Development of Navigation Safety for Marine Traffic in the Malacca Strait using AIS Data

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ABSTRACT---- *The Malacca Strait is a high density for ship traffic, which is a dense area that has a high chance of accidents. Marine traffic analysis reflect the actual conditions of ship navigation are performed to enhance maritime traffic safety. An automatic identification system (AIS) allows for the accurate investigation of actual ship encounters, ship collisions, and sea traffic management systems. For this study, an AIS receiver installed at the Universiti Teknologi Malaysia (UTM) provided AIS data, which focused on a selected area in the Malacca Strait. The 1972 International Regulations for Preventing Collisions at Sea (COLREG) guided the assessment of navigation safety based on real conditions using AIS and geographic identification systems (GIS). Based on the calculation of the probability index and the consequences, risk matrix indicate the level of risk. This study also established a security measurements. The analysis shows that ship safety will increase significantly if the ship follows the guidelines set out in this study.*

Keywords---- Navigation safety, Ship collision, Malacca Strait, AIS data
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List of symbols

ρ_s	Traffic density (ships/m^2)
N_m	Number of ships using the channel (ship/hours)
D_c	Length of channel (m)
W_c	Width of channel (m)
Pa	Collision probability per passage
Ni	Probability number of collisions per passage
Pc	Failures per passage or encounter
μ_c	Failures per hour
T	Time taken per passage
B	Mean beam of meeting (m)
L	Mean length of meeting (m)
Na	Number of collisions per year

1. INTRODUCTION

Sea transportation safety is an important aspect that must be a major concern. Boat accidents occur due to many factors such as the condition of the ship, environmental factors, human error, damage to machinery and electricity, and so on. [10] The area of this study is the Malacca Strait. The Strait is a strategic area that is important for sea transportation trade. However, this is a high-risk area for navigation because collisions are a major security problem in many sea ports. To improve navigation safety, an analysis of the safety of sea traffic in the Malacca Strait is very important. [1].

The increase in international shipping associated with the development in East Asia has resulted in increasing traffic through the Malacca Strait, which poses significant risks to the biodiversity and the marine environment, the livelihood of the coastal communities, and the fishing and tourism industries. An examination of the casualty data in the Malacca Strait between 1975 and 1995 shows the serious accidents primarily occurred in the high-density traffic regions [2]. Therefore, current safety measures require improvement and the subsequent support with relevant complementary services to face the challenges of increased maritime traffic.

This study uses AIS data to analyze the density of ship traffic in the Malacca Strait. Risk analysis is used to find out the risk level in the strait based on AIS data.

2. LITERATURE REVIEW

Regarding this reserch, there are authors have published several methods about risk of navigation. Qu Xiaobo et al. [3] studied ship collision risks in the Singapore Strait. In this study, real-time ship locations and sailing speeds provided by Lloyd's MIU AIS enable an estimate of three risk indices for the Singapore Strait.

Mou et al. [4] used AIS data to study collision avoidance in busy waterways by performing statistical analyses of ships involved in collisions, establishing the risk assessment model via the SAMSON program. For this model, the authors only took into account the ships (own ships) that encountered a TSS in the port of Rotterdam.

Pedersen et al. [5] explore the pattern of calculating collision risk labels in dense areas. In the research, the distribution of various traffic categories was discussed; then determined the diameter of individual geometric collisions; and integrating the number of meetings. Otto et al. [6] carry out risk analysis on the roro ferry for ship collisions. the consequences of collisions and grounding scenarios are estimated

Zaman et al. [10] examined the maritime safety in the Malacca Strait using AIS data and an analytic hierarchy process (AHP). This data enabled the ranking of situations based on a score that measured danger. Zaman et al. [12, 13] established the ship collision probability based on its AIS data. The probability calculation took into account the traffic density in the channel. For the risk analysis, the results of the probability and consequence analyses comprise the risk matrix.

This study focuses on the use of AIS and GISs to establish a safety protocol for navigation. Risk assessments, including probability and consequence analyses, are conducted.

3. DATA OF SHIP MOVEMENT

3.1 AIS receiver system

On the AIS there is platform for ship's traffic information that is capable of building, enhancing and supporting the operation of ship radars for collision avoidance. The AIS is able to provide real time information on ships. through the port or between ships. Through very high frequencies (VHF), AIS information transmits between ships, from ship to coast, or vice versa. In other words, AIS is an important technology to support ship navigation systems and help improve safety and facilitate communication and real time information. To avoid collisions, AIS records information on ship movements. It is very useful to support navigation operations and prevent ship accidents. Information provided by AIS includes ship names, characteristics, type of ship, MMSI, destination, position of ship, speed of ship, COG and so on.

AIS also transmits and receives data regarding another ship. The real time data includes ship identity, ship position, ship speed, COG, and other information. communication and information between ships can easily use AIS to improve safety. and display this information on a dedicated AIS display, a chartplotter, or a PC that uses 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 2002 IMO, AIS information should include 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.

3.2. AIS data analysis

Figure 1 describes the area analyzed in this study. Figures 2 and 3 show the trend of the number of ships passing through the area per day and hour, in June 2010. in figure 2, it could be seen that the highest number of ships passing through the Malacca Strait on 6/1/2010 reached 657. The lowest number of ships passing through the Straits of Malacca is 575 on 6/27/2010. Figure 2 also shows that the number of ships increased on 6/1/2010.

Figure 3 shows number of ships passing through per hour on 6/1/2010. The number of ships peaks at 19:00, when the number of ships was 164. The lowest number of ships passed through in the morning hours after 24:00 and remained continuous until around 03:00

Figure 4 shows the type of ships passing through the Malacca Strait on 4/6/2010. The type of ships that passed through the Malacca Strait were as follows: 46% tanker ships, 27% cargo ships, 8% tugs, 8% passenger ships, 5% LNG, and 5% other ships.

Based on the AIS data in the selected area, figure 5 shows the LOA on the ship. The LOA percentage can be analyzed as follows: 48%, LOA> 200 m; 32%, LOA = 100–200 m; 8%, LOA = 50-100 m; and 12%, LOA <50 m.

AIS data also provides speed and heading information, as shown in Figure. 6. Percentage of heading is in the range 245 ° –270 °.

To improve ship safety, the navigation system is very important to be supported by AIS. AIS data obtained when sailing ships are also needed in this study. The scenario in this study took AIS data in the Malacca Strait at different times and conditions. It is important to know the volume density used for risk analysis and safety on ships. The study also explores mitigation measures to reduce the risk of ship accidents that occur. AIS data is very useful to support this study.

4. RISK ASSESSMENT FOR SHIP'S NAVIGATION

4.1 Ship collision probability

Assessment of risk based on AIS data was carried out in this study. Information from ais data can be used to calculate probabilities and consequences. the level of risk produced can be used to provide input to the navigator in Malacca Straits to be more careful and improve safety.

Risk analysis consists of two main activities: calculation of probability and calculation of consequences. In this study, in-

depth determination of the probability of collisions was determined based on AIS data converted to GIS and hazard analysis in the Malacca Strait area. The factors analyzed in assessing the probability of ship collisions are as follows: head-on, crossing, and overtaking conditions, as well as the traffic density, which was based on AIS and GIS data. The traffic density is determined as

$$\rho_{S=} \frac{N_m}{D_c \ x \ W_c},$$
(1)

where N_m is the ship's number on the channel, D_c is the length of channel, and W_c is the width of channel. Figure 1 shows the selected area to determkine the traffic volume and probabilty of ship collision.

The probability of ship collision per passage is established as:

$$P_a \ = \ N_i \ x \ P_c$$
(2)

where *Ni* is the probability number of collisions per passage and P_c is the failures per passage or encounter. P_c can be expressed as

$$P_c \ = \ \mu_c \ x \ T$$
(3)

where μ_c is the failures per hour and *T* is the time taken per passage.
The probability number of collisions in the head-on and overtaking conditions per passage are expressed as

$$N_i = 4 \ x \ B \ x \ D \ x \ \rho_s$$
(4)

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

$$N_i = 2 \ x \ D(L + B)\rho_s$$
(5)

In Equations 4–5, *B* is the mean beam of meeting (m), *L* is the mean length of meeting (m), *D* is the sailing passage distance, and N_m is arrival frequency of meeting ships (ships/time). In this study, Equations 3–5 are used based on AIS and GIS data. The number of collisions per year can then be determined as

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

Table 2–4 shows the calculation of the probability of a ship collision in the Malacca Strait in the selected area. Tables 2–4 also show Nm, the frequency of meeting ship arrivals. In this study, Nm was determined based on AIS and GIS data, and Ni was calculated according to Equations 4 and 5.

The scenarios in this study were conducted at different times. AIS data in the Malacca Strait is taken as an ingredient to calculate probabilities. This is shown in figure 1. The scenarios taken are adjusted to AIS data, which is taken at a time that has high traffic density. This happens at 02:00, 10:00 and 22:00. Probability assessment results are classified in Table 2-4.

4.2 Analysis of Consequence
In this study, analysis of consequence for each scenario was condusted. There are five categories consisting of the level of risk that is built using a risk matrix. Table 1 shows the index of probability and the categories of consequence. Consequential analysis is classified as follows: *does not result in injuries, minor injuries, major injuries, death or total disability, and death or total disability of several people.* The consequence analysis results are plotted as a risk matrix.

4.3 Constructing risk matrices
Figures 8, 9, and 10 show the risk matrix for probability and consequence analysis. The probability assessment scenarios are carried out at different times using actual data. In this case, the scenarios taken in the following times have high traffic areas: 02:00, 10:00, and 22:00.
The scenario at 2.00 is seen in Figure 8. The risk matrix describes the level of risk that occurs at 2.00. In this risk matrix, probabilities and consequences have been determined. In accordance with the calculations based on AIS data converted to GIS, the number of vessels produced in 3 positions, namely head on, crunching and overtaking. The number of ships is obtained based on the ploting area selected shown in figure 1. the number of vessels for the head on position is 12. While the number of vessels at the head on position is 15. In the overtaking position, the number of vessels is 36. According to figure 8, calculation probability index has been obtained for head on (4), crossing (4) and overtaking (5) positions. Whereas based on the consequence analysis analyzed based on AIS data and AIS, the results obtained are; head on (C), crossing (C)

and overtaking (D). In this condition, head on and crossing are categorized as tolerable, and overtaking is included in intolerable conditions.

The risk level shown by the risk matrix is very useful for input to stakeholders, maritime actors and ship crews sailing in the Malacca Strait.

The risk matrix for the scenario at 10:00 is shown in Figure 9. AIS data has provided information on the density at 10:00. The scenario at this time was taken because at 10.00 a high density time for traffic in the Malacca Strait. In accordance with the area specified in figure 1, the number of vessels for the head on position is 25. The crossing condition has a number of 35 vessels. The highest number of vessels is in the overtaking position, which reaches 68 vessels.

Based on the AIS data, the next scenario is taken at 22.00. This can be seen in Figure 10. At this hour, the traffic density in the Malacca Strait has increased. The number of vessels at head on are 19, then when crossing reaches 26, then when overtaking reaches 48. According to the risk matrix in figure 10 are: tolerable for head on position, tolerable for crossing and intolerable for overtaking positions.

Scenarios with different times are very important to be able to produce varied risk levels. AIS data is very useful as a data source for analyzing and assessing risks in the ship navigation process. Thus, this will be a recommendation to the crew to improve ship safety.

5. SAFETY MEASURES

This step aims at proposing an effective and practical safety measure. High-risk areas are identified from the information obtained in the 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 consequences. Figure 8-10 shows a safety measure to reduce risk. This is a mitigation step so that the risk level can be lowered. This measured step in the safety measure is very useful if it is used to carry out cost benefit analysis as a step to improve mitigation. The steps taken in this safety measure are based on the results of the risk assessment conducted.

6. CONCLUSION AND FUTURE WORK

The implementation of AIS to determine the level of risk in the Malacca Strait is very useful to improve transportation safety. AIS provides data information in real time and can be used for further analysis. Based on AIS, information about traffic density is very important as an input in calculating the value of risk. This risk assessment based on AIS data is very useful for input to stakeholders and crew members who pass through the Malacca Strait. The scenario taken in this study in conducting a risk assessment is to take 3 positions according to the aggregate, namely head on, crossing and overtaking. The time scenario is taken according to the time which has a high density at 10:00, 22:00 and 2:00. Risk assessment produces a level of risk that has been plotted in the risk matrix. Probability and consequences are obtained based on AIS data and field observations. For future work, research based on AIS needs to be followed up with other topics of safety and analysis.

7. ACKNOWLEDGMENTS

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Table 1 Index of probabilty an conequence

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 people		

Table 2 Collision probability at 02:00

Node		N_m	ρ_s	N_i	μ_c	$D_c(m)$	$L(m)$	$B(m)$	T	P_c	P_a	P
1	Head-on	12	4.4321E-08	0.1313	2E-05				1	1.5E-05	1.96953E-06	0.207
2	Overtaking	15	5.5401E-08	0.16413	2E-05	24688	180	30	1	1.5E-05	2.46192E-06	0.323
3	Crossing	36	1.3296E-07	1.37867	2E-05				1	1.5E-05	2.06801E-05	6.521
	Total	63									8.37051E-06	

Table 3 Collision probability at 10:00

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

Table 4 Collision probability at 22:00

Node		N_m	ρ_s	N_i	μ_c	$D_c(m)$	L (m)	B(m)	T	P_c	P_a	P
1	Head-on	19	7.0174E-08	0.2079	2E-05				1	1.5E-05	3.11843E-06	0.519
2	Overtaking	26	9.6028E-08	0.28449	2E-05	24688	180	30	1	1.5E-05	4.26732E-06	0.972
3	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 Safety measure of ship collision

Accident	Hazard		Probability/Consequence		Risk	Safety Measure to reduce risk
	Event	Causes	Probability	Consequence		
Collision	Human error	Fatigue &lack of or knowledge &skills	Frequent	Death/disability	Intolerable	Increase knowledge & skills & promote culture of safety
	Ship Conditions	Type of ships, length, speed, state of loading	Probable	Death/disability	Tolerable	Replace old ships with new ships and conduct careful examinations of the ships conditions
	Environmental Factors	Distance between vessels is close	Probable	Major injury	Tolerable	Make navigational aids available
	Machinery factors	Failure of main engine or electronics	Probable	Major injury	Tolerable	Conduct regular maintenance
	Navigational factors	Inappropriate crew manning	Probable	Major injury	Tolerable	Increase crew manning capabilities

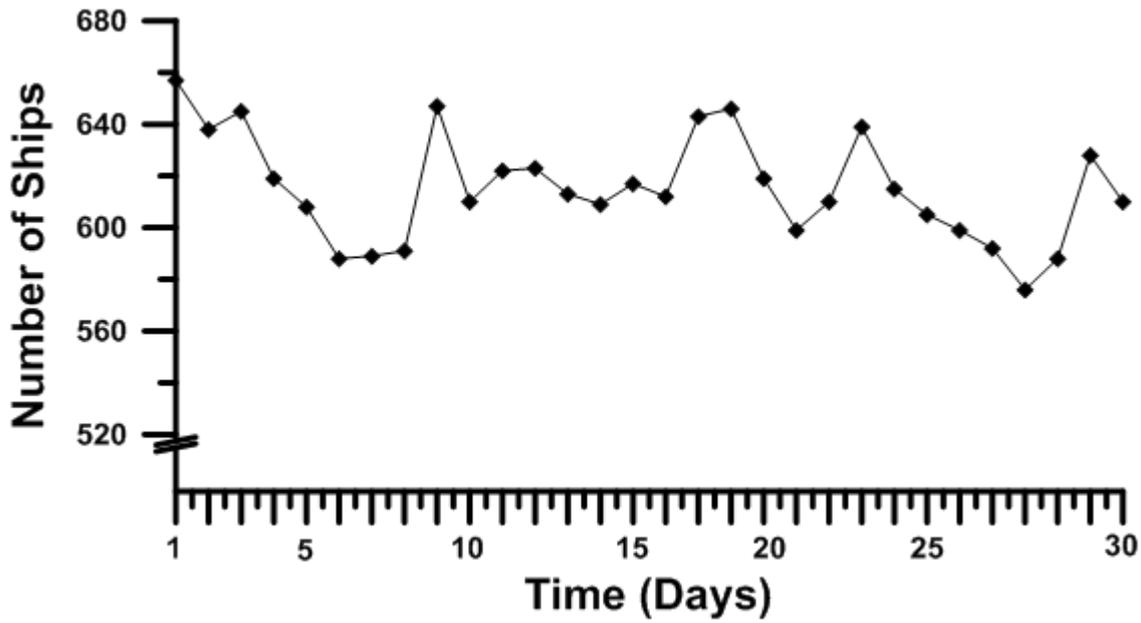Fig. 1. Ship tracking and photograph using AIS and GIS data in Strait of Malacca

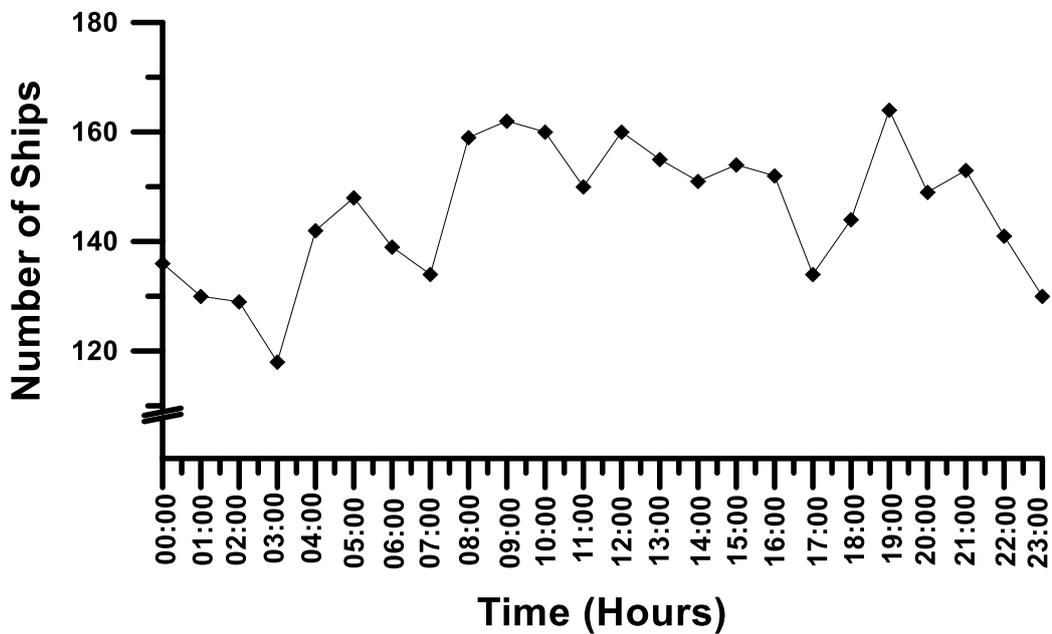Fig. 2 Ship's traffic per day in June 2010
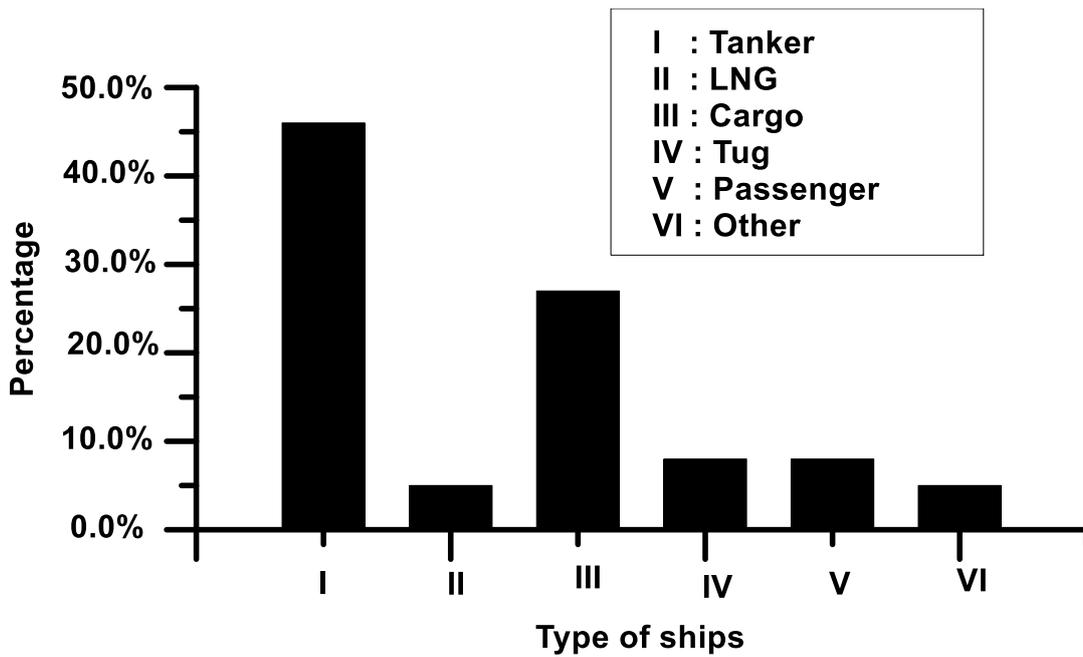

Fig. 3 Ship's traafic per hour in June 2010

Fig. 4 Type of ship in June 2010
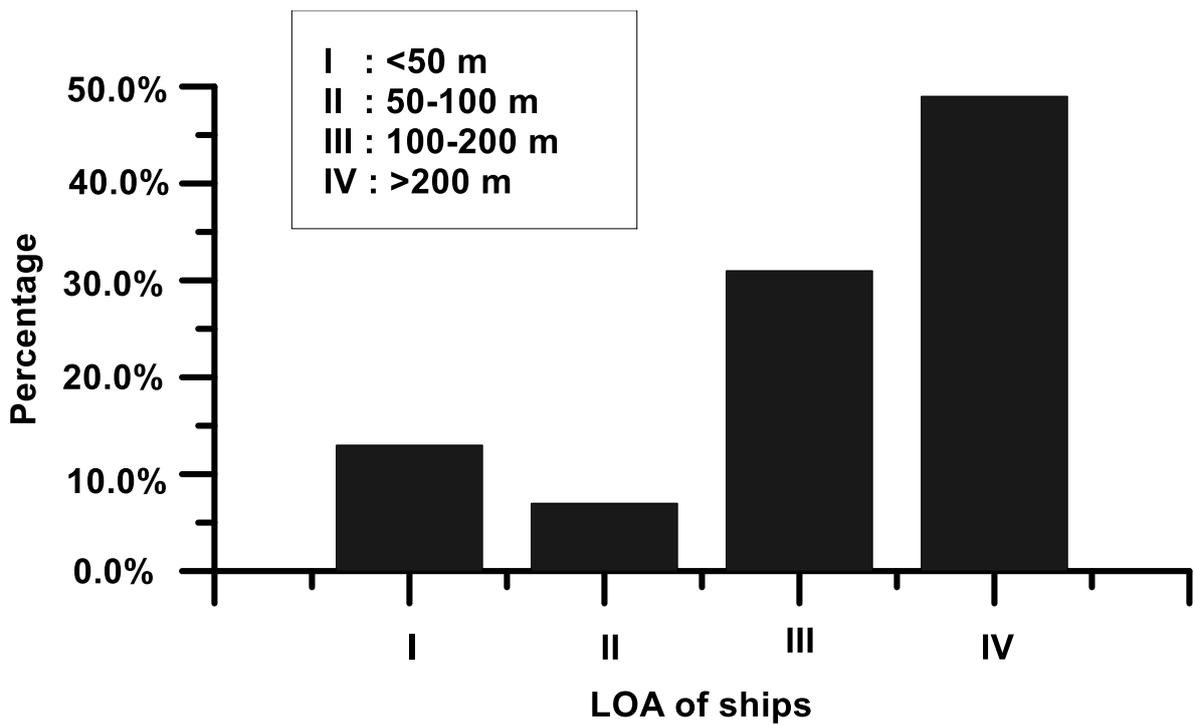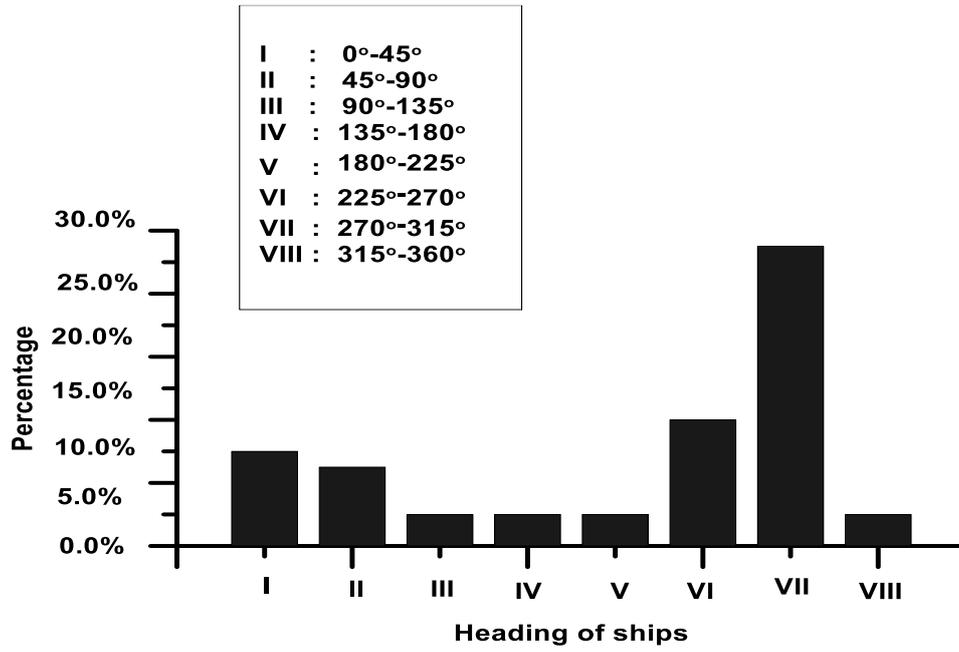

Fig. 5 LOA categorization of ships

Fig. 6 Heading categorization of ships
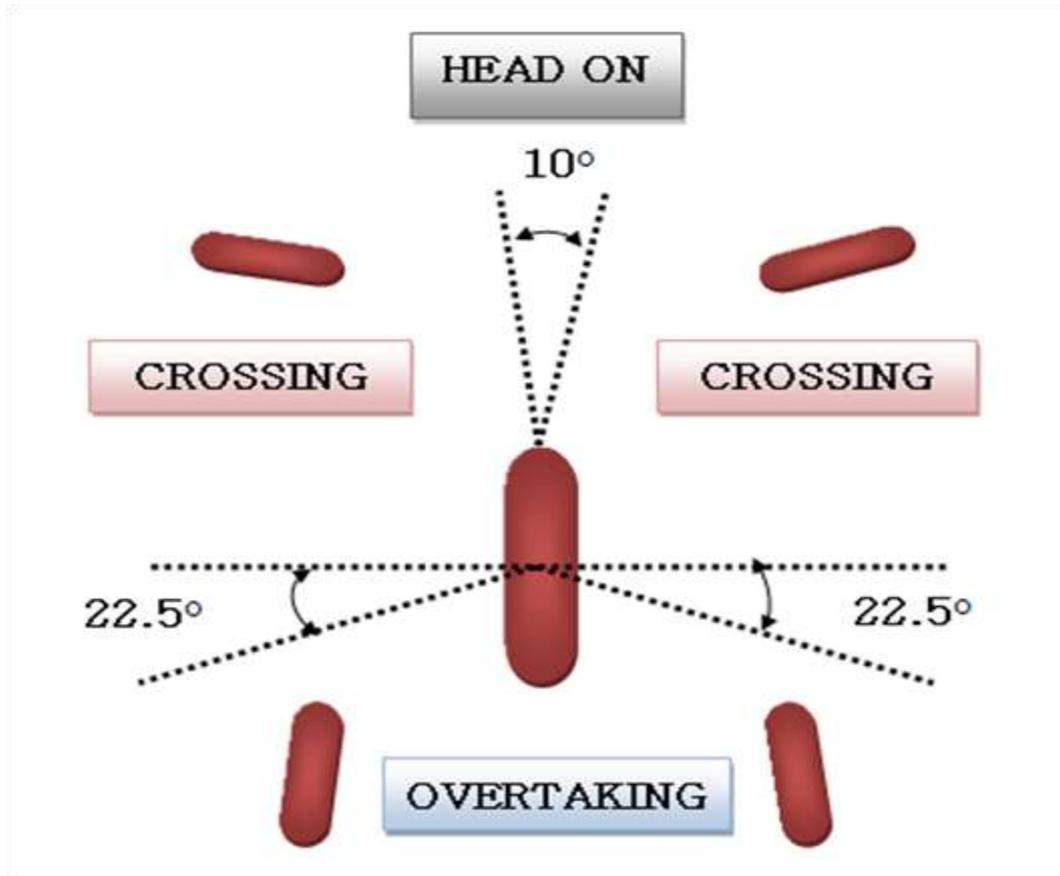
Fig. 7 Encounter types according to COLREG

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

Fig. 8 Risk matrix based on AIS data at 02:00

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

Fig. 9 Risk matrix based on AIS data at 10:00

Probability

		1	2	3	4	5
Consequence	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

Fig. 10 Risk matrix based on AIS data at 22:00