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Risk Assessment of Marine Accident in Tanjung Pelepas Port Limit Due To Reclamation of Tanjung Piai Maritime Industrial Park

Ab Saman Abd Kader and Muzlifah Mansor

Faculty of Mechanical Engineering,
Universiti Teknologi Malaysia,
81310 UTM Johor Bahru, Johor Bahru,
Malaysia

*Corresponding email: muzlifah2@fkm.utm.my

ABSTRACT

This study is centered on the problem related to the reclamation work for the building of Tanjung Piai Maritime Industrial Park in the Tanjung Pelepas port limit. The main aim is to identify the potential risk and probability of marine accident during the reclamation phases. The existing condition of the waterway will be used as the baseline to compare with future condition. For the purpose of analysis, the Formal Safety Assessment (FSA) method and Fault Tree Analysis (FTA) technique are deployed, coupled with the AIS data and marine accidents report provided by Johor Port Authority and Malaysian Marine Department. The result of the analysis indicates that navigational risk is originated from human error and navigational safety would improve significantly if the vessels follow the mitigation measures recommended in this study.

Keywords: *Risk Assessment; Marine Accidents; Formal Safety Assessment; Fault Tree Analysis*

1.0 INTRODUCTION

Located at the tip of Southwest Johor, the reclamation work for the man-made island of the Petroleum Hub and Maritime Industrial Park is currently ongoing. The reclamation work will cover a total area of 3,487 acres, will be reclaimed in three phases and is expected to take fifteen years to complete. After obtaining a full environmental impact assessment (EIA) approval in June 2016, the first phase of the project is expected to be operational by early 2020 [1].

As shown in Figure 1, with its position at the end of the Straits of Malacca, the reclamation area is just over one kilometer south of the Tanjung Bin Power Plant, and the navigation channel for the Port of Tanjung Pelepas (PTP) runs parallel to the eastern boundary of the project site.The Port of Tanjung Pelepas is among the busiest shipping container ports in the world. The same waterway is also used by influxes of ships entering and leaving Tanjung Bin Power Plant. In addition to that, there are other marine industries around Sungai Pulai, for instance the Asia Terminal Hub (ATB). Therefore, there is a strong likelihood that the waterway will be congested with marine traffic during the reclamation process.

The purpose of this study is to identify the potential marine accident that might occur due to the existence the reclamation area and will address the type of accident and consequences and propose mitigation measure in order to reduce such potential accident. The risk assessment was carried out using Formal Safety Assessment (FSA) incorporates with Fault Tree Analysis (FTA). The authority, such as the Marine Department of Malaysia and Johor Port Authority can benefit from the outcome from this study by adopting effective measures to enhance safety in navigation due to the existence of the reclamation area.

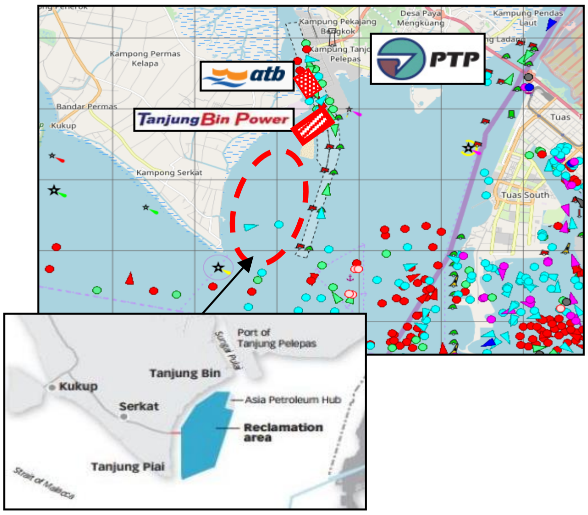

Figure 1 Reclamation Area (Benalec, 2017)

2.0 Literature Review

A number of studies have been conducted to assess risk and ship accidents in narrow waterway. The moment a ship is caught up in a marine accident there will be series of potential disasters with distinct consequences [2].

2.1 Method

Many methods have been used in previous studies for risk assessment such as Fault Tree Analysis (FTA), Bayesian Networks (BN), Formal Safety Assessment (FSA), Event Tree Analysis (ETA) and Quantitative Risk Assessment (QRA). Three methods are selected and discussed due to the frequency of use in marine accident analysis in recent years. Based on the literature search using an academic bibliographic database in field of safety and engineering (Science Direct, December 2017), BN, FTA and FSA have been frequently used for risk assessment during the period of 2013-2017 (key words “Bayesian network” , “Fault Tree Analysis”, “Formal Safety Assessment” and “risk assessment” resulted in 3,129 scientific papers).

The FSA method has been promoted by the International Maritime Organization (IMO) as a frame work for risk assessment and management. Various maritime risk assessments have been conducted using the FSA guideline [3]; [4]. FSA method deploys the technique of risk and cost-benefits assessment to assist in making decision, and is considered a proven approach to marine safety [4]. In Zhang et al. [4] the method was applied to estimate the navigation risk of Yangtze River. In fact, the International Maritime Organization (IMO) has recommended the method as an integrated safety system to all maritime sectors [3]. However, Goerlandt [5] claimed that there is a possibility of imprecise risk measurement due to subjective judgments and uncertainty of risk while performing FSA.

The FTA is the graphical illustration of the logic combination of causes associated with an undesirable event or situation [6].In Ugurlu et al. [7] the study focused on collision occurring in oil tanker and used FTA programed to carry out risk assessment. They used FTA method to analyze the reasons of an undesirable event and it consists of two stages which are qualitative and quantitative. The collision data in the study was obtained from Global Integrated Ship Information System (GISIS), and the data was used to classify accidents and to put recommendation to prevent reiteration of such accident. In line with Ugurlu et al. [7], in Ugurlu [6] the study used FTA method to determine significant level of the root causes of F&E accident in oil tanker and also used Fuzzy extended AHP (FAHP) to describe the correlation between the root causes of accident and their causative factors. The author investigated maritime accident report on fire and explosion (F&E) which occurred in oil tanker and accident data was also taken from GISIS accident report. Another application of FTA in ship collision assessment was made by Kum and Sahin [8]. To prevent future incidents from happening and to clarify the causes the study proposed Root Cause Analysis (RCA). In order to propose a recommendation to reduce the occurrence probabilities, the FTA was applied. FTA can also be used in a qualitative manner in accident analysis to help identify underlying causes of accident and identify what can be done to prevent similar accident in the future [6].FTA is a complicated process and it requires a considerable amount of time to complete [8].

The BN model has been a popular method for risk assessment especially for the modelling of rare accident [9]. Similar to FTA, BN modelling consists of both qualitative and quantitative part. In Afenyo et al. [10], they reviewed that BN offers the opportunity to researchers to model interdependencies among the casual factors. They claimed that this is not likely in conventional methods such as the Fault Tree. They presented methodology to analyze arctic shipping accident scenario using BN and the same methodology can be applied to a scenario involving a collision between a vessel and iceberg. Alternatively Goerlandt and Montewka [11], proposed a framework for risk analysis of maritime transportation systems and BN modelling was applied for probabilistic risk quantification.

To select the appropriate method for the study, various factors must be taken into account. Bases on the above discussion, it is very clear that the Formal Safety Assessment (FSA) method and Fault Tree Analysis (FTA) Technique would serve as a viable mechanism to carry out the study. This is due to the fact that both methods have been proven to be accurate and sustainable.

2.2 Data Sources

Various responsible factors are to be considered for the causes of ship collision such as weather, route selection, personnel training, use of equipment and human factors. There are various types of data sources that can be used to analyze the accident factors such as Automatic Identification System (AIS) data, Port State Control Inspection (PSCI) record, Global Integrated Ship Information System (GISIS), government document and expert group.

AIS data is increasingly considered as a valuable source of information for marine accident studies such as in Chai et al. [2], Zhang et al. [9].and Xiao et al. [2].AIS is a technology which makes ships visible to each other [2]. AIS data consists of MMSI (Maritime Mobile Service Identity) number, latitude and longitude position, speed, ship type, destination and etc. and AIS is made applicable to vessel 300 GT in international traffic and 500 GT engaged in domestic voyages and all tankers and passenger ships irrespective of size [12].

In Chai et al. [2], they developed a Quantitative Risk Assessment (QRA) model to evaluate the risk of a ship being involved in a ship collision. The study approximately calculated the frequency and consequence of possible accident scenarios using event tree analysis, and a case study was developed based on one month real time ship movement from AIS data in the Singapore Strait. Similarly with Chai et al. [2], Zhang et al. [9] used AIS data to enhance Novel Model method for detecting near miss ship-ship encounter. Xiao et al. [12] also used AIS data to explore actual behavior of ships but it is narrowed to restricted waterway in China and Netherlands. The same measure was also adopted in Balto [13] where the study analyzed risk of ship collision in the Barents Sea in 2030 due to the expectation that the Barents Sea will be a major contributor to oil and gas production. The study used simulation tool IWRAP Mk2 and used AIS data to create a density plot for the traffic of a particular area. Zaman et al. [14] analyzed human error using m-SHEL model and the model was used to establish collision avoidance. The International Regulations for Preventing Collisions at Sea 1972 (COLREG) and AIS data are used to establish the m- SHEL analysis.

As far as the Port State Control inspection (PSCI) is concerned, it is used to inspect foreign ships entering national ports to check the condition of the ship and its equipment and also to ensure the ship is manned and operated under requirements of international regulations [15]. In Hanninen and Kujala [16] the use of BN for risk analysis was studied. They used PSCI data to find out the interaction between the numbers of various types of deficiencies found on a ship and ship involvement in marine traffic accident. They found that the limitation in the deficiencies data is due to inspector’s interpretation which might be biased, and thus it is uncertain whether there has been a recorded deficiencies indicator of safety.

To minimize accident, it is vital to determine the root causes and the factor behind the root causes [7]. In that study, causative factors were determined using expert opinion. Similarly in Ugurlu [6] the causative factors were determined by an expert group. And also similar in Zhang and Thai [9]. where they analyzed expert’s involvement in BN application for maritime modelling. They claimed that the expert’s knowledge plays an important role in the establishment of the BN structure and defining the relative probability but they found that involvement of expert’s judgment would bring uncertainty and biases.

Mou et al. [17] presented a study of vessel traffic safety in busy waterway by referring to a case study of accidents in the port of Shenzhen. The accident data and vessel traffic patterns were collected from Shenzhen Maritime Safety Administrator (MSA). The study proposed a framework of safety indexes to evaluate risk level in busy waterway. Similar to that, Balto [13] used government documents to simulate the frequency of ship collision using simulation tool IWRAP Mk2.

Bases on the above discussion, it is very clear that the Formal Safety Assessment (FSA) method and Fault Tree Analysis (FTA) Technique would serve as a viable mechanism to carry out the study. This is due to the fact that both methods have been proven to be accurate and sustainable.

This study also will use AIS data and government record to study characteristic of vessel traffic and utilize the data to further improve safety navigation in Tanjung Pelepas Port limit. And most importantly AIS data is the only data that is relevant to the specific kind of reclamation impact in this study due to the fact that AIS displays both static and dynamic ship data.

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3.0 Incorporates the FSA Method and FTA Technique

This study will focus on the application of the first route of the FSA flowchart as shows in Figure 2 which includes Steps 1, 2 and 5 to the Tanjung Pelepas Port Limit. The risk will be identified with reference to AIS and historical data, strengthened with experts' judgment identifying the actual circumstances of hazard that may occur in Tanjung Pelepas port limit, followed by ranking all potential hazardous scenarios that could lead to significant consequences and prioritize them by risk level.

Finally, the risk assessment to analyse the causes and consequences of the hazardous scenarios will be modelled in a FTA in accordance with a risk matrix, considering both probability and consequences of the navigational risk.

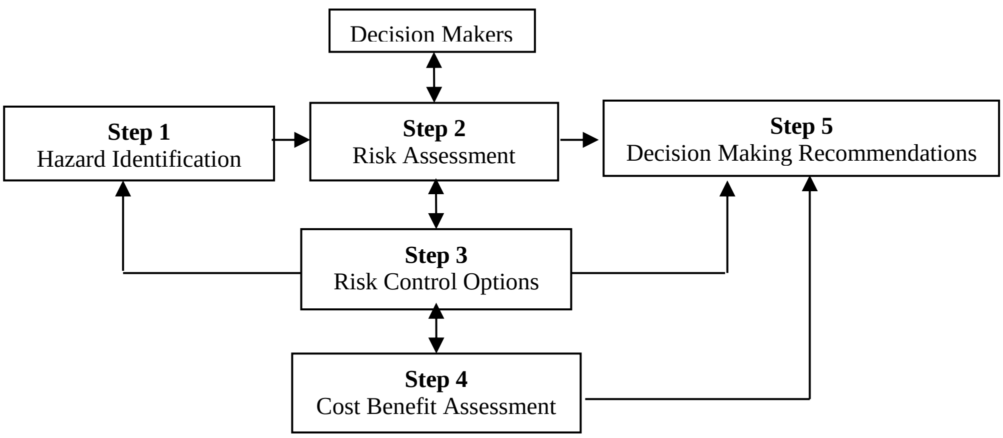

Figure 2 FSA Flowchart (MSC Circ., 2002)

3.1 Hazard Identification (Step 1)

In this section, the main objective are to systematically identify all conceivable and relevant hazards of a marine accident that have the potential to cause harm to human life, environment or any other third party. The expert judgments, AIS and historical data of the marine accidents that happened between 2015 and 2017 in the Tanjung Pelepas port limit are used to identify hazard.

3.1.1 Marine Accidents Statistic

Figure 3 shows the types of marine accidents, separated into five categories as given by the Johor Port Authority (JPA) namely, collision, grounding, contact, oil spill and others. Their individual percentage in terms of accident numbers in the past years from 2015 to 2017 are shown in Table 1. During in the 3 years period, 33 accidents occurred, resulting in 61% oil spills, 15% collisions, 9% contacts, 9% grounding and 6% others.

The finding from the marine accident investigation record in 3 years periods (2015-2017) provided by Marine Department Malaysia (MARDEP) as presented in Figure 4 shows that the most common cause of accident in the Tanjung Pelepas Port limit is due to personal failure. Based on this data, collision and grounding accidents should be noted as it may be possible to cause total losses or un-seaworthiness to the ship, and may also cause negative consequences to the personnel and environment.

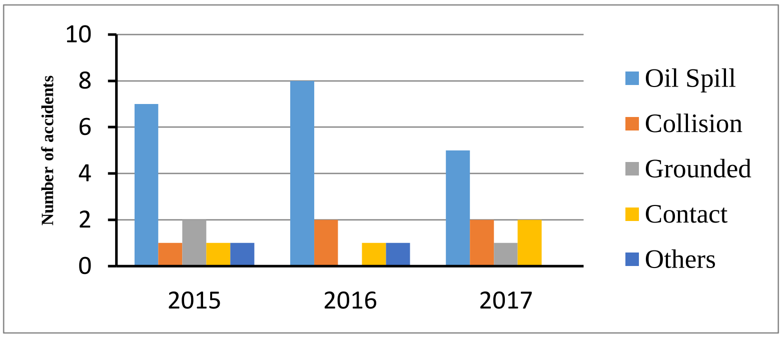

Figure 3 Marine Accident Statistics in Tanjung Pelepas Port Limit, (JPA, 2018)

Table 1: Ship Accidents Categories (2015-2017) in Tanjung Pelepas Port Limit (JPA, 2018)

Accident Categories	Occurrences	Percentage %	Rank
Oil spill	20	61	1
Collision	5	15	2
Grounding	3	9	3
Contact	3	9	3
Others	2	6	4
Total	**33**	**100**	

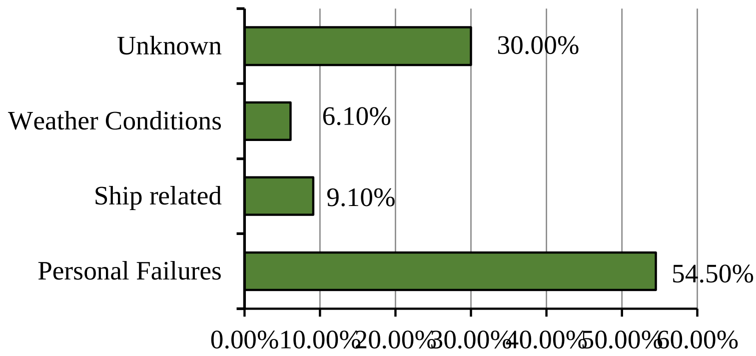

Figure 4 Accident Causes (MARDEP, 2018)

3.1.2 AIS Database

In the three years period, the traffic development has witnessed a continuous growth from 8390 to 9918 vessels as presented in Table 2. Among the traffic volume, containers and tankers are the dominant vessels. However, ships in other categories are also increasing over the three years. According to JPA, "sand carrier" has been placed in "others" category and the increasing traffic volume in this category is probably due to the influx of sand carriers. This development of traffic density justifies the need to be alert of potential marine accident assessment in the study.

Table 2 Traffic Development in Tanjung Pelepas Port Limit (JPA, 2018)

Year / Types	Container	Tanker	Tug & Barge	Bunker	Bulk Carrier	Others	**Total**
2015	4572	2057	204	1095	95	367	**8390**
2016	4318	2573	438	897	108	498	**8832**
2017	4231	2744	583	879	111	1370	**9918**

Data given by MARDEP reveals that four types of vessels have obtained operating permission to works at the reclamation area since 2016 as presented in Table 3. Based on Figure 6, the data shows that 89% vessels which are workings with the reclamation project are registered outside Malaysia.

3.1.3 Expert Judgment

Expert judgment is needed to identify the actual circumstances of hazard that may occur in Tanjung Pelepas port limit. In this study, the judgment from an expert team from the Marine Department Malaysia (MARDEP) has been sought to. The team has used the Checklist Analysis method to identify marine accident scenarios between sand carrier / tug and barge and commercial marine vessel within Tanjung Pelepas port limit. Based on the discussion with the expert team, the checklist questionnaire to identify hazards due to reclamation activity has been produced. If a majority of the questions are answered "Yes," the navigational risk in Tanjung Pelepas port limit risk is high.

Table 3: Vessels used at the reclamation area (MARDEP, 2018)

Type of vessel	Percentage %
Flat Top Barge	36
Tug boat	31
Sand Carrier	24
Crane Barge	9
Total	**100**

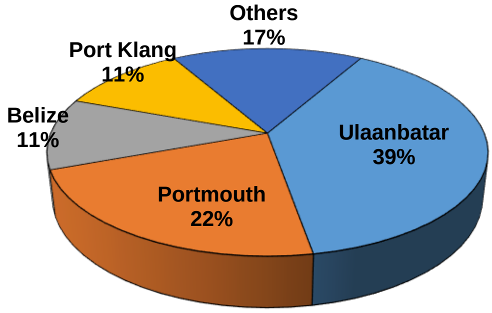

Figure 5 Port Registers of Marine Vessel Working at the Reclamation Area (MARDEP, 2018)

3.1.4 Risk Rank

The objective of this step is to rank all potential hazardous scenarios in Tanjung Pelepas Port Limit that could lead to significant consequences and to prioritise them by risk level. Risk ranking matrix is done by expert judgement and supported by historical and AIS data. Ranked risk is developed starting from the most severe as recommended in IMO guidelines. The risk matrix allocates each hazard to a probability and severity category and then gives form of ranking of the risk that is associated with that hazard. Risk can be characterized as equation 1. Finally the risk index or risk ranking number is achieved by adding the probability and severity indices as equation 2.

$$\text{Risk} = \text{Probability (P)} \times \text{Severity (S)} \quad (1)$$

$$\text{Risk Index} = \text{Probability Index} + \text{Severity Index} \quad (2)$$

The scale to determine the Probability Index and Severity Index is constructed based on IMO (MSC Circ. 1023, 2002) as shown in Table 4 and 5. As a result, the Risk Index to the Tanjung Pelepas Port limit is as presented in Table 6.

Table 4: Probability Index

PI	Frequency	Definition	F (per ship year)
7	Frequent	Likely to occur once per month on one ship	10
5	Reasonably probable	Likely to occur once per year in a fleet of 10 ships	0.1
3	Remote	Likely to occur once per year in fleet of 100 ships	10^{-3}
1	Extremely remote	Likely to occur once in the lifetime (20 years) of fleet of 1000 ships	10^{-5}

Table 5: Severity Index

Severity Index			
SI	**Severity**	**Effect on human, environment & ship**	**S** (Equivalent Fatalities)
1	Minor	Single slight injury and requiring first aid. Minor damage and operational disruption.	0.01
2	Significant	Multi minor or single major injury and requiring more than first aid. Some environmental damage and spill can be limited within the immediate incident area. Damage to vessel with longer operational disruption and financial loss.	0.1
3	Severe	Severe and multiple major injuries requiring hospitalization or single fatality. Major environmental impact with release of hazardous or polluting substances with the potential of spreading outside port boundary. Major damage to vessel with major operational disruption.	1
4	Catastrophic	Multiple fatalities. Extreme environmental impact with major release of hazardous or polluting substances with significant threat to environmental amenity. Loss of vessel, navigational disruption over an extended period.	10

Table 6: Risk Index

Risk Index (RI)					
		Severity Index (SI)			
		1	**2**	3	4
PI	**Frequency**	**Minor**	**Significant**	**Severe**	**Catastrophic**
7	Frequent	8	9	10	11
6		7	8	9	10
5	Reasonably probable	6	7	8	9
4		5	6	7	8
3	Remote	4	5	6	7
2		3	4	5	6
1	Extremely remote	2	3	4	5

Low Risk (2≤ score ≤ 4), Medium Risk (5≤ score ≤ 8), High Risk (Score ≥ 9)

3.1.5 Risk Index Scoring

Table 7 presents Risk Index Scoring and Risk Rank to Tanjung Pelepas Port limit. In this study, risk is explained by the probability of event which causes damage and its severity, thus the risk can be considered low even the severity is high, if an event has a low probability. Hazards are identified through the highest score of risk index. The highest score indicates the likelihood of hazards.

Table 7: Risk Index Scoring to Tanjung Pelepas Port Limit

Risk Rank	Risk Category	Possible Hazardous Scenarios	Probability Index (PI)	Severity Index (SI)	Risk Index (RI)
1	Collision	Inbound/outbound vessel from PTP/ North Sungai Pulai comes in contact with sand carrier / tug and barge due to miscommunication	7	4	11
2	Collision	Small vessel comes in contact with sand carrier / tug and barge	7	3	10
	Collision	Sand carrier / tug and barge comes in contact with other vessel or vice versa due to miscommunication	5	4	9
3	Collision	Westbound vessels come in contact with sand carrier / tug and barge	5	4	9
4	Collision	Inbound/outbound vessel from PTP/ North Sungai Pulai comes in contact with sand carrier / tug and barge due to restricted visibility (heavy rain, storm, haze)	5	4	9
5	Collision	Between Inbound/outbound VLCC and sand carrier / tug and barge approaching towards to PTP	5	4	9
6	Collision	Sand carrier/ tug and barge comes in contact with Ship to Ship vessel	5	3	8
7	Collision	Sand carrier / tug and barge comes in contact with daughter vessel	5	3	8
6.	Collision	Sand carrier / tug and barge comes in contact with mother vessel due to misjudgment of	5	3	8

		current flow			
8	Collision	Sand carrier / tug and barge accidently comes in contact with anchorage vessel	5	2	7
9	Collision	Small vessel comes in contact with sand carrier / tug and barge due to miscommunication	5	2	7
10	Collision	Sand carrier / tug and barge comes in contact with other vessel or vice versa due to inadequate space	3	4	7
11	Collision	Sand carrier/ tug and barge comes in contact with other vessel or vice versa due to inadequate lighting	3	4	7
12	Grounding	Sand carrier/ tug and barge grounding due to attempt to avoid fishing vessel	5	2	7
13	Grounding	Sand carrier / tug and barge tries to avoid any westbound vessel resulting in grounding	5	2	7
14	Collision	Sand carrier / tug and barge comes in contact with reclamation vessel at Benalec area or vice versa	3	3	6
15	Grounding	Sand carrier / tug and barge grounding to reclamation due to shallow patches	1	2	3
16	Collision	Sand carrier / tug and barge suffers engine failure	3	1	1

4.0 Risk Assessment (Step 2)

In this section, the main objective is to analyse the causes and consequences of the hazardous scenarios identified in Step 1 using FTA. Based on these assessments, existing risk control measures are reviewed and additional or improved control measure will be recommended.

4.1 FTA for Collision and Grounding

In this study FTA is used to construct risk contribution diagrams based on expert judgments. The objective is to determine the probability of hazard which has been identified in Step 1. When the combination of causes of the hazard are defined and constructed, the next step is to build a logical relation between reasons using minimal cut sets. A minimal cut set represents the smallest combination of component failure. In the event of all failure, the top event will occur. The collision and grounding accident FTA are shown on Figure 6 and Figure 7.

4.2 Minimal Cut Sets for Collision and Grounding Accident

From the FTA analysis, 11 single component minimum cut sets and 2 double component causing occurrence of collision accidents have been found. This formula shows that collision accident can be caused by events P1, OR P2, OR P3, OR P4, OR P5, OR P6, OR P7, OR P8, OR P9, OR P10, OR P11, OR P12 AND P13 OR, and P14 AND P15, Where events P2, P3, P4, P5, P6, P7, P8, P9, P12 and P13 are associated with human errors.

There are 8 single component minimum cut sets and 2 double component causing occurrence of grounding accidents. This shows that the grounding accidents can be caused by events P1, OR P2, OR P5, OR P6, OR P9, OR P10, OR P3 AND P4, OR P7 AND P8, where event P1, P2, P5, P6, P7 and P8 are associated with human errors. Hence, from this analysis human error is a common-cause failure to cause collision and grounding accident.

5.0 Decision making and recommendation (Step 5)

From the risk analysis, most marine accidents are caused by human error. In order to reduce marine accidents affected by human error, the perceptible recommendations are as below:

i. **Malaysian crew on-board:** Early initial communication is important to synchronize vessels movement throughout operating within the Tanjung Pelepas Port Limit. Language barrier to communicate with local vessel especially with fishing vessel contributes to marine casualties. Every working construction vessel at the reclamation project must fit at least one Malaysian crew who can communicate with both local vessel and vessel with multi-national crews on-board.

ii. **Pilotage:** Pilotage is compulsory for every marine construction vessel when entering and leaving the Tanjung Pelepas Port Limit. No exception is allowed due to the limitation and constraints of marine traffic especially at the south of the reclamation area. Generally, the authority may only grant exemption after 10 movements of a vessel by the same master.

iii. **Collision Regulation at Sea (COLREG) 72**: Every master of marine construction vessel should navigate with caution in accordance with the International Regulation For Preventing Collision at Sea (COLREG) such as proceeding at safe speed, posting additional look outs, exhibiting navigational light, using appropriate sound signal and monitoring ship radar and AIS to detect presence of ship in its vicinity. Reviewing and updating the training of crew working on board with the project could be helpful.

iv. **Safety Inspections:** Every marine construction vessel involved in the reclamation area must undergo safety inspection before work permission is granted. Any poor vessel should not be allowed to operate in the project area. Periodical safety inspection every 6 months to every vessel which has gained working approval should be the practice.

v. **Navigation watch:** Additional watch keeping on bridge shall be imposed when transiting during dark hours, when visibility is restricted or during heavy weather and haze. The officer in charge shall at all the time keep a close look out for every approaching vessel, especially with fishing vessel and navigation, to check for any sign of drifting or while at anchor.

6.0 Conclusion

There are six hazards that have high level of risk namely inbound/outbound vessel from PTP/ North Sungai Pulai coming in contact with sand carrier / tug and barge due to miscommunication, small vessel coming in contact with sand carrier / tug and barge, sand carrier / tug and barge coming in contact with other vessel or vice versa due to miscommunication, westbound vessels coming in contact with sand carrier/ tug and barge, inbound/outbound vessel from PTP/ North Sungai Pulai coming in contact with sand carrier / tug and barge due to restricted visibility and between inbound/outbound VLCC and sand carrier / tug and barge approaching towards to PTP.

The mains root of occurrence of collision and grounding accidents in Tanjung Pelepas Port limit is related to human fault namely improper voyage plan, selection of inappropriate anchorage area, use of inappropriate navigation chart, violation of navigation safety notice, fatigue, communication failure, pilotage failure, lack of situational awareness, non-compliance with regulation and deviation from suggested route.

Based on the study, the reclamation project will further cause navigational constriction within the port limit with imminent danger lurking to happen. Therefore, it will only be safe to proceed with the reclamation project if all the mitigations measures recommended in this study are followed and adhered to by the parties concerned. This work has just started the beginning; there is still much work need to do. From this study finding, detail study on listed below need to be further analysed:

- Study on marine accidents in other ship types to reveal the accident reasons.
- Simulation study on marine construction vessel when entering and leaving the port limit to gauge the level of safety.
- Study on actual ship speed by monitoring AIS which are valuable in real time risk analysis in the Tanjung Pelepas port limit.

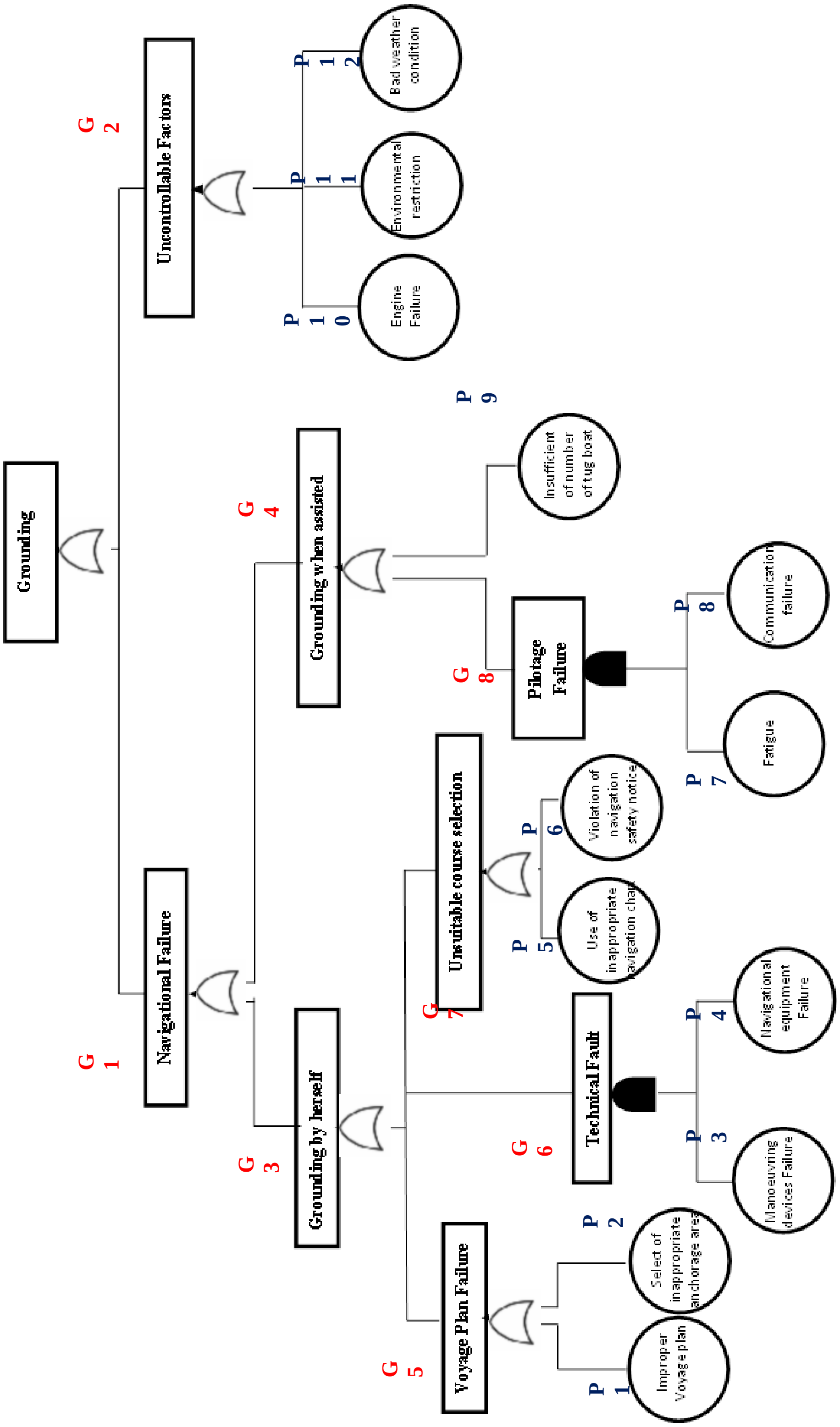

Figure 6 Fault Tree for Grounding Accident

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