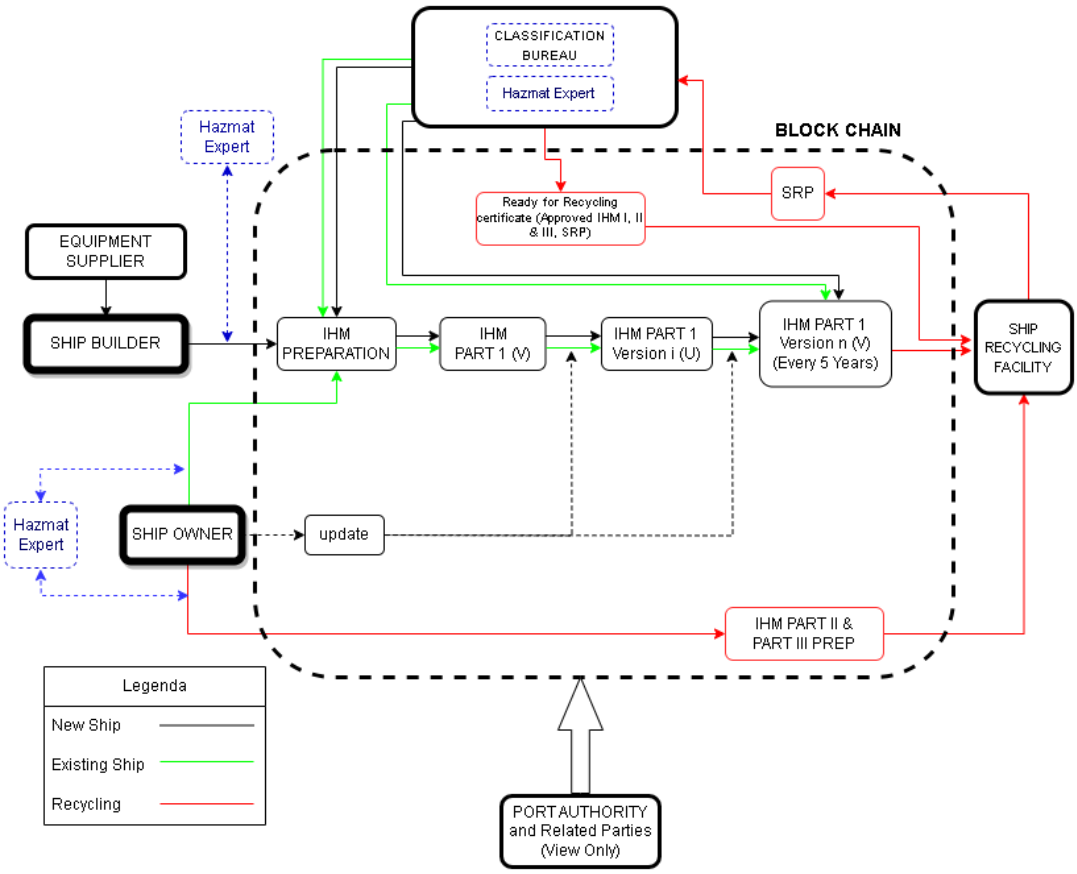

Figure 8 blockchain on IHM Process

The flowchart of IHM Registration for new build ship explain as follows:

1. The shipbuilder, as the responsible stakeholder for preparing IHM Part I, identifies all hazardous materials according to the Hong Kong Convention for the Safe and Environmentally Sound Recycling of Ships 2009 and the Regulation (EU) 1257/2013 of the European Parliament-Council on Ship Recycling.
2. The equipment supplier provides Material Declaration (MDs) and Suppliers Declaration of Conformity (SDOC) to the shipbuilder.
3. During inventorying, the shipbuilder will be assisted by a Hazardous Material Expert in matching the MDs and SDOC with the hazardous materials used in the ship's construction. The results will be handed to the Classification Bureau.
4. The Classification Bureau issued the official Inventory of Hazardous Materials Part I Certificate. The certificate provides detailed information about each type, location, and quantity of hazardous materials, which a consensus mechanism will validate. The consensus mechanism will ensure that the established regulation is complied with.
5. The inventory that relates to the IHM information will be transmitted to every stakeholder. This also makes the data decentralized. A consensus mechanism will be used in this phase so that every alteration of the inventory can be validated by every ledger holder, which is the stakeholder.
6. The shipowner is obliged to inform the Classification Bureau of any modifications in the IHM Part I every five years. Hazardous Material experts are being involved again in the updating process. Again, the consensus mechanism of blockchain is utilized to ensure the validation of the certificate.

7. Before the ship is recycled, the last version of IHM Part I should be handed to the Ship Recycling Facility (SRF). The last version of the certificate is the results of the last survey being carried out by the Classification Bureau and Hazardous Material Expert

The flowchart of IHM registration and maintenance process for operating vessel explain as follows:

1. Ship Owner is required to conduct IHM Preparation by employing a Hazmat Expert (expert company) approved by the Classification Bureau. The stages carried out in preparing the IHM Preparation document carried out by the Shipping Company are as follows:
   a. Collect information about the ship;
   b. Assess collected information;
   c. Prepare Visual and Sampling Check Plan;
   d. Onboard visual and sampling check;
   e. Send samples for laboratory analysis & preparation of IHM and IHM inspection report

   The entire process requires close cooperation of several parties and at best it would need one month until the IHM inspection report is finalized.
2. The Classification Bureau's Plan Approval Engineer reviews and approves the IHM and IHM inspection reports. After the approval is given, an IHM initial survey of the ship is conducted by a surveyor of the Classification Bureau. If the IHM Initial Survey passes, the surveyor will issue an IHM certificate or Statement of Compliance with a maximum validity period of 5 years, aligned with the date of renewal of the ship's main class.
3. The ship owner is responsible for keeping the Inventory of Hazardous Material Part I up to date. Part I of the Inventory shall be appropriately maintained and updated, especially after any repair or conversion of a ship. An IHM maintenance procedure shall be implemented including the assignment of a designated person, by keeping records of changes.
4. The IHM renewal survey is required for every five years after the IHM initial survey. The requirements are as follows:
   a. Ship's existing IHM certificate and IHM Part I;
   b. The updated IHM (Part I), reflecting any change, replacement, or significant repair of the structure, equipment, systems, fittings, arrangements, and materials since the last survey;
   c. The ship's IHM Part I maintenance record, Material Declarations (MD), and Supplier's Declaration of Conformities (SDoCs) reflect the ship's hazardous materials management since last IHM survey.

The data required to register for IHM will be protected with a blockchain system. In the above, the blockchain system will play a role in the processes involved.

The data that needs to be entered into the system:

1) The name of product
2) Material classification (EU SSR/HKC)
3) Approximate quantity
4) Parts were used
5) Used date
6) Material location
7) Material categorization (PCHM/CHM)

The IHM certificates need to be updated when the ship construction starts and throughout its lifetime. Blockchain with smart contracts and consensus mechanisms can protect the continued authenticity of the data.

Smart contract mechanisms require MDs and SDOCs to be uploaded along with the necessary data. This is useful to ensure authenticity and synchronization throughout the life of the vessel.

The consensus mechanism of the blockchain system in the IHM certification process only applies to Classification Societies and Shipping Companies. They mutually validate the data entered the system, so that if there is a fault in entering the data, either stakeholder can refuse to validate the data.

Below are the concise diagram of the blockchain process validating data and the authorization of each stakeholder:

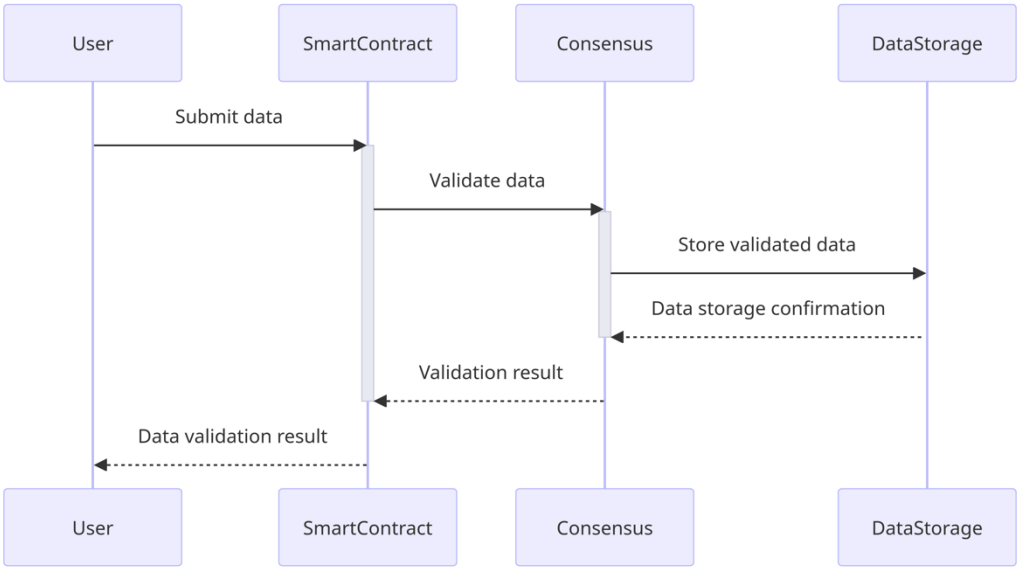

Figure 9 Data validation process on the blockchain

Table 3 Stakeholder authority differences

Stakeholder	Authority			
	Input	Modify	Validate	View
Classification Societies	✓	✓	✓	✓
Shipping company	✓	✓	✓	✓
Shipyard	✓			✓
Ship Recycle Facilities				✓
Hazardous Material Expert				✓
Port Authority				✓
Global Organization				✓
Insurance Companies				✓
Environmental Organization				✓
Ship Brokers				✓

Interviews were conducted to get an overview of the expected IHM standard from stakeholder, Port Authority. The result of the interview was analyzed with atlas.ti to answer the second sub-question. Moreover, the keywords that are frequently found on processed data were used to generate code on the following network below.

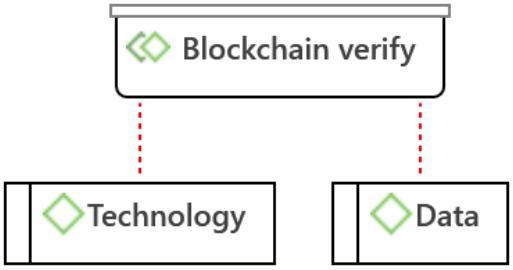

Figure 10 Network of codes for blockchain verify

i. Technology
Blockchain technology can be used to validate and secure data, also to ensure authenticity. This section indicates that verification systems will be the most effective for making IHM more accurate. Moreover, blockchain technology also provides a transparent and trusted method for managing data, which contributes to the integrity of the system. It records all changes and logs them for accountability and traceability, guaranteeing the authenticity and integrity of the data.

ii. Data
By implementing block chain technology, it makes it easier to monitor data and ensure that everything complies with regulations. This is because the data collected must be accurate, up-to-date, and verifiable. Moreover, it enables secure and transparent data management. In addition, IHM data must be constantly updated to reflect any changes in the inventory of hazardous materials on board.

4.3 Potential barriers to implementing blockchain technology in the maritime shipping industry and strategies for overcoming them

In this section, the third sub-question raised will be answered which is; What are the potential barriers to implementing blockchain technology in the Inventory of Hazardous Materials (IHM) in the maritime shipping industry?
In addressing this query, atlas.ti was employed to conduct interviews with three stakeholders to find potential barriers to implement blockchain. Although numerous factors were pinpointed, this report particularly emphasizes those that were repeatedly brought up during the discussions.
During the examination of the interview transcripts, commonly recurring terms mentioned by the participants were pinpointed. These terms were then employed to create a coding system to represent different potential barriers. In Figure 11 Network of codes for potential barriers, visually depicts the interconnections between these codes.

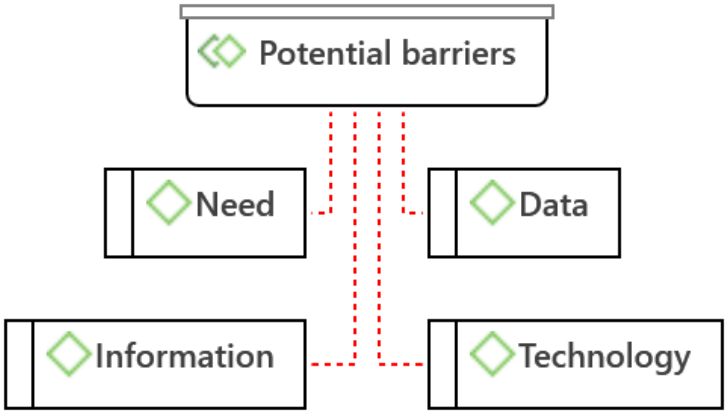

Figure 11 Network of codes for potential barriers

Several factors might be a potential barrier to implementing blockchain technology in inventory of hazardous materials:

i. Need
The need for blockchain technology in hazardous materials inventory management must be clearly established. This includes understanding the specific problems that blockchain can solve and the benefits it can bring to the process. If the need is not well-defined or if alternative solutions can address the same issues more efficiently or cost-effectively, this can be a barrier to blockchain implementation.

ii. Data
Data-related challenges can include issues such as data privacy concerns, data compatibility for information exchange, and the time required for processing transactions. There may also be issues related to the size of the blocks in the blockchain and the capacity of the distributed ledger system. Additionally, the lack of global standards and industry-level best practices for data management in blockchain can pose challenges.

iii. Information
Information-related barriers can include a lack of understanding or knowledge about blockchain technology, which can obstruct its adoption. This can be due to a lack of training or education about technology. Additionally, there may be issues related to information overload, where the large amount of data generated by blockchain technology can be overwhelming and difficult to manage.

iv. Technology
Technological barriers can include issues related to the integration of blockchain technology with existing systems, the reliability and functionality of the technology, and the availability of capable staff. There may also be regulatory uncertainties that can obstruct the implementation of blockchain technology.

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6 Appendix

Stakeholder: Shipping Company Interviewee name: Gofar Company: PT. Meratus Swadaya Maritim Position: Marine Superintendent		
No.	**Question**	**Answer**
1.	Overview of IHM management:	
	Can you describe the shipping company's current process for managing the Inventory of Hazardous Materials (IHM)?	The shipping company sort of documented process for managing the inventory of hazardous material throughout the ship's operational life, covering data collection, verification, regulatory compliance, stakeholder communication, and continuous improvement
	What are the key challenges you face in maintaining an accurate and up to date IHM?	Key challenges include obtaining complete and accurate IHM data from suppliers, keeping the IHM updated over time and ensuring all relevant staff are aware of the IHM procedures, and communicating IHM information clearly to stakeholder
	How do you ensure that IHM information is adequately communicated and shared among relevant stakeholders within the company?	To ensure effective communication my company assigned IHM responsible person, IHM information integrated into a company management system, structured processes for distributing updates, and access control defining what can view it
2.	Data collection and verification:	
	What methods do you use to collect and verify IHM data?	We use Supplier Declarations of Conformity (SDoC) and Material Declarations (MD) from manufacturers, cross-checking against technical documentation, visual/sampling checks during surveys, and testing by approved laboratories
	How do you ensure the accuracy and reliability of the IHM data you collect?	To ensure reliability, we use a documented quality management system governing data collection and verification activities, independent checks of submitted declarations, robust sampling methodology, use of accredited testing methods, and mandatory training for personnel involved.
	What challenges do you face in obtaining complete and accurate IHM data from suppliers and contractors?	Some partners like suppliers, not provide complete and accurate declarations, and the surveyors lack the necessary knowledge, for sampling proving is difficult for hard-to-access materials, testing labs have inconsistent competence, sometimes

		class societies interpreting regulations differently
3.	Regulatory compliance and enforcement:	
	How do you interact with regulatory bodies to clarify IHM requirements and address compliance issues?	We engage the regulatory bodies to clarify specific IHM requirements and discuss any compliance things
	How do you ensure that IHM data is readily available to those who need it for operational and regulatory compliance purposes?	It must be integrated with company management systems and accessible for shoreside and shipboard personnel. The status should be monitored and reported.
4.	Stakeholder engagement and communication:	
	How do you engage with and communicate IHM information to relevant stakeholders, such as materials suppliers, bureau classification, and port authorities?	Push communication and on-demand access are needed to provide information to the stakeholders
	What challenges do you face in communicating IHM information in a clear, concise, and understandable manner to different audiences?	There are differences in stakeholders' knowledge levels, information needs, and terminology used. Also, the lack of standardized IHM data formats can also cause confusion
	How do you ensure that stakeholders have access to the IHM information they need to make informed decisions and comply with regulations?	We need to identify specific stakeholders, determine their precise information requirements, establish structured communication plans, and simply/standardize IHM data as much as feasible
5.	Lessons learned and recommendations for improvement:	
	What lessons have you learned from your experience in managing IHM?	The need for expert guidance early on, extensive planning for surveys, continuous maintenance processes, integrating IHM into management systems, and proactive regulatory engagement
	What recommendations would you make to improve the process of managing IHM in the maritime shipping industry?	Starting the IHM process early, especially for existing ships, leveraging quality software solutions, focusing on supplier engagement, designating internal IHM experts and anticipating future regulations

Stakeholder: Classification Bureau
Interviewee name: Efe Akyurek
Company: Dutch Lloyd
Position: Technical Manager

No.	**Question**	**Answer**
1.	General questions:	
	What are the key challenges you face in managing the Inventory of Hazardous Materials (IHM) for ships under your classification?	There is lack of awareness of some ship owners because this is depending on the client profile of the each classification society. The society is a bit more focused with some small-cost

		owners and they are lack of awareness of regulation. The IHM regulation also one of the key challenge for us.
	What are the main sources of difficulty or inefficiency in this process?	There is no inefficiency in the process, but the main difficulty is lack of training for the shipping companies and the crew. The crew have no certificate or something. Lack of training is one of the difficulty for the industry.
2.	Challenges related to data collection and verification:	
	How do you ensure the completeness and accuracy of information provided by shipyards and owners regarding hazardous materials onboard classified ships?	They are on board classified ships during the actually I attempt some link, one of our inspector is still on board so they always attend on board say and so they check if the sample have been taken or not. So on accuracy of the something itself, it's very accurate on our site, but how the laboratory is emulating this sample actually they are also satisfied by some accreditations. So we believe they do, they do their business carefully, but of course we don't know sometimes, but we have to trust their certifications. So maybe there might be some inaccuracy on that part and during the manual preparation. So the IHM sampling company gets the sample results, the prepare the manual and they present us, sometimes they don't do the minimum required sampling.
	What challenges do you face in verifying the location and quantity of hazardous materials on ships?	So again this surveyor who goes on board, they do the check. But of course start we send it to surveyor checklist, that's where to be sampled at least. So the one of our surveyor is constantly on board to observe if the sampling is done correct or not ad put the certification. The lifetime of certificate is part year and during this part year sometime on one ship they do a lot of maintenance and maybe they change a lot of this as it does not carry on.
	How do you address inconsistencies or discrepancies in IHM data?	In the reality we don't do any check of course with the laboratory, but sometimes we suspect of some materials then we ask for resampling of isolated points. But to be honest, I have never seen any discrepancies until today. So it's quite accurate, looks like.
3.	Challenges related to IHM maintenance and updates:	
	How do you ensure that IHMs (Inventory of Hazardous Materials) are kept up-to-date as ships undergo modifications, repairs, or changes in equipment?	This is the most challenging part actually because this is the responsibility of the shipowners or the managers and the crew.

4.	Challenges related to IHM sharing and accessibility:	
	How do you share IHM information with relevant stakeholders, such as recycling facilities?	Of course we will share the IHM information with the recycling services if they request it. We also inform the ship owner, so with their approval we cannot do such thing because it's the fleet related data. But if the owner and the ship breaking agrees, we can always share it. Before ship goes to recycling, there must be also an additional sampling to be done.
	What measures are in place to ensure that IHM data is secure and accessible only to authorized users?	So it's you cannot control it actually, but the thing that I would like to remind you that after these manuals are prepared for the ship, we send it to the owners. The this is the information actually provide to the owners for actually maritime authorities up in the request, but we just approve it. So of course as an approval body we store the data, but we always hesitate to share it.
5.	Recommendations for improvement:	
	What changes or improvements would you recommend to the current IHM management process?	The most important thing is the training for the company
	What new technologies or tools could be used to address the challenges you face in managing IHMs?	There are some studies on blockchain technologies because it's also related to the share of information, so that can be easily done. Now we prefer some sort of technologies that can be updated automatically. Use of some computer programs are also very good solution.

Stakeholder: Port Authority
Interviewee name: Atika Khoirul Umaroh
Company: Port Management Unit of Tanjung Redeb
Position: Technical Staff

No.	**Question**	**Answer**
1.	General question about IHM management:	
	What are the key challenges you face in managing the Inventory of Hazardous Material (IHM) for ships entering and exiting your port?	The key challenges is ensuring the update and the accurate information of IHM itself. So because there's so many different things and different jurisdiction as well. So it's a bit difficult to inspect all of them. If we did some inspection of the inventory and managing the inventory
	How do you ensure the accuracy and completeness of IHM data for ships visiting your port?	We did a small meetings and then we did interview the staff who in hand with this activities. Then we review all of the document requirement. We follow all of

		the system that we developed before as well. And also this is based on the Bureau classification. We also collaborate with the other stakeholders
	What are the main sources of difficulty in verifying IHM information provided by ship operators?	Some of the information is incomplete, it's a bit difficult to verify
	What measures do you take to enforce compliance with IHM regulations?	I think all the authority around the world did the same, we have a guideline from the IMO. So based on that we make a list as an apply books, we used the list to do the inspection and then force the company to accomplish with all the IHM regulation, if not they will get fined.
	How do you measure the effectiveness of the current IHM management practices?	As I mentioned before we have a lot a list of guidelines and based on that we tried maximal to reduce the potential raise. And also maybe during the inspection we got some communication with other stakeholders like PSC, flag state and class as well. So we always communicate and one of the reason of the communication we measure to get the effectiveness of the in the core IHM
2.	Challenges specific to port authorities:	
	How does the volume and frequency of ship traffic impact your ability to effectively manage IHM data?	So when because I were in the small part and in monthly we are handling more than 300 ship then this would quarter there. So the traffic will influence the ability of how we manage the IHM data. So yeah it's challenging to get and then maintenance the data we need to provide the up to date data and then is this challenging because of the pure critical as well in Indonesia we maybe like the technology to help us but yeah you know the connection and then if everything's is quite challenging so maybe like how to get the that up to date from financial is it will be impact the effectiveness of the managing your IHM
	What resources does your port authority dedicate to IHM management?	For IHM management the first important thing is the human resource. Even though you implement the advance technology but the human is not capable to operate and the to implement it, it will be useless and so is human research and then technology and we thought the and then also the import.
	How do you collaborate with bureau classification and shipping companies to address IHM-related challenges?	We do it every month and then then it's also to engage how we engage the stakeholders And then in that meeting

		we're talking about the challenges, what is the problem etc.
	What measures are in place to ensure that IHM data is secure and accessible only to authorized used?	We need to keep all those secret information and then not every data we will we will open to the publics because you know the.
3.	Future challenges and opportunities in IHM management:	
	What emerging trends or technologies do you see shaping the future of IHM management in the maritime industry?	if you're following the current trend then or the digitalization, the puts in the digital twin right now it's hot topic and and every country try to implement it. I I think Indonesia's still running, but if you look at Europe like Rotterdam and Open Hamburg, they they are implement the digital clean technology and digitalization. But I think in Indonesia, we are support authority and administrative transportation right now. We try to do everything with digitalization because digital digitalization and technology will help us and everything they'll just help us and then change the way we work, not like not changing the people, but just changing how we work
	How do you see the role of port authorities in evolving IHM management practices?	I think it's just for monitoring and everything the the IHM management and then ensuring that everything is comply with the regulation that we did
	What recommendation would you make to improve the effectiveness of IHM management in the maritime industry as a whole?	The recommendation might be if you are the board manager authority or board manager you need to train your staff. So you need to have a capabilities to train your staff and then investment in technology as well and then manage the data. And I think the data technology or the technology or the data collection technology is more important than the data equipment. So ensure that your data collection for managing the data from the HM is advanced. if you have advanced technology but the maybe in I in the software is not good for the data collection, it will be useless, and also, the collaboration right now.