TransNav
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 9
Number 1
March 2015

DOI: 10.12716/1001.09.01.08

Formal Safety Assessment (FSA) for Analysis of Ship Collision Using AIS Data

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ABSTRACT: Currently, Maritime safety is the best issue in the world. International Maritime organization (IMO) have recommended FSA methodology to enhance maritime safety. In this paper, the research conducted in the Malacca Strait. Malacca Strait is an area that has a high risk for shipping navigation. Many accidents occur in the area are like collision, fire, grounding and so on. Therefore a study on improving safety in this area is very important. it is to produce an output that can be used to provide input to the master and multiple stakeholders to improve safety on board at the time of sailing. In this study, AIS is used as a data source. Sea condition data collected actual traffic through the Automatic Identification System (AIS) equipment installed at Kobe University, Japan, and Universiti Teknologi Malaysia (UTM) in Johor, Malaysia. The data is applied to define a method with the help of Geographic Information Systems (GIS).

1 INTRODUCTION

Navigational safety has traditionally focused on issues of security and the loss of lives and property. Moreover, concern for environmental protection and collision avoidance is increasing significantly. In the Malacca Straits, an examination of the casualty data between 1975 and 1995 shows that serious accidents have occurred in this high-density traffic area. (8)

The Malacca Straits are a high-risk area for navigation. The channel of 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 southeastern end. At approximately 500 miles (800 kilometers) long, the Malacca Straits are the longest straits in the world used for international navigation. They form the main seaway connecting the Indian Ocean with the China Sea, and provide the shortest route for tankers trading between the Middle East and Asian countries. (2)

In this study, an AIS is implemented to study ship collision probabilities under The International Regulations for Preventing Collisions at Sea 1972 (COLREG) guidelines. In this context, the AIS is used as the source of data for the hazard identification and risk evaluation steps of the FSA.

2 LITERATURE REVIEW

Several authors have explored risk assessments for ship collisions in the channel. Mou et al (2010) 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. J. Wang et al. (2010) explored the formal safety assessment (FSA) of containerships. In their study, they used fault tree analysis (FTA) for hazard identification and risk evaluation. Kobayashi et al. (2008) presented guidelines for ship evacuation during a tsunami. To do so, they analyzed AIS data from a ship that passed in Osaka Bay, Japan. Pitana et al. (2010) analyzed the evacuation of a large passenger vessel in the case of a pending tsunami using a stochastic approach, a discrete event simulation (DES). In this study, they obtained AIS data for calculating the sea traffic in the area. Zaman et al. (2013) 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. (2013) established the ship collision using FMEA FUZZY based on its AIS data. The probability calculation took into account the traffic density in the channel.

3 ANALYSIS OF AIS DATA

The study area of this research is shown in figure 1, and a breakdown of the number of ships tracked in June 2010 is shown in figures 2 and 3.

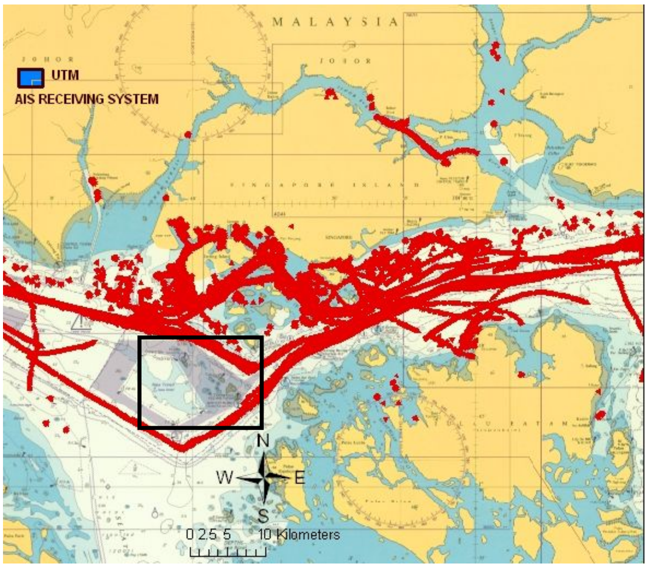

Figure 1. Study area

The most data received on a single day was on the 6/2/2010, when the number of ships transmitting information was 1372. The figure also shows that the number of ships tends to rise on 6/2/2010 before declining from 6/3/2010. The fewest ships were in the Straits on the 6/6/2010, when only 1249 ships were recorded.

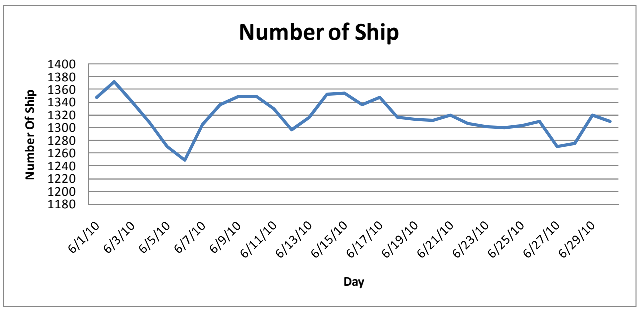

Figure 2. Number of ship per day in June 2010

Fig. 3 shows the number of ships using the Straits per hour on 6/2/2010. A sharp rise in the number of ships can be seen around 07.00h and 08.00h, when the number of ships was 1047. The period with the fewest ships occurs in the early hours of the morning, until around 04.00h.

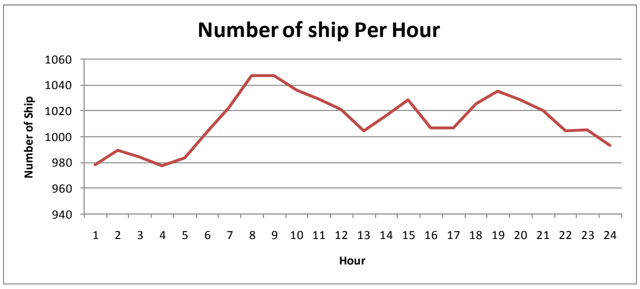

Figure 3. Number of ship per hour on 2 June 2010

Table 1 shows the population of ships passing through the Malacca Straits on 6/02/2010. The types of ship can be broken down as: tanker ships 37%, cargo ships 26%, tugs 9%, passenger ships 3%, towing and fishing ships 1%, other ships 10%, and unknown vessels 14%.

Table 1. Ship population by type in June 2010

Type of Ship	Percentage of Ship`s Number
Tanker	37%
Cargo	26%
Other Ship	10%
Tugs	9%
Passenger	3%
Towing	1%
Unknown	14%

4 FORMAL SAFETY ASSESSMENT

According to the IMO, the 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 formal and integrated approach to assessment. The purpose of applying this method is to use the five-step procedure of the FSA to make an overall analysis and enhance maritime safety. [3]

The five-step procedures of FSA are: hazard identification, risk assessment, establishes safety measure, cost-benefit assessment and recommendation for decision making. The FSA is a tool designed to assist maritime regulators in the process of improving and deriving new rules and regulations.

4.1 *Hazard Identification*

Hazard identification for ships in the Malacca Straits is an essential part of the risk assessment process. Hence, a list of hazards that have befallen ships in this region is important in order to identify relevant risks.

FMEA-Fuzzy Hazard Identification of Ship Collisions

The traditional Failure Mode and Effect Analysis (FMEA) determines the risk priorities of failure modes through the risk priority number (RPN), which is the product of the probability (P), severity (S), and detection (D) of failure. That is,

$$RPN = P \times S \times D \quad (1)$$

In the proposed method, the fuzzification process uses a singleton method to map a crisp point into a fuzzy set, and the fuzzy set rule base comprises a collection of fuzzy if-then rules. The fuzzy inference engine performs a mapping from fuzzy sets, based on these fuzzy if-then rules and the compositional rules of inference. In the defuzzifier, the Weighted Mean of Maximum (WMoM) is used for calculating a crisp output from the system. The input linguistic variables are created based on FMEA. These are the P, S, and D of Equation (1). The output of this fuzzy decision is the priority number

To create a FMEA model using a fuzzy method, ten scenarios were established based on AIS and other data. Such hypothetical scenarios will be explored. Those scenarios created as scope domain in the fuzzy logic method. The value of the membership function ranges from 0 to 1. Defuzzified values for each of the scenarios were thus obtained, and the results are shown in Table 2.

Table 2. Defuzzified values of ten collision scenarios

Scenarios	Value
Over Traffic Density	5.23
Distance between vessels are very closed	3.56
Problem in Head Situation and Human Error	2.87
Problem in Overtaking Situation and Human Error	6.56
Problem in Crossing Situation and Human Error	4.68
Error of Navigation	5.80
Failure of Machinery and Electricity	6.13
Bad Weather	5.90
Characteristic area is not good	5.75
Human Factors	1.16

4.2 *Risk Assessment*

The second step of the FSA is the risk assessment. The risk analysis is composed of two main activities: *probability modeling and consequence modeling*.

4.2.1 *Probability Analysis*

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:

$$\rho_s = \frac{N_m}{D_c W_c} \quad (2)$$

where N_m is the number of ships using the channel, D_c is the channel length, and W_c is the channel width. Fig. 1 shows the area selected to calculate the traffic density and ship collision probability, based on AIS and GIS data.

Fig. 1 Area selected for ship collision probability calculation, based on AIS and GIS data

The ship collision probability per passage can be expressed as:

$$Pa = N_i \times Pc \quad (3)$$

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

$$Pc = \mu_c \times T \quad (4)$$

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:

$$N_i = 4 \, x \, B \, x \, D \, x \, \rho_s \quad (5)$$

and according to the reference, [7] the number of collisions in the crossing condition per passage is:

$$N_i = \frac{N_m}{D_c}\left(\frac{4}{\pi}L + 2B\right) \quad (6)$$

In Equations (5)–(6), B is the mean beam of meeting (m), L is the mean length of meeting (m), and D_s is the sailing passage distance, and N_m is arrival frequency of meeting ships (ship/time). In this paper, equation 5-6 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:

$$Na = Pa \times (365 \times 24 / T) \quad (7)$$

Tables 3–8 show estimations of ship collision probabilities in the selected area of the Malacca Straits. In the table 3-8 also show that N_m is arrival frequency of meeting ships. In this case, N_m is determined based on AIS and GIS, and N_i is determined according to equation 5 and 6.

Table 3. Collision probability based on AIS data at 02.00h

Node		Nm	Ni	μ_c	Dc(m)	L(m)	B(m)	T	Pc	Pan	Pa	Class
1	Ship Head on	12	0.0115287	0.000015				1	0.000015	1.729E-07		
2	Ship Overtaking	15	0.0144108	0.000015	24688	264	32	1	0.000015	2.162E-07	**0.0159154**	**Occasional**
3	Ship Crossing	36	0.0951823	0.000015				1	0.000015	1.428E-06		
	Total Number of Ship	**63**								**1.817E-06**		

Table 4. Collision probability based on AIS data at 06.00h

Node		Nm	Ni	μ_c	Dc(m)	L(m)	B(m)	T	Pc	Pan	Pa	Class
1	Ship Head on	23	0.0230655	0.000015				1	0.000015	3.46E-07		
2	Ship Overtaking	35	0.0350996	0.000015	24688	167	31	1	0.000015	5.265E-07	**0.029533**	**Occasional**
3	Ship Crossing	65	0.1665912	0.000015				1	0.000015	2.499E-06		
	Total Number of Ship	**123**								**3.371E-06**		

Table 5. Collision probability based on AIS data at 10.00h

Node		Nm	Ni	μ_c	Dc(m)	L(m)	B(m)	T	Pc	Pan	Pa	Class
1	Ship Head on	25	0.0465466	0.000015				1	0.000015	6.982E-07		
2	Ship Overtaking	35	0.0651652	0.000015	24688	315	50	1	0.000015	9.775E-07	**0.0513325**	**Probable**
3	Ship Crossing	68	0.2789462	0.000015				1	0.000015	4.184E-06		
	Total Number of Ship	**128**								**5.86E-06**		

Table 6. Collision probability based on AIS data at 14.00h

Node		Nm	Ni	μ_c	Dc(m)	L(m)	B(m)	T	Pc	Pan	Pa	Class
1	Ship Head on	14	0.0039360	0.000015				1	0.000015	5.904E-08		
2	Ship Overtaking	23	0.0064663	0.000015	24688	44	8	1	0.000015	9.699E-08	**0.0047686**	**Remote**
3	Ship Crossing	37	0.0258884	0.000015				1	0.000015	3.883E-07		
	Total Number of Ship	**74**								**5.444E-07**		

Table 7. Collision probability based on AIS data at 18.00h

Node		Nm	Ni	μ_c	Dc(m)	L(m)	B(m)	T	Pc	Pan	Pa	Class
1	Ship Head on	16	0.0171589	0.000015				1	0.000015	2.574E-07		
2	Ship Overtaking	35	0.0375352	0.000015	24688	232	32	1	0.000015	5.630E-07	**0.029074**	**Occasional**
3	Ship Crossing	63	0.166569	0.000015				1	0.000015	2.499E-06		
	Total Number of Ship	**114**								**3.319E-06**		

Table 8. Collision probability based on AIS data at 23.00h

Node		Nm	Ni	μ_c	Dc(m)	L(m)	B(m)	T	Pc	Pan	Pa	Class
1	Ship Head on	19	0.0199517	0.000015				1	0.000015	2.993E-07		
2	Ship Overtaking	26	0.0273024	0.000015	24688	190	32	1	0.000015	4.095E-07	**0.0228851**	**Occasional**
3	Ship Crossing	48	0.1269097	0.000015				1	0.000015	1.904E-06		
	Total Number of Ship	**93**								**2.612E-06**		

4.2.2 *Consequence assessment*

The consequence analysis for each scenario was carried out. Five categories comprise the built risk level by using a risk matrix. Table 7 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. The results of the consequence analysis are plotted as a risk matrix.

Table 7. 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 people

4.2.3 *Risk Matrix*

Figures 4, 5, and 6 show the risk matrices for probability and consequence analyses in the Malacca Strait based on AIS and GIS data. Based on AIS data, the scenario of probability assessment was carried out with 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. Figure 4 shows the risk matrix at 02:00, based on AIS data. In this case, the risk matrix is established based on the results of the probability and consequence assessments. In this condition, the number of ships in head-on encounters is 12, in crossing encounters is 15, and in overtaking encounters is 36.

The numbers of ships is determined based on AIS data in the selected area in the Malacca Strait. Based on the probability index, the head-on, crossing, and overtaking encounters are classified, respectively, at points 4, 4, and 5. Based on the consequence analysis, the head-on, crossing, and overtaking encounters are classified, respectively, at points C, C, and D. The tolerable conditions are for the head-on and crossing encounters. An intolerable condition is the overtaking encounter.

Figure 5 shows the risk matrix at the 10:00 scenario based on AIS for which the risk level was established in the head-on, crossing, and overtaking conditions. Based on AIS data, the number of ships in head-on conditions is 25, crossing conditions is 35, and overtaking conditions is 68. Based on the probability index, the head-on, crossing, and overtaking conditions are classified, respectively, at points 4, 5, and 5. In addition, based on consequence analysis, head on, crossing and overtaking are classified, respectively, at point C, D, and D. In this case, risk level conditions are the following: a tolerable level for head-on, an intolerable level for crossing, and an intolerable level for overtaking.

Figure 6 shows the risk matrix at 22:00 based on AIS data. The risk level was established in the head-on, crossing, and overtaking conditions. In these conditions, the number of ships in head-on is 19, in crossing is 26, and in overtaking is 48. The risk level conditions are the following: a tolerable level for head-on, a tolerable level for crossing, and an intolerable level for overtaking. The results of navigation safety based on risk assessments using AIS data for different times are important for navigators to observe if in transit in this area. These results are also useful to ensure safety measures and risk mitigation for enhancing safety in the Malacca Strait.

N = Negligible; T = Tolerable; I = Intolerable

	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

Figure 4. Risk matrix based on AIS data at 02:00

	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

Figure 5. Risk matrix based on AIS data at 10:00

	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

Figure 6. Risk matrix based on AIS data at 22:00

4.3 *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. Structural review techniques may be used to identify all possible risk control measures for cost-effective decision-making. The safety measures are generated from the results of the risk assessment, which is established based on AIS data.. Table 9 shows the safety measures adopted to reduce risk during ship collision.

4.4 *Cost Benefit Analysis*

The technique of cost-benefit assessment consist on the following three steps:
1 Estimation of the benefit
2 Estimation of the cost
3 Combination of benefit and cost

After complementing the cost-benefit assessment, the results with the highest overall scores are selected

4.5 *Recommendation*

Based on analysis of FSA from step 1-4, then there are some recommendation as follows:
1 Improved safety at sea transportation is very important. It is necessary caution when navigating a ship at sea.
2 All crew of ships should improve the ability and experience to the training.
3 For avoid human error at the time of sailing on a ship, it would require good coordination and communication between the crew when the ship
4 Maintenance great vessels necessary for the condition of machinery, electrical and navigation systems operate properly.

Table 9 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

5 CONCLUSIONS

This paper presented an implementation of the AIS for a study on FSA. In this context, the AIS was 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 37%, cargo ships 26%, other ships 10%, tugs 9%, passenger ships 3%, towing and fishing ships 1%, and unknown vessels 14%.

In this paper, the identification of hazards analysis has established. The ranking of hazard analysis are problem in head situation (6.56), Error of navigation (6.13), failure of machinery and electricity (5.9), problem in crossing situation (5.8), bad weather (5.75), over traffic density (5.23), problem in overtaking situation (4.68), Distance between vessels are very close (3.56), Speed of own ship and target ship (2.87) and characteristic area is not good (1.16).

The risk analysis comprised two main activities: probability modeling and consequence modeling. In this paper, probabilities were established based on AIS data and hazard analysis.

A number of situational and traffic density factors were analyzed in order to calculate ship collision probabilities based on AIS and GIS data. In this case, based on hazard analysis, the head on condition, overtaking condition and crossing condition taken to make analysis of ship collision probability in the Malacca Straits. The result of ship collision probability calculation taken based on AIS data and GIS at 02.00h, 10.00h and 22.00h.

ACKNOWLEDGMENT

The authors wish to thank members of the maritime safety system laboratory at Kobe University for their assistance and continuous support of analysis and evaluation of the AIS and other data.

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