Implementation of Automatic Identification System(AIS) for Analysis of Marine Traffic Safety

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(Degree)
博士（工学）
(Date of Degree)
2013-09-25
(Date of Publication)
2014-09-01
(Resource Type)
doctoral thesis
(Report Number)
甲第5969号
(URL)
https://hdl.handle.net/20.500.14094/D1005969

Doctoral Dissertation

Implementation of Automatic Identification System (AIS) for Analysis of Marine Traffic Safety

（ＡＩＳデータの海上交通安全性評価への応用に関する研究）

July 2013

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Dedicated to my beloved: Kristina Ekawati (wife), Nathania Aurellia Maharani (daughter), Zaskia Annisa Jasmine (daughter), Kinara Nayla Dewi (daughter), Ahmad Zubairi (father), Siti Alfiyah (mother)

Contents

List of Figures

List of Tables

Abstract

The Malacca Straits considered to be the busiest and is one of the world's most dangerous shipping lanes in the world because of its heavy traffic, narrowness, sharp turns, and many other critical factors. Therefore, maritime safety in the Strait of Malacca is an important issue. With a length of approximately 500 mi (800 km), the Strait of Malacca is the longest strait in the world used for international navigation. It forms the main seaway connecting the Indian Ocean with the China Sea and provides the shortest route for tankers shuttling between the Middle East and Asian countries. Therefore, this strait is the busiest shipping lane in the world. Safety of navigation has been focusing on issues of security, loss of lives and property. Moreover the concern for environmental protection and collision avoidance are going significantly. The objectives of International Maritime Organization (IMO) of implementing an automatic identification system (AIS) are to enhance the safety and efficiency of navigation, safety of life at sea, and protection of maritime environment.

The thesis conducted the implementation of AIS for analysis and evaluates the marine traffic safety in the Malacca Straits. The purpose of research studies are summarized as follow: to evaluate the danger score in the Malacca Straits, to evaluate the risk of collision in the Malacca Straits and to assess the safety of navigation in the Malacca Straits. In order to purpose of this research, several chapters are established.

In Chapter 1, the background consisting of the reason of the research studies is explored. In addition, the study areas are described. In Chapter 2, AIS installation and investigation were described. AIS implemented as source of data for the analysis and evaluate the marine traffic safety in the Malacca Straits. In Chapter 3, the evaluation of marine traffic safety in the Malacca Straits is established. In this chapter, the danger score in the Malacca Straits using Analytic Hierarchy Process (AHP) and AIS are conducted. AIS is implemented as a source of data that describe the characteristics of ship traffic density determined using a geographic information system (GIS). AHP is then used for evaluating the safety level in the Strait of Malacca. In this case, weighting factors are determined using AHP. The evaluation criteria were divided into five: Ship condition, human factor, environmental factor, machinery factor and management factor. Each criterion divides into sub criteria and sub-sub criteria.

In Chapter 4, the evaluation of risk for formal safety assessment (FSA) is established. In this study, hazard identification and risk evaluation of ship collision as step of formal safety assessment have been established. In this case, the traditional failure mode and effects analysis (FMEA) determines the risk priorities of failure modes called risk priority numbers (RPNs), which require the risk factors like the occurrence (O), severity (S) and detection (D). The risk factors O, S, D as fuzzy variable and evaluate them using fuzzy method. an Automatic Identification System is implemented for the study on collision using fuzzy logic method under The International Regulations for Preventing Collisions at Sea 1972 (COLREG) guidelines. AIS implemented as source of data and input for the hazard identification and risk evaluation using fuzzy logic method as step of formal safety assessment.

In Chapter 5, the safety of navigation assessment by considering traffic density is established. This study focus for usage of AIS and GIS to establish risk based navigation. Risk assessment includes the probability analysis and consequence analysis. In this case, the analysis of risk determined in the different condition and different time based on AIS data taken from AIS receiver system which have installed in the UTM Malaysia by Kobe University. Analysis of risk divided into 3 conditions; head on condition, crossing condition and overtaking condition.

In Chapter 6, the discussions regarding how the results of research in Chapter 2 until chapter 5 are described. Several consideration of analysis and implementation of AIS for marine traffic safety in the Malacca Straits are shown in respect to ship safety of navigation in the marine traffic. Finally, the further researches are shown.

Chapter 1

Introduction

1.1 Background

The Malacca Straits is vital strategic for seaborne trade. However, it is a risk area for navigation. The analysis of marine traffic safety in the Malacca Straits is very important to enhance navigational safety. Navigational collisions are major safety concern in many sea ports. The Malacca Straits, considered to be the busiest shipping lane in the world, is located between the east coast of Sumatra Island in Indonesia and the west coast of Peninsular Malaysia, and is linked to the Straits of Singapore at its southeast end. With a length of approximately 500 miles (800 km), the Malacca Straits is the longest strait in the world used for international navigation. It forms the main seaway connecting the Indian Ocean with the China Sea and provides the shortest route for tankers shuttling between the Middle East and Asian countries. The Malacca Straits is a high-risk area for navigation. For centuries, concerns over safety in navigation have focused on issues of security and loss of lives and property. Currently, there is growing concern over environmental protection. The increasing traffic through the Malacca Straits poses significant risks to the navigation, marine environment, and to the fishing and tourism industries.

Based on the statistical data for the types of casualties for 1978–1994 in the Malacca Straits; the following set of vessel-related casualties in the Malacca straits were considered: (1) fire explosions, (2) stranded/grounded, (3) spring leaks, (4) collisions, and (5) other. Based on that fact, the analysis and evaluation of safety navigation in the Malacca Straits should be established. Using AIS data, the evaluation of marine traffic safety is conducted.

Regulation 19 of SOLAS (Safety of Life at Sea) Chapter V - Carriage requirements for shipborne navigational systems and equipment - sets out navigational equipment to be carried on board, according to ship type. IMO (International Maritime Organization) adopted a new requirement (as part of a revised new chapter V) for all ships to carry AIS capable of providing information about the ship to other ships and to coastal authorities automatically.

Figure 1.1: Actual condition in the Malacca Straits

In this research, human factors are founded as greatest factors than other that contribute the accident in the Malacca Straits.   Fig. 1.1 shows the actual condition in the Malacca Straits. Some navigators feel worried during pass in the Straits. This condition needed to be more careful when transiting the Straits. The danger score by considering ship condition, human factors, environmental factors, machinery factors, and navigational factors are established using AHP and AIS, which are described in Chapter 3, followed by AIS system installation works described in chapter 2

The collision is important issue which has occurred in the Malacca Straits. In this research, as shown in Chapter 4, risk evaluations of ship collision are evaluated as step of formal safety assessment. The result is value of risk ranking which has determined using failure mode effect analysis and fuzzy logic method. AIS data is used as source data for make classification of ship behaviour and traffic volume.

The results of research in Chapter 5 show the analysis of safety of navigation by considering the traffic density. In this case, risk assessment is established. Based on AIS data, the scenario of risk assessment have been carried out with different time with actual data. The risk level has been established in Head on condition, crossing condition and overtaking condition. scenario taken in the time which have high traffic area, on 2.00h, 10.00h, and 22.00h. The discussion of ship collision probability analysis and consequence analysis are explored in this Chapter.

1.2 Study Area of Research

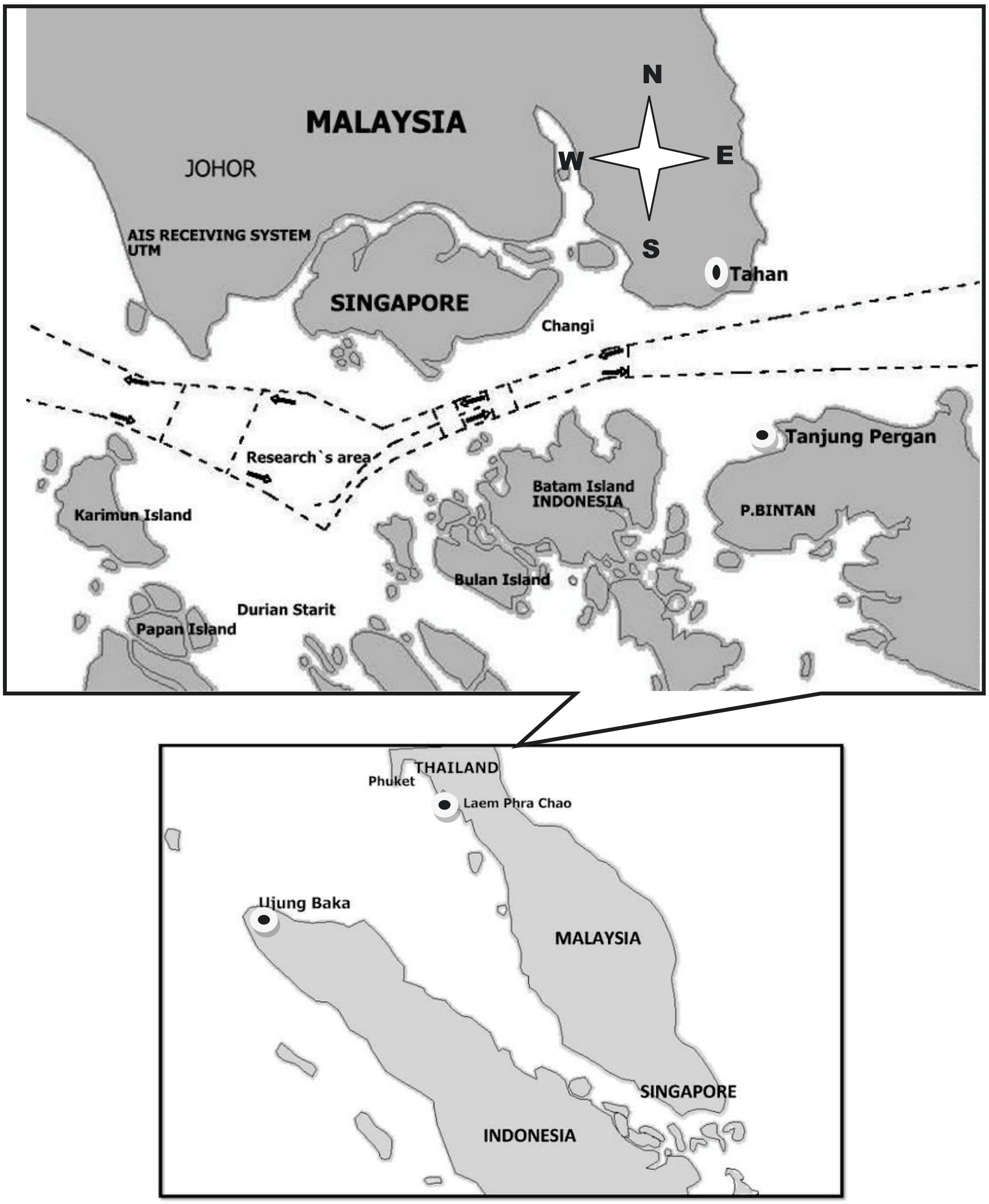

Figure 1.2: study area of research

The study area is located in the Malacca Straits. In this area, there are several straits and several ports. The selected area is located in the Singapore Straits area. Fig.1.2 shows the area of research. Based on the fact, the Malacca Straits is classified as busy area in the world. The Malacca Strait is the longest strait in the world used for international navigation. It has long been an important trade route linking the Indian Ocean to the South China Sea and Pacific Ocean. The Strait of Malacca is located between the east coast of Sumatra Island in

Indonesia and the west coast of Peninsular Malaysia, and is linked with the Strait of Singapore at its south-east end.

The Strait of Malacca is bordered on the north-west by a line from Ujung Baka (5°40’N, 95°26’E), the north-west extremity of Sumatra, to Laem Phra Chao (7°45’N, 98°18’E), the south extremity of Ko Phuket Island, Thailand, and on the south-east by a line from Tahan (Mount) Datok (1°20’E, 104°20’N) and Tanjung Pergam (1°10’E,104°20’N). The increasing traffic through the Malacca Straits poses significant risks to the biodiversity and the marine environment, to the livelihood of the coastal communities and to the fishing and tourism industries. Therefore, current safety measures should be improved and supported with the relevant complementary services to face the challenges of development in East Asia associated with the increase in international shipping.

Chapter 2

Automatic Identification System (AIS)

2.1 Background of AIS

An automatic identification system allows monitoring of ships and other ships from the land station (Vessel Traffic Service), and operating on VHF frequency band. The AIS is a Very High Frequency (VHF) radio broadcasting system that transfers packets of data over the VHF data link (VDL) and enables AIS equipped vessels and shore-based stations to send and receive identification information that can be displayed on an electronic chart, computer display or compatible radar. This information can help in situational awareness and provide a means to assist in collision avoidance. In addition, AIS also has the characteristics and the ability to improve navigation safety and efficiency of the management of marine traffic. AIS also can be used as an aid to navigation, by providing location and additional information on buoys and lights.

The AIS station is a radio transmitter capable of sending ship information such as position, speed, ship length, ship type and cargo information, etc by VHF electric waves. When used with graphic displays, AIS on ships allow to receive the information quickly, automatic and precision of information about risk by calculating closest point of approach (CPA) and time to closest point of Approach (TCPA) of vessel position information is transmitted.

Since 2002, new ships and later all larger sea-going vessels (>300 GT) and all passenger vessels are required to carry an AIS on board. IMO and SOLAS requires AIS to be fitted aboard international voyaging ships with gross tonnage (GT) of 300 and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size.

The regulation requires that AIS shall:

- provide information - including the ship's identity, type, position, course, speed, navigational status and other safety-related information-automatically to appropriately equipped shore stations, other ships and aircraft.
- receive automatically such information from similarly fitted ships, monitor and track ships.
- exchange data with shore-based facilities.

2.2 AIS Installation

The AIS is a tool that has many applications. AIS works best over a range of a few miles as the AIS signal is more or less limited to line of sight to the horizon (usually 10-20 miles). However, by getting together a group of amateur shipping enthusiasts around the country equipped with suitable receivers and aerials, ships can be tracked over longer distances.

Based on IMO Resolution MSC.74 (69), Annex 3 about Recommendation on Performance Standards for An Universal shipborne an automatic identification system, these standards establish the basic performance requirements for AIS equipment and are used by the International Telecommunications Union and the International Electro Technical Commission standard in technical development and testing. The AIS should improve the efficient for ship safety navigation, environmental protection, and operation of Vessel Traffic System (VTS), by following some of the following conditions:

a. Can avoid collision / accident between vessels
b. To find information about the ship and its cargo
c. AIS is as a tool for VTS for traffic management

The data transmitted by the AIS are:

a. For Class A AIS each 2 to 10 seconds will provide information in accordance with the speed of the vessel, and every 3 minutes at anchorage, will provide the following information:

1. MMSI (maritime mobile service identity) number – unique reference able identification.
2. Navigation status – not only are “at anchor” and “under way using engine” currently defined, but “not under comment” is also currently defined.
3. Rate of turn – right or left, 0 to 720 degrees per minute.
4. Speed over ground – 1/10 knot resolution from 0 to 120 knots.
5. Position accuracy – differential GPS or other and an indication if RAIM processing is being used.
6. Longitude – to 1/1000 minute and latitude – to 1/10000 minute.
7. Course over ground – relative to true north to $1/10^{th}$ degree .
8. True heading – 0 to 359 degrees derived from gyro input.
9. Time stamp – the universal time to nearest second that this information was generated.

In the class A, for each 6 minute AIS will provide the following information:

1. MMSI number – same unique identification used above, links the data above to described vessel.
2. IMO number – unique reference able identification (related to ship’s construction).
3. Radio call sign – international call sign assigned to vessel often used on voice radio.
4. Name – name of ship, 20 characters are provided.
5. Type of ship/cargo – there is table of possibilities that are available.
6. Dimensions of ship – to nearest meter.
7. Location of ship where reference point for position reports is located.
8. Type of position fixing device – various options from differential GPS to undefined.
9. Draught of ship – 1/10 meter to 25.5 meters (note “air-draught” is not provided).
10. Destination – 20 characters are provided.
11. Estimated time of arrival at destination –month, day, hour, and minute in UTC.

There are two classes of AIS, Class A and Class B, as well as different types of AIS used for shore stations (AIS Base Stations), aids to navigation (AIS AtoN), AIS on search and rescue aircraft and AIS search and rescue transmitters (AIS SART).

Table 2.1: Class of AIS

AIS Class A	Class A has been mandated by the International Maritime Organization (IMO) for vessels of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages, as well as passenger ships (more than 12 passengers), irrespective of size.
AIS Class B	Class B provides limited functionality and is intended for non-SOLAS vessels. It is not mandated by the International Maritime Organization (IMO) and has been developed for vessels such as work craft and pleasure craft.
AIS Base Station	Base Stations are provided by aids to navigation authority to enable the ship to shore / shore to ship transmission of information. Networked AIS Base Stations can assist in providing overall maritime domain awareness.
AIS aids to navigation (AtoN)	AIS AtoN provide an opportunity to transmit position and status of buoys and lights through the same VDL, which can then show up on an electronic chart, computer display or compatible radar.
AIS SART	Search and Rescue Transmitters using AIS can be used to assist in determining the location of a vessel in distress.
AIS on Search and Aircraft	Search and Rescue Aircraft may use AIS to assist in their operations.

For this research, the actual sea traffic conditions of the Malacca Straits were recorded by an AIS data receiving system installed in the Universiti Teknologi Malaysia, Malaysia. The equipment was used to collect the data. All AIS data received by the equipment were continuously and automatically stored on the hard disk of a PC. The data could be retrieved from the PC via the Internet and analyzed on another PC at any time.

2.3 AIS Data Analysis

2.3.1 AIS Data Analysis for Evaluate Marine Traffic Safety

Below are results of AIS data investigation in the Malacca Straits. These data used for analysis of marine traffic safety in the Malacca Straits.

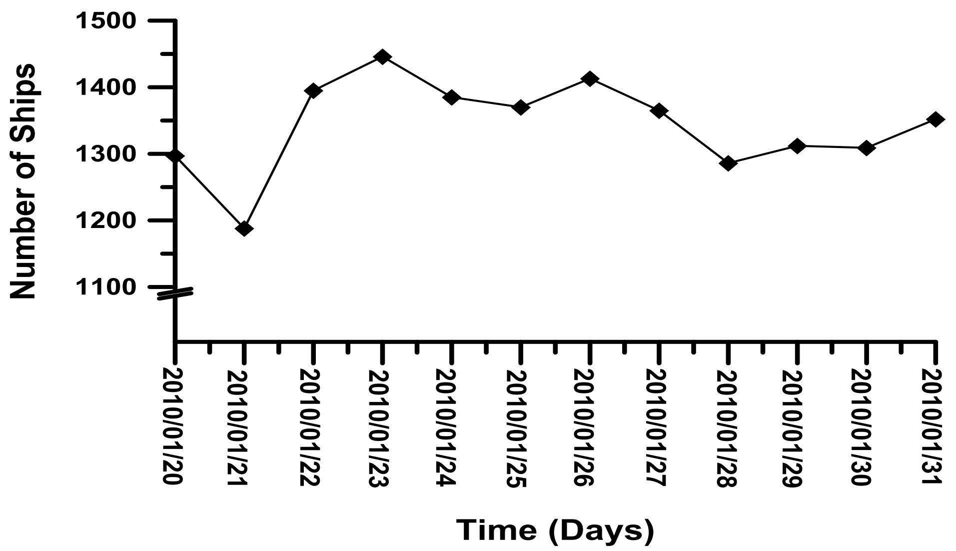

Figure 2.1: Traffic volume of 12 days in January 2010

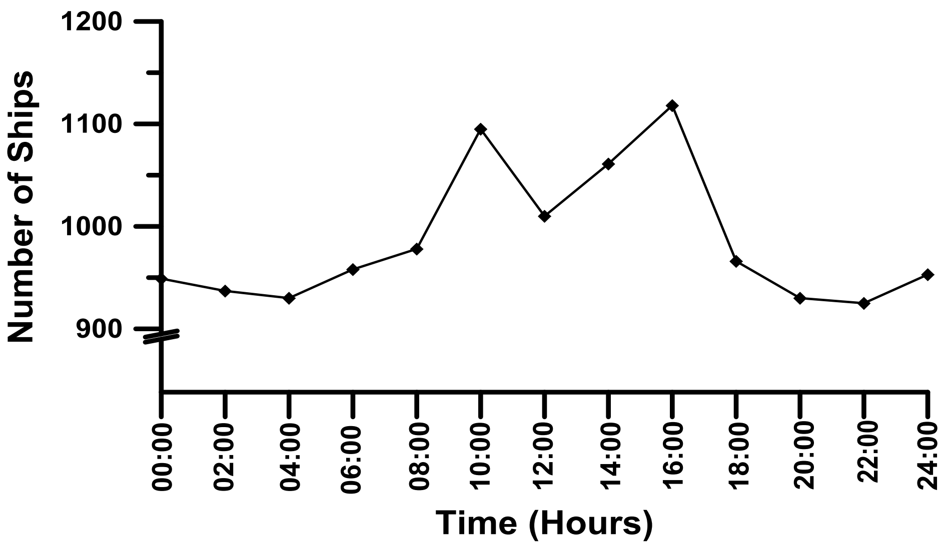

Figure 2.2: Traffic volume per hour in January 2010

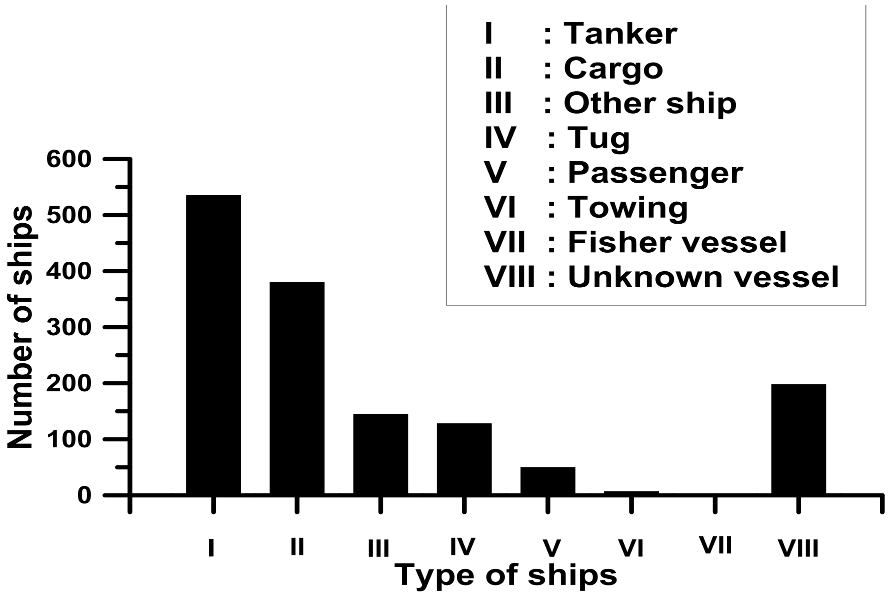

Figure 2.3: Ships population data in January 2010

The analysis results of the traffic volume in January 2010 are shown in Figs. 2.1 and 2.2. Figure 2.1 shows the traffic volume of 12 days in January. The greatest volume of data per day was received on 1/23/2010, when the number of ships was 1,446. The fewest ships were in the Straits on the 1/20/2010, when only 1, 149 ships were recorded.

Figure 2.2 shows the traffic volume per hour on 1/23/2010. A sharp rise in the number of ships can be seen around 16.00h, when the number of ships was 1,118. The period with the fewest ships occurs in the early hours of the morning, until around 04.00h.

Figure 2.3 shows the population of ships passing through the Strait of Malacca on 1/23/2010. This is broken down between: tanker ships (37%), cargo ships (26%), tugs (9%), passenger ships (3%), towing and fishing vessels (1%), other ships (10%), and unknown vessels (14%).

2.3.2 AIS Data Analysis for Risk Evaluation

The AIS data analysis for risk evaluation of marine traffic is shown in figure 2.4-2.10. On the basis of the AIS data, an analysis of ship encounter situations has been established. The AIS data analysis is also useful for analyzing the traffic density, the ship collision probability and the area dangerous for navigation.

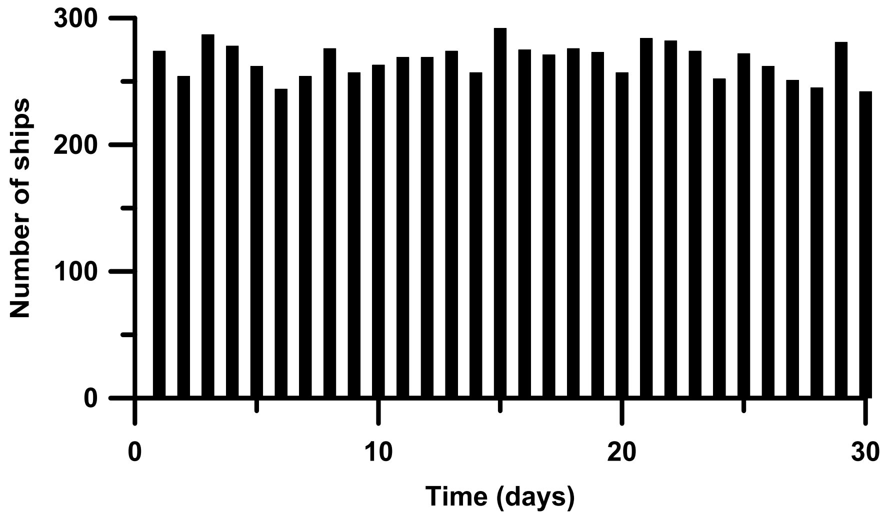

Figure 2.4: Traffic volume per day in June 2010

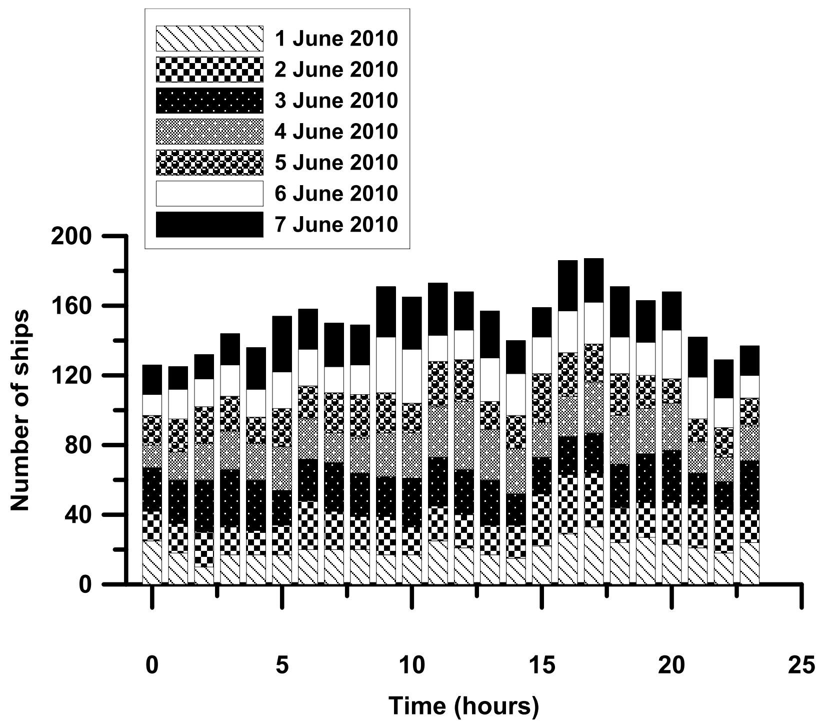

Figure 2.5: Traffic volume per hour during one week in June 2010

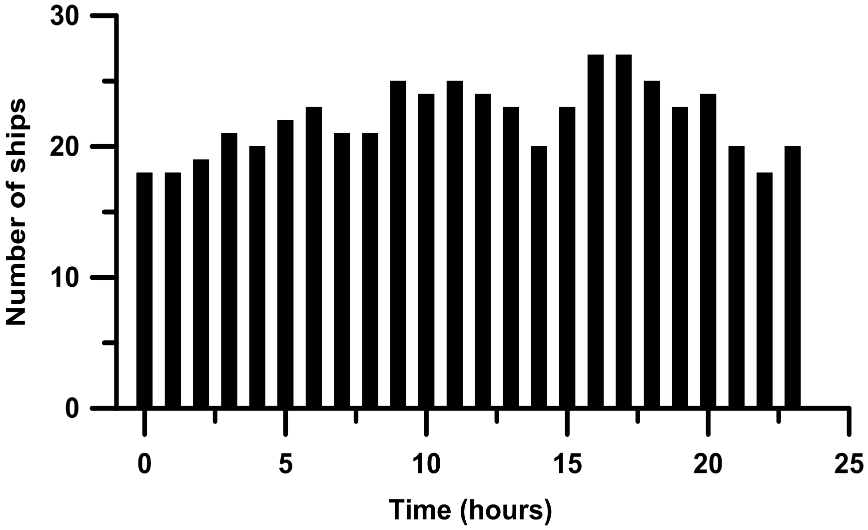

Figure 2.6: Average number of ships per hour in June 2010

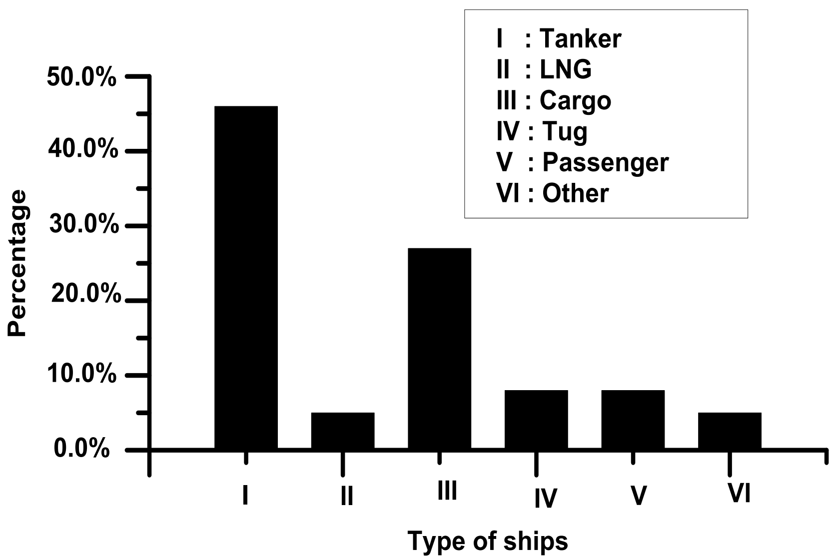

Figure 2.7: Type of ships

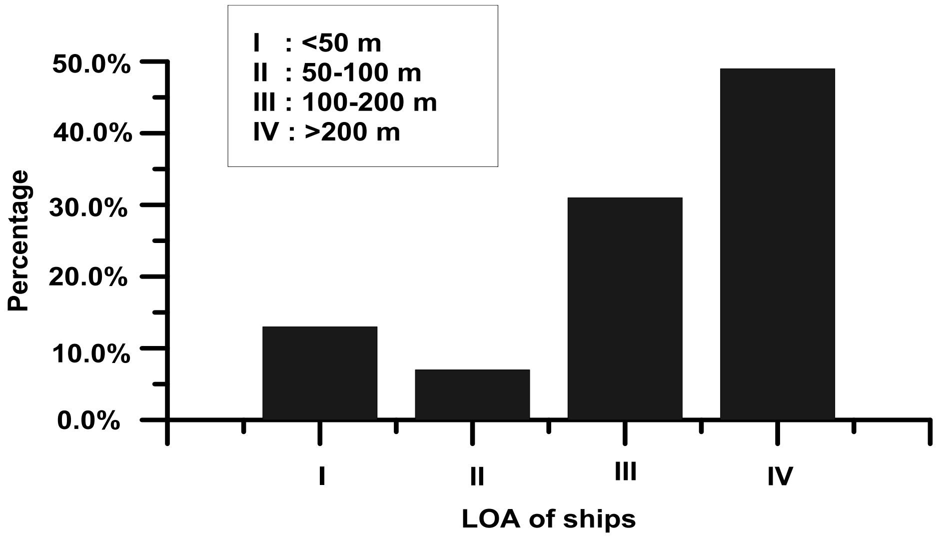

Figure 2.8: LOA of ships

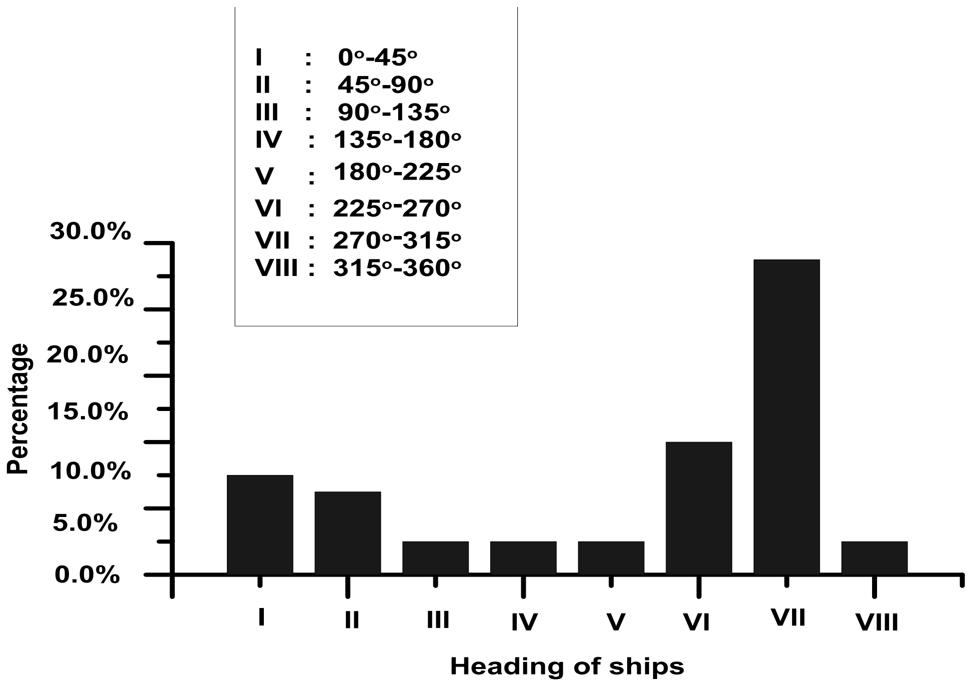

Figure 2.9: Heading angle of ships

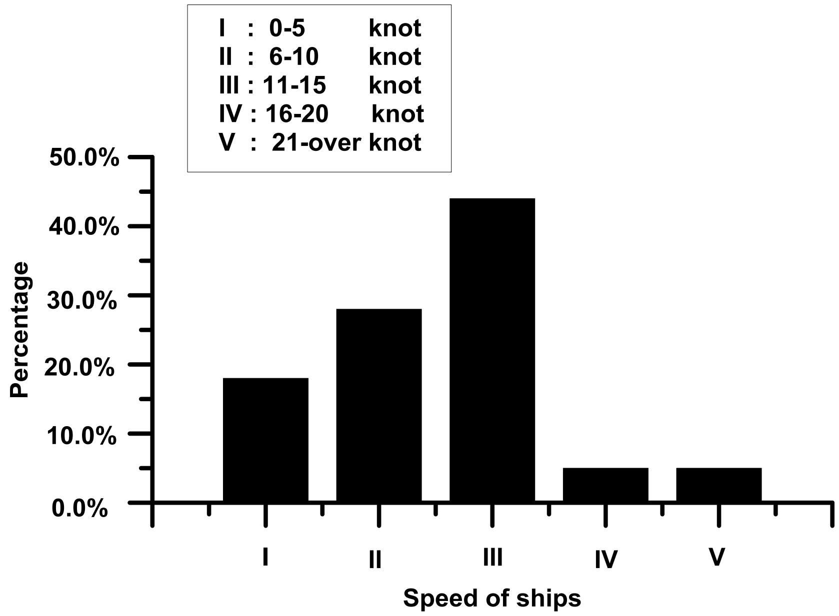

Figure 2.10: Speed of ships

The analysis results related to the number of ships in June 2010 are shown in Figs. 2.4, 2.5, and 2.6. Figure 2.4 shows that the highest number of ships was recorded on 06/15/2010, when the number of ships was 287. Figure 2.4 also shows that the number of ships tends to gradually decrease from 06/21/2010 except for the sharp increase on 06/29/2010. The lowest number of ships was recorded on the 6/30/2010 when the number of ships was 242.

Figure 2.5 shows the traffic volume data that was recorded during one week from 06/01/2010 to 06/07/2010. The figure also shows that the traffic volume tends to mostly rise from 00.00h to 17.00h before declining from 18.00h. The lowest traffic volume period occurred in the early morning hours between 00.00h and 03.00h. Additionally, the highest traffic volume was recorded on 4 June 2010 at 12.00h. The lowest number was recorded on 1 June 2010 at 2.00h. The average of number of ships per hour during the whole week from 06/01/2010 to 06/07/2010 is shown in Fig.2.6.

The type of ships passing through the Malacca Straits on 06/04/2010 are shown in Fig.2.7. It is broken down as: tanker ships (46%), cargo ships (27%), tugs (8%), passenger ships (8%), LNG (5%) and other ships 5%.

The lengths over all (LOA) of the ships that are passing through the selected area in the Malacca Straits are shown in Fig. 2.8. The percentages are as follows: LOA>200m (49%), 100<LOA<200m (31%), 50<LOA<100m (7%) and LOA <50m (13%).

The ship's heading angle and their respective speeds are also analyzed based on the AIS data. They are shown in Figs. 2.9 and 2.10. The highest percentages of heading angles are for the range where the heading angle is between 270° and 315° as shown in Fig. 2.9. The percentage of ships speeds in the selected research area are classified as follows: 0-5 knot (18%), 6-10 knot (28%), 11-15 knot (44%), 16-20 knot (5%) and 21-over (5%).

2.3.3 AIS Data Analysis for Safety of Navigation

The AIS data analysis for safety of navigation are shon in Figure 2.11 and 2.12. Base on AIS data, the analysis of afety of navigation is established with different time by focusing on head on, crossing and overtaking according to COLREG.

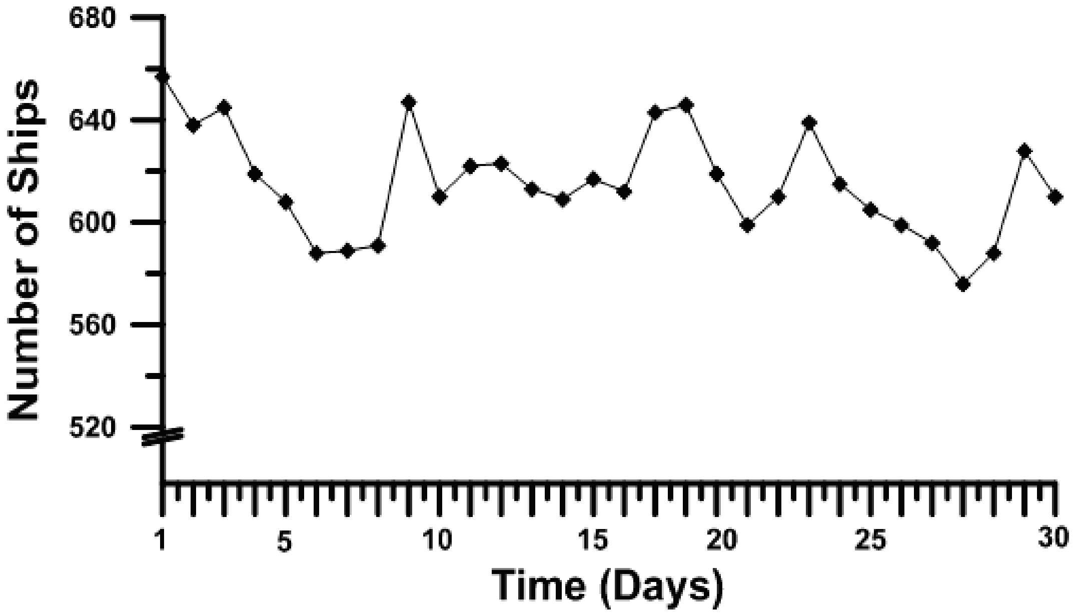

Fig. 2.11: Number of ship per day in June 2010 based on selected area.

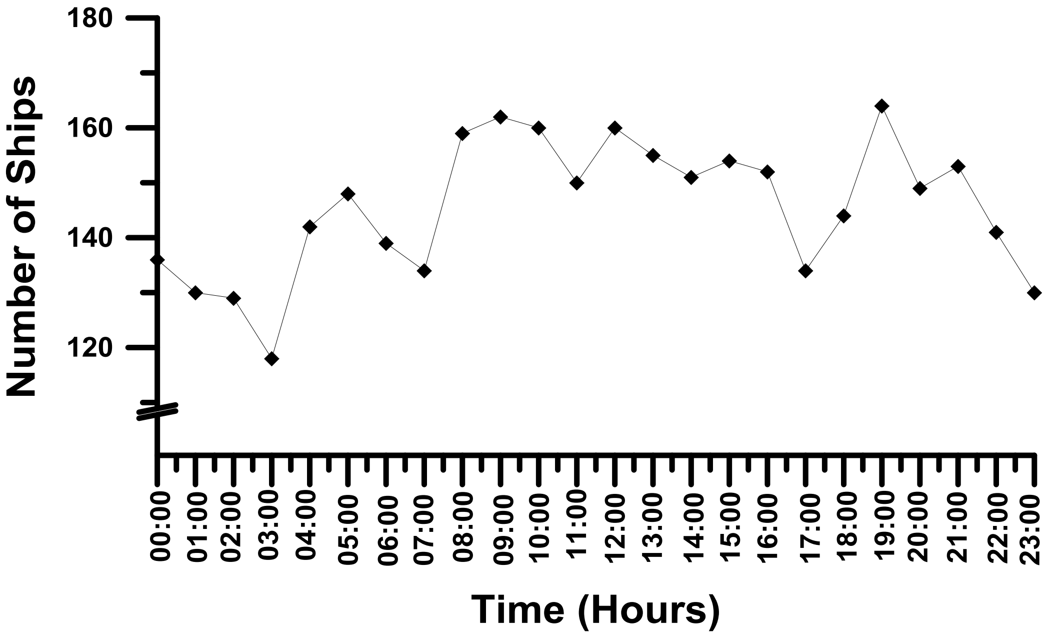

Fig.2. 12: Number of ship per hour in June 2010 based on selected area.

The analysis results of number of ship in June 2010 are shown in Fig. 2.11 and 2.12. Highest number of ships was found on 6/1/2010, when the number of ships was 657. Lowest number of ships period occurs on the 6/27/2010 when the number of ships was 575.

The Fig. 2.11 also shows that the number of ships tends to rise on 6/1/2010 before declining from 6/5/2010. Fig. 2.12 shows the ship traffic density per hour on 6/1/2010. It shows that the number of ships tends to rise 19.00h, when the number of ships was 164. The lowest number of ships period occurs in the morning hours after 24.00 and continuous until around 03.00.

2.4 Conclusions

This chapter presents the AIS analysis for evaluation of marine traffic safety. The actual sea traffic condition of the Malacca Straits was recorded by an AIS data receiving system installed at the Universiti Teknologi Malaysia. In this study, the analysis of AIS data is required in order to evaluate the dangerous area and risk of collision and safety of navigation in the Malacca Straits.

Chapter 3

Evaluation of Marine Traffic Safety

3.1 Introduction

The Strait of Malacca, considered to be the busiest shipping lane in the world, is located between the east coast of Sumatra Island in Indonesia and the west coast of Peninsular Malaysia, and is linked to the Straits of Singapore at its southeast end. With a length of approximately 500 miles (800 km), the Strait of Malacca is the longest strait in the world used for international navigation. It forms the main seaway connecting the Indian Ocean with the China Sea and provides the shortest route for tankers shuttling between the Middle East and Asian countries.

The Strait of Malacca is a high-risk area for navigation. It is not surprising that in a recent survey; more than 80% of captains of VLCC (Very Large Crude Carrier) responded that they are worried when navigating the strait. For centuries, concerns over safety in navigation have focused on issues of security and loss of lives and property. Currently, there is growing concern over environmental protection. For the Strait of Malacca, an analysis of the casualty data between 1975 and 1995 shows that serious accidents have occurred in high-density traffic areas .The objectives of IMO of implementing an automatic identification system are to enhance the safety and efficiency of navigation, safety of life at sea, and protection of maritime environment (IMO, 2001). The principal aim of this study is to determine the danger score in the Strait of Malacca by the analytic hierarchy process (AHP) using the AIS data. In this study, the AIS is implemented as a source of data that describes the characteristics of ship traffic density determined using a geographic information system. AHP is then used for evaluating the safety level in the Strait of Malacca. In this study, weighting factors are determined using AHP.

This Chapter is organized as follows. In the first section, The background of the researches introduced present a literature review in the second section. Herein, we have discussed the originality of this research and the applicability of the selected method through the literature review. In the third section, we investigate the sea traffic in the Strait of Malacca using the AIS data and GIS, which includes the traffic volume of the strait. In the fourth section, an AHP for the evaluation of marine traffic safety is described. Here, the construction of AHP is discussed. Finally, the simulation result of the danger score is presented.

3.2 Literature Review

Several authors have used AHP for research purpose in several fields. Hoang Nguyen [6] has discussed the application of AHP in the risk estimation for ship systems. AHP has been used for estimating the proportional contributions of individual subsystems and units in the reliability structure of propulsion systems.

Arslan et al. [4] analyzed the marine casualties in the Strait of Istanbul using SWOT-AHP. The objective of this study was to examine SWOT factors in greater detail and more systematically and then formulate clear and applicable strategies for safe marine operations in the Strait of Istanbul. They also developed a strategy action plan for ships, ship operators, ship management companies, and seafarers through a SWOT analysis and the AHP, to ensure safer navigational operations in the Strait of Istanbul and prevent the re-occurrence of marine casualties.

Kwok et al. [5] used AHP to determine priorities in a safety management system. In this case, AHP was used to determine the priority of processes outlined in the BS8800 Guide to Occupational Health and Safety Management System for the Hong Kong construction industry.

Ying et al. [10], in their paper, have discussed about combining the AHP with a GIS for the synthetic evaluation of eco-environmental quality. Using the GIS and the regional eco-environmental information system database and assuming the county as the evaluation unit, they evaluated the eco-environmental quality of hunan province by integrating an eco-environmental evaluation index method and a spatial analysis.

Qigang et al. [8] used AHP and a GIS for the evaluation of hazard degrees in the Wanzahou district of the Three Gorges Reservoir area. The model was established by GIS techniques using land use/cover, stratum characteristics, slope aspect, slope gradient, elevation difference, and slope shape as the evaluation factors. The weights of the factors were established by AHP.

Tesfamariam et al. [9] analyzed risk-based environmental decision-making using a fuzzy analytic hierarchy process (F-AHP). In their paper, vagueness-type uncertainty is considered using fuzzy-based techniques. The AHP is modified into fuzzy AHP using a fuzzy arithmetic operation. The concept of risk attitude and the associated confidence of a decision-maker on the estimates of pair-wise comparisons are also discussed.

There are some studies in the literature that consider the issue of an automatic identification system. Mou et al. [7] used AIS data to analyze collision avoidance in busy waterways. They performed statistical analysis of ships involved in collisions. The authors take only into account ships (own ships) that have an encounter in the Traffic Separation Schema (TSS) of the port of Rotterdam.

Pitana et al. [2] analyzed the evacuation of a large passenger vessel in the case of a pending tsunami using discrete event simulation (DES), which is considered to be a stochastic approach. In this paper, the authors used the AIS data to calculate the sea traffic in the area.

Kobayashi et al. [1] proposed a guideline for ship evacuation in the case of a tsunami attack. In their paper, AIS data was used for an analysis of ships passing through Osaka Bay, Japan.

The main focus of this research is to determine the danger score in the Strait of Malacca using the AHP based on the AIS data. In this study, the AIS is implemented as a source of data that describes the characteristics of ships' traffic volume determined using a geographic information system. AHP is therefore used for evaluating the safety level in the Strait of Malacca. In this case, weighting factors are determined using AHP. The evaluation criteria are divided into five items: ship condition, human factor, environmental factor, machinery factor and navigational factor. Each criterion divides into sub-criteria and sub-sub-criteria.

3.3 Investigation of Sea Traffic by AIS

The AIS is designed to provide information about a ship to other ships and to coastal authorities, automatically. Regulation 19 of SOLAS Chapter V "Carriage requirements for shipborne navigational systems and equipment" sets out the navigational equipment that must be carried on board ships, based on ship type. In 2000, the IMO added a new requirement (as part of a revision to Chapter V) for all ships to carry AIS capable of providing information about the ship to other ships and to coastal authorities, automatically.

The AIS is also designed to transmit and receive information about a vessel. This information includes its identity, position, speed, and course, along with other relevant information. Vessels within the AIS range can receive information transmitted by other vessels and display this information on a dedicated AIS display, a chartplotter, or a PC using navigation software. Combined with a shore station, this system also offers port authorities and maritime safety bodies the ability to manage maritime traffic and reduce the hazards of marine navigation.

According to the IMO, in 2002, AIS information includes static, dynamic, and voyage-related elements. Static information is programmed into the unit at the time of commissioning. Dynamic information is derived from interfaces with a ship's GPS and other sensors. Voyage-related data are entered manually by the ship's captain using a password-protected routine.

3.3.1 AIS Receiving System

The actual sea traffic conditions of several ships in the Strait of Malacca were investigated using an AIS receiver installed at Universiti Teknologi Malaysia (UTM) in Malaysia. All AIS data received by the equipment were continuously and automatically stored on the hard disk of a PC. The data could be retrieved from the PC via the Internet and analyzed on another PC at any time.

In this context, static information includes the vessel's maritime mobile service identity, the name of the vessel, radio call sign, ship length, the draft of the ship, the IMO number, ship width, type of ship, and antenna position. Dynamic information includes the longitude, latitude, time, course, rate of turn, and speed over ground. Voyage-related information includes the draft of the ship, destination, and type of cargo.

3.3.2 AIS Data Analysis

Figure 3.1 shows the photograph of AIS receiving system at Universiti Teknologi Malaysia in Malaysia.

The study area of this research is shown in Fig 1.2.

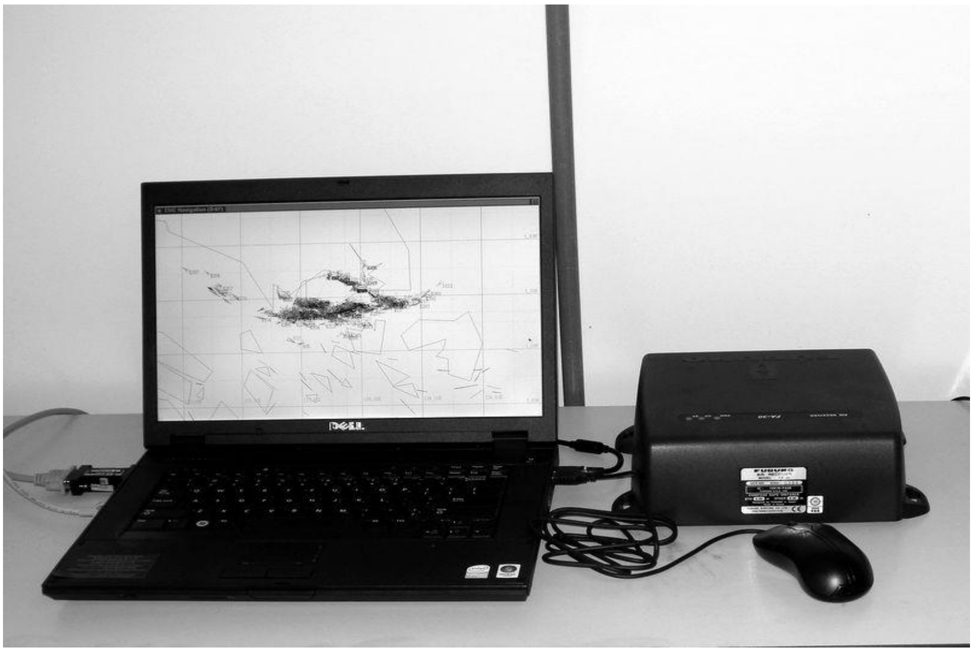

Figure 3.1: Photograph of AIS receiving system

The analysis results of the traffic volume in January 2010 are shown in Chapter 2, in Figs. 2.1 and 2.2.

3.4 The AHP Methodology

The AHP is a method and a simple decision-making tool developed by Saaty (1980) to deal with complex, unstructured, and multi-attribute problems. The AHP integrates an expert's opinion and evaluation scores and converts the complex decision-making system into a simple elementary hierarchy system. There are some key steps to making decisions in an organized way, to generate priorities and to decompose a complex multi criteria decision-making (MCDM) problem. These steps include:

1. Define the problem and determine the objective.

2. Develop the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) to the lowest level.

3. Construct a set of pair-wise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below.

4. Use the priorities obtained from the comparisons to weigh the priorities in the level. Continue this process of weighting and adding until the final priorities of the alternatives in the bottom most level are obtained.

In the AHP, the structure of the hierarchy is a very important factor. The AHP initially breaks down a complex MCDM into a hierarchy of interrelated decision elements. Figure 3.2 shows the structure of the constructed hierarchy. The decision goal is at the top level, while the decision criteria are sub-criteria in the middle level and sub-sub-criteria are in the bottom level.

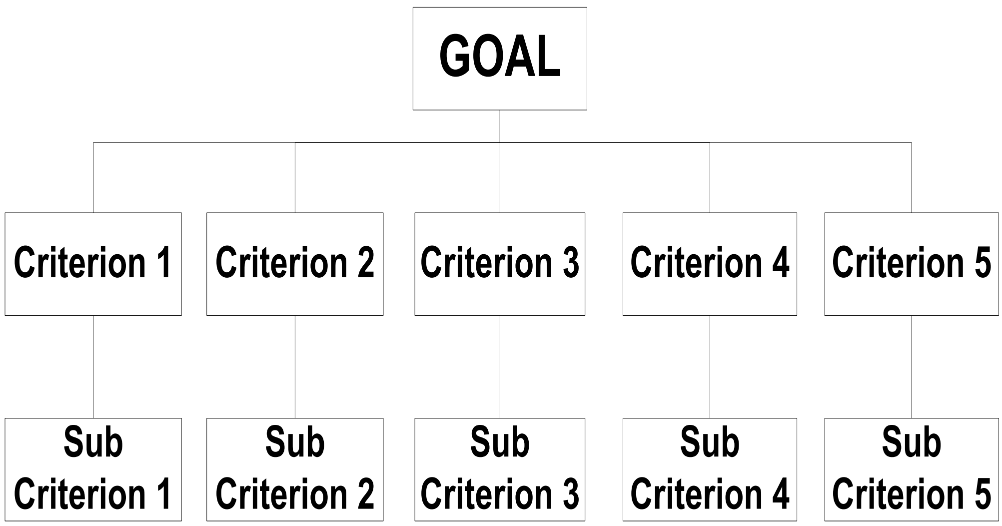

Figure 3.2: Hierarchy for MCDM problem

Table 3.1 shows a nine-point pair-wise comparison scale typically used in the AHP. The AHP helps to perform a pair-wise comparison the criteria at a particular level of the hierarchy, to find out which of the criteria the decision-maker wants to assign the highest priority. While comparing those criteria qualitatively, some corresponding scale values are assigned to them.

Table 3.1: Nine-point pair-wise comparison scale of AHP

Point	**Definition**
1	Indifferent
3	Weak preference (moderately more important)
5	Preference (more important)
7	Strong preference (strongly more important)
9	Very strong preference (extremely more important)
2, 4, 6, and 8	Intermediate values between the two adjacent scale values (used to represent compromise between the priorities listed above)

Table 3.2: Random inconsistency index (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

3.4.1 Calculation of Comparison Matrix

In this step, the pair-wise comparison matrix is calculated. The matrix is expressed by:

$$A = \begin{array}{c} \cdot \\ A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_n \end{array} \begin{bmatrix} A_1 & A_2 & A_3 & \cdots & A_n \\ w_1/w_1 & w_1/w_2 & w_1/w_3 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & w_2/w_3 & \cdots & w_2/w_n \\ w_3/w_1 & w_3/w_2 & w_3/w_3 & \cdots & w_3/w_n \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ w_n/w_1 & w_n/w_2 & w_n/w_3 & \cdots & w_n/w_n \end{bmatrix} \tag{3.1}$$

3.4.2 **Priority Vector**

Having a comparison matrix, we can compute the priority vector, which is the normalized eigenvector of the matrix. In this case, the relative weight can be easily obtained from each of the rows of matrix A. In other words, matrix A has rank 1, and the following holds:

$$A\,W = n\,W \qquad (3.2)$$

where $W = (w_1,w_2,..,w_n)$ and n is the number of elements. In matrix algebra, n and W in (3.2) are called the eigen value and the right eigenvector of matrix A.

In the AHP, the evaluator does not know W and, therefore, is unable to accurately produce the pair-wise relative weights of matrix A. Thus, the observed matrix A contains inconsistencies. The estimation of $\widehat{W}$ could be obtained similarly by:

$$\widehat{A}*\widehat{W} = \lambda_{max} * \widehat{W} \qquad (3.3)$$

where $\widehat{A}$ is the observed matrix of pair-wise comparisons, λ_{max} is the largest eigenvalue of $\widehat{A}$, and $\widehat{W}$ is its right eigenvector. $\widehat{W}$ constitutes the estimation of W.

3.4.3 **Consistency Index and Consistency Ratio**

We test the consistency of the judgment matrix to make sure it is maintained. We define CI as follows:

$$CI = (\lambda_{max} - n)/(n-1) \qquad (3.4)$$

where CI is the consistency index, λ_{max} is the largest principal eigenvalue of the matrix, which can be easily calculated, and n is the order of the matrix. Then, the consistency ratio (CR) is calculated as follows:

$$CR = CI/RI \leq 0.1 \qquad (3.5)$$

where RI is the random inconsistency index, which depends on the order of the matrix [26].

The RI is the average value of the CI, if the entries in the pair-wise comparison matrix were chosen at random. RI values determined from Saaty`s information and Saaty`s procedure. To calculate the CI/RI score, the team first gets the standard RI value from Saaty`s information. If CR≤0.10, the pair-wise comparison matrix is thought to have an acceptable consistency. Otherwise, the matrix should be changed. The calculated results for the weights are accepted when the consistency ratio is satisfactory. Table 3.2 shows the value of the random inconsistency index for a pair-wise comparison matrix with orders of 1 to 10.

3.5 Proposed Model Using AHP

In this research, the AHP was combined with AIS data in order to determine the danger score in the Strait of Malacca. AIS is implemented as a source of data that describes the characteristics of ship traffic volume determined using a geographic information system. The AIS data is also used for determining the number of ships, ships' behavior and ships' traffic in the strait. AHP is therefore used for evaluating the navigation safety level in the Strait of Malacca. In this case, weighting factors are determined using AHP. The evaluation criteria were divided into five: ship condition, human factor, environmental factor, machinery factor and navigational factor. Each criterion divides into sub-criteria and sub-sub-criteria. Combining AHP and AIS, the danger score could be determined. In this paper, the danger score in the Strait of Malacca was determined for different ships at different time steps.

3.6 AHP Design and Application to Assessment of Danger Score

3.6.1 Conceptual Framework of Danger Score

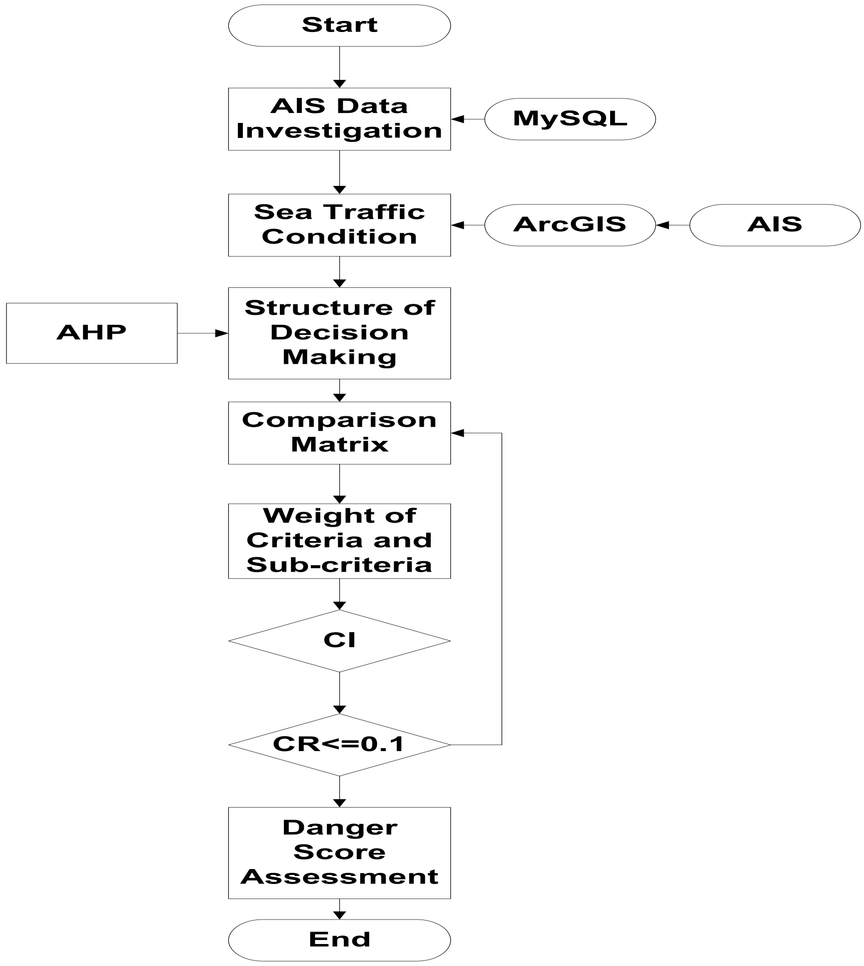

Figure 3.3: Framework for assessment of danger score by AHP

Figure 3.3 shows the framework for the assessment of danger score. In this framework, several steps are shown, which are related to the Strait of Malacca, marine traffic safety analysis, AHP, an automatic identification system and a geographic information system. What follows next is the investigation of the AIS data using MySQL. In this step, several data pertaining to the ship, such as size, velocity, longitude, latitude, IMO Number, MMSI, type, name, etc., are obtained. The population of ships and the traffic densities, per day and per hour are calculated. These data are then input into the GIS to visualize the location of ships in the Strait of Malacca.

Next, a questionnaire is prepared to collect perception data. In this research, A total of 41 questionnaires were distributed among pilots (10), masters (10), officers (10), and others crewmembers (11) who have navigated across the Strait of Malacca. The results of the questionnaire are required to determine the danger score using AHP and the comparison matrix and to determine the weight of different criteria and sub criteria. In the next step, the danger score assessment and simulation using the AIS and GIS are carried out.

3.6.2 Selection of Assessment Criteria and Construction of Hierarchical Structure

This study attempts to evaluate the marine traffic safety in the Strait of Malacca based upon an assessment of danger scores. In this step, the structure of the AHP is designed as shown in Figure. 3.4. For the proposed methodology in this research, the establishment of the hierarchical structure for danger score assessment is important. In this context, selection criteria and sub criteria was conducted. Some keys and steps involved in this methodology are: (1) Proposed selection criteria and sub criteria of hierarchical structure for danger score from the literature. (2) Interview to the relevant experts and professionals in the maritime field about the factors that contribute to the accidents and danger in the Strait of Malacca. To accomplish the proposed model using AHP, a questionnaire was designed based on AHP structured for data collection that was distributed to the navigators and crew members who have experience in passing through the Strait of Malacca. A questionnaire has been compiled based on the AHP structure. In this context, respondents who are selected to fill out the questionnaire were navigators and other crewmembers of ships that have knowledge of and experience in passing through the Strait of Malacca.

Based on the hierarchical structure of the AHP and a comparison matrix, we can compute the priority vector, which is the normalized eigenvector of the matrix. In the AHP structure, a goal is specified at the top level, all the objectives or criteria are listed at the second level and the last level presents all sub- criteria. For this application, the evaluation criteria were divided into five categories: ship condition, human factors, environmental factors, machinery factors and navigational factors.

The ship condition consists of 4 sub criteria: type of ship, length of ship, speed of ship, and state of loading. Human factors consist of 5 sub criteria: communication, knowledge and skills, experience, overworked, and fatigue. The criteria of environmental factors consist of 10 sub criteria: wind effect, current influence, speed relative to another ship, other vessel's length, relation between water line and depth, distance between vessels, own ship course and course of another ship, time zone, influence associated with day of the week and characteristics of the area. Characteristic of area defines the encountered ships areas: head on area, crossing area and overtaking area. In the characteristics of the area, the configuration of the Strait of Malacca as a congested area is also considered. The traffic volume, the narrowness of the strait, the sharp turns etc. are also taken into account. The machinery factors consist of 6 sub criteria: failure of main engine and electrical, failure of rudder, failure of propulsion, failure of lubricating oil, failure of navigation equipment, and failure of hull equipment. The navigational factors consist of three sub criteria: inappropriateness of ship operation regulation management, inappropriateness of crew manning, and inappropriate navigational aids.

The sub-criteria of type of ship, length of ship, speed of ship, and state of loading consist of several sub-sub-criteria or indicators. The sub criteria of current influence, speed relative to another ship, other vessel's length, relation between water line and depth, distance between vessels, own ship course and course of another ship, time zone, and influence of the day of the week also consist of several sub-sub-criteria or indicators.

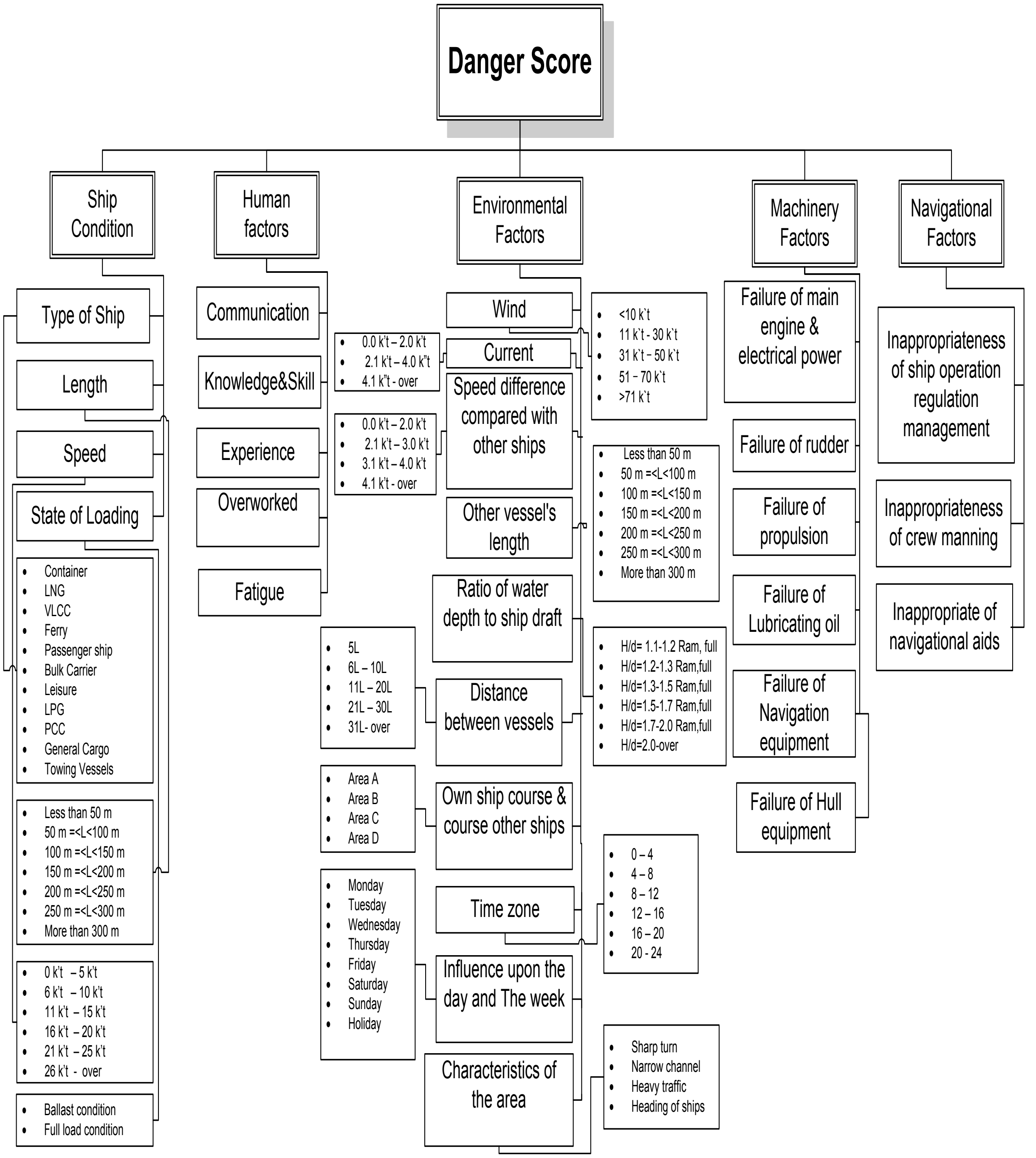

Figure 3.4: Hierarchical structure for danger score assessment

3.6.3 Results of AHP Application

To analyze the survey findings, the judgment matrices were compared, pair-wise, and calculated. The local priority weights of all main criteria and sub-criteria were first calculated, and then combined with all successive hierarchical levels in each matrix to obtain a global priority vector. The higher the mean weight of the global priority vector, the greater is the relative importance. This helps to distinguish the more important elements from the less important ones.

Figure 3.5 shows the weight of the main criteria. Respondents reported that human factors (0.33) were the highest contributors to marine accidents in the Strait of Malacca, followed by ship condition (0.25), machinery factors (0.22), environmental factors (0.08) and navigational factors (0.12).

The weights of sub criteria for ship condition are shown in Figure. 3.6. Respondents indicated that the type of ship (0.07) was the lowest contributing factor to marine accidents in the Strait of Malacca, while the speed of the ship and length (0.32) were the most important contributors to accidents in marine traffic safety. These were followed by the state of loading (0.29).

The sub-criteria of human factors are shown in Figure. 3.7. In this figure, respondents indicated that experience (0.36) was the leading factor, followed by knowledge and skill (0.26), communication (0.21), fatigue (0.09), and over worked (0.08).

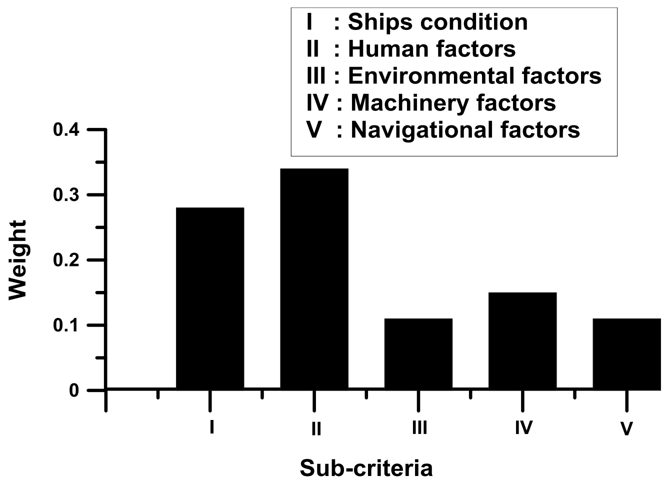

Figure 3.5: Weight of main criteria

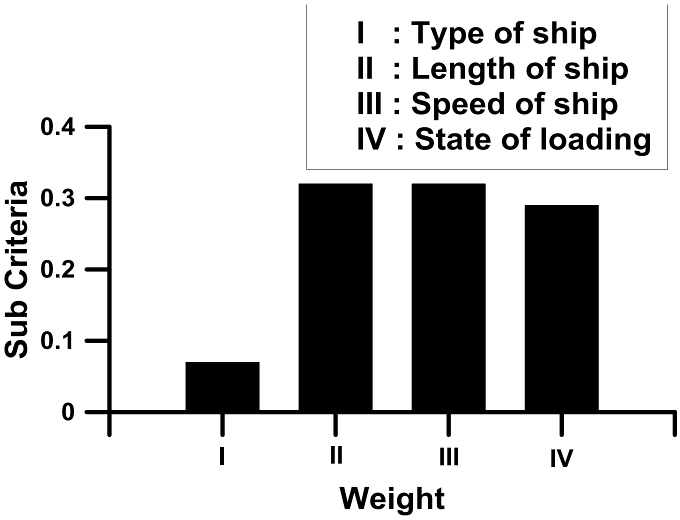

Figure 3.6: Weight of ship condition

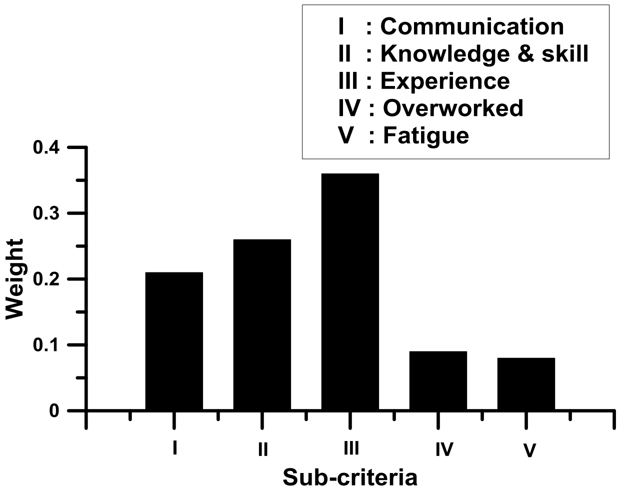

Figure 3.7: Weight of human factors

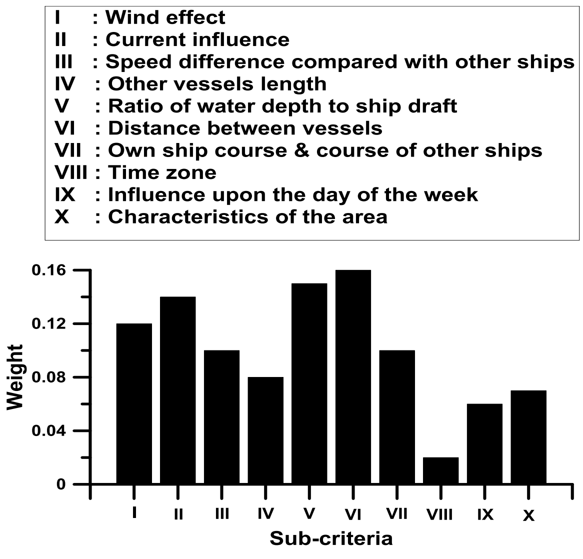

Figure 3.8: Weight of environmental factors

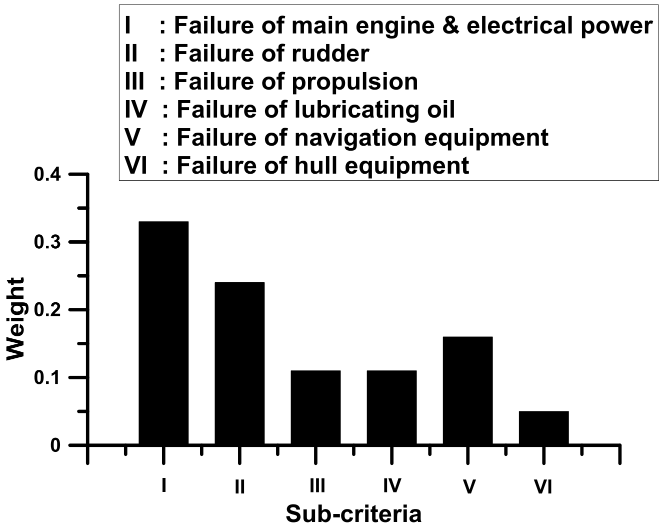

Figure 3.9: Weight of machinery factors

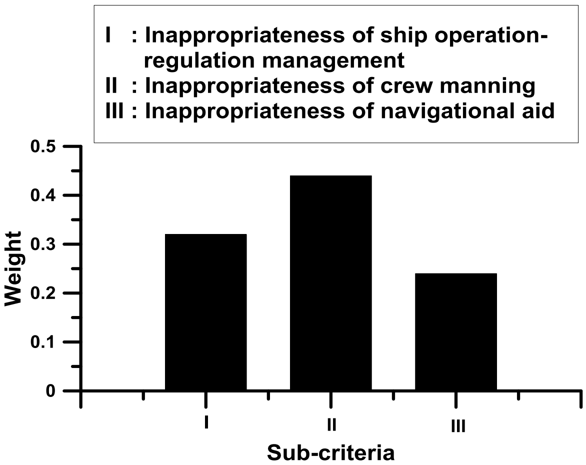

Figure 3.10: Weight of navigational factors

Figure 3.8 shows the weights of environmental factors. Distance between vessels (0.16) was continuously perceived as the most important sub-criteria of the environmental factors. This was followed by the ratio of ship draft to water depth (0.15), current influence (0.14), wind effect (0.12), speed difference compared with other ships (0.10), own ship course and course of other ships (0.10), characteristics of the area (0.08), influence upon the day of the week (0.06) and time zone (0.02).

The failure of main engine and electrical sub-criterion (under the main criterion of `machinery factors`), in Figure. 3.9, was perceived as the most important (0.33). This was followed by failure of rudder (0.24), failure of navigation equipment (0.16), failure of lubricating oil (0.11), failure of propulsion (0.11), and failure of hull equipment (0.05).

As shown in Figure. 3.10, inappropriateness of crew manning (0.44) was indicated as the most important sub-criteria of the navigational factors. This was followed by inappropriateness ship operation regulation (0.32) and inappropriateness of navigation (0.24).

Table 3.3 shows the indicator of ship condition. The type of ship indicator shows that LNG (0.17) were the most important, followed by VLCC(0.13), LPG (0.12), leisure(0.11), container ship (0.09), large passenger ship (0.09), ferry (0.08), bulk carrier (0.07), towing vessel (0.06), reefer ship(0.05) and PCC (0.04).

Respondents reported that ship indicators of 250 m =< L< 300 m (0.2) and more than 300 m (0.2) were the most important, followed by those of 200 m =< L < 250 m (0.14), 50 =< L <100 m (0.13), 150 m =< L < 200 m (0.13), less than 50 m (0.09), and those of 100 m =< L < 150 m (0.09).

With regard to the speed of the ship, respondents indicated that values of 0–5 knots (0.02) were least important, followed by 6–10 knots (0.07), 11–15 knots (0.07), 16–20 knots (0.13), 21–25 knots (0.16), and over 26 knots (0.29). This shows that ship speeds over 26 knots are the most important condition. In this condition, navigators must be careful to navigate the ship in the Strait of Malacca. Responses suggest that, for the state of loading indicator, ballast condition (0.23) is the most important, followed by full load (0.77).

Table 3.3 and 3.4 show the value of each sub-criterion. The value is the function used to calculate the danger score. In Table 3.3, the criteria of ship condition consist of four sub-criteria, namely: type of ship, length of ship, speed of ship, and state of loading. In the sub criteria of type of ship in table 3.3, LNG is more important or has higher danger score than other ships. In this case, respondents considered that LNG has largest effect if accident occurred such us fire, explosion, etc. On the other hand, LNG vessel can be damaged because of an external impact for example: another vessel, floating objects, the sea floor, submerged objects, the quay or other structures. Concerning the sub-criteria related to the length of ship, the respondents considered that the ships with a length 300 m-more have a higher chance of danger than those of a smaller length. The ships with a speed exceeding, 26 knot are more important or have a higher danger score if navigators bring the ships passing through the Strait of Malacca, because the strait of Malacca is categorized as very busy shipping lane. In this case, navigators feel worried when transiting the Strait by high speed. In the state of loading, full-load condition is more important than the ballast condition the sub-criteria related to ship condition, type of ship, length of ship, speed of ship and state of loading are separately considered during the analysis.

Table 3.3: Ship condition indicators

SHIP CONDITION			
Sub Criteria	**Indicator/Function**	**Weight**	**Value**
Type of ship	LNG	0.17	100
	VLCC	0.13	76
	LPG	0.12	71
	Leisure	0.11	65
	Container Ship	0.09	53
	Large passanger ship	0.09	53
	Ferry	0.08	47
	Bulk carrier	0.07	41
	Towing Vessels	0.06	35
	Reefer ship	0.05	29
	PCC	0.04	24
Length of ship	Less than 50 m	0.09	45
	50 =< L <100 m	0.09	45
	100 m= <L <150 m	0.13	65
	150 m =< L < 200 m	0.13	65
	200 m =< L < 250 m	0.14	70
	250 m =< L< 300 m	0.2	100
	More than 300 m	0.2	100
Speed of Ship	Less than 5 k't	0.02	7
	5 k't=<k't<10 k't	0.07	24
	10 k't=<k't<15 k't	0.07	24
	15 k't=<k't<20 k't	0.13	45
	20 k't=<k't< 25 k't	0.16	55
	More than 26 k't	0.29	100
State of Loading	Ballast	0.23	30
	Full Load	0.77	100

Table 3.4: Environmental indicators

Environmental factors			
Sub-riteria	**Indicator / Function**	**Weight**	**Value**
Influence of current	Less than 2.0 k't	0.12	22
	2.0 k't=< k't<4.0 k't	0.33	60
	More than 4.1 k't	0.55	100
Speed difference compared with other ship	Less than 1.0 k`t	0.4	100
	1.0 k`t - 2.0 k`t	0.19	48
	2.0 k`t - 3.0 k`t	0.18	45
	3.0 k`t - 4.0 k`t	0.12	30
	More than 4.1 k`t	0.11	28
Other vessel`s length	Less than 50 m	0.08	38
	50 m=< L <100 m	0.11	52
	100 m= <L < 1 50 m	0.12	57
	150 m =< L < 200 m	0.14	67
	200 m =< L < 250 m	0.17	81
	250 m =< L< 300 m	0.17	81
	More than 300 m	0.21	100
Ratio of water depth to ship draft	H/d＝1.1 - 1.2 Ram,full	0.14	78
	H /d= 1.2 - 1.3 Ram, full	0.15	83
	H/d＝1.3 - 1.5 Ram,full	0.17	94
	H/d＝1.5 - 1.7 Ram,full	0.18	100
	H/d＝1.7 - 2.0 Ram,full	0.18	100
	H/d＝2.0 - over	0.18	100
Distance between vessels	Less than 5 L	0.24	100
	5L =< L < 10 L	0.17	71
	10L=< L < 15 L	0.16	67
	15L=< L <20L	0.16	67
	20L=< L <30L	0.14	58
	More than 30L	0.13	54
Ship course and course of other ships	Area A	0.26	100
	Area B	0.21	84
	Area C	0.25	96
	area D	0.24	92
Time zone	0-4	0.2	100
	4-8	0.14	70
	8 - 12	0.13	65
	12-16	0.18	90
	16-20	0.2	100
	20-24	0.15	75
Influence upon the day of the week	Monday	0.16	80
	Tuesday	0.18	90
	Wednesday	0.14	70
	Thursday	0.09	45
	Friday	0.2	100
	Saturday	0.05	25
	Sunday	0.07	35
	Holiday	0.12	60
Characteristics of the area	Heading of ship	0.31	100
	Sharp turn	0.24	77
	Narrow channel	0.31	100
	Heavy traffic	0.14	45
Wind effect	Less than 10 k't	0.12	41
	10 k't=<k't< 30 k't	0.16	55
	30 k't=<k't< 50 k't	0.19	65
	50 k't=<k't<70 k't	0.24	82
	More than 70 k't	0.29	100

Table 3.4 shows the sub criteria related to the environmental factors. In this context, criteria of environmental factors consist of 10 sub-criteria. For the sub–criteria of influence of current, respondents argued that the 4.1 knots - over have a higher function value than others. In the sub-criteria: the differences of speed with encountered vessels, respondents agree that 0, 0 knots – 0, 1 knot difference has a higher value of AHP function. Respondents considered that the smaller the difference in speed with other encountered ships is the more dangerous the navigation condition becomes. On the sub-criteria of length of the other ship, respondents adjusted that the difference of length over 300m has a higher danger score.

Regarding the ratio of water depth to ship draft to, respondents indicated that values of H/d= 2.0-overare more important to be analyzed. In the sub-criteria of distance between vessels, the highest function is for the distance of 5L-less. Respondents agree that, if the distance between the ships is getting closer, then the hazard rate will be higher. Sub-criteria of ship course and course of other ships consists of area A, area B, area C and area D. Area A is area for head on of ship, area B and area D are (area) for crossing, and area C is (area) for overtaking. Respondent argues that the area A has a higher danger level than the area C, B and D. Sub-criteria of time zone, the times between 00.00h-04.00h and 16.00h-20.00h are considered more important than in the other times. In this case the respondents confirmed that during that time periods, the maritime traffic is considered to be the busiest. Considering the sub-criteria of upon the day of the week, Friday has a more important influence than any other days.

In the criteria of ship condition and environmental factors, danger score is established based on AIS data. It is calculated from static and dynamic data of the AIS data. Static data includes the type of ships, length of ships, speed of ships, IMO number, MMSI (Maritime Mobile Service Identity) number and call sign. Dynamic data includes the longitude, latitude, time, course, rate of turn, speed over ground, voyage-related information including the draft of the ship, destination, and type of cargo. In the environmental factors, the data related to current and wind is obtained from the Maritime and Port Authority of Singapore (MPA).

3.7 Danger Score Assessment

AS shown in Figure. 3.4, the goal of the hierarchy structure is to determine the danger score. Five criteria are considered: ship condition, human factors, environmental factors, machinery factors and navigational factors.

To assess the danger score, criteria of human factors, machinery factors and navigational factors could not be evaluated using AIS data. These criteria were determined from a series of questionnaire. The questionnaire was distributed among the navigators who have experienced passing through the Strait of Malacca.

As a complex system with multiple subjects and multiple levels of ship safety navigation, an evaluation index of ship navigational safety was compiled to make the levels more certain and accurate using AIS data. The process of the assessment is as follows:

At first, the weight of the evaluation index of each criteria (ship condition, human factors, environmental factors, machinery factors and navigational factors) and its related sub-criteria are established using AHP. Therefore, the value of the function of sub-sub-criteria is determined based on AIS data. The danger score is obtained by the sum of weight of the criteria and the sub-criteria multiplied by the corresponding sub-sub-criteria function values as shown in Eq. (3.6):

$$\mathrm{DS} = \sum_{i=1}^{n} W_i f_i \tag{3.6}$$

where DS is the danger score index, $\boldsymbol{f_i}$f' is the value of function of each index, obtained based on the weight of sub-sub- criteria in Tables 3.3 and 3.4. In this case, the function is obtained by dividing the largest value of the weights in each sub-criteria and multiplying them 100 times on each index. w is the weight on each index, and n is the total number of indices, i = 1,2,3,……..,n.

The evaluation of danger score is divided into five danger areas: very low danger area, low danger area, middle danger area, high danger area and very danger area. Table 3.5 shows the division indexes of the established danger score in Strait of Malacca.

Table 3.5: Division indexes of danger score in Strait of Malacca

Area	Score range
Very low danger (Safe condition)	0-50
Low danger (Safe condition)	50-100
Middle danger	100-150
High danger	150-200
Very high danger	>200

Below is the resulting calculation of the danger score for a tanker (subject ship A), container (subject ship B) and passenger (subject ship C) that passed through the Strait of Malacca on 1/23/2010 at 16.00h. The ship data are given in Tables 3.6, 3.7 and 3. 8.

Table 3.6: Ship data of Pacific Lagoon

Name of ship	Pacific Lagoon
Ship Type	Tanker
LOA (m)	333
DWT (t)	305839
Speed (knot)	14.9
Flag	Belgium
Year of build	1999

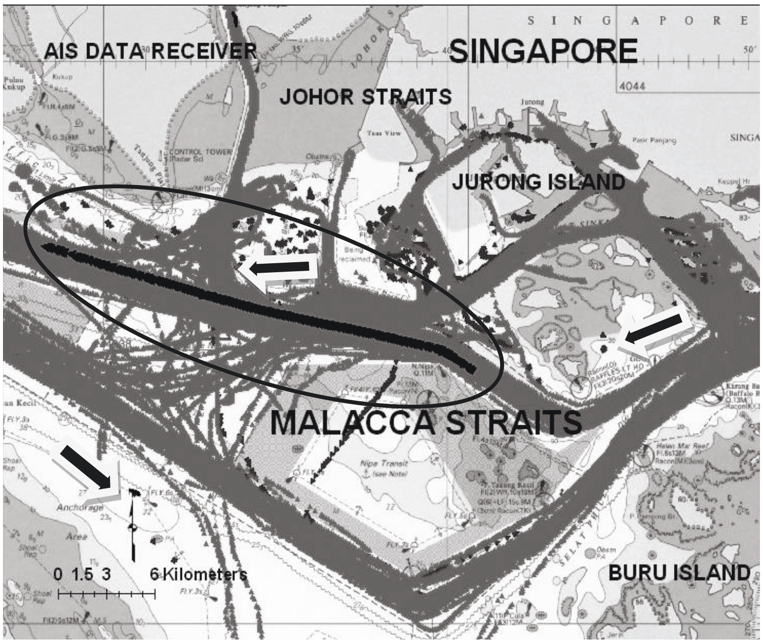

Figure 3.11: Ship tracking and danger score area of subject ship A based on AIS and GIS

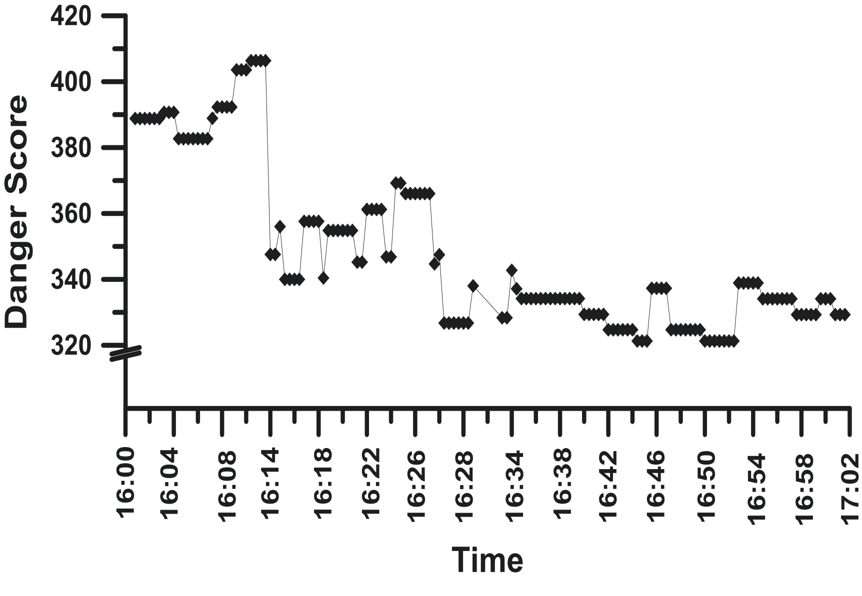

Figure 3.12: Danger score of subject ship A between 16.00h and 17.00h.

Table 3.6 shows the data of the ship. The calculation and simulation of the danger score have been established. The data were gathered for one period of time of one hour. In this case, data were gathered on 1/23/2010 at 16.00h. Based on AIS data, the largest volume of data is at 16.00h, when the number of ships was 1,118. Figure 3.11 shows the path of a tanker ship (will be hereafter referred as subject ship A) on 1/23/2010 at 16.00h. The ellipse line in Figure. 3.11

shows the subject ship A passing through this area for one hour between 16.00h and 17.00h. Ship tracking and danger score area for subject ship A are established based on AIS and GIS data. In this study, GIS is used to manage geographically and to visualize the vessel's tracks obtained from the AIS data. In this study, using MySQL, AIS data is converted to GIS and can be visualized. A geographic information system is a modern information technique with powerful functions of storing, disposing, managing, analyzing, and displaying all forms of geographically referenced information. GIS also allows us to view, understand, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. The danger score for the subject ship A is shown in Figure. 3.12, where the danger is the highest between 16.08.26 and 16.09.48. At that time, the ship is navigating in the main strait of the Strait of Malacca. Her speed is 14.9 knot sailing from the east gate to the west gate of the Strait of Malacca. The danger score of subject ship A which is higher than 200 is classified as a very high danger according to the division indexes of Table 3.5. In the subject ship A, the index of human factors are obtained from AHP and described in the criteria and sub-criteria as shown in Figures. 3.5 and 3.7.

Table 3.7: Ship data of Maersk Line

Name of ship	**Maersk Line**
Ship Type	Container
LOA (m)	352
Total Tonnage (t)	109000
Speed (knot)	19.1
Flag	Denmark
Year of build	2003

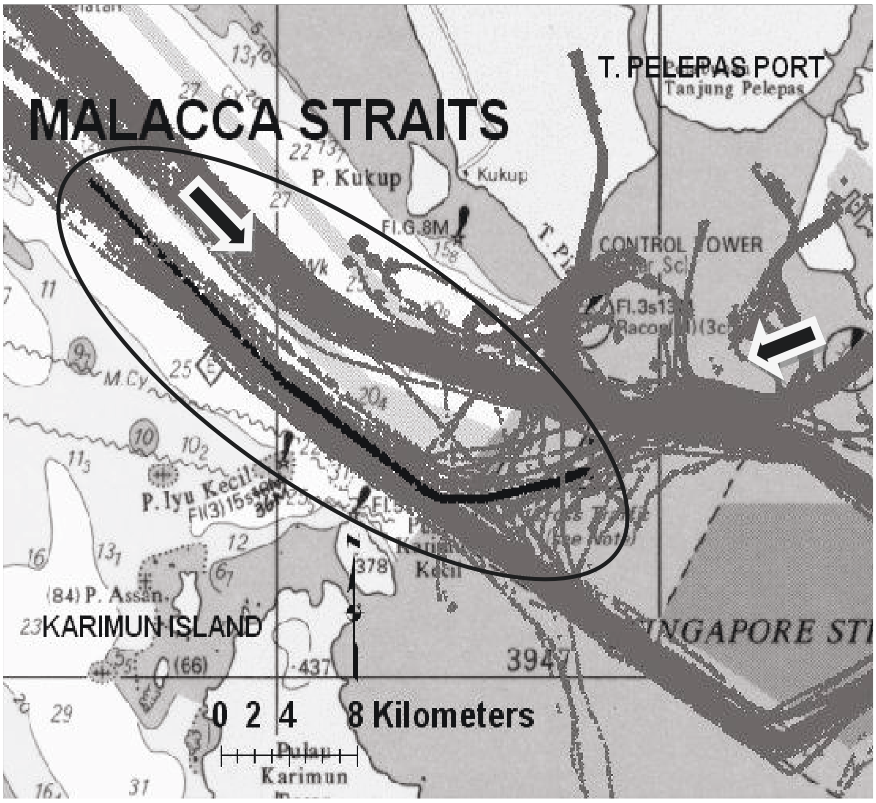

Figure 3.13: Ship tracking and danger score area of subject ship B based on AIS and GIS

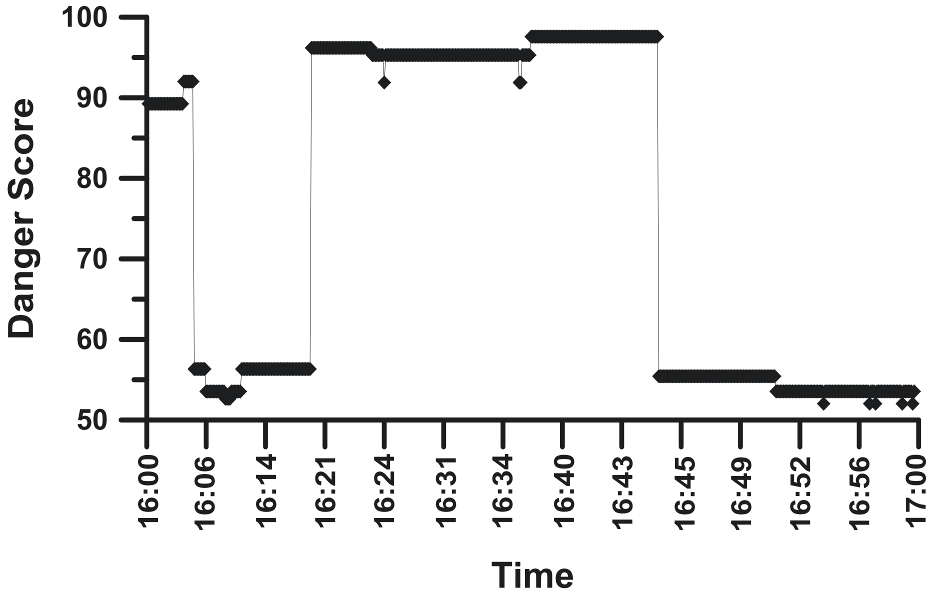

Figure 3.14: Danger score for subject ship B between 16.00h and 17.00h

Table 3.7 shows the data of a container ship. The ellipse line in Figure. 3.13 shows the path of the container ship (will be hereafter referred as subject ship B) passing through the Strait of Malacca area on 1/23/2010 for one hour between 16.00h and 17.00h. The simulated results of the danger score for the subject ship B is shown in Fig.3.14, where the danger score was the highest between 16.36.54 and 16.43.54. The danger scores which higher than 50 and lowest than 100 is classified as a low danger according to the division indexes of table 3:5. The index of human factors in subject ship B are obtained from AHP and described in the criteria and sub-criteria as shown in Fig. 3.5 and 3.7.

Table 3.8: Ship data of Wave Master

Name of ship	Wave master
Ship Type	Passenger
LOA (m)	38
Speed (knot)	23.9
Flag	Singapore
Year of build	2001

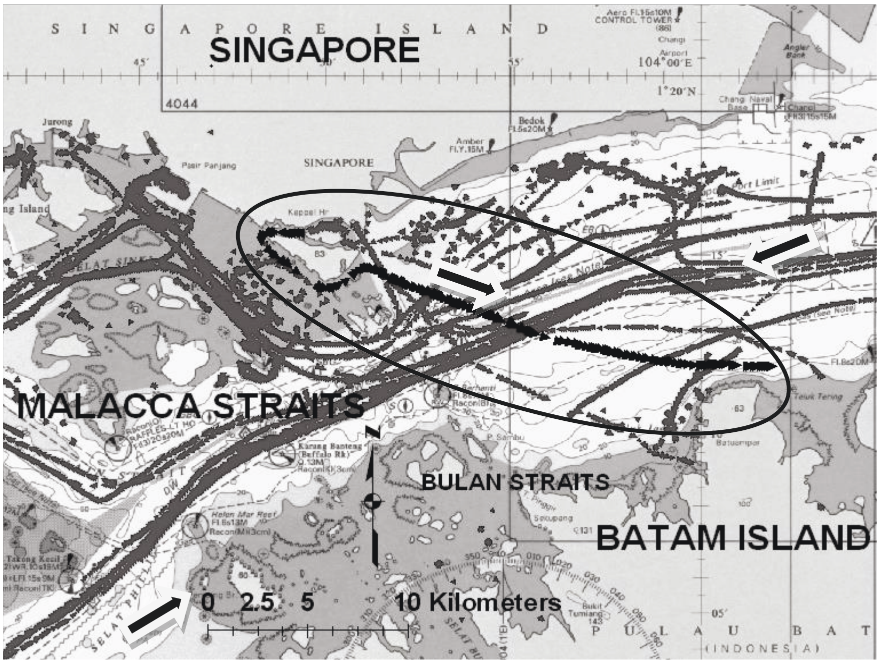

Figure 3.15: Ship tracking and danger score area of subject ship C based on AIS and GIS

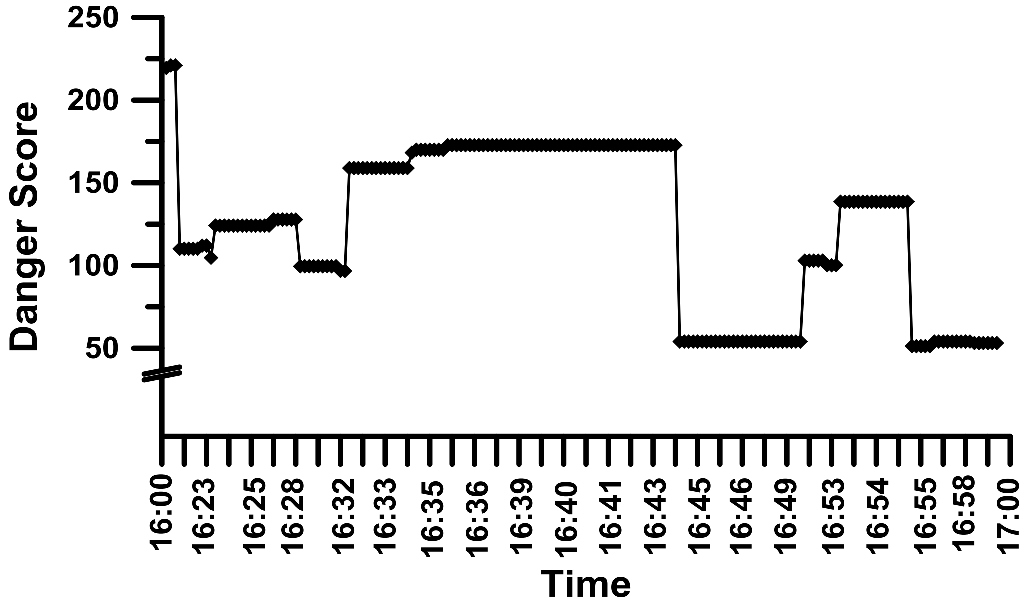

Figure 3.16: Danger score for subject ship C between 16.00h and 17.00h

Table 3.8 shows the data for the passenger ship. Figure 3.15 shows the tracking and danger score of a passenger ship (will be here after referred as subject ship C) on 1/23/2010 at 16.00h. The ellipse line in Fig. 3.15 shows the passenger ship course line passing through this area for one hour between 16.00h and 17.00h. The simulation results for the danger score of the passenger ship is shown in Fig. 3.16. The danger was the highest (more than 200) from 16.17.07 to 16.17.24. During that period of time, the danger score of subject ship C is classified as a very high danger. The danger score between 16:32:17 and 16:44:27 is within the range 150-200. This is considered as high danger. The middle danger with a value between 100 and 150 was obtained from 16:18:25 to 16:27:35. Finally, the low danger occurred from 16:44:15 to 16:52:24 and from 16:55:10 to 17:00:00 where the danger score was between 50 and 100. In the subject ship C, the index of human factors are obtained from AHP and described in the criteria and sub-criteria as shown in Figures. 3.5 and 3.7.

3.8 Conclusions

This study presents an evaluation of marine safety in the Strait of Malacca based on the AIS data and AHP. Using the AHP, several factors that contribute to accidents in the Strait of Malacca were revealed. In the Strait of Malacca, from 1975 to 1995, a total of 496 casualties were recorded. These involved collisions, contacts, foundering, standings, fire, engine troubles, bilging and leakages. 35 of the 111 collision cases have caused foundering of the ships, led to fire and explosion or leakages leading to wrecks. An analysis of several factors that contribute to accidents in the Strait of Malacca indicates the following. First: Ship condition. In the ship condition, the following items are considered: type of ship, length of ship, speed of ship and state of loading. In the actual accident based on type of ship, General cargo ships are at the top the list at 53.15%, followed by tankers at 20.59%, bulk carriers at 6.72%, fishing craft at 4.41%, container ships at 2.94% and liquefied gas carriers at 1.68%. . Secondly, the human element is the most important factor. Several accidents occurred caused by human error. In this case, experience and knowledge, fatigue, overwork, communication are factors that are important for navigators. Thirdly, the environmental factors will be discussed. In fact, serious accidents have occurred in high traffic density areas. Current, speed other ships, length of other ships, distance between vessels, wind effect, characteristics of area are factors that have contributed to the accidents in the Strait of Malacca. Further on, the machinery factors are described. The high percentage of leaking ships and ships limping with machinery problems must be viewed with deep concern because such casualties can easily develop into or cause catastrophic accidents. In the machinery factors, failure of main engine and electrical power, failure of lubricating oil system, failure of navigation equipment, failure of rudder, failure of hull equipment and failure of propulsion should be considered. Finally, the navigational factors are discussed. This factor can contribute to the accident in the Strait of Malacca. Inappropriateness of ship operation regulation management, inappropriateness of crew manning, inappropriateness of navigational aid are important variable that should be evaluated in order to increase the navigational safety in the marine traffic.

This research found an alternative way to assess the danger score of a vessel by considering a case study of vessel traffic in the Strait of Malacca. It was also found that AHP is considerably powerful in evaluating the weight of each criterion of the danger score. This was proved by the consistency ratio of all the criteria. The leading criteria that contribute to accidents in the Strait of Malacca are human factors. Based on AIS data, the ship population passing through the strait on 1/23/2010 was calculated. The following type of ships were examined: tanker ships 37%, cargo ships 26%, tugs 9%, passenger ships 3%, towing and fishing ships 1%, other ships 10%, and unknown vessels 14%.

In this research, an evaluation index of ship navigational safety was compiled to determine more certain and accurate levels using the AIS data. Figs. 3.11, 3.13, and 3.15 show the tracking of a tanker ship, container ship, and passenger ship, respectively, on 1/23/2010 at 16.00h. The resulting danger scores including danger condition and safe condition are shown in Figures. 3.12, 3.14, and 3.16.

Possible future works include analysis and assessment of collision avoidance in the Strait of Malacca. For this purpose, the closest point of approach (CPA) and time closest point of approach (TCPA) will be explored.

Chapter 4

Risk Evaluation of Ship Collision

4.1 Introduction

Safety of navigation has been focusing on issues of security, loss of lives and property. Moreover the concern for environmental protection and collision avoidance are growing significantly. An examination of the casualty data in the Malacca Straits between 1975 and 1995 shown that serious accidents have occurred in high density traffic area [3].

The Malacca Strait that is located between the east coast of Sumatra Island in Indonesia and the west coast of the Peninsular Malaysia is linked with the Strait of Singapore at its south-east end. The Strait of Malacca is bordered on the north-west by a line starting from Ujung Baka (5°40’N, 95°26’E), north-west extremity of Sumatra, to Laem Phra Chao (7°45’N, 98°18’E), south extremity of Koh Phuket Island, Thailand, and on the south-east by a line that starts from Tahan (Mount) Datok (1°20’E, 104°20’N) to Tanjung Pergam (1°10’E, 104°20’N) as shown in Figure 1.2.

The channel of the Malacca Straits is connecting the Indian Ocean to the South China Sea. It lies between Sumatra and the Malay Peninsula. It is 500 miles (800 km) long and is funnel-shaped; only 40 miles (65 km) wide in the south, it broadens in the north to 155 miles (249 km). Numerous islets hinder passage at its southern entrance creating the shortest sea route between India and China and one of the most heavily traveled shipping channels in the world.

The implementation of an Automatic Identification System by the IMO in that area was done in order to enhance safety and efficiency of navigation, safety of life at sea, and to ensure the maritime environmental protection. In this study, an Automatic Identification System is implemented for the study of ship collision risk using fuzzy logic method under the International Regulations for Preventing Collisions at Sea 1972 (COLREG) guidelines.

Accordingly, the AIS is implemented as source of data and as input data for the hazard identification and risk evaluation using fuzzy logic method as a step of Formal Safety Assessment.

In this research, the investigation of sea traffic using AIS data and GIS in the Malacca Straits is carried out. The proposed FMEA (failure mode effect analysis)-fuzzy method for the evaluation of ship collision risk is described. Finally, the risk evaluation results are discussed.

4.2 Literature Review

Several researchers in the risk evaluation field have used fuzzy methods and FMEA. However, most object of previously used the fuzzy-FMEA method not for marine traffic and ship navigation issue. Wang *et al*. [11] discussed risk evaluation in failure mode by using the fuzzy weighted geometric mean. In their research, for ranking purposes, the fuzzy risk priority numbers (FRPNs) were defuzzified using a centroid defuzzification method in which a new centroid defuzzification formula based on alpha-level sets was derived. However, in that calculation did not appear to consider any countermeasure for the safety.

Kentel *et al.* [12] analyzed probabilistic-fuzzy health risk modeling. They proposed a combination of fuzzy set theory with probability theory in order to incorporate uncertainties into the health risk analysis. They identified this approach as probabilistic-fuzzy risk assessment. However, in this paper did not consider the consequence for the risk.

Karimi *et al.* [13] used a fuzzy method for determining a probabilistic earthquake risk assessment system. They outlined a risk assessment system for evaluating not only the expected structural damage but also the consequent financial losses and casualties due to a likely earthquake under conditions of elevated uncertainty; namely, for situations where neither the statistical data nor the seismological and engineering knowledge are sufficient for such an evaluation. The proposed approach has also been compared with an alternative approach for obtaining a fuzzy possibility-probability distribution. However, this research did not appear to consider the severity and detection to enhance the safety.

Chin *et al.* [14] discussed the development of a fuzzy FMEA method based on a product design system. The proposed framework of this fuzzy FMEA method was based on approaches to the evaluation of new product concepts. They also carried out research with the purpose of exploring the applicability of fuzzy logic and knowledge-based systems technologies to the competitive design and development of products today, with an emphasis on the design of high-quality products at the conceptual design stage. However, the countermeasures did not appear in this paper. The countermeasure is very important step to reduce the risk.

Ung *et al.* [15] used fuzzy modeling in addition to failure mode, effects, and criticality analysis (FMECA) for assessment and management of port security risk, thus illustrating a different way of thinking about security assessment. However, the research did not analyze the condition in the ship navigation.

Tesfamariam *et al.* [9] analyzed risk-based environmental decision making through a fuzzy analytic hierarchy process (F-AHP). Uncertainty of the vagueness type was considered using fuzzy-based techniques. The AHP was modified to a fuzzy AHP by using a fuzzy arithmetic operation. The F-AHP methodology integrated the attitude of the decision-maker as well as confidence in the final decision-making process. However, for more than one decision-maker, the problem becomes complex and the best solution is the one that will be accepted by all decision-makers. The F-AHP methodology can be extended to multi-expert MCDM.

Tay *et al.* [16] proposed a generic method for simplifying the fuzzy-logic-based FMEA methodology by reducing the number of rules that an FMEA user needs to provide for the fuzzy risk priority number in the modeling process. In their research, the Gaussian membership function was implemented.

In addition, several studies have investigated an automatic identification system. Mou *et al.* [7] used AIS data for analyzing ship collision avoidance in busy waterways. A statistical analysis of ship collisions was carried out. Only ships (own ships) that had an encounter in the Traffic Separation Scheme (TSS) for the Port of Rotterdam were taken into account. This paper did not appear to consider the human factors. Human factors are great factors that contribute the accident in the marine traffic area.

Kobayashi *et al.* [1] proposed guidelines for evacuation of a ship in the event of a tsunami. However, AIS data was not used to analysis the risk in the marine traffic. In their study, AIS data were used for analyzing the behavior of ships navigating through Osaka Bay, Japan.

Pitana *et al.* [2] analyzed the evacuation of a large passenger vessel in the case of a pending tsunami by using a discrete event simulation (DES) considering a stochastic approach. The AIS data were used for calculating the sea traffic in the research area. However, that calculation did not appear to consider the collision of ship and any accident during tsunami.

Pan *et al.* (2012) established an AIS data visualization model for assessing the maritime traffic situation in Xiamen Bay and Meizhou Bay, China. However, the research did not show the combination the AIS with any method to evaluate the risk in the marine traffic. They proposed a new visualization model that can gauge the maritime traffic situation based on data from the automatic identification systems of ships.

Zaman *et al.* (2013) used the analytic hierarchy process (AHP) to analyze the implementation of the AIS in the Malacca Strait. In their study, a danger score assessment was established. The AHP is therefore used for evaluating the safety level in the Strait of Malacca. In this case, weighting factors are determined using the AHP. There are five evaluation criteria: the ship condition, human factor, environmental factor, machinery factor, and navigational factor. Each criterion divides into sub-criteria and then sub-sub-criteria. However, this research did not analyze risk probability, severity of risk and detection. The countermeasure also did not appear to consider for enhancing navigation safety in the Malacca Straits.

The focus of this study is on identifying hazards and evaluating the marine navigation risk using fuzzy FMEA. In this case, the result of risk evaluation is useful to establish FSA for further. FSA is methodology which have recommended by IMO. By the fuzzy FMEA method, fuzzy risk priority numbers are obtained.

The method proposes that fuzzy FMEA method is good in establishing the risk evaluation in the Malacca Straits based on AIS data. In this study, ten scenarios have been established on the basis of AIS data, other data sources, and the GIS. Aspects such as ship type, ship condition, regional characteristics, and distance between vessels were classified on the basis of AIS data and the GIS. Therefore, a questionnaire was conducted with navigators that had experienced navigation through the Malacca Strait.

In this method, linguistic variable such as the occurrence, severity, and detection as risk factors in the FMEA can be represented as members of fuzzy set, described using linguistic priority terms associated with corresponding membership values (fuzzy inputs) and combined by matching rules in rule base. The outcome of such a combination is referred to as a set of fuzzy conclusions. By the deffuzification taking into account the consequent membership functions, the risk level of an event in terms of deffuzzified value can be realized. Lists of risk priority of those events are then developed based on deffuzification. Fuzzy risk priority numbers are determined for each scenario.

The actual sea traffic conditions and the ship collision analysis are established using AIS data provided by a receiving system installed at Universiti Teknologi Malaysia.

4.3 AIS Data Processing and Collection

4.3.1 Data Source and AIS Installation

The AIS is an information and communication system that utilizes maritime VHF frequencies to send and receive data between two suitably equipped vessels and between suitably equipped vessels and shore stations. The information communicated includes data directly associated with navigation such as the vessels identity, position, speed and course and other information in a message format. The IMO added a new requirement (as part of a revision to Chapter V) for all ships to carry an AIS System capable of providing information about the ship to other ships and to coastal authorities automatically.

As mentioned in Chapter 3, AIS information includes static, dynamic, and voyage-related elements. Static information is programmed into the unit at the time of commissioning. Dynamic information is derived from interfaces such as ship's GPS and other sensors. Voyage-related data are entered manually by the ship's captain using a password-protected routine.

Through dedicated VHF frequencies, AIS information is transmitted between vessels, from vessels to shore, or vice versa. In simple terms, AIS is a technology which makes ships visible to each other. As an aid to collision avoidance, it records the information of ship behavior, including the effects of human action and ship maneuverability. The information includes the vessel's name, its particulars, ship type, registration numbers, and destination as well as the vessel's position, speed, and heading.

The actual sea traffic conditions of the Malacca Straits were recorded by an AIS data receiving system installed at the Universiti Teknologi Malaysia. The equipment was used to collect the data. All AIS data received by the equipment were continuously and automatically stored on the hard disk of a PC. The data could be retrieved from the PC via the Internet and analyzed on another PC at any time. Figure 4.1 shows the overview of the AIS receiving system used in this study and installed at Universiti Teknologi Malaysia in Malaysia.

4.3.2 AIS Data Analysis

In this paper, the AIS data analysis are established for the month of June, 2010. The data include the type of ships, length over all (LOA), speed, heading, and traffic volume per day and per hour. The AIS data analysis are carried out in some selected research area within a longitude varying between 103°74’N and 103°85’N, and a latitude varying between 1°10’E and 1°20’E. The selected area is known as a typical busy area for maritime traffic as shown in Fig. 4.2.

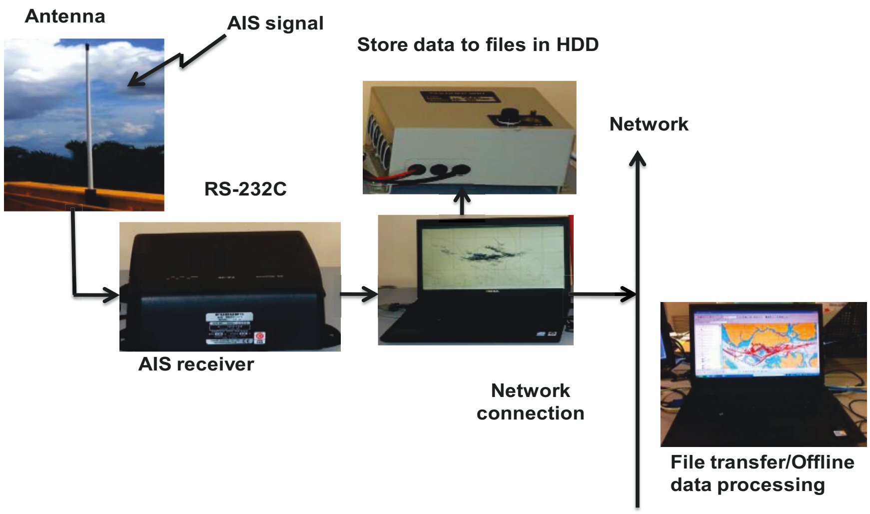

Figure 4.1: AIS data installation

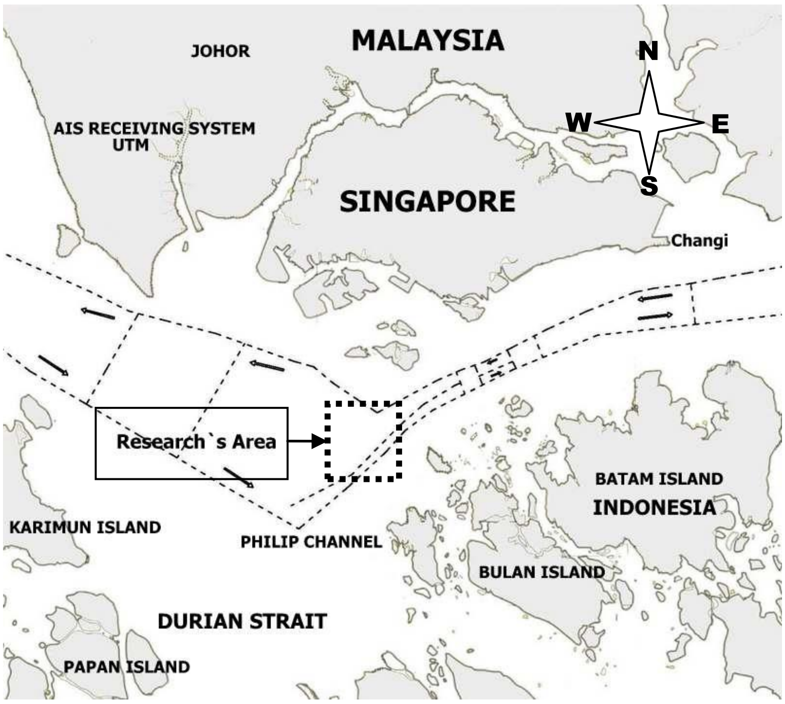

Figure 4.2: Selected research area (dotted box) based on AIS data

The analysis results related to the number of ships in June 2010 are shown in Figs. 2.4-2.10 in Chapter 2.

Based on the AIS data investigation that was shown in Figures 2.4-2.10, the analysis of ship encounter situations has been established. The AIS data analysis is also useful for analyzing the traffic density, the ship's collision probability and the dangerous area for navigation. In this paper, the analysis of AIS data is required in order to evaluate the ship's collision risk in the Malacca Straits. The scenarios of ship's collision are identified. The analysis of ship's collision scenarios will be deeper explained in the next sections.

4.4 Failure Mode and Effects Analysis (FMEA)

4.4.1 The FMEA Procedure

Failure mode and effects analysis (FMEA) is a widely used engineering technique for defining, identifying, and eliminating the known or potential failures, problems, and errors in a system, design, process, or service before this reaches the customer. The failure mode is defined as the manner in which a component, system, subsystem, or process could potentially fail to meet the design intent. A failure mode in one component can be the cause of a failure mode in another component. A failure cause is defined as a design weakness that may result in a failure. For each failure mode identified, the ultimate effects need to be determined, usually by an FMEA team. A failure effect is defined as the result that a failure mode has in the function of the product or process as perceived by customer. A system, design, process, or service can usually have multiple failure modes, causes, and effects. In this situation, each failure mode or cause needs to be assessed and prioritized in terms of its risks so that high-risk (the most dangerous) failure modes can be corrected with top priority. The traditional FMEA determines the risk priorities of failure modes through the risk priority number (*RPN*), which is the product of the occurrence (*O*), severity (*S*), and detection (*D*) of a failure. That is,

$$RPN = O \times S \times D \qquad (1)$$

Occurrence is defined as the likelihood that a specific cause or mechanism will arise. Severity is an assessment of the effect of a potential failure mode on the next component, subsystem, or customer. Detection is an assessment of the ability of a current design control to detect a potential cause or mechanism. In general, these three factors are estimated by experts using a scale from 1 to 10 based on the commonly agreed evaluation criteria described in Tables 4.1–4.3. As the *RPN* is a measure of the risk of each failure, it can be used to rank failures and prioritize actions. The failure modes with higher *RPN*s are assumed to be more important and will be given higher priorities for correction.

Table 4.1: Crisp rating for occurrence of a failure

Rating	Probability of occurrence	Failure probability
9–10	Very High: failure is almost inevitable	> 1 in 2 1 in 3
7–8	High: repeated failures	1 in 8 1 in 20
4–6	Moderate: occasional failure	1 in 80 1 in 400 1 in 2000
2–3	Low: relatively few failures	1 in 15,000 1 in 150,000
1	Remote: failure is unlikely	< 1 in 1,500,000

Table 4.2: Crisp rating for severity of a failure

Rating	Effect	Severity of effect
9–10	Very High	Ship collision has a very serious effect on people, sea traffic, and environment
7–8	High	Ship collision has a serious effect on people, sea traffic, and environment
4–6	Moderate	Ship collision has a moderately serious effect on people, sea traffic, and environment
2–3	Low	Ship collision has little serious effect on people, sea traffic, and environment
1	Remote	Ship collision has no serious effect on people, sea traffic, and environment

Table 4.3: Crisp rating for detection of a failure

Rating	Detection	Likelihood of detection
9–10	Remote	Remote chance that the design control will detect potential cause or mechanism and subsequent failure mode
7–8	Low	Low chance that the design control will detect potential cause or mechanism and subsequent failure mode
5–6	Moderate	Moderate chance that the design control will detect potential cause or mechanism and subsequent failure mode
3–4	High	High chance that the design control will detect potential cause or mechanism and subsequent failure mode
1–2	Very High	Very high chance that the design control will detect potential cause or mechanism and subsequent failure mode

4.4.2 FMEA for Marine Traffic Areas

FMEA was first adopted as a formal design methodology in the 1960s by the aerospace industry seeking to enhance the levels of safety and reliability (Sankar and Prabju, 2000). Since then, it has been applied in many industries to ensure the safety and reliability of products. Usually FMEA is applied to identify the potential failure modes of the system and evaluate their impact on each system component.

The focus of this research is on hazard identification as the first step of an FSA of the Malacca Strait. The aim of this step is to identify the hazards of a specific problematic area and list these according to the likelihood of occurrence and the severity of the consequences for marine traffic in terms of human life, property, and the environment. This first step provides the basis or the reference point for the next step.

There are several methods for hazard identification and risk evaluation, such as fault tree analysis (FTA), event tree analysis (ETA), and FMEA. In this research, an FMEA based on AIS data is used as a method of hazard identification and risk evaluation for ship collisions in the Malacca Strait. This is because it has several advantages:

- The Malacca Strait is categorized as a high-risk area for navigation. It is very important to enhance the navigational safety. In this case, FMEA is a good method for evaluating the risk and identifying the collision hazards for ships. FMEA can be used for defining, identifying, and eliminating the known or potential failures, problems, and errors for navigational activities in the Malacca Strait.
- FMEA determines the risk priorities of failure modes through the risk priority number (*RPN*), which is the product of the occurrence, severity, and detection. Those risk factors are very applicable to marine traffic safety and ship navigation.
- The three risk factors (occurrence, detection, and severity) are evaluated using the 10-point scales described in Tables 4.1–4.3. This condition is useful in conducting marine traffic and in ship navigation.

In this study, a fuzzy FMEA is performed to evaluate the risk of ship collisions in the Malacca Strait. This is because for several reasons FMEA has proven to be one of the more important early preventive actions in a process that will prevent failures and errors. However, the crisp *RPN* has been severely criticized for a variety of reasons. Significant criticisms include the following:

- Different combinations of O, S, and D may produce exactly the same value of RPN, but the hidden risk implications may be totally different.
- The relative importance among O, S, and D is not taken into consideration. The three risk factors are assumed to be equally important. This may not be the case when considering a practical application of FMEA.
- The three factors are difficult to estimate precisely. Much of the information in FMEA can be expressed linguistically in terms such as moderate, high, or very high.

To overcome the above disadvantages, fuzzy logic has been widely applied in FMEA. This will be explored in the next section.

4.5 The Proposed Model Using Fuzzy FMEA

The traditional FMEA determines the risk priorities of failure modes by using criteria such as occurrence, severity, and detection. In this study, the criteria O, S, and D are applied to determine the risk ranking based on the min-max approach.

Figure 4.3 shows the framework of the fuzzy FMEA procedure. A preliminary analysis of the AIS data on the Malacca Strait was carried out.

The data received by the AIS are classified as static data, dynamic data, or voyage-related data. The static data of the vessel include the name, radio call sign, Maritime Mobile Service Identity (MMSI), length, beam, ship type, and antenna location. The dynamic data include the current location, time, navigational speed, and direction. The voyage-related data include the draft, destinations, and estimated times of arrival.

Moreover, a ship collision classification based on both statistical data and the AIS data has been carried out. Subsequently, all potential failure modes of each process and the causes of each failure mode are determined. Furthermore, the detection process is established.

Design of the membership function for the linguistic priority term has also been carried out. The input membership functions are classified as follows: severity membership function, occurrence membership function, and detection membership function. The last steps of the framework are related to the development of a fuzzy rules base, the fuzzy conclusions for each scenario, and the defuzzification process. These steps are taken in order to obtain the risk ranking from which the risk scenario ranking can be obtained.

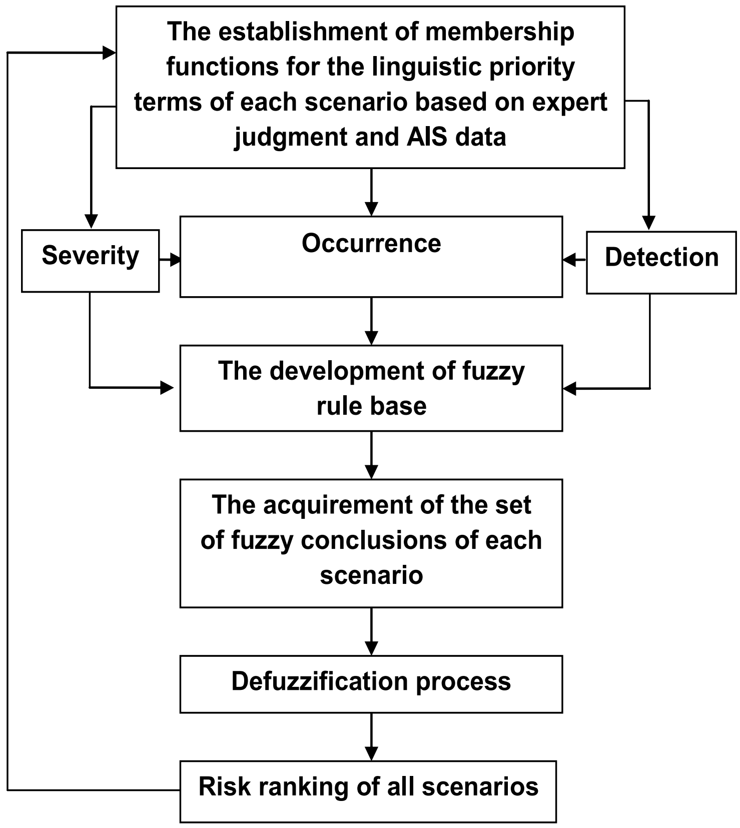

Figure 4.3: Framework of fuzzy FMEA procedure

In the proposed method, the fuzzification process uses a singleton method to map the crisp point into a fuzzy set, and the fuzzy set rules base is a collection of fuzzy if-then rules. The fuzzy inference engine performs a mapping from the fuzzy sets on the basis of the fuzzy if-then rules in the fuzzy rules base and the compositional rules of inference. In the defuzzifier, the weighted mean of maximums (WMoM) is used for calculating a crisp output from the system. The input linguistic variables are created by means of FMEA. Explicitly, these are occurrence, severity, and detection. Figure 4.4 shows the risk evaluation process using fuzzy modeling. The risk ranking is determined by the WMoM method as follows:

$$\boldsymbol{WMoM} = \frac{\sum \boldsymbol{w_i x_i}}{\sum \boldsymbol{w_i}} \qquad (2)$$

where w_i is the degree of truth of the membership function of the ith linguistic priority term and x_i is the risk rank at the maximum value of the membership function of the ith linguistic priority term.

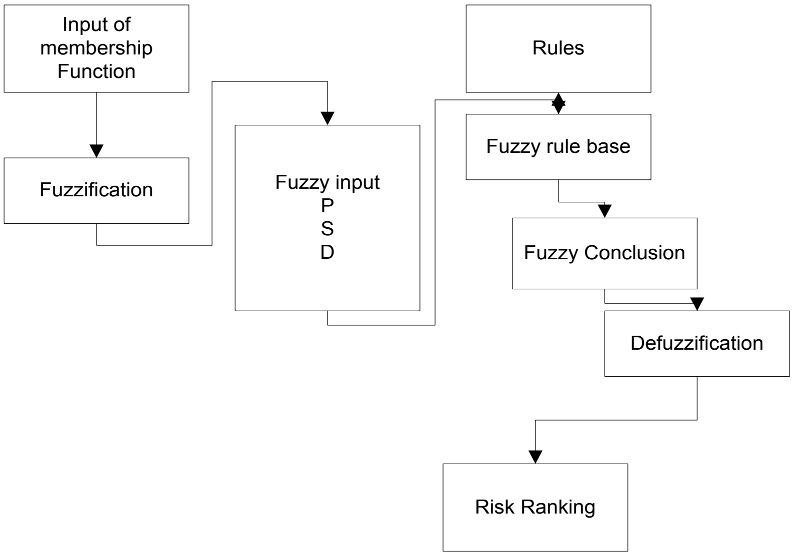

Figure 4.4: Risk evaluation using fuzzy modeling

4.5.1 Establishment of Membership Function

A fuzzy set is a collection of elements in a universe of information where the boundary of the set is ambiguous, vague, and otherwise fuzzy. It is specified by a membership function, which assigns a value within the unit interval [0, 1] to each element in the universe of discourse.

The assigned value is called the membership degree, which specifies the extent to which a given element belongs to the fuzzy set. If the assigned value is zero, the given element does not belong to the set. If the assigned value is unity, the element fully belongs to the set. If the value lies within the interval [0,1], the element partially belongs to the set. Therefore, any fuzzy set can be uniquely determined from its membership function.

There are various types of fuzzy numbers and its nomenclature is associated with its format, such as: sine numbers, bell shape, polygonal, trapezoids, triangular, and so on. The function itself can be an arbitrary curve whose shape we can define as a function that suits us from the point of view of simplicity, convenience, speed, and efficiency.

In fuzzy FMEA, the three input factors of the RPN function, i.e. occurrence, severity, and detection are assumed to be the input factors of the fuzzy RPN function as well. In this paper the triangular fuzzy numbers are established. The triangular membership function is used to represent each linguistic term. It is chosen because the simplest is the *triangular* membership function and the simplest membership functions are formed using straight lines. This function is nothing more than a collection of three points forming a triangle.

The triangular is also adopted since it has a smooth transition from one linguistic priority term to another. It facilitates also easy defuzzification of each linguistic priority term. The membership function for each linguistic priority term is evaluated within its limits on an arbitrary scale from zero to unity.

Besides, past experiences have indicated that it is a suitable choice in many applications, and has been a reliable performer including fuzzy controllers, fuzzy models, and classification schemes. Perhaps, the most obvious motivation behind their utilization stems from a striking simplicity of this form of the membership functions (that could be eventually exploited in further steps of processing) and a fairly limited availability of the pertinent information about the linguistic terms.

The most commonly used fuzzy numbers are triangular fuzzy number, whose membership function is defined as:

$$(x) = \begin{cases} 0; \;\; x \leq a \text{ or } x \geq c \\ \frac{x-a}{b-a}, \;\; a \leq x \leq b, \\ \frac{c-x}{c-b}, \;\; b \leq x \leq c, \end{cases} \tag{3}$$

The triangular membership function is denoted as *(a,b,c)*.

In this study, by using triangular, five membership functions were established. Then, five linguistic priority terms were employed to describe the linguistic variables of each scenario and their interpretations (occurrence, severity, and detection) are provided in Tables 1–3. The output of this analysis is that each element of a scenario has at least one membership function value associated with one linguistic priority term.

4.5.2 Fuzzy Rules Base and Defuzzification Process

A fuzzy rules base is collection of knowledge from experts. A fuzzy if-then rule is an if-then statement in which some words are characterized by a continuous membership function. It provides a systematic procedure for transforming a knowledge base into a nonlinear mapping. The priority level of specific scenario is decided on the basic of the fuzzy rule base developed. In this paper, "min-max Approach" or Mamdani method is established. It is chosen because the most widely used rule of inference is the min-max one. This was originally proposed by E. H. Mamdani who based it on ideas of L. A. Zadeh presented. The Mamdani method (min-max) is also widely accepted for capturing expert knowledge. It allows us to describe the expertise in more intuitive, more humanlike manner. Besides, The Mamdani FIS has output membership functions which are used in this paper. Past experiences also have indicated that Mamdani method is a suitable choice in many applications and in the safety issue.

The other method is Sugeno method. Sugeno method is computationally efficient and works well with optimization and adaptive techniques, which makes it very attractive in control problems, particularly for dynamic non linear systems. These adaptive techniques can be used to customize the membership functions so that fuzzy system best models the data. However, Sugeno FIS has no output membership functions. In this paper, output membership function is established to make fuzzy conclusions. This method is not suitable for this research, because this research needs output membership function in fuzzy inference system.

By using "min-max" approach, the set of fuzzy conclusions of the scenario is obtained in terms of membership function values associated with linguistic priority terms. In this case, "min-max" approach is established to make easy to associate with deffuzification process. When applying the "min-max" approach, the following steps are conducted:

- Identify the possible combination of O, S, and D in which the membership values associated with the corresponding linguistic priority terms are not zero. The outputs of such combinations can be obtained from the fuzzy rule base developed.
- Determine the minimum value of each combination by comparing the values obtained from each element and the value of the belief degree established in the priority level.
- Determine the highest minimum values obtained from step 2 with respect to each linguistic priority term.

There are three approaches that used in the fuzzy inference system in Mamdani method which are some of the most commonly used aggregation operators are the maximum, the sum and the probabilistic sum. In this study, the maximum is used. In the sum method, the fuzzy conclusion is obtained by determine bounded-sum to all output of fuzzy. That is different with probabilistic OR method. In this method, the implication is obtained by conduct product to all output of fuzzy.

The deffuzification process creates a crisp ranking from the fuzzy conclusion set to express the riskiness of the design so that corrective actions and design revision can be prioritized. The deffuzification process is required to decipher the meaning of the fuzzy concussions and their membership values, and resolve conflicts between different results, which may have been triggered during the rule evaluation (Chin *et al*, 2008)

In the case of defuzzification to determine a failure mode critically ranking, the defuzzification strategy should result in continuous range of critically rankings, and consider all of the rules fired during the rule evaluation according to the degree of truth of the conclusion. Several defuzzification algorithms have been developed, there are; *(a) Centroid average (CA).* Centroid defuzzification returns the center of area under the curve. If we think of the area as a plate of equal density, the centroid is the point along the *x* axis about which this shape would balance. *(b) Bisector.* The bisector is the vertical line that will divide the region into two sub-regions of equal area. It is sometimes, but not always coincident with the centroid line. *(c) Mean of maximum (MOM), (d) Smallest of maximum (SOM) and (e) Largest of maximum (LOM).* MOM, SOM, and LOM stand for Middle, Smallest, and Largest of Maximum, respectively. These three methods key of the maximum value assumed by the aggregate membership function.

In Mamdani method there are several ways to defuzzify this kind of aggregated areas but the two most popular are the mean of maximum and centroid average. The one selected for use in this study is the MOM or WMoM. That method is chosen because “min-max” method was established in the fuzzy conclusion, and one of the variable values at which the fuzzy subset has its maximum truth value is chosen as the crisp value for the output variable.

The WMoM method is also appear the algorithm averages the points of maximum possibility for each priority level of the scenarios, weighted by the degrees of truth at which the membership functions reach the maximum values. The defuzzification value can be determined as shown in Equation 2.

4.6. Risk Evaluation for FSA

4.6. 1 Formal Safety Assessment

According to the IMO, an FSA is a rational and systematic process for assessing the risks associated with any sphere of activity and for evaluating the costs and benefits of different options for reducing those risks. The FSA is also a systematic, formal, and integrated assessment approach. The application of this method to maritime safety and navigation consists of a five-step FSA procedure that establishes an overall analysis. The FSA approach is a standardized holistic approach in risk assessment. The approach involves several standard elements, which are illustrated by the five-step procedure shown in Figure 4.5.

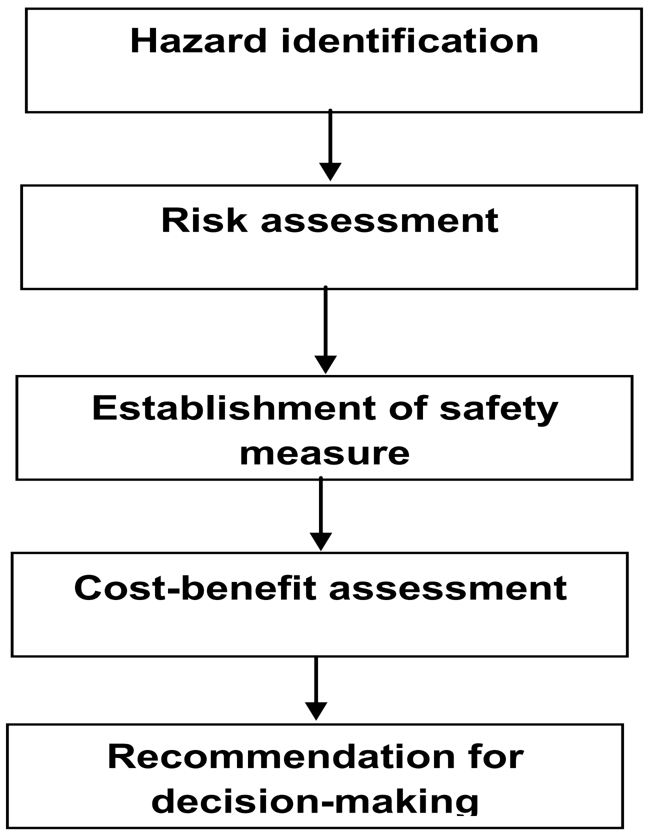

Figure 4.5: The five-step procedure of the FSA

Table 4.4: Percentage of casualty occurrences for each ship type

Type of vessel	Number	Percentage
General cargo	253	53.15%
Tanker	98	20.59%
Bulk carrier	32	6.57%
Fishing	21	4.41%
Container	14	2.94%
Liquefied gas tanker	8	1.68%
Tug	7	1.49%
Ore carrier	6	1.26%
Ferry	3	0.63%
Landing craft	3	0.63%
Passenger	3	0.63%
Roro cargo	3	0.63%
Supply ship	3	0.63%
Tug or Supply ship	3	0.63%
Vehicle carrier	3	0.63%
Livestock carrier	2	0.42%
Aggregate carrier	1	0.21%
Barge carrier	1	0.21%
Cable layer	1	0.21%
Crane pontoon	1	0.21%
Destroyer	1	0.21%
Drilling ship	1	0.21%
Hopper dredge	1	0.21%
Processing tanker	1	0.21%
Refrigerated cargo	1	0.21%
Utility vessel	1	0.21%
Unknown	4	0.84%
TOTAL	476	

The five-step FSA procedure includes the following: hazard identification, risk assessment, establishment of safety measures, cost-benefit assessment, and recommendations for decision-making. FSA is a tool designed to assist maritime regulators in the process of improving and deriving new rules and regulations. It is also a powerful tool in helping to evaluate navigational risks. This study focuses on hazard identification as the first step of an FSA. In this step, the criteria for the risk factors are obtained from a failure mode and effects analysis. The criteria are determined from three risk factors: occurrence, severity, and detection. The risk factors O, S, and D are set as fuzzy variables and are later evaluated using a fuzzy method.

4.6. 2 Ship Casualties in the Malacca Strait

Hazard identification for ships in the Malacca Strait is an essential part of the risk assessment process. A list of relevant hazards that occurred in the Malacca Strait was established. Table 4.4 lists statistical data based on the casualties reported for different types of vessels in the Malacca Strait between 1978 and 1994 (Gran, 1999).

It can be observed from the table above that most of the casualties occurred for general cargo ships (53.15%), followed by tankers (20.59%). Table 4.5 lists the statistical data on the types of casualties that occurred in the Malacca Strait between 1978 and 1994 (Gran, 1999). The categories of the vessel-related casualties in the Malacca Strait are as follows: 1) fire or explosion, 2) stranding or grounding, 3) leaking or engine trouble, 4) collision, and 5) other. Table 4.5 shows that 101 collisions occurred between 1978 and 1994, representing 21% of the casualties in that period. The analysis of the number of collisions in the Malacca Strait is an important issue. Implementation of the AIS was very important for enhancing the navigational safety. In addition to static information, the AIS provides accurate real-time dynamic information about the navigating ships. It yields an important database that can be used in decision-making and management for collision avoidance.

Table 4.5: Types of casualties

Type of casualty	Number	Percentage
Fire or Explosion	183	17%
Grounding or Stranding	153	32%
Leaking or Engine trouble	123	26%
Collision	101	21%
Other	81	4%

4.7 Fuzzy Model for Risk Evaluation

4.7.1 Establishment of Scenarios and Risk Priority Numbers (*RPN*s)

To create the FMEA model, 10 scenarios were established on the basis of AIS data and previously recorded data. These hypothetical scenarios will be explored. Scenarios are created to determine values of *RPN* and to serve as the scope (or domain) in the fuzzy logic method. In the fuzzy FMEA, the value of the membership function ranges between zero and unity. Figures 4.6–4.9 show the risk assessment made using fuzzy FMEA modeling for ship collisions in the Malacca Strait. The three risk factors are described and evaluated in Tables 4.7–4.9. The failure modes with higher risk rankings are assumed to be more important and will be given higher priorities for correction.

Ten scenarios have been established on the basis of AIS data, other data sources, and the GIS. First, aspects such as ship type, ship condition, regional characteristics, and distance between vessels were classified on the basis of AIS data and the GIS. Therefore, a questionnaire was conducted with navigators that had experienced navigation through the Malacca Strait. The scenarios were also based on previous literature related to the safety of navigation in the Malacca Strait. The hypothetical scenarios and resultant *RPN* values are listed in Table 4.6.

Once the 10 scenarios were defined, another questionnaire was distributed to the navigators and crew members that had experienced navigation through the Malacca Strait. The total number of navigators was 41. The content of the questionnaire was classified using

FMEA methodology. In this case, the questionnaire was conducted on potential failures, potential effects of failures, potential causes of failures, and current control of failures. The scale of the questionnaire was 1–10, which matched the scale of the FMEA method. A classification weight was assigned to each group of navigators according to the extent of their navigational experience: 5–10 years (0.2), 10–15 years (0.3), and 15 or more years (0.5). The following formula was applied to obtain the average values of the responses:

$$\bar{X}_{O,S,D} = \sum_{i=1}^{n} \frac{x_i}{n} \qquad (4)$$

where X_i is the value of the response and *n* is the number of respondents.

The formula for determining the questionnaire score was as follows:

$$S_{O,S,D} = \bar{X}_{O,S,D}\ x\ W_i \qquad (5)$$

where $S_{O,S,D}$ is the questionnaire score, $\bar{X}_{O,S,D}$ is the average value of the responses for each criterion (occurrence, severity, or detection), and W_i is the weight of the expert judgment (based on the experience of the navigator).

The scores of the questionnaires are values of *O*, *S*, and *D* that are then used as input to obtain the membership function value for each criterion. *RPN* values were calculated using Equation 1. Results for *RPN* are listed in Table 4.6.

Table 4.6: *RPN* values

Scenario	Process steps	Occurrence	Severity	Detection	RPN	RPN Rank
1	**High traffic density**	8.19	7.91	7.47	483.928263	9
2	**Short distance between vessels**	8.28	8.04	7.64	508.603968	8
3	**Speeds of own ship and target ship**	7.86	7.65	7.86	472.61394	10
4	**Danger in head on situation and Human Error**	9.05	8.95	8.83	715.207925	4
5	**Danger in overtaking situation and Human Error**	9.11	9.02	8.83	725.580526	3
6	**Danger in crossing situation and Human Error**	9.07	9.29	8.88	748.231464	2
7	**Error of navigation and Human Error**	8.31	8.26	8.34	572.462604	5
8	**Failure of machinery and electricty system**	8.16	8.18	8.16	544.670208	7
9	**Bad weather conditions**	8.38	8.38	7.9	554.77276	6
10	**Human error in General**	9.6	9.56	9.27	850.76352	1

4.7.2 Establishment of Membership Function

The membership function is established for linguistic priority terms with linguistic variables *O*, *S*, and *D* as shown in Figures 4.6–4.8. The descriptions are detailed in Tables 4.8–4.10.

The membership function value is between zero and unity. The interpretation of the descriptive terms for occurrence and severity is as follows: remote (R), low (L), moderate (M), high (H), and very high (VH). The linguistic priority terms for detection are plotted in the direction opposite to that for occurrence and severity by starting from very high and ending with remote. The risk factors are evaluated using the 10-point scale that divides them into bins labeled very high, high, moderate, low, and remote.

An example of determining the input membership function value for the first of the previously defined hypothetical scenarios is shown in Figures 4.6–4.8. The values for the other nine scenarios can be obtained in a similar way as shown in Figures 4.6–4.8.

Table 4.7: Interpretation of the linguistic priority term for probability of occurrence

Linguistic priority term	Interpretation	Fuzzy numbers
Very High	Failure is almost inevitable	(7.5, 10, 10)
High	Repeated failures	(5, 7.5, 10)
Moderate	Occasional failure	(2.5, 5, 7.5)
Low	Relatively few failures	(0, 2.5, 5)
Remote	Failure is unlikely	(0, 0, 2.5)

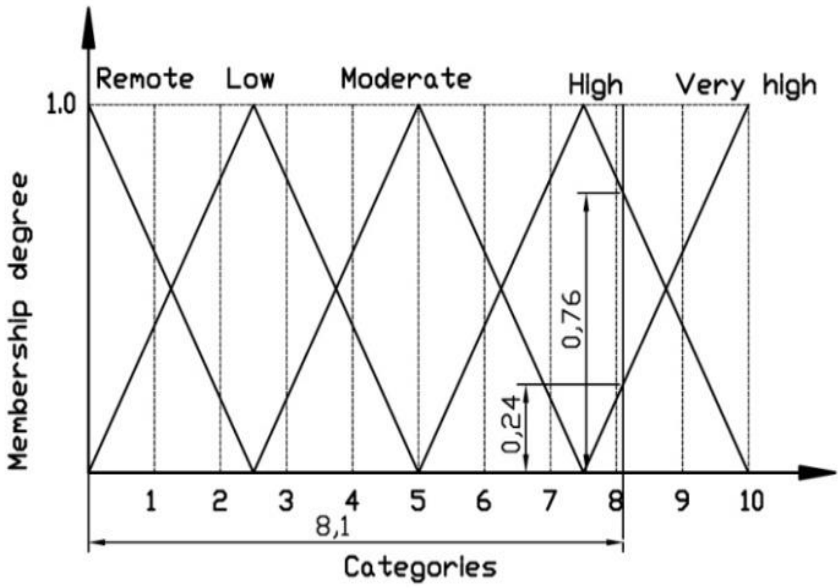

Figure 4.6: Fuzzy membership functions for linguistic variables reflecting probability of occurrence

Table 4.8: Interpretation of the linguistic priority term for severity

Linguistic priority term	Interpretation	Fuzzy numbers
Very High	Ship collision has a very serious effect on people, sea traffic, and the environment	(7.5, 10, 10)
High	Ship collision has a serious effect on people, sea traffic, and the environment	(5, 7.5, 10)
Moderate	Ship collision has a moderately serious effect on people, sea traffic, and the environment	(2.5, 5, 7.5)
Low	Ship collision has a minor effect on people, sea traffic, and the environment	(0, 2.5, 5)
Remote	Ship collision has no serious effect on people, sea traffic, and the environment	(0, 0, 2.5)

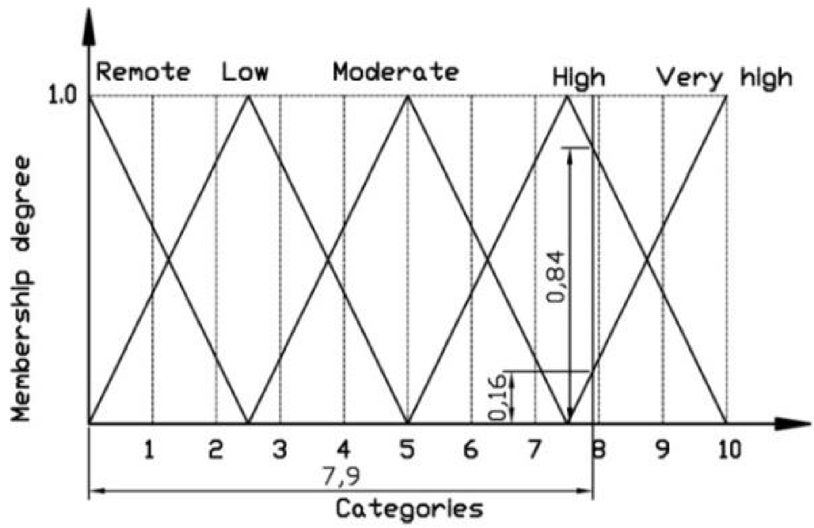

Figure 4.7: Fuzzy membership functions for linguistic variables reflecting severity

Table 4.9: Interpretation of the linguistic priority term for detection

Linguistic priority term	Interpretation	Fuzzy numbers
Remote	Remote chance that the AIS and navigation system will detect potential cause or mechanism and subsequent failure mode	(7.5, 10, 10)
Low	Low chance that the AIS and navigation system will detect potential cause or mechanism and subsequent failure mode	(5, 7.5, 10)
Moderate	Moderate chance that the AIS and navigation system will detect potential cause or mechanism and subsequent failure mode	(2.5, 5, 7.5)
High	High chance that the AIS and navigation system will detect potential cause or mechanism and subsequent failure mode	(0, 2.5, 5)
Very High	Very high chance that the AIS and navigation system will detect potential cause or mechanism and subsequent failure mode	(0, 0, 2.5)

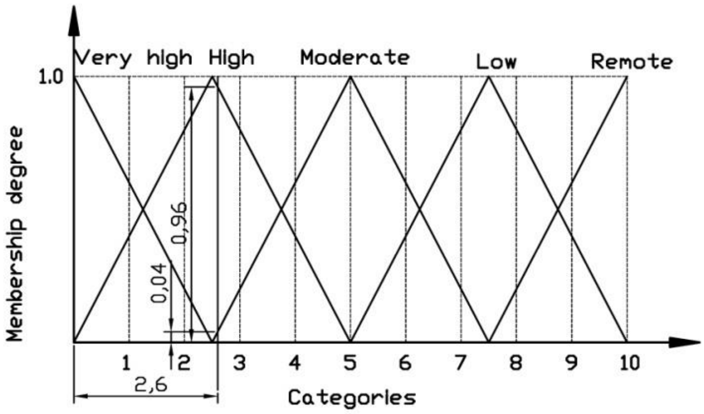

Figure 4.8: Fuzzy membership functions for linguistic variables reflecting detection

Table 4.10: Interpretation of the linguistic priority term for priority level

Linguistic priority term	Interpretation	Fuzzy numbers
Very High	Very high risk level for ship collision scenario	(7, 8.5, 10)
High	High risk level for ship collision scenario	(5.5, 7, 8.5)
Moderate	Moderate risk level for ship collision scenario	(3, 5, 7)
Low	Low risk level for ship collision scenario	(1.5, 3, 4.5)
Remote	Remote risk level for ship collision scenario	(0, 1.5, 3)

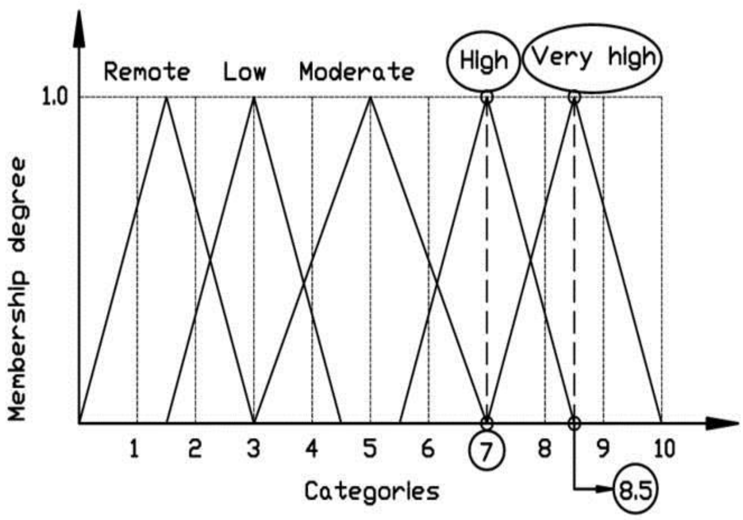

Figure 4.9: Fuzzy membership functions for linguistic variables reflecting priority level

4.7.3 Establishment of Fuzzy Rule and Conclusions

Figure 4.9 shows the membership function of the output that is called the priority level. In this study, the output takes five membership function values: remote (1), low (2), moderate (3), high (4), and very high (5), as described in Table 10.

In order to obtain a security risk ranking, two steps are required. First, the linguistic priority terms and the associated membership values reflecting the risk levels for the *O*, *S*, and *D* of each scenario are carefully decided. Second, the fuzzy set conclusion of each scenario is obtained from the fuzzy rules base using the so-called min-max approach. Hence, the fuzzy set conclusions of Scenario 1 are obtained as follows:

- List the membership function values. The combinations of membership function values for Scenario 1 are shown below. In a similar way, the combinations of membership function values for other scenarios can be produced.
  - If *O* = High 0.76, *P* = High 0.84, and *D* = Moderate 0.96, then the priority level is 1 High.
  - If *O* = High 0.76, *P* = High 0.84, and *D* = Low 0.96, then the priority level is 1 Very High.
  - If *O* = Very High 0.24, *P* = High 0.84, and *D* = Moderate 0.96, then the priority level is 0.7 High.
  - If *O* = Very High 0.24, *P* = High 0.84, and *D* = Low 0.04, then the priority level is 0.2 Very High.
  - If *O* = High 0.76, *P* = Very High 0.16, and *D* = Moderate 0.96, then the priority level is 0.8 High.
  - If *O* = High 0.76, *P* = Very High 0.84, and *D* = Low 0.04, then the priority level is 0.5 Very High.
  - If *O* = Very High 0.24, *P* = High 0.16, and *D* = Moderate 0.96, then the priority level is 1 High.
  - If *O* = Very High 0.24, *P* = High 0.16, and *D* = Low 0.96, then the priority level is 0.5 Very High.
- Determine the minimum value of each combination by comparing the values obtained from each element and the weight established for the priority level. In the first combination shown above, *O* = High 0.76, *S* = High 0.84, *D* = moderate 0.96, and the priority level is High. Therefore, the minimum value of *O*, *S*, and *D* is 0.76. The

minimum values of the other combinations can be determined in a similar way.

- Determine the maximum value of the minimum values obtained from the previous step. This can be done for two categories: High and Very High. The maximum value of the linguistic priority High is 0.76, and the maximum value of the linguistic priority Very High is 0.04. Table 12 lists these maximum values. The maximum values are used for calculating the fuzzy risk ranking based on Equation 2.

The fuzzy set conclusions of the other scenarios can be obtained in a similar way.

Table 4.11: Maximums of minimums for Scenario 1

Category	Maximum value
High	0.76
Very High	0.04

4. 8 Collision Risk Ranking

Based on Equation 2, the defuzzified values of all scenarios were calculated and then plotted as shown in Figure 4.10. By using Equation 1 in the defuzzification process and taking into account the risk rank at the maximum values of the membership function, the defuzzified value of Scenario 1 can be expressed as follows:

$$WMoM = \frac{\sum w_i x_i}{\sum w_i} = \frac{0.04\ .\ 8.5 + 0.76\ .\ 7}{0.04 + 0.76}. \qquad (6)$$

The defuzzified values of all other scenarios are obtained in a similar way.

The scenarios with higher defuzzified values are considered to be more risky. Human error has the highest risk ranking. It is followed in rank by crossing situation, head-on situation, short distance between vessels, speeds of own ship and target ship, high traffic density, overtaking situation, error in navigation, bad weather conditions, and failure of machinery or electrical system. This result, called the fuzzy risk ranking, is very important in that it gives useful information to navigators passing through the Malacca Strait. It is useful for navigators seeking to prevent accidents and reduce the ship collision risk in the Malacca Strait. Additionally, by improving this approach, important risk factors can be identified and thoroughly analyzed in further studies.

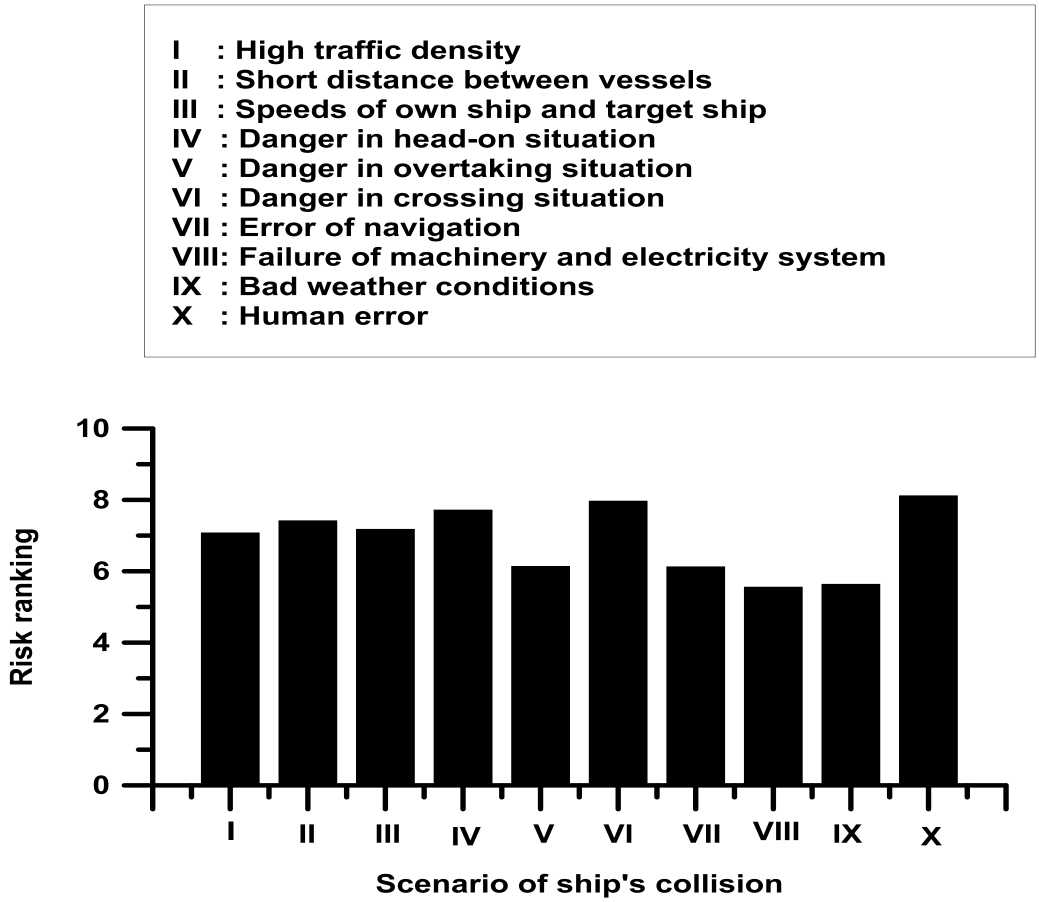

Figure 4.10: Fuzzy risk priority numbers for ship collisions.

Table 4.12: Fuzzy risk priority numbers and countermeasures

Scenario	Process steps	FRPN	FRPN Rank	Countermeasure
1	**High traffic density**	7.08	7	Development of marine traffict management
2	**Short distance between vessels**	7.42	5	Use of detection and monitoring system
3	**Speeds of own ship and target ship**	7.18	6	Development of control system of navigation
4	**Danger in head on situation and Human Error**	7.72	3	Improvement of skill of navigation
5	**Danger in overtaking situation and Human Error**	6.14	8	Improvement of skill of navigation
6	**Danger in crossing situation and Human Error**	7.97	2	Improvement of skill of navigation
7	**Error of navigation and Human Error**	7.48	4	Establishment of ability of crew manning
8	**Failure of machinery and electricty system**	5.56	10	Development of reliability and maintenance system
9	**Bad weather conditions**	5.64	9	Use of communication system
10	**Human error in General**	8.12	1	Improvement of skill of navigation

4.9 Conclusions

This paper has proposed an evaluation of ship collisions in the Malacca Strait on the basis of fuzzy knowledge. In this study, the AIS was implemented as a source of input data for a fuzzy logic method that performed both hazard identification and risk assessment as steps of a formal safety assessment. By using a fuzzy FMEA, risk evaluations for ship collisions in the Malacca Strait were conducted. The fuzzy FMEA considered three risk factors: occurrence, severity, and detection. Risk priority numbers and fuzzy risk priority numbers were established.

Hazard identification for ships in the Malacca Strait is an essential part of the risk assessment process. In this study, a list of relevant hazards that have occurred in the Malacca Strait was identified.

In order to establish the FMEA model using the fuzzy method, 10 scenarios were defined on the basis of AIS data and other data. These hypothetical scenarios were explored. Scenarios create a scope (or domain) in the fuzzy logic method. The value of the membership function ranged between zero and unity. The risk ranking for each scenario was determined, and “human error in general” had the highest risk number while “failure of machinery or electrical system” had the lowest.

To lower the risk of collisions and ensure the safety of marine traffic, countermeasures were established for each scenario as listed in Table 4.12.

The continuation of this research will be not only to assess risk by using a risk matrix but also to develop a risk mitigation and cost-benefit analysis, both of which are recommended for decision-making as steps of an FSA.

Chapter 5

Safety of Navigation Assessment

5.1 Introduction

The Malacca Straits is vital strategic for seaborne trade. However, it's have risk area for navigation. The analysis of marine traffic safety in the Malacca Straits is very important to enhance navigational safety. Navigational collisions are a major safety concern in many sea ports.

The increasing traffic through the Malacca Straits poses significant risks to the biodiversity and the marine environment, to the livelihood of the coastal communities and to the fishing and tourism industries. An examination of the casualty data in the Malacca Straits between 1975 and 1995 shows the serious accidents have occurred in high density traffic area [3]. Therefore, Current safety measures should be improved and supported with the relevant complementary services to face the challenges of development in East Asia associated with the increase in international shipping.

The three littoral States of Indonesia, Malaysia and Singapore have been co-operating since the early 1970s to enhance navigational safety in the Straits of Malacca and Singapore. Various measures to enhance navigational safety and environmental protection in the Straits of Malacca and Singapore have been proposed by the three littoral States and adopted by the IMO. The measures adopted by the IMO in the Straits of Malacca and Singapore include the following: Sea lanes and Traffic Separation Schemes , vessel Traffic Systems, mandatory ship reporting system and routing measures such as under keel clearance requirements and deep water routes.

Regulation 19 of SOLAS Chapter V - Carriage requirements for shipborne navigational systems and equipment - sets out navigational equipment to be carried on board ships, according to ship type. IMO adopted a new requirement (as part of a revised new chapter V) for all ships to carry AIS capable of providing information about the ship to other ships and to coastal authorities automatically.

In this study, an AIS is implemented for the study on risk assessment of ship collision under the International Regulations for Preventing Collisions at Sea 1972 (COLREG) guidelines. In this context, AIS implemented as source of data and input for the risk assessment.

5.2 Literature review

There are several authors have established the risk assessment for ship collision at the channel. Qu Xiaobo et al. [19] establish ship collision risk assessment for the Singapore Strait. In this paper, these three risk indices for the Singapore Strait are estimated by using the real time ship locations and sailing speeds provide by Lloyd's MIU AIS.

Mou et al. [7] used AIS data to analyze collision avoidance in busy waterways. They performed statistical analysis of ships involved in collisions. Risk Assessment by Samson model has been established. The authors take only into account ships (own ships) that have an encounter in the Traffic Separation Schema (TSS) of the port of Rotterdam.

Pedersen et al. [20] introduced a model to calculate the collision risk in a congested shipping lane: (1) investigate the distribution of different categories of the traffic; (2) determine the individual geometrical collision diameter; and (3) integrate the number of encounters.

Otto et al. [21] discussed about the element of risk analysis for collision and grounding of RoRo passenger ferry. In this study, the consequences of collision and grounding scenarios were estimated by introducing damage criteria that link the calculated distribution of damage size and damage location to monetary units.

Jiacai et al. [17] established an AIS data visualization model for assessing maritime traffic situation. In this paper, propose a novel visualization model to appraise the maritime traffic situation based on ship's automatic identification system.

J. Wang et al. [22] explored formal safety assessment (FSA) of containership. In their paper, they use fault tree analysis (FTA) for hazard identification and evaluation of risk. Kobayashi et al. [1] purposed about the guideline for ship evacuation from tsunami attack. In their paper, AIS data used for analysis the ship which passed in the Osaka Bay, Japan. Pitana et al. [2] analyzed the evacuation of a large passenger vessel in the case of a pending tsunami using discrete event simulation (DES), which have considered a stochastic approach. In this paper, they are used the AIS data for calculated the sea traffic in the area. Zaman et al. [23] analyzed the maritime safety in the Malacca Straits using AIS data and Analytic Hierarchy Process (AHP). In this case, the dangerous score analyzed based on AIS data and AHP.

This study focus for usage of AIS and GIS to establish risk based navigation. Risk assessment includes the probability analysis and consequence analysis. In this case, the analysis of risk determined in the different condition and different time based on AIS data taken from AIS receiver system which have installed in the UTM Malaysia by Kobe University. Analysis of risk divided into 3 conditions; head on condition, crossing condition and overtaking condition.

5.3 Investigation of AIS data

5.3.1 AIS installation

AIS provides an independent platform of traffic information that is able to enhance and support ship's radar in collision avoidance manoeuvring. Depending upon the system's specifications, near real-time Rate of Turn (ROT) and engine-speed may also be available, while voyage information and navigational status can be obtained via the AIS network. Through dedicated VHF frequencies, AIS information is transmitted between vessels, from vessels to shore, or vice versa. In simple terms, AIS is a technology to make ships good to each other. As an aid to collision avoidance, it records the information of ship behaviour, including the effects of human action and ship manoeuvrability. The information includes the vessel's name, its particulars, ship type, registration numbers, and destination as well as the vessel's position, speed, and heading.

AIS is also designed to transmit and receive information about a vessel. This information includes its identity, position, speed, and course, along with other relevant information. Vessels within AIS range can receive information transmitted by other vessels and display this information on a dedicated AIS display, a chartplotter, or a PC using navigation software. Combined with a shore station, this system also offers port authorities and maritime safety bodies the ability to manage maritime traffic and reduce the hazards of marine navigation.

According to the IMO, 2002, AIS information includes static, dynamic, and voyage-related elements. Static information is programmed into the unit at the time of commissioning. Dynamic information is derived from interfaces with a ship's GPS and other sensors. Voyage-related data are entered manually by the ship's captain using a password-protected routine

The actual sea traffic conditions of several ships in the Malacca Straits were investigated using an AIS receiver installed at Universiti Teknologi Malaysia (UTM) in Malaysia. All AIS data received by the equipment were continuously and automatically stored on the hard disk of a PC. The data could be retrieved from the PC via the Internet and analyzed on another PC at any time.

In this context, static information includes the vessel's maritime mobile service identity (MMSI), the name of the vessel, radio call sign, ship length, the draft of the ship, the IMO number, ship width, type of ship, and antenna position. Dynamic information includes the longitude, latitude, time, course, rate of turn, and speed over ground. Voyage-related information includes the draft of the ship, destination, and type of cargo.

5.3.2 Analysis of the AIS data

The study area of this research is shown in fig 1.2. The analysis of AIS data are shown in Fig.2.11-2.12 in Chapter 2. They are very useful for analysis of traffic density and probability. In this research, the probability assessment has been conducted based on AIS data investigation. The result calculation will be explored in the next section.

5.4 Safety of Navigation Analysis

5.4.1 Risk Model based on AIS Data

Risk assessment established based on AIS data and GIS. In this case, the actual data from AIS could analyze the probability and consequence. Figure 5.1 shows the encounter types according to COLREG. Based on AIS data and GIS, the analysis of risk is categorized into 3 parts: Head on, crossing and overtaking.

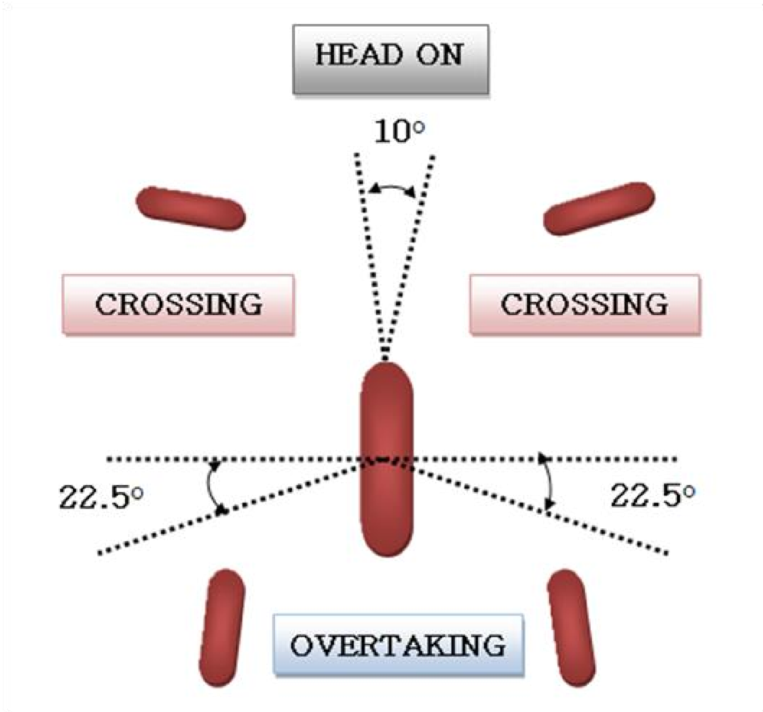

Fig.5.1: Encounter types according to COLREG.

The risk analysis is composed of two main activities: probability modelling and consequence modeling. In this paper, probabilities have been established based on AIS data and hazard analysis. The factors analyzed in assessing the ship collision probability are the head-on situation, crossing situation, overtaking situation, and traffic density, based on AIS and GIS (Geographic Information System) data. The traffic density can be determined as:

$$\rho_{s} = \frac{Nm}{D \, x \, W} \qquad (5.1)$$

where N_m is the number of ships using the channel, D is the channel length, and W is the channel width. Fig. 5.1 shows the area selected to calculate the traffic density and ship collision probability, based on AIS and GIS data.

The ship collision probability per passage can be expressed as:

$$P_a = N_i \, x \, P_c \qquad (5.2)$$

where N_i is the probability number of collisions per passage, and Pc is failures per passage or encounter. P_c can be expressed as:

$$P_c = \mu_c \, x \, T \qquad (5.3)$$

where μ_c is failures per hour and T is the time taken per passage.

The probability number of collisions in the head-on and overtaking condition per passage can be expressed. As follows, assuming that four groups of ships have identical characteristics such as head on, overtaking, left and right side crossing. The expression is:

$$N_i = 4 \, x \, B \, x \, D \, x \, \rho_s \qquad (5.4)$$

The number of collisions in the crossing condition per passage is:

$$N_i = 2xD \, (B + L)\rho_s \qquad (5.5)$$

In Equations 5.4–5.5, B is the mean beam of meeting (m), L is the mean length of meeting (m). In this paper, equation 5.3-5.4 taken for calculation of ship collision probability in the Malacca Straits based on AIS data and GIS. The number of collisions per year can then be determined as:

$$Na = Pa \times (365 \times 24 / T) \qquad (6)$$

Tables 5.1–5.3 show estimations of ship collision probabilities in the selected area of the Malacca Straits. In the table 5.1-5.3 also show that Nm is arrival frequency of meeting ships. In this case, Nm is determined based on AIS and GIS, and Ni is determined according to equation 5.4 and 5.5.

Based on AIS data, the scenario of probability assessment have been carried out with different time with actual data in the selected area. In this case, scenario taken in the time which have high traffic area, on 2.00h, 10.00h, and 22.00h. Result of probability assessment could be classified as shown in table 5.1-5.3. The probability indexes and consequence categories are shown in table 5.4. The factors analyzed in assessing the ship collision probability are the head-on situation, crossing situation, overtaking situation, and traffic density, using both AIS and GIS data.

Table 5.1 Collision probability based on AIS data at 02.00h

No		N_m	ρ_s	N_i	μ_c	$D_c(m)$	L (m)	B(m)	T	P_c	P_a	P
1	Ship Head-on	12	4.4321E-08	0.1313	2E-05	24688	180	30	1	1.5E-05	1.96953E-06	0.207
2	Ship Overtaking	15	5.5401E-08	0.16413	2E-05				1	1.5E-05	2.46192E-06	0.323
3	Ship Crossing	36	1.3296E-07	1.37867	2E-05				1	1.5E-05	2.06801E-05	6.521
	Total	63									8.37051E-06	

Table 5.2 Collision probability based on AIS data at 10.00h

Node		N_m	ρ_s	N_i	μ_c	$D_c(m)$	L (m)	B(m)	T	P_c	P_a	P
1	Ship Head-on	25	9.2334E-08	0.27355	2E-05	24688	180	30	1	1.5E-05	4.10319E-06	0.895
2	Ship Overtaking	35	1.2927E-07	0.38296	2E-05				1	1.5E-05	5.74447E-06	1.761
3	Ship Crossing	68	2.5115E-07	2.60416	2E-05				1	1.5E-05	3.90624E-05	23.268
	Total	128									1.63034E-05	

Table 5.3 Collision probability based on AIS data at 22.00h

Node		N_m	ρ_s	N_i	μ_c	$D_c(m)$	L (m)	B(m)	T	P_c	P_a	P
1	Ship Head-on	19	7.0174E-08	0.2079	2E-05	24688	180	30	1	1.5E-05	3.11843E-06	0.519
2	Ship Overtaking	26	9.6028E-08	0.28449	2E-05				1	1.5E-05	4.26732E-06	0.972
3	Ship Crossing	48	1.7728E-07	1.83823	2E-05				1	1.5E-05	2.75735E-05	11.59
	Total	93									1.16531E-05	

Table 5.4 Probability index and consequence categories.

Probability Index	Description		
1	Very unlikely	Less than once per 1000 years	P<1/1000
2	Remote	Once per 100-1000 years	P<1/100
3	Occasional	Once per 10-100 years	P<1/10
4	Probable	Once per 1-10 years	P<1
5	Frequent	More than once per year	P=1
Consequence categories	Description		
A	Does not result in injuries		
B	Minor injuries		
C	Major injuries		
D	Death or total disability		
E	Death or total disability for several person		

5.4.2 Consequence assessment

The consequence analyses for each scenario have been carried out. For built risk level by using risk matrix, five categories are used as shown in Table 5.4. To determine the consequence analysis, five categories comprise the built risk level by using a risk matrix. Consequence analysis established in the different time based on AIS data scenario. The scenario taken in the time that has high traffic areas: 02.00, 10.00, 22.00.

Table 1 shows the probability index and the consequence categories. The consequence analysis is classified as the following: *does not result in injuries, minor injuries, major* *injuries, death or total disability, and death or total disability of several people.* To determine the consequence analysis, the consequence categories areas are established based on Kristiansen model. In this case, categories of consequence are based on result of probability index on probability calculation. The results of the consequence analysis and probability analysis are plotted as a risk matrix.

5.4.3 Constructing Risk Matrix

Table 5.5, 5.6, 5.7 shows the risk matrix for analysis probability and consequence in the Malacca Straits based on AIS data and GIS. Based on AIS data, the scenario of probability assessment have been carried out with different time with actual data. In this case, scenario taken in the time which have high traffic area, on 2.00h, 10.00h, and 22.00h.

Table 5.5 shows the risk matrix at 2.00h scenario based on AIS. In this case, Risk matrix is established based on result of probability assessment and consequence assessment. In this condition, number of ship in head on encounter is 12, crossing encounter is 15, and overtaking encounter is 36. The numbers of ships are determined based on AIS data in the selected area in the Malacca Straits as shown in Fig.1. Based on probability index, head on, crossing and overtaking are respectively classified at point 4, 4, 5. And based on consequence analysis, head on, crossing and overtaking are respectively classified at point C, C, D. The tolerable condition is for head on and crossing encounters. And Intolerable condition is for overtaking encounter.

Table 5.6 shows the risk matrix in the 10.00h scenario based on AIS. The risk level has been established in Head on condition, crossing condition and overtaking condition. Based on AIS, the number of ship in head on is 25, crossing is 35 and overtaking is 68. Based on probability index, head on, crossing and overtaking are respectively classified at point 4, 5, 5. And based on consequence analysis, head on, crossing and overtaking are respectively classified at point C, D, D. In this case, risk level conditions are: head on in the tolerable level, crossing in the intolerable level and overtaking in the intolerable level.

Table 5.7 shows the risk matrix in the 22.00h scenario based on AIS. The risk level has been established in Head on condition, crossing condition and overtaking condition. In this condition, number of ship in head on is 19, crossing is 26 and overtaking is 48. The risk level conditions are head on in the tolerable level, crossing in the tolerable level and overtaking in the intolerable level.

The result of safety of navigation based on risk assessment using AIS data in the different time is very important for navigators to be careful if transit in this area. Those results are also useful for make safety measure and risk mitigation to enhance a safety in the Malacca Straits.

Table 5.5: Risk matrix based on AIS data at 02.00h.

Probability

Consequence

	1	2	3	4	5
A	N	N	N	N	T
B	N	N	N	T	T
C	N	N	T	T (H,C)	I
D	N	T	T	I	I(O)
E	T	T	I	I	I

N *Negligible*
T *Tolerable*
I *Intolerable*

Table 5.6: Risk matrix based on AIS data at 10.00h.

Probability

Consequence

	1	2	3	4	5
A	N	N	N	N	T
B	N	N	N	T	T
C	N	N	T	T(H)	I
D	N	T	T	I	I (C,O)
E	T	T	I	I	I

N *Negligible*
T *Tolerable*
I *Intolerable*

Table 5:7 Risk matrix based on AIS data at 22.00h.

Probability

Consequence	1	2	3	4	5
A	N	N	N	N	T
B	N	N	N	T	T
C	N	N	T	T (H,C)	I
D	N	T	T	I	I (O)
E	T	T	I	I	I

N	*Negligible*
T	*Tolerable*
I	*Intolerable*

5.5 Conclusions

In this context, the AIS were implemented as a source of data for the hazard identification and ship collision probability of the risk assessment step of the FSA.

Based on the AIS data, the ship population passing through the Malacca Straits on 6/2/2010 was calculated. This was broken down as: tanker ships 46%, cargo ships 27%, tugs 8%, passenger ships 8%, LNG 5% and other ships 5%.

Based on AIS data, the scenario of risk assessment have been carried out with different time with actual data. The risk level has been established in Head on condition, crossing condition and overtaking condition. scenario taken in the time which have high traffic area, on 2.00h, 10.00h, and 22.00h.

The future work is establishing the reduction of risk and safety measure (risk control option), cost benefit analysis and recommendation of decision making.

Chapter 6

Discussions and Conclusions

6.1 Discussions

The analysis and evaluation of marine traffic safety using AIS data in the Malacca Straits were conducted. In this research, additional assessment may be required to develop a safety of navigation that is useful to increase the ship safety navigation in the high risk area such as the Malacca Straits. The information which required explained below:

6.1.1 Safety Measure and Cost-Benefit Assessment

The safety measure and cost benefit assessment are steps of formal safety assessment that recommended by IMO. High risk areas can be identified after establishing a risk assessment and then the development of risk control measures can be initiated. Risk control measures can assist in reducing the occurrence likelihood of failures and/or mitigating their possible effects and consequences. Structural review techniques may be used to identify all possible risk control measure for cost-effective decision making. The safety measure is generated from the results of risk assessment which is established based on AIS data. In this case, the data about the ship's collision from navigators and stakeholder in the maritime field are required.

6.1.2 Optimization of Safety Route of Navigation

By using AIS data, the establishments of danger score, evaluation of risk and safety navigation assessment have been conducted in this research. However, the development of safety navigation by optimization of safety route of navigation is very important to enhance the safety in the high risk area such as Malacca Straits. The collision avoidance will be established by using the optimization of safety rote of navigation. There are several method for determine the safety route of navigation, such as fuzzy logic method, Genetic Algorithm etc. The method can be combined with the AIS data and GIS technologies.

6.1.3 Evacuation Assessment of Ship's Accident in the Channel

The Malacca Straits is high risk area for navigation. The ship's accidents have occurred in this area frequency. The evacuation assessment is required to enhance the safety of navigation. The evacuation assessment can be conducted for the ships and for the passengers. By using AIS data, the evacuation assessment can be established.

6.2 Conclusions

The analysis of marine traffic safety in the Malacca Straits had been established. The evaluation of dangerous area, the evaluation of the risk collision and the safety of navigation assessment had been carried out. The evaluation of marine traffic safety by determining the danger score are conducted in Chapter 3. The risk evaluation of ship collision in the marine traffic had been explored in the Chapter 4, and the safety navigation assessment by establishing the risk matrix had been carried out in Chapter 5.

In chapter 3, the implementation of AIS for evaluate marine traffic safety in the Malacca Straits had been carried out. The AIS is implemented as a source of data that describes the characteristics of ships' traffic volume determined using a geographic information system (GIS). AHP is therefore used for evaluating the safety level in the Strait of Malacca. In this case, weighting factors are determined using AHP. The evaluation criteria are divided into five: Ship condition, human factor, environmental factor, machinery factor and navigational factor. Each criterion divides into sub-criteria and sub-sub-criteria. By combining AHP method and AIS, the simulation and calculation results of the danger score are presented.

In Chapter 4, the risk evaluation of ship's collision in the Malacca Straits had been established. The evaluations of risk and hazard identification are useful to enhance the safety.

In this Chapter, ten scenarios established. The investigation of sea traffic using AIS data and GIS in the Malacca Straits is carried out. The proposed FMEA-Fuzzy method for the evaluation of ship collision risk is described. Finally, The risk ranking results are explored.

In Chapter 5, the assessment of safety navigation using AIS data had been carried out. In this chapter, the traffic density and probability assessment is calculated based on AIS data. Consequences analysis had been determined. In this Chapter, scenario of risk matrix established based on actual condition using AIS data with different time and different encounter situation. The head on situation, crossing situation and overtaking situation had been analyzed.

The conclusions of research are summarized as follows:

1. Using the AHP, several factors that contribute to accidents in the Strait of Malacca were revealed. In the Strait of Malacca, from 1975 to 1995, a total of 496 casualties were recorded. These involved collisions, contacts, founderings, standings, fire, engine troubles, bilgings and leakages. 35 of the 111 collision cases have caused foundering of the ships, led to fire and explosion or leakages leading to wrecks.
2. An analysis of several factors that contribute to accidents in the Strait of Malacca indicates the following. First: Ship condition. In the ship condition, the following items are considered: type of ship, length of ship, speed of ship and state of loading. In the actual accident based on type of ship, General cargo ships are at the top the list at 53.15%, followed by tankers at 20.59%, bulk carriers at 6.72%, fishing craft at 4.41%, container ships at 2.94% and liquefied gas carriers at 1.68%. . Secondly, the human element is the most important factor. Several accidents occurred caused by human error. In this case, experience and knowledge, fatigue, overwork, communication are factors that are important for navigators. Thirdly, the environmental factors will be discussed. In fact, serious accidents have occurred in high traffic density areas. Current, speed other ships, length of other ships, distance between vessels, wind effect, characteristics of area are factors that have contributed to the accidents in the Strait of Malacca. Further on, the machinery factors are described. The high percentage of leaking ships and ships limping with machinery problems must be viewed with deep concern because such casualties can easily develop into or cause catastrophic accidents. In the machinery factors, failure of main engine and electrical power, failure of lubricating oil system, failure of

navigation equipment, failure of rudder, failure of hull equipment and failure of propulsion should be considered. Finally, the navigational factors are discussed. This factor can contribute to the accident in the Strait of Malacca. Inappropriateness of ship operation regulation management, inappropriateness of crew manning, inappropriateness of navigational aid are important variable that should be evaluated in order to increase the navigational safety in the marine traffic.

3. To assess the danger score, criteria of human factors, machinery factors and navigational factors could not be evaluated using AIS data. These criteria were determined from a questionnaire. The questionnaire was distributed among the navigators who have experienced passing through the Strait of Malacca. As a complex system with multiple subjects and multiple levels of ship safety navigation, an evaluation index of ship navigational safety was compiled to make the levels more certain and accurate using AIS data. The process of the assessment is as follows:

   At first, the weight of the evaluation index of each criterion (ship condition, human factors, environmental factors, machinery factors and navigational factors) and its related sub-criteria are established using AHP. Therefore, the value of the function of sub-sub-criteria is determined based on AIS data.

4. In order to obtain and create the model of ship collision in the Malacca Straits using Fuzzy method, ten scenarios have been established based on AIS data, GIS and other data source. Firstly, the classification of the ship's behavior such as type of ship, ship condition, characteristics of the area, distance between vessels, etc. were analyzed based on AIS data and GIS. Therefore, interviews with the navigators that have experienced passing through the Malacca Straits have been conducted. The scenarios are also defined based on previous literature related to the safety of navigation in the Malacca Straits.

5. The scenarios with higher defuzzified values are considered to be more risky. Human error has the highest risk ranking. It is respectively followed by crossing situation, head on situation, short distance between vessels, speed of own ship and target ship, high traffic density, overtaking situation, error of navigation, bed weather condition and failure of machinery and electrical system. This result, called fuzzy risk ranking, is very important as it gives useful information to the navigators when passing through the Malacca Straits. It is also useful for

navigators in order to prevent from accidents and to reduce the ship's collision risk in the Malacca Straits.

6. The risk assessment in safety of navigation is composed of two main activities: probability modeling and consequence modeling. The probabilities have been established based on AIS data and hazard analysis. The factors analyzed in assessing the ship collision probability are the head-on situation, crossing situation, overtaking situation, and traffic density, based on AIS and GIS.
7. Based on AIS data, the scenario of risk assessment have been carried out with different time with actual data. The risk level has been established in Head on condition, crossing condition and overtaking condition. scenario taken in the time which have high traffic area, on 2.00h, 10.00h, and 22.00h.

There are correlation regarding chapter 3, chapter 4 and chapter 5.

In the chapter 3, Evaluation of marine traffic safety in the Malacca Straits as busy area has been carried out using AIS data. Danger score assessment using AHP method has been established by considering several factors such as ship condition, human factors, environmental factors, machinery and electrical factors and navigational factors. By combination with AIS, the danger score was determined. The danger area in the Malacca Straits is useful for navigational field. The information regarding danger score area based on actual data is useful to enhance navigation safety.

After, danger score has established, the establishment of risk for collision has been conducted. In this case, in chapter 4, Fuzzy FMEA modelings are used. Several considerations in the chapter 4 such as human factors, environmental factors and condition ship are including in this analysis. However, in the chapter 4 did not appear the probability analysis, severity and detection. In the chapter 4, probability, severity and detection using Fuzzy FMEA modeling have been carried out. By using this method and AIS, risks ranking of collision in the Malacca Straits are established. The countermeasures are conducted to enhance the safety of navigation.

Establishment of safety of navigation has been conducted in chapter 5. The scenario by the different time has been carried out base on AIS data. The traffic density is determined for establish the probability analysis and consequence analysis. Based on chapter 3 and chapter 4, the head on situation, crossing situation and overtaking situation are categorized as danger situation. By using risk matrix, the risk area with different time, risk of head on situation, crossing situation and overtaking situation are established.

The analysis and evaluation of marine traffic by using AIS and AHP method, Fuzzy FMEA method and Risk Matrix are useful to enhance the marine traffic safety.

6.3 Further Researches

The analysis of marine traffic safety in the Malacca Straits based on AIS data had been conducted. Based on discussion and result of assessment, there are several possibilities of further research could be established in order to enhance the safety of navigation in the high risk area such as Malacca Straits as follows:

1. The establishment of the safety measure and cost-benefit assessment using AIS data.
2. The development of optimization for safety route of navigation using AIS data.
3. The evaluation of ships evacuation for ship's accident using AIS data. The assessment of ship evacuation for ship's accident is very important to enhance the safety of navigation in the high risk area.

Acknowledgments

I would like to gladly acknowledge to my supervisor, Prof. Eiichi Kobayashi. There are many discussions which were done during carrying out the research. Without his constant encouragement and advice either the originality or completions of dissertation during three years could not be achieved. I also thank to him in respect of valuable comments for developing the research.

I would like to acknowledge to Prof. Masao Furusho for discussing about Human factors and ship navigation. There are many discussions about human factors and ship navigation which were done.

I would like to acknowledge to Prof. Michiyasu Odani for encouragement and advice for developing this research. Also, I would like to acknowledge to Prof. Wataru Sera for comment and advice for developing this research.

I would like to acknowledge to ITS and Indonesian government for supporting to study in Kobe University, Japan. Without its permission and support, the completion of study could not be achieved.

I would like to acknowledge to members of the maritime safety system laboratory at Kobe University for their assistance and continuous support regarding analysis and evaluation of the AIS and other data.

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