FRONT PAGE

AMIRUL KAMIL MUNAWWAR BIN AZHAR MASTER OF SCIENCE 2025

MARINE TRAFFIC RISK ASSESSMENT OF THE TERENGGANU RIVER NAVIGATION CHANNEL AT DUYONG ISLAND TERENGGANU

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MASTER OF SCIENCE
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TITLE PAGE

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AMIRUL KAMIL MUNAWWAR BIN AHAR

Thesis Submitted in Fulfilment of the Requirement for the Degree of Master of Science
Maritime Studies in the Faculty of Maritime Studies
Universiti Malaysia Terengganu

MARCH 2025

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Dedicated this thesis to:

My all: Abah, Mama & Adik Yaya

I owe you guys, big time

Thanks a lot

May Allah bless

Abstract of thesis presented to the Senate of Universiti Malaysia Terengganu in fulfilment of the requirements for the degree of Master of Science

MARINE TRAFFIC RISK ASSESSMENT OF THE TERENGGANU RIVER NAVIGATION CHANNEL AT DUYONG ISLAND TERENGGANU

AMIRUL KAMIL MUNAWWAR BIN AZHAR

FEBRUARY 2024

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Co-Supervisor	**:**	**Captain Noor Apandi Osnin, Ph.D**
Co-Supervisor	**:**	**Mohd Hafizi Said**
Faculty	**:**	**Faculty of Maritime Studies**

The Terengganu River, an essential transport waterway in Terengganu, Malaysia, has experienced a significant rise in vessel traffic due to rapid development involving sailing and offshore activities, alongside recreational events. Its proximity to vital facilities, such as the Duyong Island Marina and local shipyards, underscores its significance as a prominent maritime hub. Nevertheless, the growing maritime traffic in this navigation channel raises safety concerns, as it poses significant risks, including potential accidents and collisions, to all channel users. This situation necessitates a thorough assessment to ensure safe navigation. Therefore, this study aims to conduct a Marine Traffic Risk Assessment (MTRA) in the Terengganu River, with a focus on the area surrounding Duyong Island. The research objectives include identifying hazardous events, analysing and ranking risk levels, validating the safety of navigational channels, and proposing preventive measures to enhance safety. The study employed the Hazard Identification (HAZID) method to identify potential hazards, incorporating expert interviews and risk ranking to identify potential hazards. A risk matrix was then used to assess the severity of these risks, while the Permanent International Association of Navigation Congress (PIANC) guidelines for channel width design, coupled with simulation tests, were applied to validate navigational safety. The findings revealed that the existing channel width of 50 m is sufficient for one-way navigation but inadequate for two-way traffic navigation, which requires a minimum width of 78 m. Although no major accidents have been recorded, the study highlights the need for an increased channel width to accommodate two-way traffic safely. In summary, this research provides significant contributions in both academic and practical fields. Academically, it fills a gap in MTRA studies specific to Malaysia and demonstrates the application of PIANC guidelines. On the practical side, the study offers valuable insights for local authorities and maritime stakeholders to enhance safety measures and effectively plan future developments in the region.

Abstrak tesis yang dikemukakan kepada Senat Universiti Malaysia Terengganu sebagai memenuhi keperluan untuk Ijazah Sarjana Sains

PENILAIAN RISIKO LALUAN TRAFIK MARIN DI SUNGAI TERENGGANU DI PULAU DUYONG TERENGGANU

AMIRUL KAMIL MUNAWWAR BIN AZHAR

FEBRUARI 2024

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Fakulti	**:**	**Fakulti Pengajian Maritim**

Sungai Terengganu, sebuah laluan pengangkutan air penting di Terengganu, Malaysia, telah mengalami peningkatan trafik disebabkan peranannya dalam aktiviti pelayaran, aktiviti luar pesisir, dan acara rekreasi. Kedekatannya dengan kemudahan kritikal seperti Marina Pulau Duyong dan dok kapal menekankan kepentingannya tetapi juga menimbulkan kebimbangan mengenai keselamatan maritim. Peningkatan kesesakan ini menimbulkan risiko ketara, termasuk kemalangan dan perlanggaran, yang memerlukan penilaian menyeluruh untuk memastikan navigasi selamat. Kajian ini bertujuan untuk menangani kebimbangan keselamatan ini dengan menjalankan Penilaian Risiko Trafik Maritim (MTRA) di Sungai Terengganu, khususnya di kawasan sekitar Pulau Duyong. Objektif penyelidikan adalah untuk mengenal pasti kejadian berbahaya, menganalisis dan menyusun tahap risiko, mengesahkan keselamatan saluran navigasi, dan mencadangkan langkah-langkah untuk meningkatkan keselamatan. Dari segi metodologi, kajian ini menggunakan kaedah HAZID (Pengenalan Bahaya) untuk mengenal pasti bahaya melalui temu bual pakar dan penyusunan risiko. Matriks risiko digunakan untuk menganalisis tahap risiko, manakala keselamatan navigasi disahkan menggunakan panduan PIANC untuk reka bentuk lebar saluran dan ujian simulasi. Hasil kajian menunjukkan bahawa lebar

saluran sedia ada sebanyak 50 meter adalah mencukupi untuk navigasi satu hala tetapi tidak memadai untuk trafik dua hala yang memerlukan lebar 78 meter. Walaupun keadaan semasa belum menyebabkan kemalangan besar, kajian ini menekankan keperluan untuk lebar tambahan bagi menampung trafik dua hala dengan selamat. Penyelidikan ini menyumbang kepada bidang akademik dan praktikal. Dari segi akademik, ia mengisi kekurangan dalam literatur MTRA untuk Malaysia dan menunjukkan aplikasi panduan PIANC. Secara praktikal, ia memberikan pandangan berharga kepada pihak berkuasa tempatan dan pengendali maritim untuk meningkatkan langkah keselamatan dan menguruskan pembangunan masa depan dengan berkesan.

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APPROVALS

I certify that an Examination Committee has met on 19th February 2024 to conduct the final examination of Amirul Kamil Munawwar Bin Azhar, on his Master of Science thesis entitled **“Marine Traffic Risk Assessment of The Terengganu River Navigation Channel at Duyong Island Terengganu”** in accordance with the regulations approved by the Senate of Universiti Malaysia Terengganu. The Committee recommends that the candidate be awarded the relevant degree. The members of the Examination Committee are as follows:

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Date: 3 March 2025

This thesis has been accepted by the Senate of Universiti Malaysia Terengganu in fulfilment of the requirement for the degree of Master of Science.

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Date: 3 March 2025

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UMT or other institutions.

AMIRUL KAMIL MUNAWWAR BIN AZHAR

Date: 5th January 2025

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LIST OF ABBREVIATIONS

DNV	Det Norske Veritas
DOSH	Department of Occupational Safety and Health
ECDIS	Electronic Chart Display and Information System
FSA	Formal Safety Assessment
HAZID	Hazard Identification
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MAL	Malaysia
MARDEP	Marine Department Malaysia
MRA	Marine Risk Assessment
MTRA	Marine Traffic Risk Assessment
OSV	Offshore Supply Vessel
PIANC	Permanent International Association of Navigation Congresses
RADAR	Radio Detecting and Ranging
RV	Research Vessel
SOLAS	Safety of Life at Sea
VTS	Vessel Traffic Services

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter presents the core elements of this study, including the research background, problem statement, research questions, research objectives, research scope, justifications, and research significance. Besides, this chapter outlines a summary for each chapter in this thesis.

1.2 RESEARCH BACKGROUND

The Terengganu River is one of Terengganu's most prominent waterways. Originating from Kenyir Lake, it passes through the state capital and flows into the South China Sea. This river plays a vital role in the region's maritime activities, which include sailing, offshore operations, shipyard services, and various recreational endeavours (Wahaba, 2019). The river's proximity to essential facilities, such as the fisherman jetty on Duyong Island and MSET Shipbuilding, a shipyard with a dry dock and repair services, further underscores its importance. Moreover, offshore crews are transported via vessels from Aims Global Maritime's jetty, contributing to the existing bustling traffic.

Duyong Island, located at the mouth of the Terengganu River, has experienced a major geographical transformation resulting from sedimentation and land reclamation, leading to the merging of two formerly separated islands, Duyong Besar and Duyong Kecil (Thayalan, 2007). The island is now home to the Heritage Bay Resort, which serves as a venue for prominent yacht races, including the Monsoon Cup. Besides, the opening of the Duyong Island Marina in 2005 has changed the area into a centre for regional and international maritime events (Abdullah et al., 2015). Such developments have established Kuala Terengganu as a critical point for prestigious boating events and a training ground for sailing professionals worldwide.

Nevertheless, the increasing maritime activities have significantly intensified traffic on the Terengganu River. The growing number of vessels, along with commercial, recreational, and offshore operations, has raised concerns over the safety of the river users, including fishermen, sports enthusiasts, and commercial operators. Therefore, the economic and recreational importance of the Terengganu River warrants the safety and protection of its waterways.

In view of future development and an anticipated increase in maritime activities, a detailed risk assessment of the river navigation channel at Duyong Island is necessary. Conducting a Marine Traffic Risk Assessment (MTRA) will assist authorities and stakeholders in understanding the risk factors, implementing effective mitigation strategies, and ensuring that the river remains safe for all users. This study is essential for maintaining the region's maritime operations, safeguarding the lives of users, and preventing damage to vessels and infrastructure. Thus, it is pertinent to identify risk factors and propose mitigation measures in order to enhance marine safety, reduce the risk of accidents, and promote sustainable maritime development along the Terengganu river.

1.3 PROBLEM STATEMENT

The Terengganu River, a district hub for numerous marine activities and rapid development, faces rising maritime traffic, heightening the risk of accidents and other hazardous events. Wahaba (2019) highlighted that the river is central to various industries, including tourism and commerce, which significantly contribute to its busy waters. Faturachman (2012) further emphasized that the increase in marine traffic is a critical factor in the occurrence of maritime accidents, as the river is frequently used for diverse marine operations. Similarly, Uluscu (2009) indicated the association between the elevated traffic flow in waterways and the greater risk of hazardous situations and accidents. Given the rise in maritime activities and vessels navigating the Terengganu river, the potential for high-impact incidents poses a pressing concern that warrants attention.

1.4 RESEARCH QUESTION

1) What are the potential hazardous events that can occur at the Terengganu river?
2) What are the risk levels linked to the potential hazardous events identified in the Terengganu river?
3) How can the safety of navigational waterways in the Terengganu river be identified?
4) What recommendations can be made to create a safe marine environment for the river user?

1.5 OBJECTIVE OF THE RESEARCH

This study aims to conduct a Marine Traffic Risk Assessment (MTRA) within the Terengganu River, specifically the waters surrounding Duyong Island. The following objectives were established to achieve the aim of this study:

1) To identify potential hazardous events in the Terengganu river.
2) To analyse the risk levels associated with the potential hazardous events identified in the Terengganu river.
3) To validate the safety of navigational channels in the Terengganu river.
4) To propose safety measures to ensure a safe environment for the Terengganu river users.

1.6 SCOPE OF THE RESEARCH

The study area consists of two segments of the Terengganu river, labelled area A and area B, which are known to exhibit higher maritime activities, as shown in Figure 1.1. Area A is the location of the new Kuala Terengganu Drawbridge, where the narrow vessel navigation gap below the bridge is the primary concern. Area B covers the navigational channel near Duyong Island Fisherman Jetty, which is the primary route for river users.

Figure 1.1 Location of study area A and area B along the Terengganu river near Duyong Island. Source: Google (2020)

Figure 1.2 Location of study area A. Source: Google (2020)

Figure 1.2 shows the location of study area A. This area is located at 5° 20.4' N, 103° 08.7' E, and covers up to 108,721.92 m^2, as highlighted in the orange square. According to the Malaysian National Hydrography Centre (2020), marine navigation chart number MAL 6522 (Figure 1.4) shows that the drawbridge has a width gap of approximately 50 m for vessels to pass through underneath, with an average water depth of 7 m during low tide. This serves as the main navigation channel for vessels entering and leaving the Terengganu river.

Figure 1.3 Location of study area B. Source: Google (2020)

Figure 1.3 shows the location of study area B. This area is located at 5° 20.1' N, 103° 07.8' E, and covers up to 115,426.29 m^2, as highlighted in the orange square. According to the Malaysian National Hydrography Centre (2020), marine navigation chart number MAL 6522 (Figure 1.4) indicates that the width gap for vessel navigation channels in this area is 130 m, with an average water depth of 5 m at low tide. The presence of jetty terminals and shipyards in this location, along with its role as a primary route for vessels entering and leaving the Terengganu river, makes it a highly congested route.

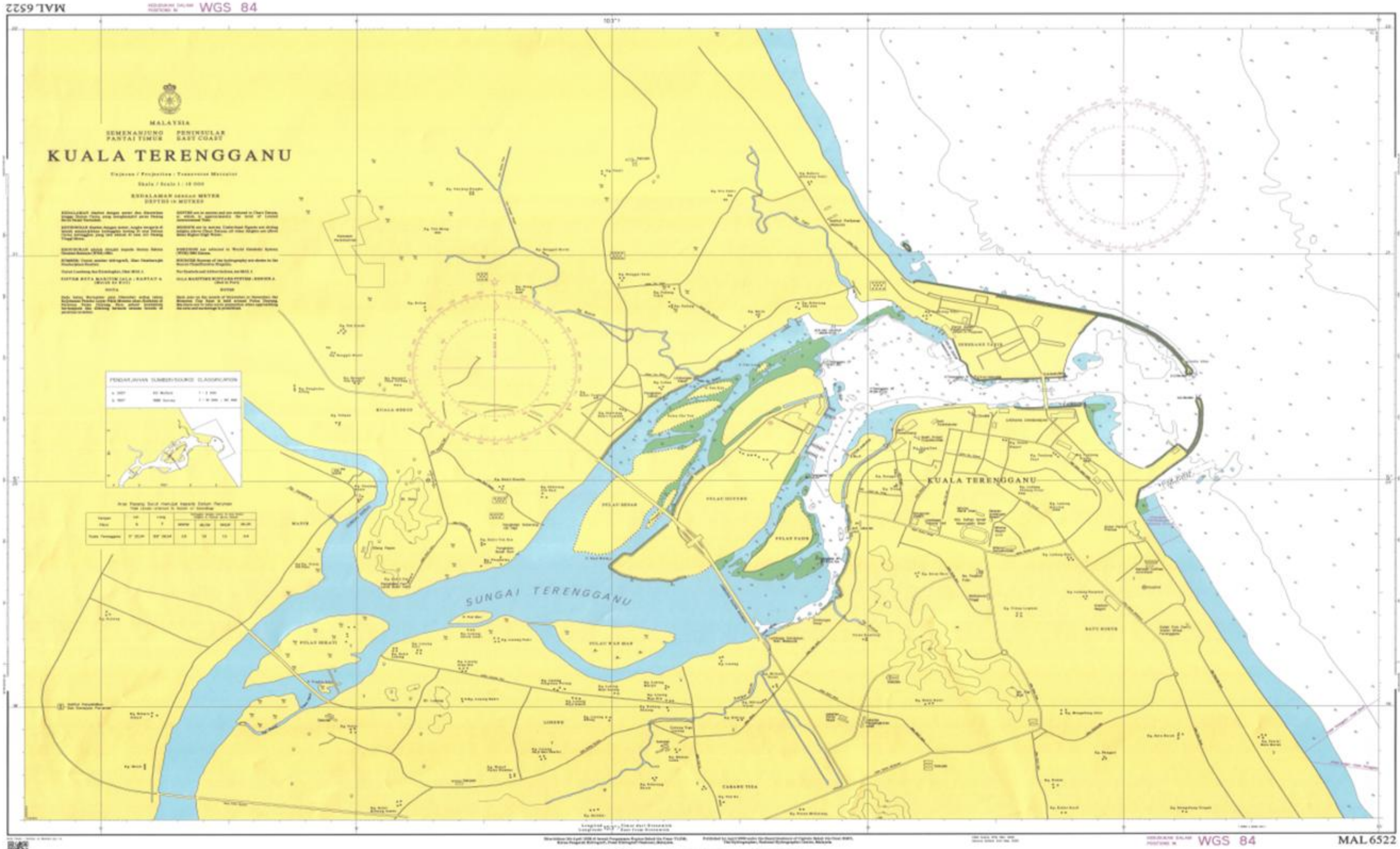

Figure 1.4 MAL 6522 Chart of Kuala Terengganu, second edition. Source: Malaysian National Hydrography Centre (2020)

1.7 JUSTIFICATION OF RESEARCH

Kori (2022) states that Terengganu experiences steady development and economic growth every. The maritime sector in Kuala Terengganu features a prominent inland waterway near Duyong Island, well known among shipwrights. Today, this area has become a bustling navigation waterway given the numerous maritime activities, including shipbuilding and repair, offshore crew transport, monsoon yacht races, fishing activities, and enforcement agencies activities.

The increase in maritime activities can affect the capacity of the marine traffic lane and may lead to major hazardous events, especially with the rising marine traffic flow in the area. As Sulaiman (2011) noted, “Collision in inland water transportation represents the biggest threat to inland water transportation; its occurrence is very infrequent but has a grave consequence that makes its avoidance a very imperative factor.” Despite their extensive experience, boatmen tend to become overly confident in their ability to ensure passenger safety, which can potentially lead to incidents (Cyber-RT, 2018).

These issues highlight the need for an assessment to mitigate the risks and hazards events associated with increasing marine traffic. The safety of marine traffic users can also be guaranteed without compromising future development projects at Terengganu river (The Star, 2009).

1.8 SIGNIFICANCE OF RESEARCH

According to MARDEP (2019), the Malaysia Shipping Notice 02/2019 stipulated under Section 491B of the Merchant Shipping Ordinance, 1952, states that marine risk assessment is mandatory in marine-related activities, especially in decision-making in marine operations in this country. The results of this study will primarily acknowledge the marine traffic safety within the study area (Duyong Island). Moreover, this study could provide authorities with valuable research data on the significance and impact of the area and the potential to save lives. As the saying goes, prevention is better than cure. Identifying and mitigating the risk of hazardous events is crucial to ensure safety, which remains the top priority, especially when it involves protecting lives and loved ones.

1.9 RESEARCH LIMITATION

This study suffers several limitations throughout the research period. Primarily, this research was performed without any research grant or external financial support, leading to insufficient resources for data collection and analysis. Secondly, secondary data, particularly related to incidents or accident records in the study area, were notably scarce. Although interviews and community engagement indicated that such accidents do occur, no official reports were filed. While some incidents were mentioned in the newspaper reports, official records of these cases were unavailable.

1.10 OUTLINE OF THESIS

Chapter 1 – Introduction

This chapter presents the research background, problem statement, research questions, research objectives, and research contributions. The justification, significance, and limitations of conducting this study are also highlighted in this chapter to establish a clear vision of this study.

Chapter 2 – Literature Review

Chapter 2 provides a comprehensive review of past literature related to, but not limited to, the MTRA, the hazardous events and risks in river waterway navigations, and the regulations associated with navigational data related to marine accidents.

Chapter 3 – Methodology

This chapter outlines the flow of research activities undertaken to achieve the research objectives. These include the research framework, research approach, research design, and research methods applied.

Chapter 4 – Data Analysis

This chapter describes in detail the data collection, analysis, and findings for the study area. All four objectives are addressed in detail, including the flowchart for each analysis method used to obtain the results for each objective. This flowchart shows the steps taken to analyse the collected data.

Chapter 5 – Results and Discussion

This chapter discusses the research findings and illustrates the results obtained based on validated outcomes to propose an informed and considered recommendation for the enhancement of marine traffic flow at Terengganu River.

Chapter 6 – Research Summary and Conclusion

This chapter summarises the study findings, the implications of the problems discussed based on the objectives, and the research contribution to the maritime industry. A list of recommendations is also provided for future works.

1.11 SUMMARY OF CHAPTER 1

This chapter presented the fundamentals of this study and the justifications for its conduct. The four main research objectives were also derived from the research questions that the study aims to achieve. The next chapter presents the initial data gathered from the literature review.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION TO CHAPTER 2

This chapter examines previous studies on the Terengganu river navigational channel and marine traffic assessments. The discussion progresses from local and global perspectives to the conceptual frameworks, which are the main highlights of this study. Terengganu River was selected for this study owing to its rich history of marine industries and the emerging development in its surroundings. The construction of the Kuala Terengganu Drawbridge and the increase in daily marine activities have contributed to the growing number of marine traffic users.

2.2 MARINE TRAFFIC RISK ASSESSMENT (MTRA)

The MTRA is part of a study under the Marine Risk Assessment (MRA). According to MARDEP (2019), MRA is a new mandatory requirement as per the Malaysian Shipping Notice 02/2019 stipulated under Section 491B of the Merchant Shipping Ordinance, 1952. MRA covers a broad scope of topics that include the marine environment, marine personal safety, the impact of construction activities on marine ecosystems, and MTRA. In contrast, MTRA focuses on assessing risks related to marine traffic. It emphasises marine navigation safety and identifies potential hazards that could harm navigation safety and lead to high-risk events. The MTRA also examines the impacts of project activities, allowing for the development of a detailed response management system.

Numerous MTRA methods have been proposed. For example, Montewka (2011) developed a specific MTRA focusing on collision and grounding hazards in the Gulf of Finland. The model summarised the calculation, which includes the probability of an unwanted event and its consequence, to validate the risk. The study also employed the minimum-distance-to-collision-based model, which was evaluated through a mathematical ship motion model to assess potential risks.

For this study, a combined method was used at Duyong Island, Terengganu. Initially, a hazard identification process was conducted, and a tabulated risk matrix was developed based on expert opinions. Then, the potential risks were assessed to obtain the risk ranking, after which mitigation measures were implemented to reduce the risk. According to Möller (2012), higher-risk surroundings lead to a lack of safety in the environment. Based on this statement, the safety of the navigation channel in this study area was assessed via mathematical calculation and simulation study.

MTRA has also been developed to identify potential hazards from various perspectives, such as natural conditions, technical failures, route conditions, ship-related factors, human or personal errors, and cargo-related factors. As stated by Bai (2014), MTRA anticipates potential accidents in the designated area and evaluates the accident outcomes based on the likelihood of occurrence and the resulting impact. The primary steps involved in MTRA encompass data collection, identification of potential hazards, conducting assessments, calculating risks, and making predictions.

Basically, the risk assessment procedure encompasses examining the company’s activities and processes, recognising potential issues, and determining relevant preventive measures to mitigate them (Dasgupta, 2017). According to Stelzenmuller (2018), risk assessment is a process aimed at minimising the likelihood of failing to achieve management objectives. For instance, this may involve managing cumulative pressures to ensure they remain below established acceptable thresholds.

MTRA aims to reduce and identify the best way to mitigate identified hazards. According to Rahman (2017), marine accidents that have occurred could have been minimised by carrying out a risk assessment. Hence, MTRA plays a vital role in the maritime industry. This feasible study could help in preventing major incidents through early assessment of hazards and risks. MARDEP (2019) mentioned that risks must be assessed and mitigated to implement adequate preventive measures, thus minimising accidents and ensuring health and safety on board a ship or working area.

Hu (2012) noted that risk management associated with marine traffic in coastal water regions is designed to foster a safety culture at sea. This culture ensures the safety of vessel traffic, optimises resource utilisation, enhances the competence of personnel engaged in coastal vessel traffic systems, promotes crew comfort with ship equipment, cargo, and diverse environments, and simultaneously reduces or eliminates safety hazards in operations. This comprehensive process encompasses hazard identification, risk evaluation, early warning systems, emergency responses, and consistent commitment to improvement, contributing to a continuous enhancement of safety in maritime traffic areas.

The regulation related to the MTRA study is governed by the International Maritime Organisation (IMO). Most risk assessment studies are guided by Formal Safety Assessment (FSA), which provides essential guidelines for risk assessment. The FSA was approved in 2002 under MSC/Circ.1023/MEPC.Circ.392, which was amended and superseded by MSC-MEPC.2/Circ.12/Rev.2. Moreover, MTRA has been recognised as a mandatory requirement in Malaysia. According to MARDEP (2019), MTRA is a vital study necessary to maintain good navigational safety and practice in the maritime industry. This further supports the need to conduct MTRA studies at the navigation channel at Duyong Island, Terengganu.

2.3 MARINE NAVIGATION

The term navigation is derived from the Latin words “navis,” signifying ship, and “agere,” meaning to guide. It refers to the precise determination of a craft or vehicle’s location and the regulation of its course. This is achieved by identifying the navigator’s position in relation to established landmarks or predefined routes (MarineLink, 2022).

According to Jalonen (2017), marine navigation refers to the process of navigating watercraft on the water surface. This involves route planning, determining position, watchkeeping, and shipping management. In the past, global trade was conducted through shipping. In the 15th century, Malacca became the world's largest entrepôt due to its strategic location. Malaccans were also renowned for their excellent shipment, especially in marine navigation. Their ability to forecast weather and knowledge of water routes give them a significant advantage in sailing across the sea.

Marine navigation has substantially evolved, with various modern equipment invented to assist navigators in navigating the waters more efficiently. Navigating tools, such as Electronic Chart Display and Information System (ECDIS) and RADAR, have proven essential for route planning and position plotting. Additionally, marine navigation equipment holds great potential to assist seafarers in navigating their vessels and reduce human error (Vu, 2019).

Marine navigation can be divided into three categories: ocean, river, and inland waterway navigation (Gosh, 2024). Ocean navigation denotes an open sea voyage where vessels navigate through the ocean. This is the least-risk navigation compared to others, as the wider area and sufficient depth of the ocean accommodate all types of vessels to navigate. Meanwhile, river navigation focuses on navigating within rivers. Potential river hazards, such as narrow rivers and sharp bendings, can lead to a high risk of grounding situations. In contrast, inland waterways usually focus on port or navigation channel areas. These areas are the most challenging to navigate due to the numerous hazards that need to be assessed, such as insufficient water depth and narrow navigating spaces. River navigation is more complicated than open sea navigation, which warrants extensive research in this particular area (Galor, 2017).

Conducting a study in the river or inland waterways is crucial since these locations are prone to high-risk incidents. With the growing marine industry and increasing activities near the river, coupled with the lack of research in this area, an MTRA study is needed, especially within Duyong Island, Terengganu.

2.3.1 Safe Navigation

Marine navigation safety is the primary motivation of this study. Risk assessment is a component of the study that provides an overview of the safety levels in navigational areas. It helps determine the level of safety for a vessel to navigate through an area by evaluating numerous factors that influence the overall risk.

The criteria for determining navigation safety include the potential hazards, risk levels, environmental conditions, vessel seaworthiness, and navigational aids. According to Choi (2007), the primary step in determining navigation route safety is reviewing weather forecasts and examining nautical charts, especially on water conditions, such as tides and depth. Next, all potential hazards in the navigation area must be identified and reported to the authority for route planning. To ensure navigation safety, vessel condition and navigation equipment on board must be in good state to prevent mechanical and engine failure and avoid equipment deficiency.

Based on IMO (2021), SOLAS Resolution A.893 states that 80% of navigation accidents are caused by human errors. Most accidents occur due to simple mistakes, such as misinterpretations of information and improper use of navigational equipment. These errors are often not due to a lack of knowledge or seamanship but rather primarily because of simple mistakes. This highlights the need to minimise human error in ensuring navigation safety.

Navigational aid is another crucial element that must be prioritised, given its essential role in determining navigation safety in certain areas. Poor navigational aids will make the area less safe for vessels to navigate, especially in river channels or inland waterways. The PIANC Harbour Approach Channel Design Guidelines (2014) emphasised the need to assess the levels of navigational aid when estimating the required safety measures in the area. This element is one of the contributing factors to calculating the safe width of a navigation channel, along with the provision of adequate navigational aids, environmental conditions, and vessel manoeuvrability.

Providing a safe navigational channel is one of the crucial parts of maintaining marine safety. To provide a safe navigation channel, a comprehensive MTRA study is needed at Duyong Island, Terengganu, to determine a safe navigation channel for its users and mitigate potential risks.

2.3.2 Concept of Hazards Marine Activities

A hazard is typically described as a potential source of harm or adverse health effects on humans, property, or the environment. Hazards can arise from various sources and can be categorised into several types, such as natural, technological, biological, and environmental (Smith, 2013).

In 2002, the International Maritime Organisation (IMO) defined a hazard as anything capable of posing a danger to human life, well-being, property, or the environment. The Canadian Centre for Occupational Health and Safety (CCOHS) in 2018 further describes a hazard as any source with the potential to cause damage, injury, or adverse health consequences to objects or individuals. In essence, anything with the potential to inflict harm upon people, the environment, property, or stakeholders in the maritime sector is considered a hazard.

Based on DNV (2001), marine hazards that could lead to major accidents, such as structural failure, collision, and capsize, must be addressed in the safety case and shown to be as low as reasonably practicable (ALARP). Other marine hazards, such as loss of position keeping and utility systems, may also be addressed in the safety case as potential initiators of major accidents or as part of the more general duty.

According to IMO (2018), under the MSC-MEPC.2/Circ.12/Rev.2, the revised guidelines for Formal Safety Assessment (FSA) have listed several hazards related to marine. Table 2.1 presents the list of hazards classified under three categories, namely, personal, on board, and external to the ship.

Table 2.1 Potential hazards listed in the revised guidelines for Formal Safety Assessment (FSA)

Hazard categories	**Potential hazard**
Personal	- Asbestos inhalation - Burns from caustic liquids and acids - Electric shock and electrocution - Falling overboard - Pilot ladder operation
On board	- Combustible furnishing - Oil/fat galley equipment - Cabling - Fuel and diesel oil for engines, boilers, and incinerators - Thermal heating fluid systems
External to the ship	- Storm - Lightning - Uncharted submerged objects - Other ships

Source: IMO (2018)

2.3.3 Hazardous Events Categories

According to Lawrynowicz (2015), a hazardous event is a hazardous situation that arises from a hazard and leads to specific consequences. In this study, the hazardous event will be the common marine incident that could happen in the study area. Based on a global study of likely maritime incidents, Ajeco (2018) identified collision, grounding, and allision as the common types of maritime accidents. According to MARDEP (2021), the reported marine accidents that commonly occur in this area include collision, grounding, allision, fire and explosion, and drifting. This information will be used to present several hazardous events to the experts familiar with the study area.

2.3.3.1 Collision

According to Nayal (2021), a collision is an incident when two or more vessels come in physical contact with each other, leading to damaging events, such as loss of life and vessel damage. In total, MARDEP (2021) has recorded 13 cases of vessel collisions throughout 2021.

2.3.3.2 Grounding

Grounding occurs when a vessel comes into contact with the seabed due to insufficient water depth. Pedersen (2000) stated that grounding can cause severe damage to the vessel hull, particularly if it strikes hard sedimentation, such as rock or coral. The damage could lead to further disruption, such as sinking.

2.3.3.3 Striking

Hofmann (2021) defines striking as a maritime accident where a vessel collides with a stationary object. The stationary objects include jetties, buoys, lighthouses, pillars or bridges, and any maritime structure. This type of event commonly occurs and can result in significant injuries.

2.4 Reviews of Hazard Identification Studies

According to IMO under FSA (2002), Hazard Identification (HAZID) is the process of analysing risk by identifying the potential hazard in the area. Well (1996) stated that HAZID aims to detect and define all possible hazards that may threaten the safety of all the components interacting in a specific operation.

HAZID studies are widely employed in the maritime sector for various applications, such as risk management in maritime logistics and supply chain (Mokhtari, 2014), marine safety in machinery spaces (McNay, 2020), and an MTRA study in the Sarawak River (Khalid, 2019). Haugen (2022) also emphasised the importance of HAZID study in maritime transportation safety management and risk analysis.

The significance and reliability of the HAZID study made it into a mandatory study, as stated by MARDEP (2019) that a complete MTRA needs a HAZID study that is conducted through workshops or interviews with a number of experts in marine-related fields. This is a mandatory requirement as per Malaysia Shipping Notice 02/2019 stipulated under Section 491B of the Merchant Shipping Ordinance, 1952.

According to DNV (2001), it is essential to address potential marine dangers in the safety case that could lead to significant incidents, such as structural failures, collisions, or capsizing. The safety case must demonstrate that these risks have been minimised to the greatest extent possible. In the safety case, additional maritime risks, including the inability to maintain position and the loss of utility systems, could be included as potential triggers for significant accidents or in line with broader safety responsibility.

2.5 PERMANENT INTERNATIONAL ASSOCIATION OF NAVIGATION CONGRESS (PIANC)

PIANC is the World Association for Waterborne Transport Infrastructure, serving as a global platform for professionals to collaborate and provide expert guidance on creating cost-effective, dependable, and sustainable infrastructure that supports the development of waterborne transportation (PIANC, 2014).

According to Sohngen (2014), PIANC is a leading organisation for international specialists to address technical, economic, and environmental challenges related to waterborne transport infrastructure. It serves as a primary resource for both government agencies and the private sector in the planning, construction, and maintenance of ports, waterways, and coastal regions.

This guideline was selected for this study as it offers the most effective guideline for assessing the safety of design in inland waterway channels. McBride (2014) also claimed that the PIANC Harbour Approach Channel Design Guidelines Report 2014 is the best guideline for addressing horizontal and vertical dimensions relating to shipping channels and manoeuvring areas.

Secondly, this guideline has been extensively used by experts, especially in conceptual design studies focused on channel and waterway designs for vessel navigation. Gardner (2019) supports this by stating that PIANC guidelines are widely used in determining the acceptable calculations for channel width clearance for vessels. The Harbour Approach Channel Design Guidelines also provide a calculation method for determining the safest width channel design for certain vessels.

No academic study has focused on channel design safety in Malaysia using the PIANC guidelines, particularly within the Terengganu River. This implies a research gap that needs to be addressed. Hence, this study aims to fill this knowledge gap by employing PIANC guidelines to assess channel design safety in the Terengganu River.

2.6 STUDY AREA BACKGROUND AND CONDITION

This section highlights Duyong Island near the Terengganu River as an essential element of the MTRA study. The marine activities conducted within this area can influence the capacity of river users. Additionally, data on the river users, such as the number and type of vessels that usually navigate this river, along with weather information relevant to the study area, are presented.

2.6.1 Marine Traffic-Related Activities

The following sections highlight various marine activities that contribute significantly to high-risk incidents in the Terengganu River. These include miner boats, yacht races, the Kuala Terengganu Drawbridge, shipyard and offshore-related operations, and the River Cruise Taman Tamadun Islam. These activities pose major hazards to navigational channels, potentially resulting in severe casualties. Other maritime activities, such as rowing or traditional boat racing, which occur less frequently, are not focused in this study.

2.6.1.1 Miner Boats

Miner boats resemble minivan-type vessels designed to transport up to 40 passengers per trip (Mahfuz, 2018). This mode of transportation was popular among local communities around the late 1970s as one of the options for crossing the river. Miner boats are still in service in the Terengganu river and have been classified as a traditional transportation, contributing to the area's tourist appeal. Figure 2.1 illustrates the transit route of miner boats from Seberang Takir to Pasar Payang, with a travel time of only 10 minutes, while Figure 2.2 displays an example of a miner boat at Kuala Terengganu.

The number of miner boats operating in the Terengganu river has reduced from 70 to only 15 due to several factors. The construction of the new drawbridge across the river has caused more people to cross the bridge than using miner boats. This shift has a negative impact on the income of boat operators and affects the condition of the boats, as boat operators struggle to cover the higher cost of maintenance. Moreover, many of these boats have operated for over 20 years (Zulkifli, 2021).

According to the Maritime Injury Guide (2022), the lack of maintenance and safety aspects for boats can result in severe events, such as engine or rudder failure, consequently leading to collisions or groundings. Such scenarios pose significant risks for all river users, especially if they do not maintain their boats while navigating routes that intersect with the navigation channel. This negligence could increase the risk to other marine traffic users.

Figure 2.1 Miner boat route from Seberang Takir to Pasar Payang. Source: Google (2019)

Figure 2.2 Passengers boarding a miner boat at Terengganu river. Source: Google (2019)

2.6.1.2 Yacht Race

Kuala Terengganu, especially Duyong Island, is a prominent avenue for yacht races. This maritime activity takes place annually with various race categories at both international and local levels. The International Monsoon Cup World Match Racing Tour, first held in 2005, is the largest yacht race event involving over 183 countries. In fact, Duyong Island was selected as the first Asian venue for this event and is recognised for its challenging race conditions and world-class marina facilities (Tourism Terengganu, 2017).

The final International Monsoon Cup World Match Racing Tour in Terengganu took place in 2011, as shown in Figure 2.3. Less prestigious domestic yacht racing events continue to take place. Due to the high demand among sailors, a Monsoon Cup Terengganu was organised in 2015. The existing facilities, such as customs, immigration, and the yacht club, with their vessel berthing and maintenance facilities, have significantly advanced the sport of sailing (David, 2016).

According to Ali (2017), the Terengganu Monsoon Challenge Sailing GP took place at Duyong Marina & Resorts, Duyong Island, from November 23 to 26, 2017. Approximately 300 local and international sailors, both professional and amateur, participated in this event. This rendered it the largest sailing event held at Duyong Island, thus categorising it as a prominent marine activity in the Terengganu River.

A yacht is a sail-driven or power-driven vessel. Most yachts use sails to manoeuvre and rely on wind power for navigation. Depending on the type and intended use, yachts are classified into monohull or multihull vessels (Sailingheaven, 2019).

Yacht race events use the same navigational channel on the Terengganu River, positioning yachts as one of the major marine traffic users. Although these events are usually held annually, the channel becomes congested with yacht boats on race days. Since many yachts are sail-driven vessels, they are more challenging to manoeuvre and difficult to avoid any dangerous situations. This congestion can pose a considerable risk to other channel users.

Figure 2.3 Several yachts docking at Duyong Marina. Source: Google (2019)

2.6.1.3 Terengganu Drawbridge

Madehow (2018) describes a drawbridge as a movable bridge that can be lowered or raised accordingly. A drawbridge is typically built over a navigational waterway to allow boats and ships to cross its path. Compared to stationary bridges, drawbridges are more expensive to operate and maintain. They can also impede water traffic when lowered and block vehicular or rail traffic when raised.

Figure 2.4 shows the Terengganu Drawbridge, an iconic architecture connecting Kuala Terengganu city centre to Kuala Nerus via Seberang Takir. Spanning across the Terengganu River, the bridge measures 632 m in length and 23 m in width, with the main purpose of reducing traffic congestion on the Sultan Mahmud Bridge (Zelan Berhad, 2018). This drawbridge became fully operational in 2019.

Workboats were actively engaged in the area during its construction process. This contributes to the increasing number of vessels navigating the Terengganu River, elevating the risk and significant hazards. Although the Environmental Impact Assessment (EIA) was conducted, the mitigation measure needs to be appropriately executed (The Sun, 2018).

New risks emerged after the drawbridge was completely operational. As stated by Hashim (2017), the navigation channel had previously been dredged in 2006, resulting in a width of 100 m and a draught of 7 m. However, the newly constructed drawbridge reduced the channel to 50 m due to its supporting pillars. Additionally, the draught is expected to decrease because of sand accumulation beneath the bridge. Furthermore, vessels face constraints related to limited air draft, with a maximum allowable height of just 10 m. The presence of the drawbridge not only raised the density of maritime traffic but also intensified the surrounding hazards, ultimately leading to a higher-risk environment.

Figure 2.4 Kuala Terengganu Drawbridge. Source: Tradelinkmedia (2020)

2.6.1.4 Shipyard and Offshore-Related Operation

Duyong Island has long been a popular location for shipbuilding operations. Today, several shipyards continue to operate in the area, including MSET Shipbuilding Corporation, Kay Marine, and Sejati Shipyard (Hashim, 2017). According to the Malaysia Defence Directory (2018), the shipyards on Duyong Island are designated for fabricating steel vessels with displacements exceeding 1,000 tonnes. These vessels include tugboats, anchor-handling tugs, support supply vessels, survey vessels, coastal product tankers, and bunker barges.

MSET Shipbuilding Corporation is the most renowned shipyard on Duyong Island. The overall area of the MSET shipyard is nearly 5.2 ha, and most of the vessels built are government vessels for the Malaysian Navy, Police, Marine Department, Customs, and Fisheries agencies. The company also managed to build over 1,000 vessels of varying sizes, with most being 60 m in length and 3 m in draft (Utusan, 2001).

Besides, Duyong Island provides offshore services. Numerous companies, including Aims Global, Tanjing Offshore, Borcos and Inai Kiara, have established their assets on the island to support offshore services, including shelter, bunker, and crew exchange operations (Hashim, 2017).

These operations at Duyong Island use the Terengganu River as their primary navigation channel. Both offshore vessels and those headed to the shipyards rely on this river as their main route. The presence of shipyards and offshore services attracts more vessels to enter this area, which increases traffic density. The growing number of vessels will consequently elevate the risk of accidents and lead to major potential hazards.

2.6.1.5 River Cruise Taman Tamadun Islam

Taman Tamadun Islam (TTI) in Kuala Terengganu offers a river cruise service. According to the TTI website (2022), this river cruise is one of the main tourist attractions. The cruise route begins at the TTI arch, passing through the Crystal Mosque, Kampung Losong, Pulau Warisan, and Taman Selera Tanjung, before returning via Kampung Duyong to Tok Ku Paloh base. This river cruise is categorised as one of the vessels that use the Terengganu River navigation channel, contributing to the increasing marine traffic and high-risk events.

In May 2014, TTI introduced a night river cruise for tourists to experience a unique cruise activity around Duyong Island after dark. However, night navigation presents higher risks due to reduced visibility, making it essential to ensure the safety of the cruise to prevent major hazards (The Sun, 2014).

2.6.2 TYPE OF VESSEL

This section provides an overview of the various types of ships that commonly navigate the Terengganu River’s channel. It also includes details of the vessels, such as the IMO number or call sign, Gross Tonnage (GT), Length Overall (LOA), breadth, and vessel draught. Understanding these characteristics is particularly significant as it offers valuable insights into the maximum size of ships navigating the channel, as emphasised by PIANC (2014).

According to Table 2.2, Paraffin is the largest type of vessel that passesed this river. As a yacht-type vessel, it is classified as a moderately manoeuvrable vessel, as stated by PIANC (2014) guidelines on vessel manoeuvrability. Vessels with good manoeuvrability typically have twin propellers, such as Offshore Supply Vessels (OSV) and Research Vessels (RV), both of which are categorised as having excellent manoeuvrability. This information is useful for calculating the appropriate width of the channel.

Table 2.2 The characteristics of vessels navigating the Terengganu River

Vessel	Model (name & IMO number)	Characteristics			
		LOA (m)	Breadth (m)	Draught (m)	Gross tonnage (tonnes)
Offshore Supply Vessel (OSV)	Aishah Aims 3 IMO: 9627409	44.75	9.6	5.2	438
Yacht	Paraffin IMO: 1006946	60	10	6.3	1092
Crew boat	Nautica Gambir IMO: 9787091	30	5	3.6	267
Passenger vessel	Jati Six IMO: 9683922	40.37	7.5	4.5	238
High-speed craft	Dm Ascentia IMO: 9787089	39	7.6	3.5	267
Research vessel	Rv Discovery IMO: 533224123	35	5	3.3	300
Fishing vessel	Class: A, B, C, C2, C3	2~50	0.5~8	1~4	>40

Source: Marinetraffic.com & Jabatan Perikanan Malaysia (2022).

2.6.3 VESSEL-RELATED ACCIDENTS

Vessel accidents are closely associated with marine traffic risk. High-risk events can lead to significant incidents, such as collision, fire/explosion, stranded, hull damage, and foundered. According to Allianz Global Corporate & Specialty (2017), the Southeast Asia region, including Malaysia, holds the record for the highest number of vessel accidents, with 30 losses out of 94 in 2017. This represents a slight decline of 4% compared to 98 losses in 2016. South China, Indochina, Indonesia, and the Philippines continue to be the leading regions for total losses.

Table 2.3 shows the type of vessel losses from 2015 to 2017. The highest losses were due to foundering, followed by stranding. Both causes are significant factors in overall vessel losses. Figure 2.5 displays the types of vessels most commonly involved in marine accidents. Given that the study focuses on river areas where fishery vessels are predominant, fishery vessels rank as the second-highest contributors to vessel accidents. This data is collected from Allianz Global Corporate & Specialty and reflects only the number of vessel types lost under the company.

Table 2.3 Number of vessel losses from 2015 to 2017 based on the type of accident

Accident/ year	**2015**	**2016**	**2017**	**Total**
Foundered	65	46	61	172
Stranded	19	15	13	47
Fire/explosion	7	8	6	21
Collision	6	1	1	8
Machinery failure	2	8	8	18
Hull damage	2	4	5	11

Source: Allianz (2017)

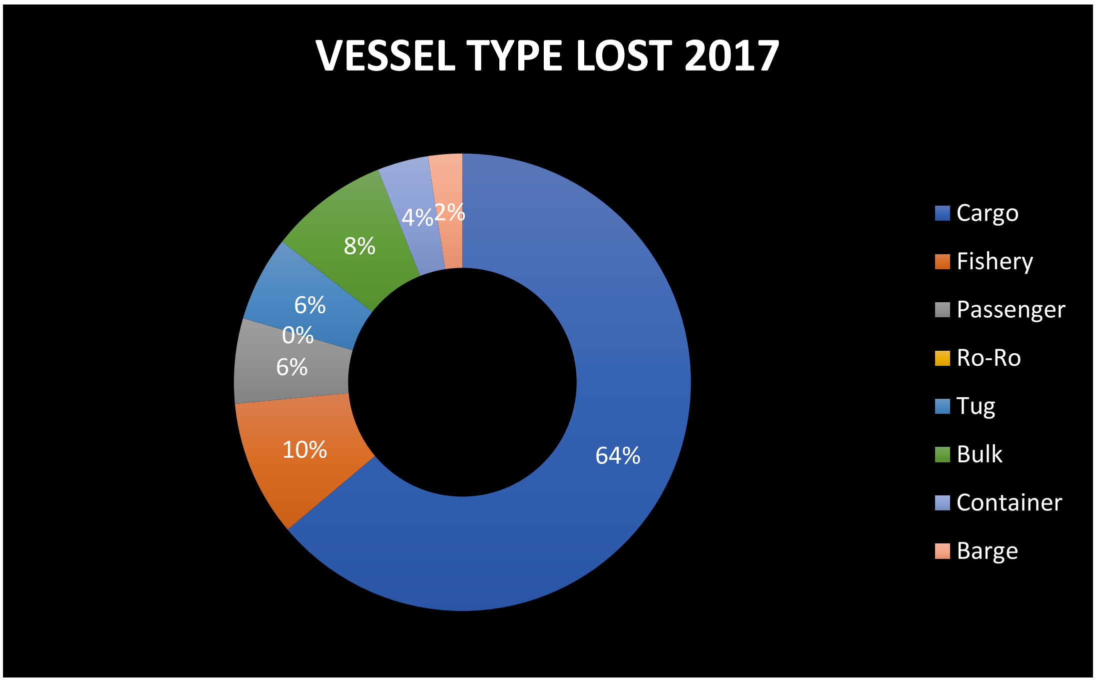

Figure 2.5 Percentage of vessels lost in 2017 based on vessel type. Source: Allianz (2017)

Figure 2.6 illustrates the number of vessels involved in unfavourable accidents based on MARDEP (2022) annual reports. The chart indicates that the easter region, which includes Terengganu, accounts for 9 out of 42 recorded accident cases. This is the highest vessel accident recorded in Peninsular Malaysia. Hence, a risk assessment study is needed to reduce the occurrence of vessels involved in unfavourable incidents.

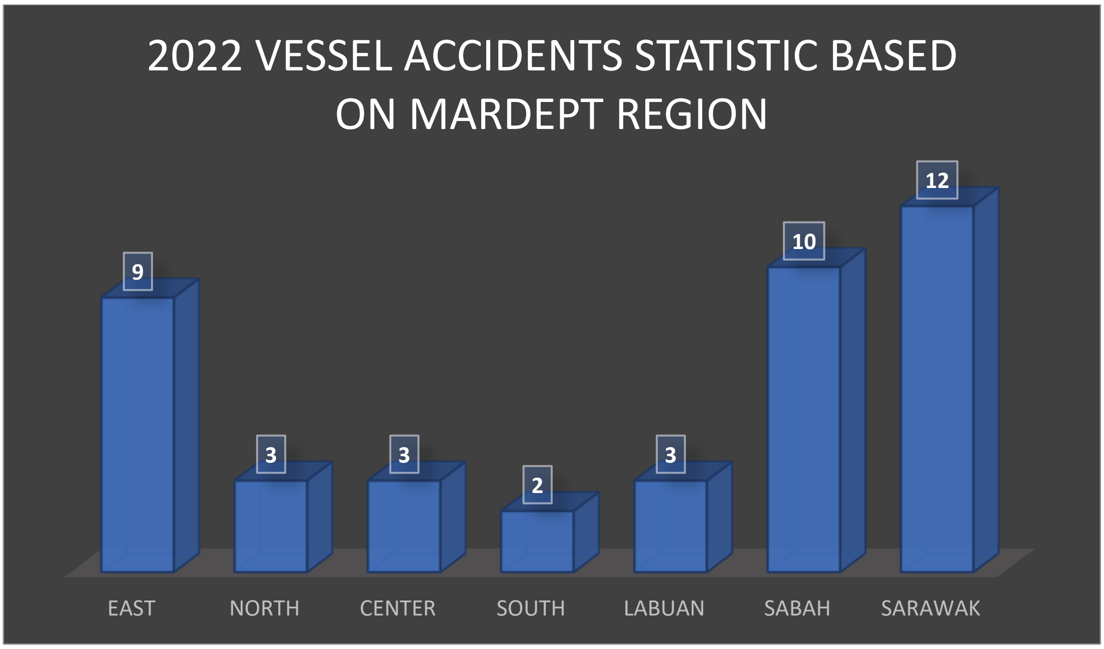

Figure 2.6 Vessel accident statistics in 2022. Source: MARDEP (2022)

2.6.4 WEATHER CONDITIONS

Ambroziak (2022) highlights that weather conditions are crucial elements in vessel navigation. These conditions significantly influence the safety passage for marine users. According to the Department of Occupational Safety and Health (2014), weather conditions are classified as a hazard. Since elements of nature cannot be controlled, this hazard could not be mitigated. Instead, it needs improvements in the safety measures and technology to reduce the risk levels. Figure 2.7 depicts the rainfall distribution across Peninsular Malaysia.

The primary elements that require significant attention for safe navigation are wind, current, and wave. As previously noted, “strong winds and their constant companions, rough seas, probably present the most serious hazard faced by yachtsmen” (Sanderson, 1994). Based on this statement, weather conditions can be classified as a significant hazard that contributes to high-risk events. Accessing the traffic risk meteorological data is essential since it affects the outcomes and risk levels.

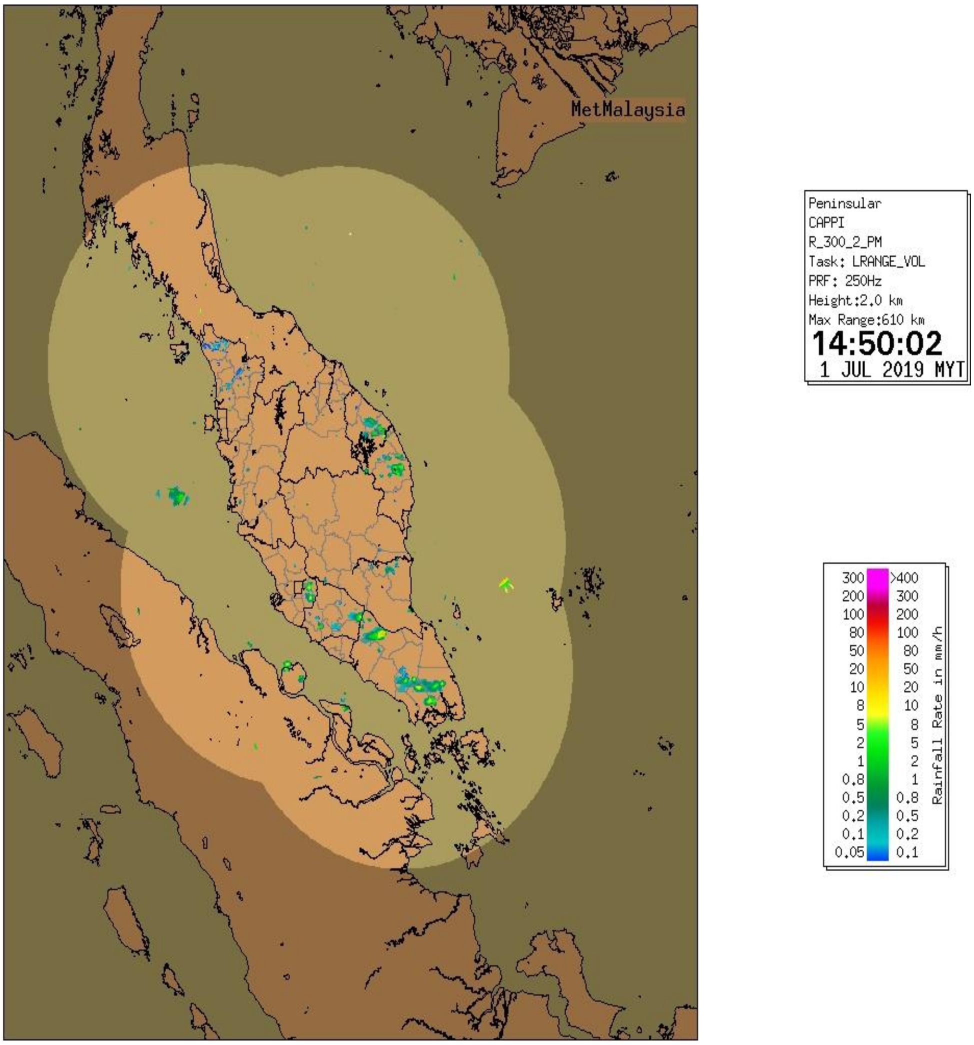

Figure 2.7 Rainfall distribution in Peninsular Malaysia. Source: Meteorology Malaysia (2019)

2.6.4.1 Wind

Wind is described as the lateral flow of air over the Earth’s surface, characterised by its direction and velocity, as highlighted by Frampton (2010). Sanderson (1994) states that wind is essentially caused by variations in atmospheric pressure between different locations, implying that its direction can fluctuate according to these pressure differences. Wind speed is typically measured in knots and can significantly impact ship navigation, particularly for vessels with substantial windage areas.

The Malaysia Meteorology Department (2019) reported that wind speeds in the vicinity of Duyong Island range from 5 to 20 knots, with severe weather conditions potentially increasing the wind speed up to 30 knots. The wind direction is predominantly from the southeast and south, as shown in Figures 2.8 and 2.9.

Figure 2.8 Direction of wind during ebbing. Source: Meteorology Malaysia (2019)

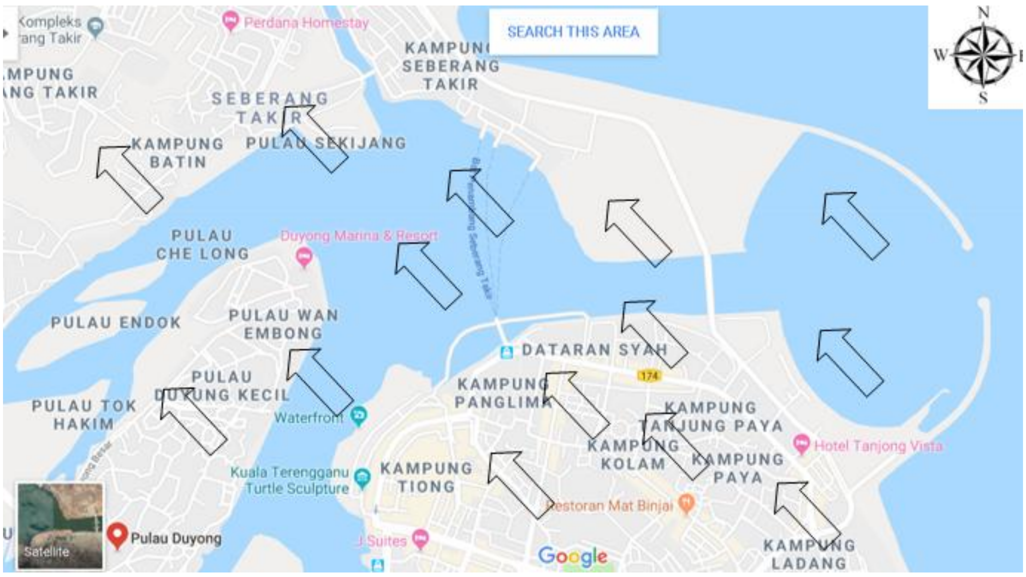

Figure 2.9 Direction of wind during flooding. Source: Meteorology Malaysia (2019)

2.6.4.2 Wave

PODAAC (2022) defines waves as “disturbances in the surface of the ocean. They can be created by wind, gravity, or other displacements of water.” According to Waseda (2021), extreme wave conditions can pose high risks to ship navigation, making wave data crucial for this study. According to the Malaysian Meteorology Department (2019), normal wave heights at Duyong Island range from 0.5 to 1.5 m, with extreme conditions generating up to 2.0 m during the monsoon season from July to December. On a normal day, wave conditions are mild, with about 0.2 knots swell.

2.6.4.3 Current

National Geographic (2019) explains that ocean currents arise as a result of seawater being set in motion by various factors, such as gravity, wind, and water density variations. These currents flow both horizontally and vertically, playing a crucial role in ship navigation, particularly for vessels with significant draught. In the examined region, the Malaysian Meteorology Department (2019) reported that current speeds during ebbing and flooding typically range from 0.5 to 2 knots.

2.6.4.4 Tidal

Ocean Service (2023) defines tides as “very long-period waves that move through the ocean in response to the forces exerted by the moon and the sun.” Tides originate in the ocean and progress along coastlines where they appear as the regular rise and fall of the sea surface.” According to Li (2022), tidal height is a significant factor that affects ship navigation, especially ship turning ability, which could lead to potential hazards. Table 2.4 lists the tidal data for the Terengganu river.

Table 2.4 Tidal data for Terengganu river

Location	**Latitude (N)**	**Longitude (E)**	**Height (m) above Datum**			
Kuala Terengganu	5°21' N	103° 08' E	MHHW	MLHW	MHLW	MLLW
			2.5	1.9	1.0	0.4

Source: Navigation Chart no: MAL 6522 Kuala Terengganu, 2022

2.7 SUMMARY OF CHAPTER 2

This chapter compiles all relevant information for this study based on the literature review. Essential information, such as vessel characteristics, environmental conditions, and vessel traffic, will be utilised throughout this study. The methodology applied in this study is discussed in the following chapter.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter describes the methods used in completing this study. Methodology is crucial as it outlines the data collection process and the approach for data interpretation and analysis. Without a proper method, the study risks deviating from its goal, potentially leading to irrelevant outcomes. Hence, several techniques and analytical methods have been applied systematically in this study. Detailed explanations of these techniques and analytical methods are described throughout this chapter.

3.2 RESEARCH FRAMEWORK

Figure 3.1 presents the overall research flow used in this study.

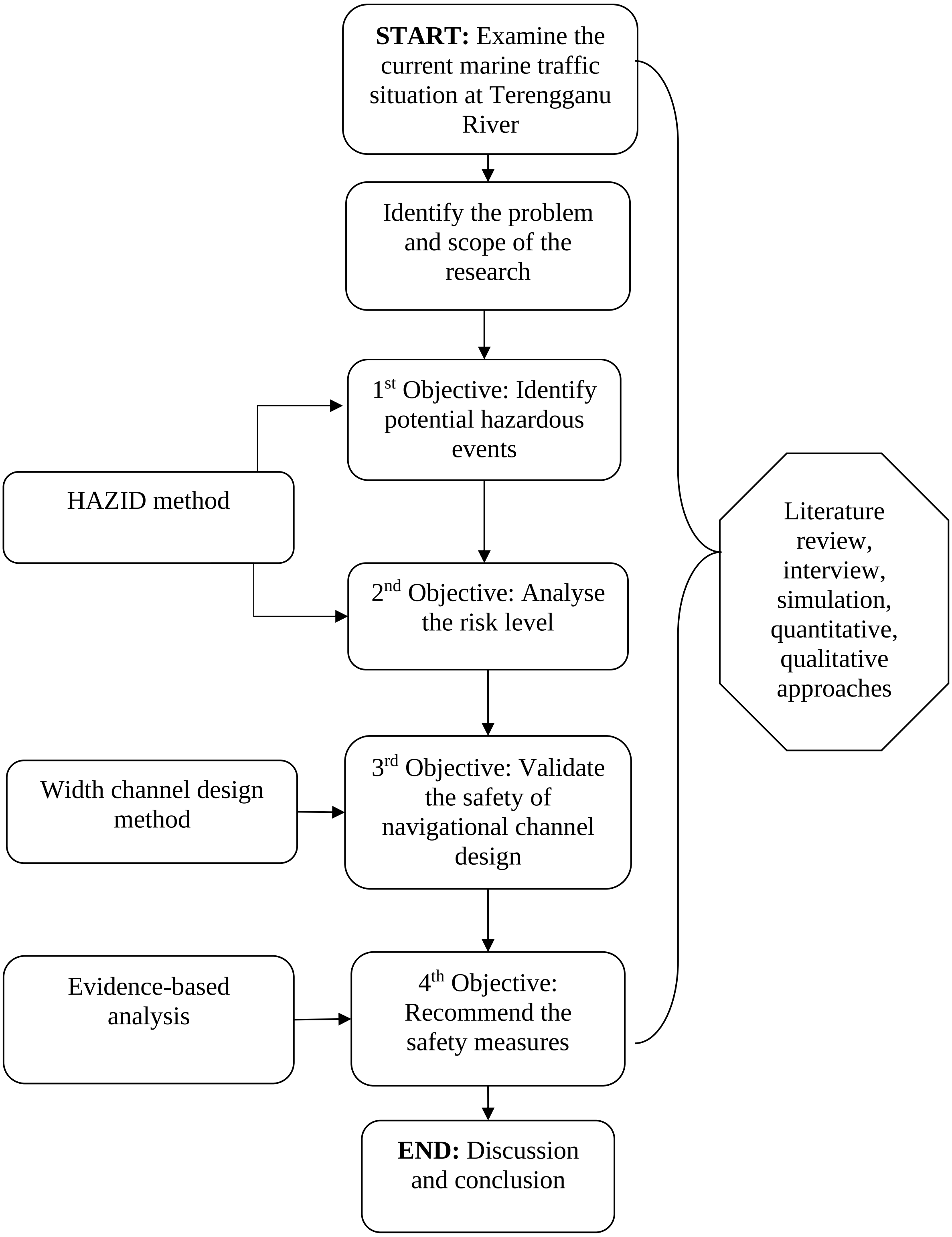

Figure 3.1 Research framework for this study

3.3 RESEARCH PHILOSOPHY/APPROACH

This study employed a pragmatic approach, which aligns with the research activities and strategies that reflect pragmatism as a guiding philosophy. Pragmatism philosophy in research incorporates data collection techniques, methods, strategy, and research approach.

According to Kaushik (2019), pragmatism serves as a tool to solve specific research problems using a particular research approach that falls under the pragmatism philosophy. For instance, pragmatism research combines both positivist and interpretivism approaches in a single research depending on the research question. This form of philosophy integrates the use of multiple research methods, such as qualitative, quantitative, or mixed methods. For the research approach, pragmatism philosophy can be deductive or inductive, while its ontology is either objective or subjective.

Since the research strategy is a combination of qualitative and quantitative, pragmatism philosophy is the most suitable philosophy for this study. The approach to achieving the first and second objectives mostly depends on expert judgment and an interview process to identify the potential hazards and risk levels. Additionally, the third objective focuses on numerical and simulation evaluations that fall under quantitative and qualitative research strategies.

3.4 RESEARCH DESIGN

The research design of this study comprises a mixed method combining qualitative and quantitative approaches. For objective one, the HAZID method was conducted, which involved interviewing experts and questionnaire distribution. Since this result is dependent on the expert judgment, this method falls under qualitative research design. For the second objective, the risk level was determined using a mixed method, where expert judgment and risk matrix were utilised to gain a numerical result that reflects the risk level. Similarly, a quantitative research design was employed to address objective three, where the navigation width channel is calculated using PIANC calculation guidelines to determine the safe passing distance for vessels to navigate in the study area. Based on these approaches, this study effectively designed a mixed-method research design to achieve its goals.

3.5 DATA COLLECTION STRATEGY

Two main strategies were employed in this study to collect data: literature review and interview. Data from these strategies were then analysed to gain valuable results to answer the predetermined objectives. It is essential for the data to be genuine to generate valid results.

3.5.1 Literature Review

Conducting a literature review is the first strategy to collect useful information regarding the present and past studies relevant to the topic. Snyder (2019) rated the literature review as the best methodological tool to provide answers to the established research questions. Most literature reviews are obtained from articles, journals, reports, and books. For this study, the most crucial part of data collection from this strategy is the existing environmental conditions around the study area, which include the weather information, wind conditions, and wave tidal information.

Another aspect of data collection focuses on the river user information and previous incident reports. The river user information includes vessel characteristics, which were selected based on the largest and most common river users. This information is valuable in the width channel design assessment and simulation analysis. Meanwhile, the incident reports were used to strengthen the objectives in determining the safety of the navigation channel. Most information was gathered from local reports and government websites.

3.5.2 Interview

The second strategy for data collection involves interviewing experts to gain experts' judgement. According to Alshenqeeti (2014), conducting interviews is more effective in extracting narrative data, enabling a deeper understanding of people's perspectives for a comprehensive investigation. This strategy entails selected respondents answering a few questions focusing on related hazards, risk levels, and mitigation measures in the study area. A total of ten experts were selected to participate in the interview and answer the questionnaire. According to Doucet (2006), the number of participants required for interviews in qualitative research depends on the epistemology, methodology, and practical issues. Regardless, a single participant is sufficient in some instances. Baker (2012) suggests that a minimum of six to ten experts is necessary for an interview.

The experts were selected based on their expertise in the maritime field, with most coming from both government and non-government agencies. This selection criterion ensures the inclusion of diverse perspectives and their familiarity with this study. According to Rosqvist (2003), expert judgment plays a pivotal role in various stages of risk assessment, including HAZID, risk estimation, evaluation, and analysis of options. Additionally, expert judgment is essential for quality assurance or verification in risk assessment processes.

The criteria for expert selection include individuals with profound knowledge of risk assessment in the study area and at least 5 years of experience in marine risk assessment studies. Berliner (2004) categorises an expert as a person with 5 to 7 years of experience in a specific field. Marine consultants commonly adopt these criteria during data collection. According to the Malaysian Marine Department, most MTRA studies and reports involve experts with over 5 years of experience in the marine industry. Valdez (2014) also employed experts to conduct a HAZID study. Objectives one and two primarily depend on this data collection method.

3.6 PHILOSOPHY OF THE SELECTED ANALYSIS METHOD

This chapter outlines the HAZID method, which is the selected analytical method for this study. After the data collection processes, the data were analysed to gain results to answer the study objectives. The risk analysis using the HAZID method includes risk ranking and the width channel design method.

3.6.1 HAZID Methodology

According to IMO (2018), under the MSC-MEPC.2/Circ.12/Rev.2, the revised guidelines for Formal Safety Assessment (FSA) state that the HAZID method consists of two major elements: identification of potential hazards and ranking of risk levels.

3.6.1.1 Identification of Potential Hazards

Figure 3.2 shows that this approach begins with the selection of a section or study area consisting of potential hazards. In this process, background and relevant information about the area, such as its historical background, environment, and user activity, are required. Background information is essential for identifying potential hazards (IMO, 2018). Subsequently, the selected experts in related fields participate in this process, as mentioned in Section 3.5.2 of this thesis. These experts discuss and outline the identified hazards before proceeding with the risk ranking process.

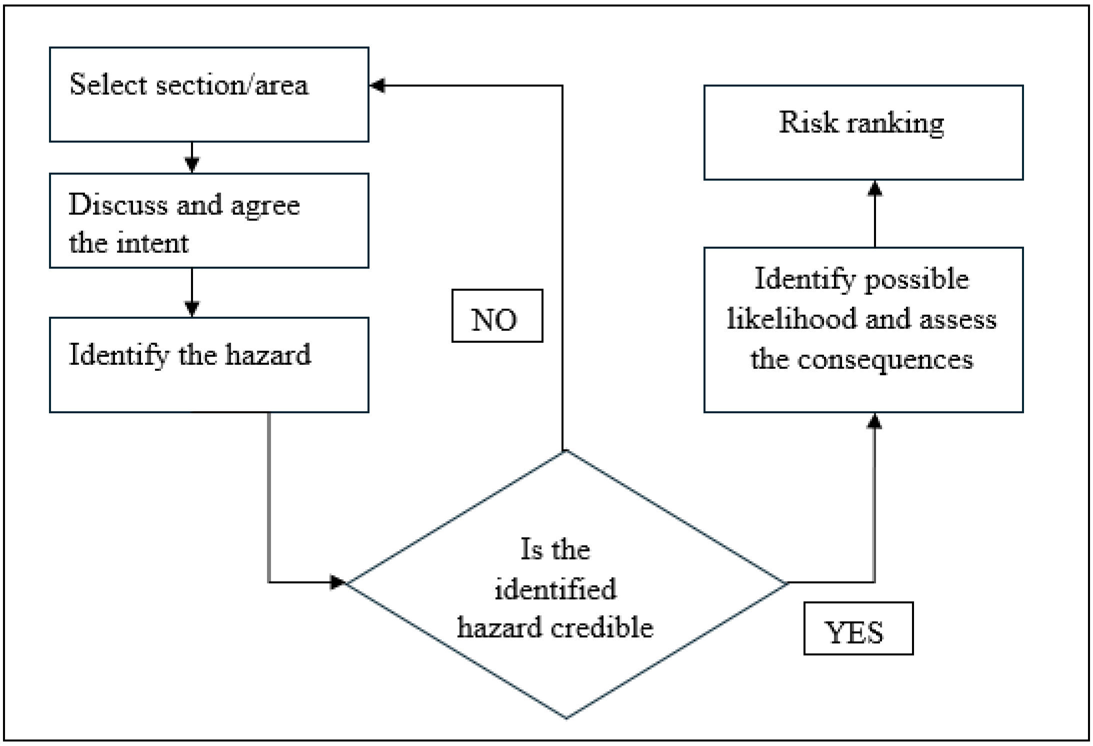

Figure 3.2 Flowchart of the HAZID methodology. Source: ESTECO (2019)

In this approach, considering functional failure may be beneficial. The evaluation group consists of experts from various fields, such as ship design, operations, and management, as well as professionals who contribute to identifying potential hazards and incorporating the human factor into the structured evaluations.

The analytical component ensures that prior experience is adequately considered, often using background knowledge. This includes relevant regulations and standards, accessible statistical information on the types of accidents, inventories of risks to individuals, hazardous materials, sources of ignition, and other factors.

3.6.1.2 Risk Ranking

The risk ranking was conducted to assess the causes and consequences of the most significant scenarios identified in the HAZID process. This can be achieved using appropriate techniques that model the risk (IMO, 2002), focusing on high-risk areas and facilitating the identification and evaluation of factors that influence the level of risk.

Numerous types of risks, including risks to the users, environment, or properties, should be addressed according to the problems faced. The analysis of the frequency and consequence should be based on the historical evidence of incidents in the Terengganu River and its jetty rather than relying solely on the experts' judgment. Risk scoring must also be the subject of a meeting involving a cross-section of the same participants involved in the hazard identification process. To complete a risk assessment, the most likely outcome of hazard realisation is first assessed against each consequence category, such as the consequences on people, property, environment, and stakeholders.

The hazards and scenarios linked to the issue should be prioritised, with those deemed less significant excluded from consideration. Hence, an evaluation of the scenario's frequency and its potential consequences is necessary. The ranking process for these scenarios relies on existing data supplemented by expert judgment. A standard risk matrix is provided in Table 3.1, which includes well-defined categories for both frequency and consequences (as outlined by IMO in 2002). The combination of a frequency category with a consequence category results in a specific risk level.

Table 3.1 A standard risk ranking matrix

Risk Assessment Matrix: Risk criteria		**Frequency**				
		Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**
		Remote	**Unlikely**	**Possible**	**Likely**	**Almost certain**
		Remote - may occur under exceptional circumstances	**Unlikely- could occur but doubtful**	**One or more times in 10 years**	**One or more times per year**	**Ten or more times per year**
Consequence	5 – Loss of vessel or severe damage to the vessel. Multiple fatalities. International news coverage. Serious long-term impact on the environment and/or permanent damage	Moderate (5)	High (10)	Extreme (15)	Extreme (20)	Extreme (25)
	4 – Major damage to vessel. Single fatality. National news coverage. Significant impact on the environment with medium-to-long-term effects	Minor (4)	Moderate (8)	High (12)	Extreme (16)	Extreme (20)
	3 – Moderate damage to the vessel. Moderate/major injury. Regional news coverage. Limited impact on the environment with short- or long-term effects	Minor (3)	Moderate (6)	Moderate (9)	High (12)	Extreme (15)
	2 – Minor or superficial damage to the vessel. Minor injuries and local news coverage. Minor impact on the environment with no lasting effects	Low (2)	Minor (4)	Moderate (6)	Moderate (8)	High (10)

	1 – Insignificant or no damage to vessel/equipment. No injuries. Insignificant impact on the environment	Low (1)	Low (2)	Minor (3)	Minor (4)	Moderate (5)
Action key	Low (1–2)	No action is required				
	Minor (3–4)	No additional controls are required, and monitoring is required to ensure no changes in circumstances				
	Moderate (5–9)	Efforts should be made to reduce risk to 'As low as reasonably practicable' (ALARP), but activity may be undertaken				
	High (10– 4)	Efforts should be made to reduce risk to 'As low as reasonably practicable' (ALARP). Activity can only be undertaken with further additional controls.				
	Extreme (15–25)	Intolerable risk. Activity not authorised				

Source: DNV.GL (2019)

3.6.2 Width Channel Design Method

The width channel design method used in this study refers to the Harbour Approach Channels Design Guidelines, with report number 121-2014 (PIANC, 2014). These guidelines confirmed the design of the vertical and horizontal measurements for the inner harbour approach channels, including the manoeuvring zones. They were also employed to establish operational limitations within the river navigation channel. The methodology used to validate the channel width followed the PIANC guidelines involving a two-stage process consisting of:

- Concept design, which used empirically-based methods.
- Simulation or detailed design, which uses fast-time or real-time ship simulation modelling to validate results from the concept design stage.

3.6.2.1 Concept Design

As outlined in the channel concept design, the horizontal dimensions were proposed and thoroughly evaluated. This process involved utilising both empirical data and ship manoeuvring simulations to verify that the suggested channel widths were adequate for safe navigation. The assessment considered various factors, including ship manoeuvrability, speed, prevailing wind, current and wave forces, navigational aid, the surface condition of the channel bed, water depth, and the level of cargo hazard.

The primary focus is limited to Chapter 3 of the PIANC report, which covers topics, such as channel width, harbour entrances, manoeuvring areas, and anchorage zones. This chapter provides a calculation method for determining the appropriate channel width to ensure safe navigation for existing ships. As per PIANC's (2014) publication, Subchapter 3.1.5 describes modern techniques for designing channel width aimed at offering adequate navigational safety during the concept design stage.

While this approach is applicable to access channels worldwide, local factors may require adjustments based on cost, operational needs, and environmental factors. These changes can be made during the detailed design phase. Notably, the study is cognizant of the current channel width, and no accidents have occurred in this area over the past several years.

$$W = W_{BM} + \sum W_i + W_{BR} + W_{BG} \quad \text{(Eq. 1)}$$

Where:

- W_{BM} = Width of the basic manoeuvring lane as a multiple of the design ship's beam B.
- $\sum W_i$ = Additional widths to allow for the effects of wind, current, and other environmental factors.
- W_{BR}, W_{BG} = Bank clearances on the red and green sides of the channel.

3.6.2.2 Simulation

The study performed extensive numerical and simulation-based modelling of the preliminary design using ship simulation and marine traffic analysis to validate, develop, and refine the proposed concept design. The operational aspects were assessed to establish safe operational limits and provide recommendations to local port authorities for improving navigation safety. The detailed design process included a reviewing process of other navigation aspects, as follows:

- Number, type, and positioning of navigational aid.
- Localised conditions and navigational restrictions specific to the study area.

The manoeuvring simulation study was recommended using a ship-handling simulator system, which enables real and fast-time simulations using either 'hands-on' control (real-time conning) or automated control via an autopilot function. This system also provides mathematical modelling of ships and other floating craft in 6 degrees of freedom, namely surge, sway, yaw, roll, heave, and pitch (Zulkurnain, 2018).

The ship-handling simulator system employed industry-standard S-57 electronic charts that provided an interactive backdrop for the simulations. To enhance accuracy, hydrodynamic current information was applied in the simulations to reflect the proposed operations, including inbound and outbound navigation. Simulator tests were conducted to validate the calculations based on the PIANC guidelines to gain a better insight into the overall safety assessments that support the hazard identified by experts and ensure the safety of commonly used navigation channels.

The fast-time simulation was performed using various parameters that represent the mariner's behaviour in controlling ship movement within the study area. This method was suitable, especially for scenarios with minimal deviation from a reference track and relatively straight approach channels. To improve accuracy, several runs were performed to obtain statistical analyses, with varying track-keeping parameters to simulate a range of operator performances.

A real-time simulation exercise was performed to examine further and validate the concept design. A human pilot was instructed to navigate the ship and, if any, support tugs to a specified port or location within the study area. This process required modelling the geographic database and bathymetric values specific to the study area within the simulator. The use of real-time simulation effectively incorporated technical ship handling and human factors, including response times and communication.

3.6.3 Evidence-Based Analysis

Evidence-based analysis is a methodical approach to decision-making or problem-solving that relies on the best available evidence, typically obtained through research, data collection, and various sources.

The results of this study serve as evidence used to generate the recommendations, which are mainly based on the HAZID findings and the channel width design method. Meanwhile, the hazards and risk rankings provide evidence used for recommendations to mitigate hazards within the study area. Additionally, the width channel design, specifically the channel clearance and simulation, supports recommendations to ensure the safety of the river navigation.

3.7 VALIDITY AND RELIABILITY

A key measure to achieve both reliability and validity is consulting experts in marine risk assessment. With their extensive experience, they can assist in identifying potential inconsistencies or errors in the data collection process. Ensuring the validity of this study is essential for obtaining accurate findings and minimising the risk of errors.

Additionally, the method employed in this study was compared with other variants of MTRA, such as the MTRA of the Sarawak River, to evaluate the consistency and effectiveness of the methodology. All MTRA reports in Malaysia must be approved by the Marine Department prior to project initiation to ensure their validity. Thus, the approval from higher marine authorities confirms the validity of the current data collection process.

Moreover, simulation testing enhances the reliability of the study by generating realistic scenarios for the study area. Estabrook (2012) supports this approach by employing simulation to verify the reliability of his research. The use of multiple simulation studies further solidifies the research validity as a mandatory practice for MTRA assessments (MARDEP, 2019). Therefore, the inclusion of simulation testing affirms the overall research validity.

3.8 SUMMARY OF CHAPTER 3

This chapter highlighted the flow of research activities conducted to achieve the stated objectives, including the research framework, approach, and design, as well as the HAZID method, channel width design assessment and ship simulation.

CHAPTER 4

DATA ANALYSIS

4.1 INTRODUCTION

This chapter presents the data analysis, details of the method used, and interprets the findings in relation to the objectives of the study. This chapter is divided into subtopics that address each of the four main objectives. A comprehensive flowchart is presented in each section that summarises the analysis methods.

4.2 1st OBJECTIVE: IDENTIFYING THE POSSIBLE HAZARDOUS EVENT WITHIN THE STUDY AREA

Figure 4.1 shows the flowchart for objective one. The first step in the data analysis involved collecting detailed information related to the study area, including the types and number of vessels, weather conditions, and incident reports from literature reviews. This information is essential for providing a general guide to the interviewees, enabling them to form a better viewpoint of the study and address the interview questions.

The second step involved the preparation for the interview process, which included selecting experts based on the criteria, as stated in Chapter 3 and developing the interview questions. Table 4.1 lists the experts involved in this study, where most of them have over 5 years of experience in marine-related fields and have participated in previous risk assessments.

Steps three and four involve data gathering and sorting. Upon completing the interview sessions, all inputs for the hazard identification process were gathered. Then, the hazardous events were sorted according to study relevance, particularly to marine traffic. Once the hazardous events were sorted, the identification process of the potential hazardous events in the study area was deemed complete.

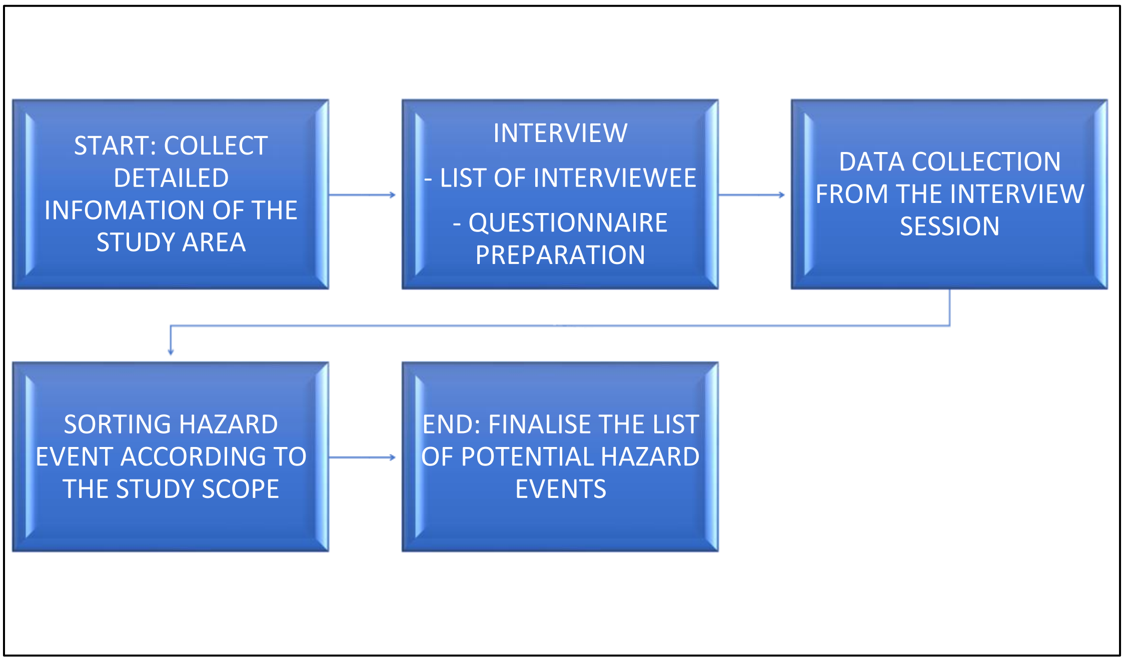

Figure 4.1 Flowchart for the first objective

Table 4.1 List of selected experts involved in the interview and questionnaire session

No.	Working/research area	Background	Years of experience
1	Marine Traffic Risk Assessment	Master Mariner, Director Spartan Maritime Sdn. Bhd.	> 20 years
2	Marine Traffic Risk Assessment	Master Mariner, Spartan Ship Care Sdn. Bhd.	> 20 years
3	Marine consultant	Master Mariner, Vastera Resources Sdn. Bhd.	> 20 years
4	Marine operation	Chief Marine, Operation Tg. Langsat Port	>15 years
5	Marine law enforcement	Malaysia Maritime Enforcement Agency	> 5 years
6	Maritime navigation simulation	Simulator Instructor, HJS Maritime Sdn. Bhd.	> 10 years
7	Marine reports and operation	Marine Officer, Marine Department Malaysia	> 6 years
8	Marine consultant	Marine Consultant, CME Sdn. Bhd.	> 10 years
9	Marine law enforcement	Navy, Simulation Instructor, Contravest Advance Devices Sdn. Bhd.	> 15 years
10	Maritime consultant	Din Millenium Resources Sdn. Bhd.	> 10 years

4.3 2nd OBJECTIVE: ANALYSING THE RISK LEVEL ASSOCIATED WITH THE POTENTIAL HAZARDOUS EVENTS IDENTIFIED WITHIN STUDY AREA

The first step in achieving the second objective is to rank the risks, which involves preparing the risk matrix. A risk matrix is a tool indicator that shows the frequency and consequence levels. As stated in FSA (2002), risk is a frequency multiplied by consequence. This establishes the link between objectives one and two, where, after identifying all potential hazardous events, each event needs to be ranked according to its risk levels. Figure 4.2 shows the flowchart for the second objective.

For this study, the risk matrix was prepared by referring to the DNV GL 2019 risk ranking table, a widely adopted industry standard. Most experts recommended this risk matrix since it has been extensively used in many MTRA reports. For instance, Fuad (2019) used the DNVGL table as a guideline to generate a custom matrix table, while Waskito (2020) utilised DNVGL to assess risk rankings. Moreover, DNVGL was adopted by a consultation company, as recorded by the Malaysia Marine Department. Most of the MTRA reports also used this risk matrix to obtain the risk ranking, including the MTRA in Sungai Sarawak, Bintulu Breakwater, and PFLNG Petronas.

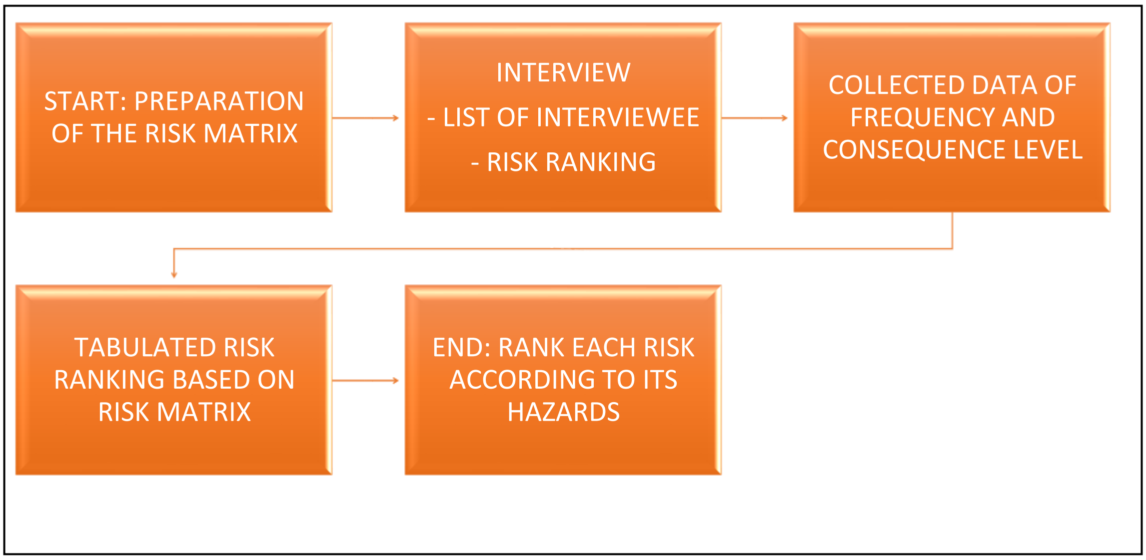

Figure 4.2 Flowchart for the second objective

Table 4.2 Risk matrix

		FREQUENCY				
		Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Risk assessment matrix: Risk criteria		**Remote**	**Unlikely**	**Possible**	**Likely**	**Almost certain**
		Remote - may occur in exceptional circumstances	**Unlikely - could occur but doubtful**	**One or more times in 10 years**	**One or more times per year**	**Ten or more times per year**
Consequence	5 – Loss of vessel or severe damage to vessel. Multiple fatalities. International news coverage. Serious long-term impact on environment and/or permanent damage	Moderate (5)	High (10)	Extreme (15)	Extreme (20)	Extreme (25)
	4 – Major damage to vessel. Single fatality. National news coverage. Significant impact on environment with medium-to-long term effects	Minor (4)	Moderate (8)	High (12)	Extreme (16)	Extreme (20)
	3 – Moderate damage to vessel. Moderate/major injury. Regional news coverage. Limited impact on environment with short- or long-term effects	Minor (3)	Moderate (6)	Moderate (9)	High (12)	Extreme (15)
	2 – Minor or superficial damage to vessel. Minor injuries and local news coverage. Minor impact on environment with no lasting effects	Low (2)	Minor (4)	Moderate (6)	Moderate (8)	High (10)
	1 – Insignificant or no damage to vessel/equipment. No injuries. Insignificant impact on environment	Low (1)	Low (2)	Minor (3)	Minor (4)	Moderate (5)

The second step in this analysis involves conducting interview sessions with experts to collect data required for objectives one and two. The list of experts remains the same as for objective one. For objective two, which focuses on risk ranking, the experts are provided with a risk matrix as a reference to rank the risks for each identified hazard, in addition to basic information about the study area.

The third step is to collect the data, including the frequency and consequence levels assigned by the experts during the interview. Subsequently, this data was tabulated and calculated to determine the risk rankings, which are crucial as they affect the final assessment of the safety of the navigation channel in the study area.

4.4 3rd OBJECTIVE: VALIDATING THE SAFETY OF NAVIGATIONAL CHANNEL WITHIN THE STUDY AREA

For objective three, the first step is to gather all information required to conduct width channel design using the PIANC (2014) guidelines and simulation tests. The required information in the study area, including environmental conditions, weather conditions, characteristics of vessels, and navigational aids, was obtained through literature review and reports. Figure 4.3 shows the flowchart for objective three.

The second step involved calculating the width of the navigation channel using the width channel design assessment according to the PIANC guidelines to ensure a safe passage by determining the appropriate width distance for vessels to pass through. The PIANC guidelines for channel width calculation consider several criteria, such as vessel manoeuvrability and environmental conditions. For this study, the largest vessel ever used on this river was assessed. The successful passage of the largest vessel through the channel demonstrates that other smaller vessels will also be able to pass it.

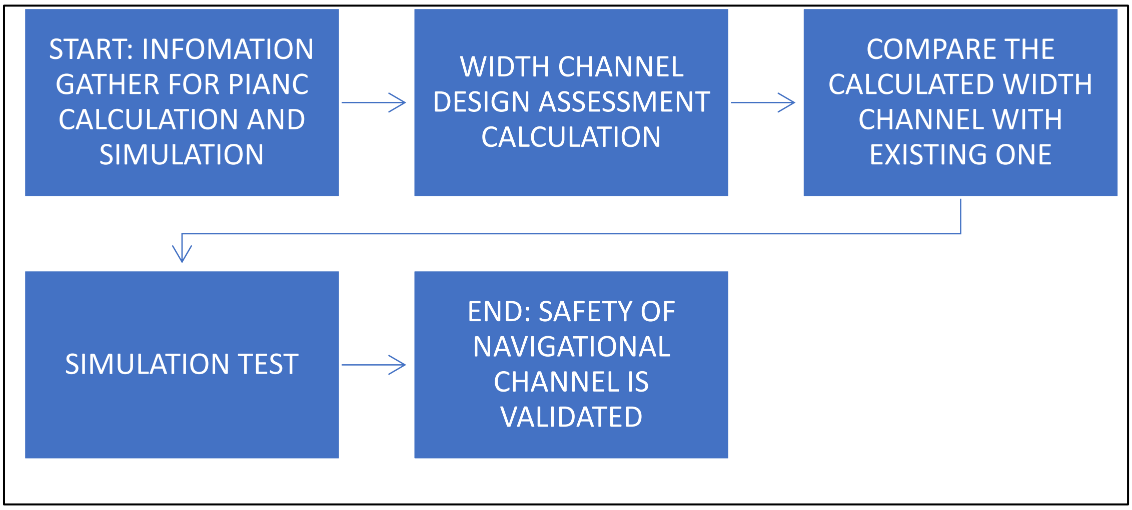

Figure 4.3 Flowchart for the third objective

Basic manoeuvring lane, W_{BM}

Table 4.3 lists the basic manoeuvring lane width (W_{BM}) for ships with good, moderate, and poor manoeuvring characteristics. Tankers and bulk carriers generally exhibit poor manoeuvrability, while container vessels, car carriers, RORO vessels, LNG, and LPG vessels have moderate manoeuvrability. Twin-propeller ships, ferries, and cruise vessels are categorised as generally having good manoeuvrability (PIANC, 2014).

Table 4.3 Basic manoeuvring lane (W_{BM})

Ship manoeuvrability	**Good**	**Moderate**	**Poor**
Basic manoeuvring lane (W_{BM})	1.3 B	1.5 B	1.8 B

Source: PIANC (2014)

Environmental and other factors, W_i

The manoeuvring lane (W_M) is the sum of the fundamental manoeuvring lane (W_{BM}) and additional width (W_i) that account for the environmental and other navigational factors that affect manoeuvrability. Table 4.4 lists these environmental adjustments, considering various factors, including the ship's speed and the channel's exposure to waves. The use of this table should be based on established operational limits when determining the dimensions of the channel width. If no such limits are available, the prevailing conditions should be employed. For instance, if operational constraints restrict channel use due to strong wind of 30 knots or less, there is no need to design for a 33-knot cross wind.

Table 4.4 Additional width (W_i) for straight channel

<table>
<tr><th>Width
W_i</th><th>Vessel Speed</th><th colspan="2">Outer Channel (open water)</th><th colspan="2">Inner Channel (protected water)</th></tr>
<tr><td>(a) Vessel speed V_s (kts, with respect to the water)
$V_s \geq 12$ kts
8 kts $\leq V_s < 12$ kts
5 kts $\leq V_s < 8$ kts</td><td>fast
mod
slow</td><td colspan="4">0.1 B
0.0
0.0</td></tr>
<tr><td>(b) Prevailing cross wind V_{cw} (kts)
- mild
$V_{cw} < 15$ kts
(< Beaufort 4)</td><td>fast
mod
slow</td><td colspan="4">0.1 B
0.2 B
0.3 B</td></tr>
<tr><td>- moderate
15 kts $\leq V_{cw} < 33$ kts
(Beaufort 4 - Beaufort 7)</td><td>fast
mod
slow</td><td colspan="4">0.3 B
0.4 B
0.6 B</td></tr>
<tr><td>- strong
33 kts $\leq V_{cw} < 48$ kts
(Beaufort 7 - Beaufort 9)</td><td>fast
mod
slow</td><td colspan="4">0.5 B
0.7 B
1.1 B</td></tr>
<tr><td>(c) Prevailing cross-current V_{cc} (kts)
- negligible $V_{cc} < 0.2$ kts</td><td>all</td><td colspan="2">0.0</td><td colspan="2">0.0</td></tr>
<tr><td>- low
0.2 kts $\leq V_{cc} < 0.5$ kts</td><td>fast
mod
slow</td><td colspan="2">0.2 B
0.25 B
0.3 B</td><td colspan="2">0.1 B
0.2 B
0.3 B</td></tr>
<tr><td>- moderate
0.5 kts $\leq V_{cc} < 1.5$ kts</td><td>fast
mod
slow</td><td colspan="2">0.5 B
0.7 B
1.0 B</td><td colspan="2">0.4 B
0.6 B
0.8 B</td></tr>
<tr><td>- strong
1.5 kts $\leq V_{cc} < 2.0$kts</td><td>fast
mod
slow</td><td colspan="2">1.0 B
1.2 B
1.6 B</td><td colspan="2">-
-
-</td></tr>
<tr><td>(d) Prevailing longitudinal current V_{lc} (kts)
- low
$V_{lc} < 1.5$ kts</td><td>all</td><td colspan="4">0.0</td></tr>
<tr><td>- moderate
1.5 kts $\leq V_{lc} < 3$ kts</td><td>fast
mod
slow</td><td colspan="4">0.0
0.1 B
0.2 B</td></tr>
<tr><td>- strong
$V_{lc} \geq 3$ kts</td><td>fast
mod
slow</td><td colspan="4">0.1 B
0.2 B
0.4 B</td></tr>
<tr><td>(e) Beam and stern quartering wave height H_s (m)
- $H_s \leq 1$ m
- 1 m < H_s < 3 m
- $H_s \geq 3$ m</td><td>all
all
all</td><td colspan="2">0.0
~0.5 B
~1.0 B</td><td colspan="2">0.0
-
-</td></tr>
<tr><td>(f) Aids to Navigation (AtoN)
- excellent
- good
- moderate</td><td></td><td colspan="4">0.0
0.2B
0.4 B</td></tr>
<tr><td>(g) Bottom surface
- if depth $h \geq 1.5\ T$
- if depth $h < 1.5\ T$ then
- smooth and soft
- rough and hard</td><td></td><td colspan="4">0.0

0.1 B
0.2 B</td></tr>
<tr><td>(h) Depth of waterway h</td><td></td><td>$h \geq 1.5\ T$
$1.5\ T > h \geq 1.25\ T$
$h < 1.25\ T$</td><td>0.0 B
0.1 B
0.2 B</td><td>$h \geq 1.5\ T$
$1.5\ T > h \geq 1.15\ T$
$h < 1.15\ T$</td><td>0.0 B
0.2 B
0.4 B</td></tr>
<tr><td>(i) High cargo hazards</td><td></td><td colspan="4">See explanation in box(i) overleaf</td></tr>
</table>

Source: PIANC (2014)

Notes and Explanation for Table 4.4:

- **Box b – Cross winds**

The additional width refers to all ships with a balanced ratio between windage surface and lateral underwater area. For instance, ships with a larger windage area, such as RORO vessels and cruise liners, require a supplementary of 0.2B to be added to the values in this box. Regardless, for this study, no additional value is required since only vessels with low windage areas navigate through the study area.

- **Boxes c and d – Currents**

The width should be calculated at various critical points along the channel if the current fluctuates. Although Table 4.4 shows cross-current magnitudes of up to 2.0 knots, it is recommended to realign the channel to avoid such high cross-currents.

- **Box e – Waves**

This box only provides a rough estimate and should be used cautiously. Wave direction relative to the ship, such as head, beam, or following seas, should be considered. Head and following seas impact the under keel clearance (UKC) and encounter period, influencing heave and pitch, while beam seas mainly cause rolling that affects UKC and the ship's drifting, which in turn impacts channel width.

- **Box f – Aids to Navigation (AtoN) and Associated Systems**

For positioning a ship in a channel, various optical, radar, and electronic devices, both onboard the ship and in the channel, require little to no additional channel width. The terms 'excellent,' 'good,' and 'moderate' are defined as:

<u>Excellent:</u>

Channel:

- Paired lighted buoys with radar reflectors
- Lighted leading lines
- VTS, if applicable

With the availability of:

- Pilots
- Differential Global Navigation Satellite Positioning System (DGPS)
- Electronic chart display and information system (ECDIS)

Good:

Channel:

- Paired lighted buoys with radar reflectors
- Lighted leading lines

With the availability:

- Pilots
- DGPS

Moderate:

Any conditions with fewer facilities than those mentioned above

- **Box g – Bottom Surface**

The effect of the bottom surface is significant only in shallow waterways. Soft materials, including silt and mud, influence both the manoeuvrability and propulsion of a ship, while hard bottom surfaces, such as rock and coral, can cause more severe damage due to grounding. If the water depth, h, exceeds 1.5 times the ship's draught (T), no additional width is needed.

- **Box h – Depth of Waterway**

This should be assessed against the ship's speed and the h/T ratio. Additional channel width at low UKC is necessary to account for the slower response of the ship, which becomes crucial if the vessel deflects from its course for any reason.

- **Box i – High Cargo Hazards**

Cargo hazards, as prescribed in IMO and national regulations, include the following:

* Toxicity
* Explosive potential
* Pollution potential
* Combustion potential
* Corrosive potential

High cargo hazards, such as LNG, LPG, and certain chemical classes, generally do not require additional width in the presence of hazardous cargo. Nevertheless, additional safety measures should be applied, including speed reduction in combination with VTS assistance, patrol vessels, and/or restricting two-way traffic channels to one-way channels for safer harbour approaches.

Additional Width for Passing Distance In Two Way Traffic

The additional width for passing distance in two-way traffic was determined using the beam of the largest passing vessel, regardless of whether it is the design ship. The values in Table 4.5 represent the distance between lanes in a two-way channel, not the hull-to-hull distance. Overtaking requires more width but is typically not considered in the concept design. For heavy traffic, defined as more than three design vessels per day, an additional width of 0.5B may be necessary.

Table 4.5 Additional width for passing distance in two-way traffic

Width for passing distance W_p	**Outer Channel (open water)**	**Inner Channel (protected water)**
Vessel speed V_s (knots)		
- fast: $V_s \geq 12$	2.0 B	1.8 B
- moderate: $8 \leq V_s < 12$	1.6 B	1.4 B
- slow: $5 \leq V_s < 8$	1.2 B	1.0 B

Source: PIANC (2014)

Figures 4.4 and 4.5 depict the width channel distance for vessel clearance. According to PIANC (2014), a channel could be labelled as safe if the width of the existing channel exceeds the calculated width. Note that this is not the definitive result, as a simulation test should still be conducted to validate the channel safety for safe passage.

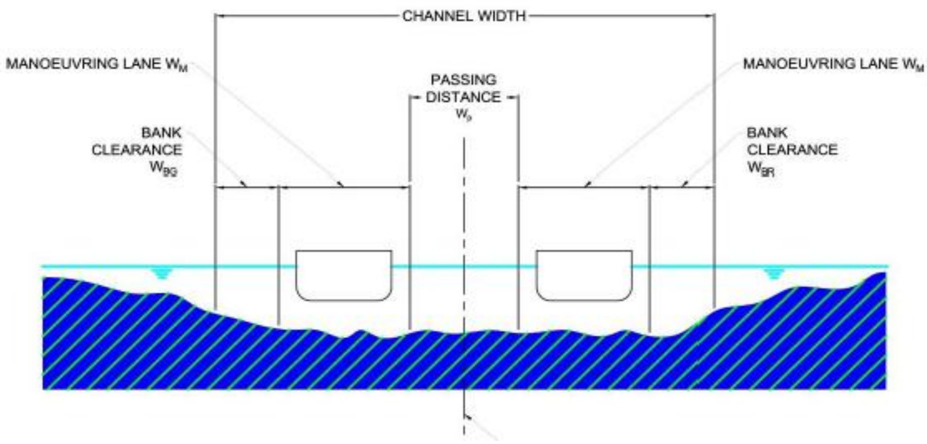

Figure 4.4 The channel width indicator. Source: PIANC (2014)

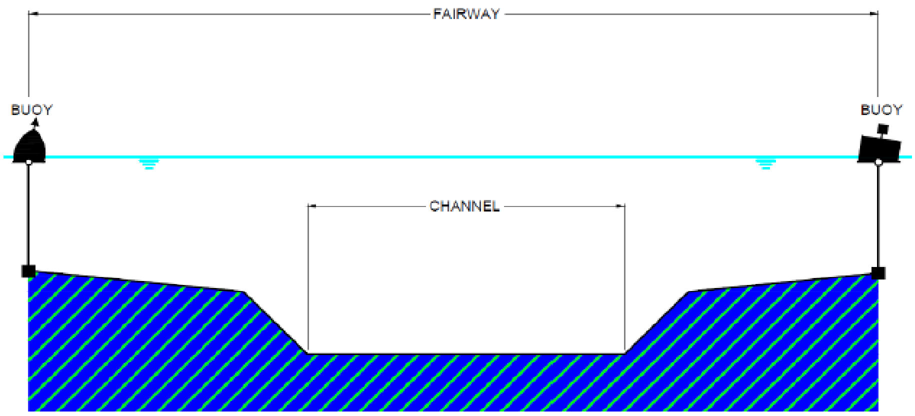

Figure 4.5 The channel width indicator. Source: PIANC (2014)

The third step in achieving objective three involved comparing the calculated channel width with the existing channel. This step is crucial for determining the safe passage of vessels. The computed width channel served as an indicator of the safe passage distance for vessels in the study area. The channel was considered unsafe if the existing channel width was more than the calculated width. However, this assessment is not the definitive result, as a simulation test is required to fully validate the safety of the existing channel.

Conducting simulation tests was the fourth and final step in achieving objective three. This test focused on vessel navigation within the existing channel in the study area. Several test runs were performed, which included the existing environment conditions and vessel specifications, as advised by experts. Most of the simulations were run under worst-case scenarios to ensure that vessels could navigate safely through the channel under the most challenging conditions. Thus, the vessels could be considered safe under normal circumstances. The vessel's characteristics were selected from the simulation library to closely match the existing vessel.

Table 4.6 Vessel simulation model

Vessel model	**Characteristics**
	LOA: 54.5 m Breadth: 10.8 m Draught: 3.0 m

Table 4.7 Simulation test conditions

Runs	**Vessel**			**Area**	**Environmental conditions**		
	LOA (m)	**Draft (m)**	**Breadth (m)**		**Wind (kts)**	**Current (kts)**	**Tidal height (m)**
1	54.5	3	10.8	A	20	2	2.0
2	54.5	3	10.8	B	20	2	1.0

The relationship between objectives two and three is to demonstrate that the navigation channel in the study area remains safe for operation, even with a higher risk level, as identified through analysis. This is supported by the calculation method and simulation tests. Both results are vital to strengthen the conclusion regarding the safety of the navigation channel in the study area.

4.5 4th OBJECTIVE: RECOMMENDING SAFETY MEASURES IN CREATING A SAFE ENVIRONMENT FOR USERS IN THE STUDY AREA

The first step was to collect data findings from the study to ensure a safe environment within the study area. Since the process followed an evidence-based analysis, the findings were derived from the results of objectives one, two, and three. From objective one, the collected data were listed in the hazardous event categories. For objective two, the findings on the risk levels within the study area were gathered. Lastly, for objective three, the findings on channel width design and its simulations were included. These data provide the foundation for the required safety measures, which were collected and reviewed during step two.

Step two involved reviewing the data findings from each objective. The collected data were sorted and analysed to determine the suitable mitigation measures. For objective one, the hazardous events were analysed to identify measures that can reduce hazardous events. For objective two, the risk levels were reduced by focusing on the prevention actions to mitigate the risks. The width channel design assists in determining the safest width measure for one-way or two-way channels, and recommendations for new designs were proposed. The simulations provided insight into the overall manoeuvring conditions within the study area, allowing for the recommendation of safe manoeuvring techniques. This process was conducted in step three. Finally, step four involved listing all the recommended measures to mitigate or avoid high-risk hazardous events as shown in figure 4.6.

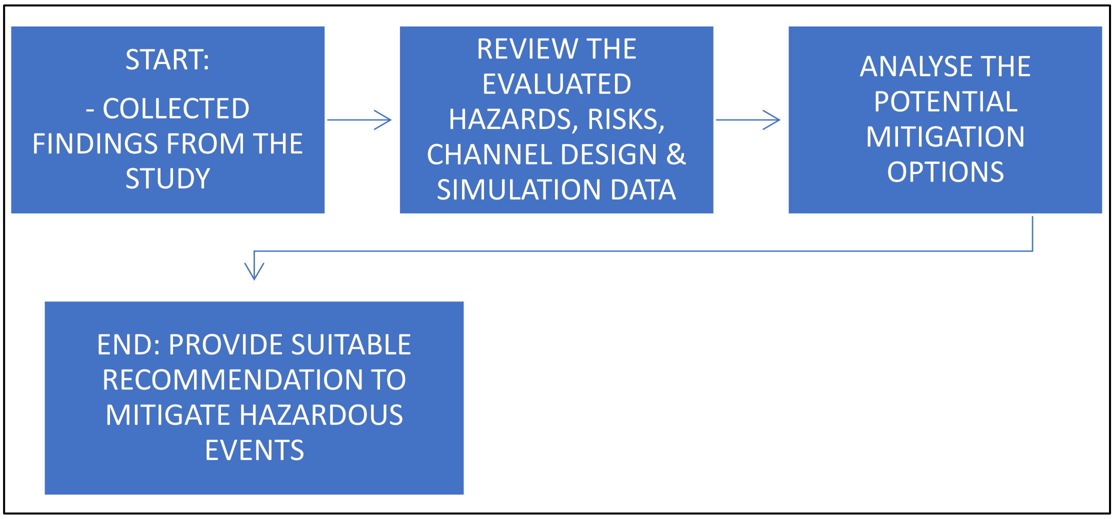

Figure 4.6 Flowchart for the fourth objective

4.6 SUMMARY OF CHAPTER 4

This chapter described the analysis methods used throughout the study to answer all the objectives listed in this study. Most of the analyses were incorporated with experts' opinions to enhance the validity and reliability of the data. The results of these analyses are discussed in Chapter 5.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 INTRODUCTION

This chapter outlines the data findings and results for each objective. The results are presented in tabulated and calculated forms according to the research objectives. Additionally, detailed discussions regarding these findings are presented, demonstrating that all objectives were achieved.

5.2 1st OBJECTIVE: IDENTIFYING POTENTIAL HAZARDOUS EVENTS WITHIN THE STUDY AREA

A hazard can jeopardise human health, their properties, and the environment. In this study, the HAZID process was conducted by identifying all potential hazardous events in the study area based on expert judgment from various backgrounds, government, and non-government agencies, as listed in Table 5.1.

According to IMO (2002), HAZID aims to identify all potential risks and their corresponding scenarios, organised in terms of their risk severity, that pertain to the particular issues being examined. To fulfil this objective, standard methods were employed to detect potential hazards that could lead to accidents, followed by an assessment utilising a combination of accessible data and expert judgment.

After several sessions and discussions with ten experts, only three types of hazardous events with a direct impact on marine traffic activities were identified. The hazardous events are listed in Table 5.1.

Table 5.1 List of hazardous events

Types of hazardous events	Experts response
Collision	- Highest possibility - Common practice of river user - Narrow traffic channel under the bridge - Congested marine traffic flow - Lost control of vessel due to vessel failure
Striking	- Collision vessel with the bridge pillar - Construction - Lost control of vessel due to vessel failure
Grounding	- Long-term - Sedimentation under the bridge - Sedimentation near to bridge pillar - Lost control of vessel due to vessel failure

Based on these results, most experts agreed that collisions exhibit the highest potential hazard due to various factors that could contribute to higher risk.

Collision

The collision described and assessed involves two ships that are both underway, with varying speeds, size of vessels, and impact type.

- Slow speed

Collisions at slow speeds reduce the consequences compared to higher-speed collisions. These hazards are likely to occur in areas near narrow channels or under drawbridges, where vessels are slower in these areas.

- Small vessels

The impact of a collision with small vessels may result in multiple fatalities, placing it in the high-risk category. Hence, mitigation measures are required to reduce this risk.

- Glancing blow

Collisions are more likely to involve glancing or oblique impacts in areas where ships pass each other. This occurs when ships on nearly reciprocal headings make contact due to misjudgement or unforeseen circumstances. The angled contact leads to less severe impacts than other types of collisions.

- Broadside

A broadside collision between ships poses a high consequence due to breaching of the hull and, in extreme cases, capsizing. Although there are no recorded incidents in this area, the possibility remains high.

Striking

Striking hazards include collisions with bridge pillars, buoys, or other structures and present hazardous risks for the ship and future vessels using the channel. Several factors, such as such as ship failure, human error, misjudgements, or bad weather can contribute to this hazard when navigating vessels within the channel.

Grounding

Grounding can be attributed to human error, equipment failure, and poor visibility. While the sea bed type can significantly affect the consequences, this study assumed a consistent seabed along the channel. The risk of grounding increases with a high number of vessels navigating the channel.

5.3 2nd OBJECTIVE: ANALYSING THE RISK LEVEL GENERATED FROM THE POTENTIAL HAZARDOUS EVENTS IDENTIFIED WITHIN THE STUDY AREA

The data findings for the second objective focus on ranking the frequency and consequences of hazards to determine the risk ranking results. Each hazard identified was ranked as a subject in the study area. Although the types of hazards may be the same, the risk rank will depend on the occurrence area.

This study employed a risk matrix based on the DNV.GL (2019) risk ranking table, as recommended by experts during HAZID data collection, as mentioned in Chapter 3. The matrix, presented in Table 5.2, was reviewed and agreed upon by the experts to assess and rank the risk levels of hazardous events within the study area. Table 5.3 provides the tabulated data collected from questionnaires distributed to the experts. This data was separated by study areas A and B. Each identified hazardous event was ranked according to the risk matrix.

Table 5.2 Risk matrix table based on DNV.GL (2019) risk ranking table

		FREQUENCY				
		Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Risk assessment matrix: Risk criteria		**Remote**	**Unlikely**	**Possible**	**Likely**	**Almost certain**
		Remote - may occur in exceptional circumstances	**Unlikely - could occur but doubtful**	**One or more times in 10 years**	**One or more times per year**	**Ten or more times per year**
Consequence	5 – Loss of vessel or severe damage to the vessel. Multiple fatalities. International news coverage. Serious long-term impact on the environment and/or permanent damage	Moderate (5)	High (10)	Extreme (15)	Extreme (20)	Extreme (25)
	4 – Major damage to vessel. Single fatality. National news coverage. Significant impact on the environment with medium-to-long-term effects	Minor (4)	Moderate (8)	High (12)	Extreme (16)	Extreme (20)
	3 – Moderate damage to the vessel. Moderate/major injury. Regional news coverage. Limited impact on the environment with short- or long-term effects	Minor (3)	Moderate (6)	Moderate (9)	High (12)	Extreme (15)
	2 – Minor or superficial damage to vessel. Minor injuries and local news coverage. Minor impact on the environment with no lasting effects	Low (2)	Minor (4)	Moderate (6)	Moderate (8)	High (10)
	1 – Insignificant or no damage to vessel/equipment. No injuries. Insignificant impact on the environment	Low (1)	Low (2)	Minor (3)	Minor (4)	Moderate (5)

Table 5.3 Risk register

No.	Area	Hazardous event	Description	Frequency	Consequence	Risk level
1	A	Collision	Collision between large ships with crew boats or fishing boats, particularly under the drawbridge	**2**	**5**	**10**
2	A	Striking	Contact with bridge pillar, construction material, and navigational aid	**3**	**2**	**6**
3	A	Grounding	Grounding due to sedimentation under the pillar	**3**	**2**	**6**
4	B	Collision	Collision between large ships with crew boats or fishing boats, particularly near to boat jetty	**3**	**5**	**15**
5	B	Striking	Contact with jetty, navigational aid	**3**	**2**	6
6	B	Grounding	Grounding with sand dunes	**2**	**1**	**2**

Collisions were identified as the highest risk within study area A, with a level 2 frequency and level 5 consequences generating a total risk score of 10. This indicates that collisions at study area A are unlikely to occur but may still happen, causing severe damage to vessels and potentially leading to multiple fatalities. In contrast, collisions in study area B recorded a level 3 frequency and level 5 consequences, yielding the highest risk score of 15. This suggests that potential collisions could occur at least once in 10 years, resulting in severe damage to vessels and multiple fatalities.

Striking events presented a similar risk level of 6 for both study areas A and B, with a level 3 frequency (possible to occur at least once in 10 years) and a level 2 consequence, implying minor damage to vessels and slight injuries.

Grounding hazardous events showed a risk level of 6 within study area A, with a level 3 frequency, indicating a possible occurrence at least once every ten years and level 2 consequences, resulting in minor damage to vessels and slight injuries. Experts noted that sedimentation under the bridge pillar could contribute to a higher frequency of grounding events. Meanwhile, study area B achieved a lower risk level of 2, with a level 2 frequency and level 1 consequences. This indicates that grounding is unlikely to occur in this area, with only insignificant damage and no injuries anticipated due to the presence of sand dunes.

5.4 3rd OBJECTIVE: VALIDATING THE SAFETY OF NAVIGATIONAL CHANNEL WITHIN THE STUDY AREA

This subtopic covers the safety of navigation channels in study areas A and B. The existing channel width was compared with the calculated channel design based on the width channel design by PIANC (2014) guidelines (Chapters 3 and 4). The results provide an overview of the safest navigation channel that can be proposed. Although the existing navigation channel width is narrower than the calculated design, the existing channel is not considered unsafe. Other factors, such as seamanship skills and human judgment, need to be assessed. This information was gathered from experts and river users during the hazard identification process.

5.4.1 Total Calculation of Safe Width Design

The calculation involved the total summation of W_{BM}, W_i, and $W_{BR}/_G$. All data gathered were analysed according to the PIANC table guidelines outlined in Chapter 4. The width measurements were calculated separately for study areas A and B, as areas have different conditions.

- ***Step One: Total Basic Manoeuvring Lane (W_{BM})***

The basic manoeuvring lane width (W_{BM}) for ships, as defined by the PIANC guidelines in Table 4.3 of Chapter 4, was designed to facilitate effective ship manoeuvring characteristics. The largest vessels recorded in the study area include twin-propeller ships, ferries, and cruise ships, all of which generally exhibit good manoeuvrability. Table 5.4 presents the basic manouvering of vessel in study areas A and B.

Table 5.4 Basic manoeuvring of vessel

Study area	Vessel characteristic	W_{BM}
A	60 m × 10 m × 6.3 m (Paraffin)	Good (1.3B)
B	35 m × 5 m × 3.3 m (RV Discovery)	Good (1.3B)

- ***Step Two: Total Environmental and Other Factors (W_i)***

The results in this section were obtained during the HAZID process, which involved discussions among experts and incorporated information gathered in Chapter 2, focusing on the existing conditions in the study area. All data collected were agreed upon by the experts and referenced the PIANC guidelines, as described in Table 4.4 of Chapter 4.

Table 5.5 displays the results of the total width addition on the environmental and other factors. The first column presents the vessel’s manoeuvring speed within the study area. According to the experts, a safe manoeuvring speed should range from than 8 kts to 5 kts since the study area is considered an inner channel. According to

PIANC guidelines, this speed is categorised as slow, resulting in a width calculation of 0.0B.

Table 5.5 Environmental and other factors

Width, W_i	**Area A**		**Area B**	
	Vessel speed	Inner channel	Vessel speed	Inner channel
Vessel speed (kts, with respect to water)	Slow	0.0B	Slow	0.0B
Prevailing cross wind (kts) - Moderate - (15 kts < wind < 33 kts)	Slow	0.6B	Slow	0.6B
Prevailing cross-current (kts) - Low - 0.2–0.5 kts	Slow	0.3B	Slow	0.3B
Prevailing longitudinal current (kts) - Moderate - 1.5–3 kts	Slow	0.2B	Slow	0.2B
Aids to Navigation (AtoN) - Good	Slow	0.2B	Slow	0.2B
Bottom surface - Smooth and soft		0.1B h < 1.5T		0.0B h > 1.5T
Depth of waterway		0.2B h < 1.5T		0.0B h > 1.5T
Total of W_i		**1.6B**		**1.3B**

Note: kts = knots

The second column represents the wind speeds within the study area. The data were obtained from weather conditions, as stated in Chapter 2. The wind speed within study areas A and B ranged between 15 kts to 33 kts, classified as moderate, resulting in 0.6B. The third column details the cross-current speeds within the area, ranging from 0.2 kts to 0.5 kts. This data was reported in the Malaysia Hydrography MAL chart. According to PIANC guidelines, this data corresponds to a width measurement of 0.3B. The fourth column addresses longitudinal current speeds, with a data range of 1.5 kts to 3 kts, yielding a width measurement of 0.2B.

The fifth column indicates the existing AtoN. Based on the Malaysia Hydrography MAL chart, there are no VTMS available within the study areas. However, buoys and beacons were present and functioning well. These conditions were considered as good according to PIANC guidelines, resulting in a width measurement of 0.2B.

The six column evaluates the bottom surface conditions. Study areas A and B have a depth measurement of 0.1B and 0.0B, respectively. Despite having the same type of bottom surface, the difference lies in the water depth of each area. The seventh column details the overall depth of the waterway for areas A and B. The cumulative results for each column indicate that the total width addition (W_i) is 1.6B and 1.3B for areas A and B, respectively.

- ***Step Three: Total Additional Width for Bank Clearance W_{BR} and W_{BG}***

This result is based on the type of riverbank, which can provide additional width clearance. The total width clearance represents only one side of the channel, either W_{BR} (riverbank clearance) or W_{BG} (riverbank guidance). Therefore, both W_{BR} and W_{BG} were summed during calculation, yielding results as shown in Table 5.6.

Table 5.6 Width bank clearance

Width for bank clearance	**Vessel speed**	**Inner channel (protected water)**	
		Area A	Area B
Gentle underwater channel slope	Slow	0.0B	0.0B
Sloping channel edges and shoal	Slow	-	0.3B
Steep and hard embarkment, structure	Slow	0.5B	-
Total		**0.5B**	**0.3B**

- ***Step Four: Total Calculation for Width Channel***

This section presents the calculation for the safest width channel for study areas A and B following PIANC guidelines.

Area A for One-way Channel:

$W = W_{BM} + \sum W_i + W_{BR} + W_{BG}$

Substituting all the formulas with determined results:

W = 1.3B + 1.6B + 0.5B + 0.5B

W = 3.9B

W = 3.9 x 10 m (vessel design breadth)

W = 39 m (calculated channel width)

Area B for One-way Channel:

$W = W_{BM} + \sum W_i + W_{BR} + W_{BG}$

Substituting all the formulas with the determined results:

W = 1.3B + 1.3B + 0.3B + 0.3B

W = 3.2B

W = 3.2 x 5 m (vessel design breadth)

W = 16 m (calculated channel width)

Based on this calculation, the safest width channel for study area A, according to PIANC guidelines, was approximately 39 m for a one-way channel. Any channel width less than 39 m was considered unsafe based on these PIANC guidelines. The 39-m width was calculated as the safest for one-way marine navigation, while the existing channel width for area A was 50 m. The 11-m difference concluded the existing channel was safe for the one-way channel. However, for a two-way channel, it was not recommended since the safest width would be 78 m, which was twice that of the one-way channel, and the existing channel width could not accommodate this required width.

For area B, the calculated safe width for a one-way channel was 16 m based on PIANC guidelines. The existing width channel for area B was 130 m, indicating that area B was safe for both one- and two-way navigation channels, as the clearance between the calculated and existing widths was significant.

5.4.2 Simulation Results

A real-time navigation simulation session was conducted to examine ship manoeuvrability. The test results were used to validate the width channel in the study area. Experts performed several runs to ensure a realistic simulation that included the human element.

Two runs were carried out to represent manoeuvrability in study areas A and B, incorporating the worst-case scenario. The model vessel used for this simulation was a marine department motor vessel with twin propellers. This model was selected because it was one of the channel users, and its characteristics suited the type of vessels that navigate this channel.

Figure 5.1 illustrates the simulation run in study area A, showing adverse weather conditions. The wind was set at 20 knots and a current of 2 knots. Based on this simulation model, experts commented that vessel manoeuvrability was challenging due to severe weather conditions. Although the simulation was successful, navigators should exercise extreme precaution when navigating their vessels around this area. Gade (2004) noted that simulations resemble real situations. The limited channel width, especially under the drawbridge, posed significant challenges for vessels to pass through.

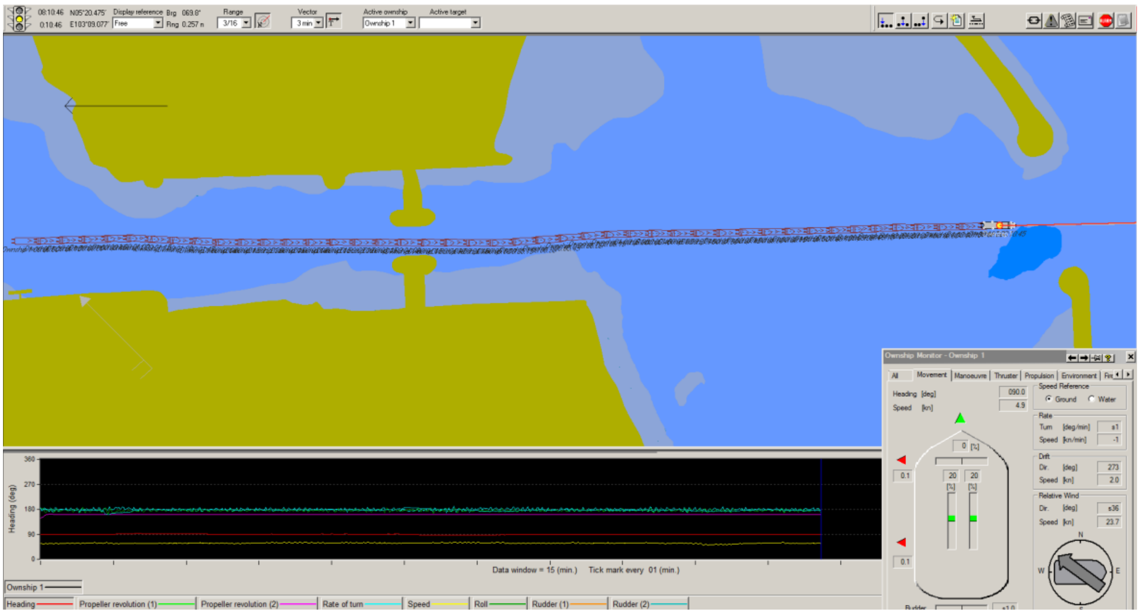

Figure 5.1 Simulation run conducted in study area A

Figure 5.2 depicts the simulation run conducted in study area B, which presented challenges due to congestion from other vessels and marine activities near the jetty. The worst-case scenario was used to assess the manoeuvrability rate of the vessel. Although the test was successful, experts advised all river users to exercise precautionary measures when navigating this area, as the high volume of traffic increases the risk of bad consequences from minor mistakes. Table 5.7 summarises the simulation results.

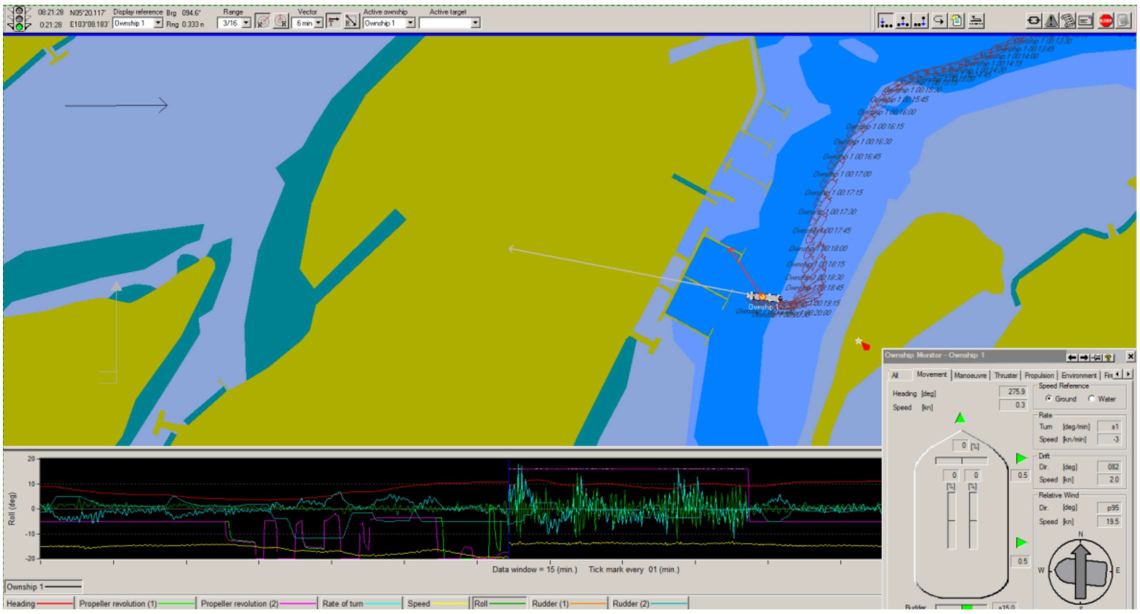

Figure 5.2: Simulation run conducted in study area B

Table 5.7 Simulation results summary

Runs	**Vessel**			**Area**	**Environmental conditions**			**Results**
	LOA (m)	**Draft (m)**	**Breadth (m)**		**Wind (kts)**	**Current (kts)**	**Tidal height (m)**	
1	54.5	3	10.8	**A**	20	2	2.0	**PASS**
2	54.5	3	10.8	**B**	20	2	1.0	**PASS**

5.5 4th OBJECTIVE: RECOMMENDING SAFETY MEASURES IN CREATING A SAFE ENVIRONMENT FOR USERS IN THE STUDY AREA

This section presents the recommendations aimed at enhancing the safety measures within the Terengganu river and ensuring a safe environment for users. The risk assessment based on the HAZID process summarises the findings and suggests actions to address identified hazards. These recommendations are designed to mitigate the risks and reduce high-risk situations into lower ones.

The Marine Department and local authorities should be fully informed of any marine activities that could increase vessel traffic, enabling them to convey effective promulgation notices to mariners. These safety information notices should provide details about the marine activities occurring in the study area. Table 5.8 presents the recommended actions to mitigate the risk associated with hazardous events.

Table 5.8 Recommendations based on hazardous events

Area	**Hazardous events**		
	Collision	**Striking**	**Grounding**
A	i) Safe vessel speed during manoeuvre - The simulation test indicates that vessels should manoeuvre at a slow speed when passing under the bridge. This allows the vessels ample time to avoid collisions ii) One-way channel of navigation - A one-way navigation channel is recommended since the width gap is too small for two-way according to PIANC guidelines calculation iii) Limitation of the maximum breadth of a vessel - An update on notice to mariner on the maximum breadth of vessels that can pass through study area A since a safe width channel design was identified and a restriction order on vessel	i) Installation of a beacon light on the structure - During the nighttime, a beacon light should be operational at the bridge pillars to help river users avoid striking it. During the simulation process, there was noticeable difficulty in identifying the presence of the bridge pillars ii) Safe vessel speed during manoeuvre - According to the simulation test, vessels should manoeuvre at a slow speed when passing underneath the bridge. This allows the vessels ample time to avoid striking the pillars iii) Establish an operational restriction - During bad weather conditions, the simulation showed noticeable difficulty in	i) Annual draft survey and sedimentation management - Preventing sedimentation build-up near the bridge pillar could reduce water depth and grounding ii) Dredging and increasing water depth - During the simulation, sluggish manoeuvring was experienced, making vessel manoeuvring challenging. Increasing water depth can avoid grounding iii) Updated navigational chart on area draft - A new updated chart and a notice to mariners should be issued to avoid vessels running aground in shallow areas

	breadth limitation should be implemented	manoeuvring vessels. An operational restriction order should be implemented during such weather conditions	
B	i) Safe vessel speed during manoeuvre - The simulation test shows that vessels should manoeuvre at a slow speed when passing near the jetty. This provides the vessels ample time to avoid collisions ii) Updated AIS data - All vessels are advised to update their AIS data, ensuring that others can access their position, speed, and conditions iii) Development of VTMS - A VTMS service should be implemented to manage the vessel traffic at the jetty area. The VTMS can also serve as a radio responder during any potential accidents	i) Installation of a beacon light on the structure - During the nighttime, a beacon light should be operational at the jetty pillar to help river users avoid striking it. During the simulation process, there was noticeable difficulty in identifying the presence of the jetty pillars ii) Safe vessel speed during manoeuvre - According to the simulation test, vessels should manoeuvre at a slow speed when passing next to the jetty. This provides the vessel ample time to avoid striking the jetty iii) Establish an operational restriction - During bad weather conditions, the simulation	i) Annual draft survey and sedimentation management - Preventing sedimentation build-up near the bridge pillar could reduce water depth and grounding ii) Dredging and increasing water depth - simulation, sluggish manoeuvring was experienced, making vessel manoeuvring challenging. Increasing water depth can avoid grounding iii) Updated navigational chart on area draft - A new updated chart and a notice to mariners should be issued to avoid vessels running aground in shallow areas

		showed noticeable difficulty in manoeuvring vessels. An operational restriction order should be implemented during such weather conditions	

5.6 SUMMARY OF CHAPTER 5

This chapter presented all results and comprehensively addressed the research objectives. The discussion offered further explanations and insights into the findings.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 INTRODUCTION

This chapter summarises the findings of the study, the implications of the discussed issues according to the study's objectives, and the contribution of this study to the maritime industry. Recommendations for future work are also provided in this chapter.

6.2 OVERVIEW OF THE RESEARCH

This research conducted an MTRA in the waters surrounding Duyong Island, specifically within the Terengganu River. Four key objectives were established to improve marine traffic safety: identifying hazardous events in the area, analysing the associated risk levels, validating the safety of navigational waterways, and proposing recommendations to enhance safety in the region.

The current marine conditions around Duyong Island were initially assessed, focusing on identifying the main challenges and defining the research scope. The first two objectives—hazard identification and risk analysis—were addressed using the HAZID method, which involved expert interviews and risk ranking. The identified risk levels were then analysed using a risk matrix, offering a clear understanding of the most significant risks. The safety of the navigational channels was validated by employing the width channel design method based on PIANC guidelines, supported by simulation tests. Ultimately, several safety recommendations were provided to improve maritime navigation in the study area.

One key finding of this study is the assessment of the safe navigation channel width at Malaysia’s iconic drawbridge near Duyong Island, Terengganu. The width channel design method determined that a width of 39 m is the safest for one-way marine navigation, while the existing channel width was 50 m. The result suggests that the existing channel is more than sufficient for one-way traffic. However, the recommended width for two-way navigation is 78 m, nearly twice the existing width, indicating that the channel is unsuitable for two-way traffic.

Although many channel users believe it is suitable for two-way navigation due to the absence of major accidents, this study highlights the need to consider other additional factors, including the frequency of large vessels, the history of recorded incidents, and human error. Despite the lack of significant accidents, the channel cannot be deemed safe for two-way navigation without further evaluation. Conclusively, the channel is only safe for one-way navigation, with recommendations to maintain this status for future use.

6.3 RESEARCH CONTRIBUTION

The study contributes to two key areas: academic and industry. Academically, this study addresses the significant gap in the literature on MTRA in Malaysia, where research in this field is still limited. By focusing on the Terengganu River, this study expands the knowledge and provides a foundation for future studies in the region. The use of the PIANC guidelines for width channel calculation in a practical application offers a valuable reference for researchers aiming to improve their understanding and implement these international standards more effectively.

In terms of industrial contribution, the identified hazardous events and risk rankings in this study provide actionable insights for government agencies and local authorities, supporting the development of safety protocols around Duyong Island. The risk assessment enhances understanding of the potential hazards in the area and prioritises precautionary measures. Furthermore, the calculation of the optimal channel width for safe navigation offers practical guidance for maritime authorities and industry stakeholders, facilitating informed decision-making on vessel operations and infrastructure planning in the region for safer navigation.

6.4 SUGGESTION FOR FUTURE WORK

Future research should focus on several key areas to further improve maritime safety around Duyong Island. Firstly, a comprehensive bathymetry survey of the study area should be performed to provide vital insights into underwater topography, enabling a more thorough assessment of navigation safety. Additionally, evaluating the effect of marine traffic on the structural integrity of the iconic drawbridge would ensure its longevity and durability despite the increasing maritime activity.

Apart from that, future works should consider designing a safe navigation channel system for Duyong Island, incorporating proper navigation aids and communication channels to guide vessels safely. As the Terengganu River is expected to experience more intense development, including growing maritime activities and vessel traffic, these measures are crucial for sustaining the long-term safety and operational efficiency of the river’s waterways for all users.

6.5 SUMMARY OF CHAPTER 6

This chapter offered a comprehensive summary of the research process, from its initiation to its completion. The study highlighted vital contributions that provide added value to both research activities and outcomes. While the study has made significant progress in addressing MTRA in the Terengganu River, there is still room for further exploration of additional aspects. Continuous research in this area could lead to more substantial contributions, expanding the impact of this work on a larger scale.

6.6 CONCLUSION

Maritime routes have long been central to human trade and exploration, and safeguarding these routes is significant to preserve their economic and cultural importance. This study aimed to assess and mitigate risks within the maritime sector, recognising that reducing risks directly enhances safety and sustainability. By examining various factors, the research findings offered reliable insights, particularly in sustaining the safety of the Terengganu River and its users.

This study identified several hazardous events and established a risk ranking system that offers valuable guidance for authorities, river users, the local marine industry, and the public. The findings contribute to creating a safer maritime environment and supporting economic activities while preserving natural resources.

Despite the critical importance of the maritime industry, public awareness regarding its value remains limited. Hence, greater understanding among the people could foster more substantial collective efforts to protect and sustain it. While this research serves an educational purpose, it also plays a crucial function in shaping future safety strategies and promoting the steady development of the marine and maritime industries for future generations.

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APPENDICES

Appendix 1

A Survey from Hazardous Event Identification and Risk Level

UNIVERSITI MALAYSIA TERENGGANU

UMT

Survey Paper

(Research Project)

Title of research

MARINE TRAFFIC RISK ASSESSMENT OF TERENGGANU RIVER NAVIGATION CHANNEL AT DUYONG ISLAND TERENGGANU

Reason of the research

To collect a set of data that will be used in conducting research for pursuing a master's degree in science.

Introduction

The purpose of this survey is to investigate the hazardous event that could possibly happen at the Terengganu River navigation channel at Duyong Island and the factors that could lead to this event. This navigational channel will be divided into two areas. Area A is where the new Kuala Terengganu Drawbridge. The vessel navigation gap below the bridge will be the focus point as the gap will be a very narrow navigation channel. Area B is where the navigational channel near the Duyong Island Fisherman jetty. This survey also investigates the level of risk and recommendations of mitigation measure which will be the important data in assessing the risk.

Objectives

From this survey paper, there are several main aims to be achieved as below:

5) To identify the possible hazardous event in the Terengganu river
6) To identify the risk level generated from the possible hazardous events in the Terengganu river.
7) To recommend the proper mitigation measures for reducing the risk.

Researcher's information

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Hopefully, all of you can give full cooperation and be honest in giving your evaluations in order to help produce a reliable data. Your cooperation and honesty are much appreciated. Thank you.

Expert's Profile/ Background

Name:			
Background:			
Year of experience:			
Have involved in MRA/ MTRA :	☐ YES		☐ NO

Instruction

- state all possible hazardous events that could occur in the area.
- rank the frequency and consequence based on the risk matrix.
- suggested a few mitigations measure that could reduce the risk

Example of the hazardous event

Collision
Grounding
Striking

RISK ASSESSMENT MATRIX: RISK CRITERIA		FREQUENCY				
		Level 1	Level 2	Level 3	Level 4	Level 5
		Remote	Unlikely	Possible	Likely	Almost Certain
		Remote - may occur in exceptional circumstances.	Unlikely - could occur but doubtful.	One or more times in 10 years	One or more times per year	Ten or more times per year
Consequence	5 – Loss of vessel or severe damage to vessel. Multiple fatalities International news coverage. Serious long-term impact on environment and/or permanent damage.	Moderate (5)	High (10)	Extreme (15)	Extreme (20)	Extreme (25)
	4 – Major damage to vessel. Single Fatality. National news coverage. Significant impact on environment with medium to long term effects	Minor (4)	Moderate (8)	High (12)	Extreme (16)	Extreme (20)
	3 – Moderate damage to vessel. Moderate / major injury Regional news coverage. Limited impact on environment with short-term or long-term effects	Minor (3)	Moderate (6)	Moderate (9)	High (12)	Extreme (15)
	2 - Minor or superficial damage to vessel. Minor injuries and local news coverage. Minor impact on environment with no lasting effects	Low (2)	Minor (4)	Moderate (6)	Moderate (8)	High (10)
	1 - Insignificant or no damage to vessel / equipment. No injuries. Insignificant impact on environment	Low (1)	Low (2)	Minor (3)	Minor (4)	Moderate (5)

ACTION KEY	Low (1 – 2)	No Action is required
	Minor (3 – 4)	No additional controls are required, monitoring is required to ensure no changes in circumstances
	Moderate (5 – 9)	Efforts should be made to reduce risk to ‘As low as reasonably practicable’ (ALARP), but activity may be undertaken
	High (10 – 14)	Efforts should be made to reduce risk to ‘As low as reasonably practicable’ (ALARP). Activity can only be undertaken with further additional controls.
	Extreme (15 – 25)	Intolerable risk. Activity not authorized

AREA	HAZARDOUS EVENT	FACTOR OF THIS EVENT		CONSEQUENCE (1~5)	FREQUENCY (1~5)
A			RISK LEVEL		
B					

MAL 6522 Chart of Kuala Terengganu, Source: Malaysian National Hydrography Center, (2019)

Location of study area A, Source: Google (2020)

Location of study area B, Source: Google (2020)

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