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Development of Risk Based Collision (RBC) Model for Tanker Ship Using AIS data in the Malacca Straits

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Abstract

Analysis of ship collision is very important to establish in the field of maritime transport, especially in areas that have a high degree of risk. Strait of Malacca is international shipping that has a high degree of risk. In these areas, tankers have a high degree of probability of an accident. Based on AIS (Automatic Identification System), Tanker has seen the highest density of traffic volume density, reaching approximately 50% every day. In this paper, a risk analysis performed using the actual data from AIS. In this case, the value of the CPA (Closest Point Approach) and TCPA (Time to Closest Point Approach) obtained from AIS is used to generate the value of risk. After we know the value of a risk, it must be measures to avoid accidents ship on sea transportation. AIS data in this study were drawn from the AIS receiver that has been installed in Malaysia UTM.

Keywords: Ship Collision, Tanker, AIS, Malacca Strait.

1. Introduction

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 Malacca Straits is a high-risk area for navigation. For centuries, concerns over safety in navigation have focused on issues of security, and the loss of lives and property. Currently of growing significance, is concern over environment protection. In the Malacca Straits, an examination of the casualty data between 1975 and 1995 shows that serious accidents have occurred in high-density traffic areas\textsuperscript{1}.

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The Strait of Malacca is the longest strait in the world and risk area for navigation. It has long been an important trade route linking the Indian Ocean to the South China Sea and the Pacific Ocean. The Malacca Strait is located between the east coast of Indonesia’s Sumatra Island and the west coast of Peninsular Malaysia, and links with the Strait of Singapore at its southeast end. The Malacca Strait extends from its northwest extremity at Ujung Baka, Sumatra (5°40’N, 95°26’E) by a line to its south extremity at Laem Phra Chao, Koh Phukit Island, Thailand (7°45’N, 98°18’E). The strait extends across its southeastern portion by a line between Tahan (Mount) Datok (1°20’E, 104°20’N) and Tanjung Pergam (1°10’E, 104°20’N). 

Therefore, current safety measures require improvement and the subsequent support with relevant complementary services to face the challenges of increased maritime traffic. Many reported collision accidents are due to human error in the ship of navigation.

To reduce accidents associated with human error actions, and enhance safety of navigation in the marine traffic area, it is necessary to increase understanding of human factors aspects of navigational operation. In our previously research, we have investigated the several factors which have contribute to the accident in the Malacca Straits using Analytic Hierarchy Process (AHP) method. There are five factors that cause accidents in ship navigation sector in the Malacca Strait: Ship condition, Human factors, environmental factors, machinery and electricity factors and navigational factors. In this case, human factors are leading for the accident contribution. The danger score assessment also carried out in this study.

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 (International Maritime Organization). The m-SHEL (Software-Hardware-Environment-Liveware with their management) model was adopted as a conceptual base of generic human factors, and extended to accommodate ship navigation domain. Collision avoidance based on human factors analysis using m-SHEL model and AIS data are very important.

Result of m-SHEL model analysis and actual data analysis from AIS are useful to make decision making for collision avoidance. According to navigation practices, especially pertaining to collision avoidance, our model defines a detailed category for each of m-SHEL interfaces. The analysis of m-SHEL model is established based on AIS data and the International Regulations for Preventing Collisions at Sea 1972(COLREG).

2. Analysis of Automatic Identification System (AIS)

The actual sea traffic conditions of the Malacca Straits were recorded by an AIS data receiving system installed in the UniversitiTeknologi Malaysia (UTM). 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 AIS is 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, 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. The AIS system is designed to recognize and monitor ship weight greater than 300 gross tons (GT) that are engaged in international travel, and ships of 500 GT or more that are travelling domestic routes.

Both static and dynamic ship data can be displayed. Dynamic information on each vessel is updated every 2-10 s depending on the speed of the vessel. The static information consists of the vessel’s maritime mobile service identify (MMSI), the name of the vessel, its call-sign, length, maximum ship draft, IMO number, ship beam, ship type, and antenna position. The dynamic information recorded includes longitude, latitude, current time, course, rate of turn, overground speed, various navigation information, current ship draft, destination, and type of cargo.

The study area of this research is shown in Fig.1. Figures 2 and 3 show the analysis results of the number of ships traveling the area per day and hour, respectively, in June 2010. Figure 2 shows that the highest number of ships, 657, passing through the Malacca Strait was on 6/1/2010. The lowest number of ships passing through the Malacca Strait was on 6/27/2010, when the number of ships was 575.

Figure 2 also shows that the number of ships tends to rise on 6/1/2010 before declining from 6/5/2010. 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. Figure 6 shows the LOA of ships passing through the selected area in the Malacca Strait. The percentages are as follows: 49%, LOA > 200 m; 31%, LOA = 100–200 m; 7%, LOA = 50–100 m; and 13%, LOA < 50 m. The heading and the speed of ships are also analyzed based on the AIS data, as shown in Fig. 6. The maximum percentages of the heading are in the range 245°–270°. The investigation of the ship’s movement based on AIS data is important and useful for the analysis of navigation safety. In this study, data on the numbers of ships, LOA, speed, type of ship, and heading of ship are used to establish the navigation safety assessment. AIS data in the Malacca Strait determined the safety analysis using different times and conditions. This study conducts the safety measures and risk mitigation, which is explored in the next section.

Fig. 1. Study area and tracking of ship based on AIS

Fig. 2 Number of ship per day in June 2010
Fig. 3 Number of ships per hour in June 2010

Fig. 4 Ship population types in June 2010

Fig. 5 LOA categorization of ships
3. Analysis of Human Error

Concept of SHEL model was developed by Hawkins. m-SHEL model is a variation of the SHEL model. It is now formally introduced as a human factor framework by IMO (International Maritime Organization). The SHEL model is a conceptual model that attempts to indicate the interactions between the various components of system and the operator. It comprises four components: Software (rules, manuals, and regulations) – S, Hardware (equipment) – H, Environment (physical factors) – E, and Liveware – L. The m-SHEL model added "m- (management)" to the SHEL model. Software represents any components such as polices, rules, computational codes and practices that define the way in which the different components of the system interact with each other and with the external environment. Hardware represents any physical and non-human component of the system, such as equipment, vehicles, tools, manuals and signs. Environment represents the socio-political and economic environment in which the different component interaction. Liveware represents the operational personnel themselves in the center. Role and communicational aspects are mainly focused. Management represents the control of whole system. Figure 7 shows the m SHEL model (physical factors) – E, and Liveware – L.

To make analysis using m SHEL model for collision avoidance in the Malacca Straits, case study of collision of ship is taken. In this case, collision has occurred in the Singapore Straits area between Bunga Kelana 3 (Tanker Ship) and MV Wally (Cargo Ship) on Mei, 25, 2010. The cause of this collision is human error. This fact is appropriate with the previously research using AHP method that human error is leading for the contribution of accident in the Malacca Straits.
Straits. The analysis is of human error is very important to enhance the safety of navigation. The definition of SHEL model for the application based on AIS data is shown in Table 1. Results of analysis are used for collision avoidance. Analysis using m SHEL model is shown in Table 2

**Table 1. m SHEL model application based on AIS data.**

<table>
<thead>
<tr>
<th>SHEL model application</th>
<th>Explanation for application</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>Management = control of whole system. In this case, management represents interaction between regulation (IMO and COLREG), navigators and crew members in the ships, and stakeholders in the marine traffic of Malacca Straits. Software = rules, manuals, and regulations. In this paper, COLREG is rule which have used in the marine traffic. Value of CPA and TCPA for collision avoidance should be according to the COLREG. In this case, value of CPA and TCPA in the Malacca Straits are established based on AIS data.</td>
</tr>
<tr>
<td>S</td>
<td>Hardware = any physical and non-human component of the system, such as equipment, vehicles, tools, manuals and signs. In this case, AIS, radar and any equipment are analyzed. Environment = In this case, environment represents the condition of marine traffic in the Malacca Straits, such as traffic density, distance between own ship and target ship, speed of ships, type of ships, wind effect, condition of current, characteristic area in the Malacca Straits. The environment conditions are analyzed based on AIS data and other data.</td>
</tr>
<tr>
<td>H</td>
<td>Liveware = In this study, liveware represents the navigators and crew members of ships that passing through the Malacca Straits.</td>
</tr>
</tbody>
</table>

As show in Table 1, the AIS data is used for analysis of S condition and E condition. In the S condition analysis, calculation of CPA and TCPA are established based on AIS data and GIS (Geographic Information System). The Environmental conditions are also determined and analyzed based on AIS data and GIS. The analysis of software condition and environmental are conducted in the selected area and according to traffic condition based on AIS data.

Based on Table 1, m shell analysis using the model could be done. in this paper, which is analyzed tanker collision that has occurred in the year 2010. Based on the data AIS, tankers ranks first in terms of traffic density as figure 2. The helmsman must be careful in driving a tanker. not only that, the entire crew of the ship will also need to be careful in carrying out their duties.

For the application of analytical models using m shell models can be seen in Table 2. Table 2 carried on a detailed analysis of each item. analysis was also conducted field surveys and observations based on AIS data. m shell analysis done to reduce the risks caused by human error. human error is always the first rank who contributed ship accidents. In Indonesia, human error to 88%.

**Table 2. analysis of collision using m SHEL model**

<table>
<thead>
<tr>
<th>SHEL model application</th>
<th>Explanation for application</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-H</td>
<td>Communication systems such as AIS, Radar, and Radio are not good in operation.</td>
</tr>
<tr>
<td>L-S</td>
<td>The ship’s operating procedure did not specify that navigators should be careful in the high risk area. CPA and TCPA are zero and navigators are did not avoid.</td>
</tr>
<tr>
<td>L-E</td>
<td>The Singapore Straits is high traffic density area and high risk area.</td>
</tr>
<tr>
<td>L-L</td>
<td>Communications between navigators are not proper.</td>
</tr>
<tr>
<td>L-M</td>
<td>Navigators should be more careful when transiting in the Malacca Straits. The communication system such as AIS, Radar, and other system should be operated properly.</td>
</tr>
</tbody>
</table>

4. **Risk Based Collision Model**

Based on AIS data in the Malacca Straits, risk collision assessment is established. In this case, Samson model is used. The development of SAMSON started in 1975, and since then the model has been continuously improved along with the development of the risk concept, such us including formal safety assessment (FSA), which was formally adopted by IMO in 2011¹.
To calculate the risk, the calculation used is as follows;

\[ N_{acc} = N_{exp} P_{acc} \]

where \( N_{exp} \) is the number of exposures to risk, representing the number of potentially dangerous situations that occurs during the selected period of time in the zone in question and \( P_{acc} \) the accident probability, involving the concept of conditional probability that defines and describes the casualty rate for the type of accident. The rate is determined according to casualty data bases by statistical methods. Additionally, the model interprets the influence of external factors on the accidents, e.g. storm, bad visibility, and management measures (Mou et al., 2010).

It is well known that risk is a concept consisting of the probability and consequences of casualties. The consequences of a casualty vary greatly. In SAMSON, the methodology focuses on practical operations and proves to be simple and efficient in Maritime Operation Services (MOSs). Ship type and size play important roles in the consequence evaluation. Ship type and size are with respect to the number of persons at risk and scale of an oil spill. Meanwhile, the draught of the ship is an indication of the amount of cargo onboard and the above-mentioned ship data can be easily read from AIS. Finally, the cost is measured in monetary unit. The model for calculating the dynamic risk is;

\[ R_{collision} = R_{basic} F_{cpa} F_{tcpa} F_{angle} \]

where \( R_{collision} \) and \( R_{basic} \) stand for the dynamic and basic risk of collision, respectively, \( F_{angle} \) accounts for the different degrees of danger as a function of the type of encounter, and \( F_{tcpa}, F_{cpa} \) are the relative multipliers of TCPA and CPA (Mou et al., 2010).

Based on AIS data and historical data of the casualty in the Malacca Straits and by convert from AIS to GIS, crossing encounter is more danger than head-on or overtaking encounters. The overtaking encounters demonstrate the lowest risk of collision. Based on AIS and historical data relating the number of collisions with the number of encounters, encounters are divided into three groups and correspondingly the value of each factor is defined below:

- Overtaking (course difference 0-60°) = 1
- Crossing (course different 60-150°) = 5
- Head-on (course different 150-180°) = 4

<table>
<thead>
<tr>
<th>No</th>
<th>CPA (nm)</th>
<th>TCPA (min)</th>
<th>Basic risk</th>
<th>Dynamic risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3</td>
<td>0.1</td>
<td>3.9E-08</td>
<td>4.3E-09</td>
</tr>
<tr>
<td>2</td>
<td>0.6</td>
<td>0.2</td>
<td>3.6E-08</td>
<td>7.6E-09</td>
</tr>
<tr>
<td>3</td>
<td>-0.5</td>
<td>0.2</td>
<td>1.8E-07</td>
<td>4.5E-08</td>
</tr>
<tr>
<td>4</td>
<td>0.3</td>
<td>0.6</td>
<td>1.9E-07</td>
<td>4.7E-08</td>
</tr>
<tr>
<td>5</td>
<td>-0.1</td>
<td>0.1</td>
<td>3.2E-08</td>
<td>2.8E-08</td>
</tr>
</tbody>
</table>

Based on Table 3, the value of CPA, TCPA, basic risk and dynamic risk for the ship in the Malacca Straits on June 1, 2010 at 19.00h for 5 scenarios, which consists of five basic risk and five dynamic risk. Based on the table 3, there are positive and negative values. Positive value means the target ship is on the left side, while a negative value means the target ship is at the right position. By knowing the risk value based CPA and TCPA, is expected to improve safety. In this context, the results of this research can be used as input to the crew of vessels passing through the Malacca Strait area to be careful when navigate the ship.

Based on m-shel model analysis and calculation of CPA, TCPA and risk assessment, decision making is step which is very important to enhance navigational safety. AIS is a very powerful tool for identifying ships and communication between ships and ship and between ships with VTS (vessel traffic system). Vessel traffic management could work very well with the AIS. CPA and TCPA calculations and risk assessments calculation based on CPA and TCPA is very important. CPA and TCPA values must be maintained and monitored. This way could enhance safety of the ship. If the value of CPA is zero, the ship’s accident could not be avoided. In this context, the role of the human factor is very important for navigation and communication between the ship. If there are human, errors, the ship accidents could not be avoided.
5. Conclusions

The Malacca Straits as high density and busy area have relative high probability of collision. Human factors are high contributed of collision. The Risk based Collision was established. By using m-shel model, analysis of human factors and related accident contribution were conducted. This study was presents the establishment of collision avoidance based on m SHEL model and AIS data.

Based on m SHEL model, analysis model of human factor is conducted. Result of analysis of m SHEL model is used to establish collision avoidance. In this case, AIS data is used to analyze S condition, hardware condition and environmental condition in m-SHEL model. CPA and TCPA are determined as S condition. By using value of CPA and TCPA, the decision making for collision avoidance could be conducted.

This paper also shows how the AIS data can be used in the studies of ship collision in the Malacca Straits by combining the result of human factors analysis using m-Shel model. In the analysis of collision avoidance, risk assessment based on SAMSON model is established. Decision making could be conducted to enhance the safety of navigation in the Malacca Straits. Decision making is established based on human factors analysis using m-shel model, value of CPA, TCPA and risk assessment using AIS data.

References