Risk Assessment of Marine Accidents in Tanjung Pelepas Port Limit Due to Reclamation of Tanjung Piai Maritime Industrial Park

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ABSTRACT

This study is centered on the problem related to the reclamation work for the construction 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 had been used as the baseline to compare with future condition. For the purpose of analysis, Formal Safety Assessment (FSA) method and Fault Tree Analysis (FTA) technique had been deployed, coupled with the AIS data and marine accidents report provided by Johor Port Authority (JPA) and Malaysian Marine Department (MARDEP). The result of the analysis indicates that navigational risk mainly originated from human error. Thus, 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

Operating 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, which 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.

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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 vessels during the reclamation process.

The purpose of this study is firstly to identify potential marine accidents that might occur due to the existence of the reclaimed area, secondly to address the type of accident and consequences, and thirdly to propose mitigation measure in order to reduce such potential accident. The risk assessment was carried out using Formal Safety Assessment (FSA), incorporated with Fault Tree Analysis (FTA). The authority, such as the MARDEP of Malaysia and JPA 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.
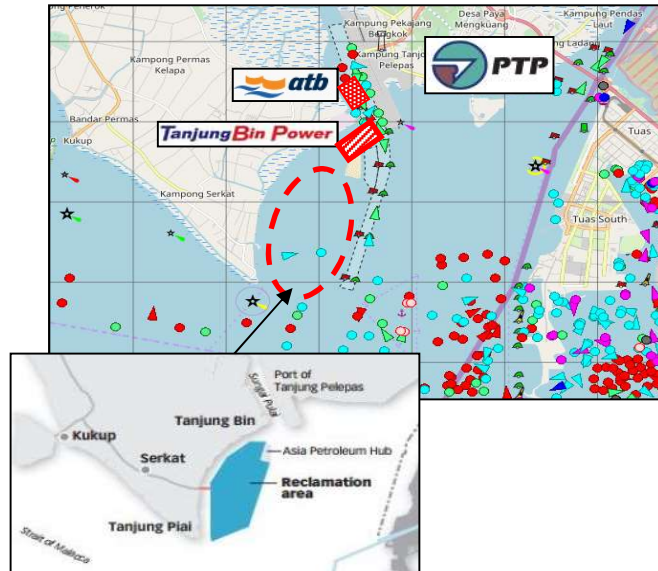

Figure 1: Reclamation area [1]

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 had 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 have been selected for discussion in this paper due to their 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.

The FSA method was introduced by the International Maritime Organization (IMO) as a frame work for risk assessment and management. Various maritime risk assessments had been conducted using the FSA guidelines [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]. 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

claimed that there is a possibility of imprecise risk measurement due to subjective judgments and uncertainty of risk while performing FSA [5].

The FTA is the graphical illustration of the logic combination of causes associated with an undesirable event or situation [6]. In [7], Uğurlu *et al.* focused on collision occurring in oil tanker and used programmed FTA to carry out risk assessment. They used FTA method to analyze the reasons of an undesirable event. This method consists of two stages, which are qualitative and quantitative. The collision data in the study was obtained from Global Integrated Ship Information System (GISIS). The data was used to classify accidents and to put recommendation to prevent reiteration of such accident. Uğurlu [6] used FTA method to determine significant level of the root causes of F&E accident in oil tanker, and used Fuzzy extended AHP (FAHP) to describe the correlation between the root causes of accident and their causative factors; in line with the findings obtained by Uğurlu *et al.* [7]. The author investigated maritime accident report on fire and explosion (F&E) which occurred in oil tanker, as well as accident data, 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 authors proposed Root Cause Analysis (RCA). In order to propose a recommendation to reduce the occurrence probabilities, 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]. Nonetheless, 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 modeling of rare accident [9]. Similar to FTA, BN modeling consists of both qualitative and quantitative part. Afenyo *et al.* reviewed that BN offers the opportunity to model interdependencies among the casual factors to researchers [10]. They claimed that this is not likely in conventional methods such as the FTA. They presented methodology to analyze arctic shipping accident scenario using BN, in which the same methodology can be applied to a scenario involving a collision between a vessel and iceberg. Alternatively, Goerlandt and Montewka proposed a framework for risk analysis of maritime transportation systems, applied with BN modeling for probabilistic risk quantification [11].

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

2.2 Data Sources

Various responsible factors need 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 existing 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 preferred as main source of information for marine accident studies such as in [2, 9, 12]. AIS is a technology which makes ships visible to each other [2]. AIS data consists of the Maritime Mobile Service Identity (MMSI) number, latitude and longitude position, speed, ship type, destination, etc. AIS is made applicable to vessel 300 GT in international traffic and 500 GT engaged in domestic voyages, as well as all tankers and passenger ships irrespective of size [12].

Chai *et al.* developed a QRA model to evaluate the risk of a ship being involved in a ship collision [2]. The study approximately calculated the frequency and consequence of possible accident scenarios using ETA, and a case study was developed based on one month real time ship movement from AIS data in the Malacca Straits. Similarly, Zhang and Thai

used AIS data to enhance the Novel Model method for detecting near miss ship-ship encounter [9]. Xiao *et al.* also used AIS data to explore actual behavior of ships but it is narrowed to restricted waterway in China and Netherlands [12]. The same measure was also adopted in [13] where the authors 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 researchers used simulation tool IWRAP Mk2 and used AIS data to create a density plot for the traffic of a particular area. Zaman *et al.* analyzed human error using m-SHEL model, and the model was used to establish collision avoidance [14]. The International Regulations for Preventing Collisions at Sea 1972 (COLREG) and AIS data are used to establish the m-SHEL analysis.

PSCI is used to inspect foreign ships entering national ports to check the condition of the ship and its equipment, besides to ensure the ship is manned and operated under requirements of international regulations [15]. They developed BN model for risk analysis. PSCI data was used 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 might be due to bias of inspector's interpretation, thus it is uncertain whether there has been any 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, the causative factors were determined using experts' opinion, similar with those in study by [6] while Zhang and Thai [9] analyzed expert's involvement in BN application for maritime modeling. 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.* presented a study of vessel traffic safety in busy waterway by referring to a case study of accidents in the port of Shenzhen [16]. 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. Similarly, Balto used government documents to simulate the frequency of ship collision using simulation tool IWRAP Mk2 [13].

Based on the above discussion, it is very clear that the FSA method and 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 uses AIS data and government record to study characteristic of vessel traffic and utilizes the data to further improve safety navigation in Tanjung Pelepas Port Limit. Most importantly, the 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 the static and dynamic ship data.

3.0 INCORPORATION OF FSA METHOD AND FTA TECHNIQUE

This study focused on the application of the first route of the FSA flowchart as shown 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, then strengthened with experts' judgment by identifying the actual circumstances of hazard that may occur in Tanjung Pelepas Port Limit. This is followed by ranking all potential hazardous scenarios that could lead to significant consequences, and finally prioritizing them by risk level.

Finally, the risk assessment to analyze the causes and consequences of the hazardous scenarios will be modelled in FTA in accordance with a risk matrix, considering both the probability and consequences of the navigational risk.
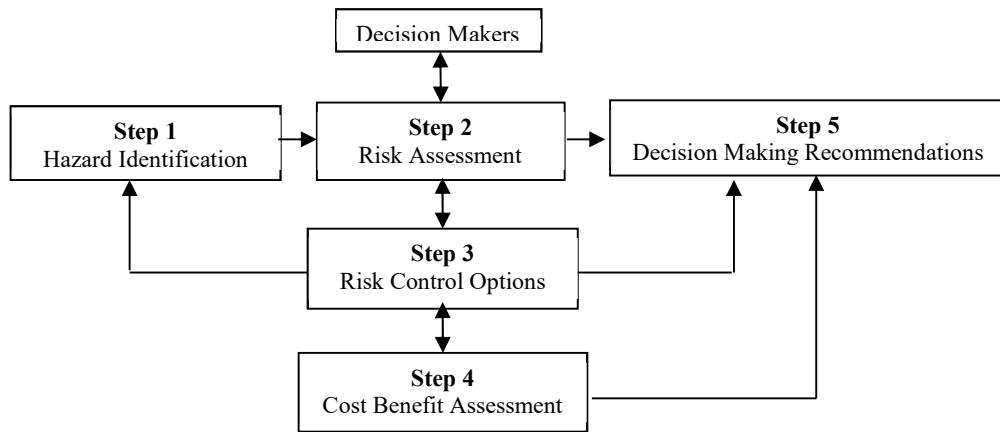
Figure 2: FSA flowchart [17]

3.1 Hazard Identification (Step 1)

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

3.1.1 Marine accidents statistic

Figure 3 shows five categories of marine accidents, as given by the 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. In the 3-year period, 33 accidents occurred, resulting in 61% oil spills, 15% collisions, 9% contacts, 9% grounding, and 6% others.

The marine accident investigation record covering 3-year period (2015-2017) provided by 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 prevented as they may cause total losses or un-seaworthiness to the ship, and may cause negative consequences to the personnel and environment.
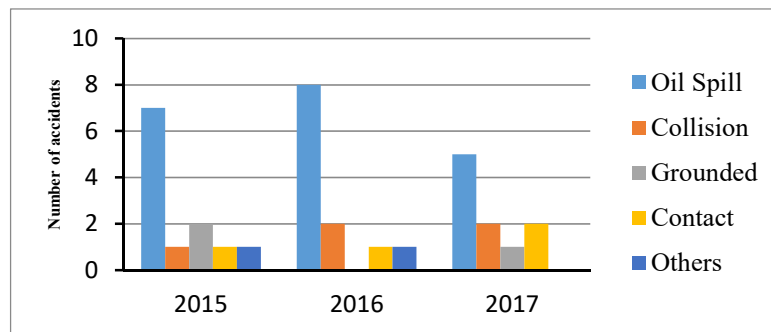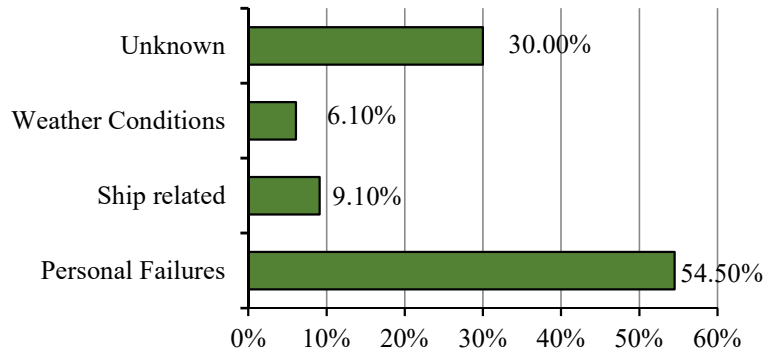

Figure 3: Marine accident statistics in Tanjung Pelepas Port Limit (Source: JPA)

Table 1: Ship accidents categories (2015-2017) in Tanjung Pelepas Port Limit

Accident Categories	Occurrences	Percentage %	Rank
Oil spill	20	61	1
Collision	5	15	2
Grounding	3	9	3

5

Contact	3	9	3
Others	2	6	4
Total	**33**	**100**	

Figure 4: Accident causes (Source: MARDEP)

3.1.2 AIS database

In the three-year period, the traffic development has witnessed continuous growth, from 8390 to 9918 vessels, as presented in Table 2. Among the traffic volume, containers and tankers are the dominant vessels. However, the number of ships in other categories has also increased over the three years. According to JPA, "sand carrier" has been placed in "others" category, by which 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

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 work at the reclamation area since 2016, as presented in Table 3. Data in Figure 5 shows that 89% vessels which are working 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 MARDEP had been sought to. The team used the Checklist Analysis method to identify marine accident scenarios between sand carrier/tug, 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 had been produced. If majority of the respondents answered "Yes," the navigational risk in Tanjung Pelepas Port Limit risk is high.

Table 3: Vessels used at the reclamation area

Type of Vessel	Percentage %
Flat top barge	36
Tug boat	31
Sand carrier	24
Crane barge	9
Total	**100**

Source: MARDEP
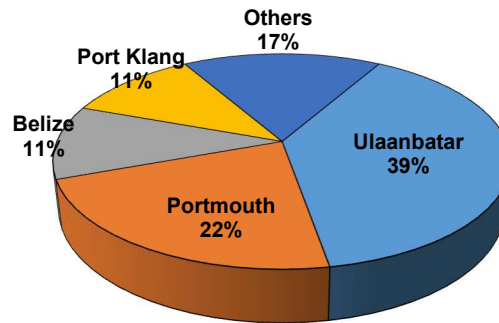
Figure 5: Port registers of marine vessel working at the reclamation area (Source: MARDEP)

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, by prioritising them by risk level. Risk ranking matrix is done by expert judgement and supported by historical and AIS data. Ranked risk starts from the most severe as recommended in IMO guidelines. The risk matrix allocates each hazard to a probability and severity category, followed by giving form of ranking of the risk that is associated with that hazard. Risk can be characterized as Equation 1. Risk Index or risk ranking number is obtained by adding the probability and severity indices as in Equation (2).

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

$$Risk\ Index = Probability\ Index + Severity\ Index \tag{2}$$

The scale to determine the Probability Index and Severity Index was constructed based on IMO (MSC/Circ. 1023, 2002) as shown in Tables 4 and 5. Meanwhile, the Risk Index of Tanjung Pelepas Port Limit is presented in Table 6.

Table 4: Probability Index

PI	Frequency (F)	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

SI	Severity (S)	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

		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 were 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 vessels 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 current flow	5	3	8
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 analyze the causes and consequences of the hazardous scenarios identified in Step 1 using FTA. Based on these assessments, existing risk control measures were reviewed and additional or improved control measure will be recommended.

4.1   FTA for Collision and Grounding
In this study, FTA was 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 were defined and constructed, the next step was 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 accidents FTA are shown in Figures A1 and A2, respectively in the Appendix.

4.2   Minimal Cut Sets for Collision and Grounding Accidents
From the FTA analysis, 11 single component minimum cut sets and 2 double component causing occurrence of collision accidents have been found. This analysis indicates 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. In comparison, 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 the 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 of 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 follows:

- **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.
- **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.
- **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.
- **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 six months to every vessel which has gained working approval should be the practice.
- **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

This paper has presented six high-level hazards as mentioned in Table 7. The main cause 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 is just the beginning; there are still much work need to do. From this study, further analyses are still necessary as follows:

- Study on marine accidents by other ship types to reveal the cause of accidents.
- 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 is valuable in real time risk analysis in the Tanjung Pelepas Port Limit.

ACKNOWLEDGMENTS

REFERENCES

1. Jasmin McDermott (Ed.), 2017. Johor: Malaysia's Most Promising Oil Cluster, *Tank Storage Magazine*, 13(4): 24–25.
2. Chai T., Weng J. and De-qi X., 2017. Development of A Quantitative Risk Assessment Model for Ship Collisions in Fairways, *Saf. Sci.*, 91: 71–83.
3. Faruk Ö. and Burak S.Z., 2015. Formal Safety Assessment for Ship Traffic in the Istanbul Straits, *Procedia - Social and Behavioral Sciences*, 207: 252-261.
4. Zhang D., Yan X.P., Yang Z.L., Wall A. and Wang J., 2013. Incorporation of Formal Safety Assessment and Bayesian Network in Navigational Risk Estimation of The Yangtze River, *Reliab. Eng. Syst. Saf.*, 118: 93–105.
5. Goerlandt F., 2015. *Risk Analysis in Maritime Transportation: Principles, Frameworks and Evaluation*, Doctoral Dissertation, Aalto University, Department of Applied Mechanics, Finland.
6. Uğurlu Ö., 2016. Analysis of Fire and Explosion Accidents Occurring in Tankers Transporting Hazardous Cargoes, *Int. J. Ind. Ergon.*, 55: 1–11.
7. Uğurlu Ö., Köse E., Yıldırım U. and Yüksekyıldız E., 2015. Marine Accident Analysis for Collision and Grounding in Oil Tanker Using FTA Method, *Marit. Policy Manag.*, 42(2): 163–185.
8. Kum S. and Sahin B., 2015. A Root Cause Analysis for Arctic Marine Accidents from 1993 to 2011, *Saf. Sci.*, 74: 206–220.
9. Zhang G. and Thai V.V., 2016. Expert Elicitation and Bayesian Network Modeling for Shipping Accidents: A Literature Review, *Saf. Sci.*, 87: 53–62.
10. Afenyo M., Khan F., Veitch B. and Yang M., 2017. Arctic Shipping Accident Scenario Analysis Using Bayesian Network Approach, *Ocean Eng.*, 133: 224–230.
11. Goerlandt F. and Montewka J., 2015. A Framework for Risk Analysis of Maritime Transportation Systems: A Case Study for Oil Spill from Tankers in A Ship-ship Collision, *Saf. Sci.*, 76: 42–66.
12. Xiao F., Ligteringen H., Van Gulijk C. and Ale B., 2015. Comparison Study on AIS Data of Ship Traffic Behavior, *Ocean Eng.*, 95: 84–93.
13. Balto J.B.H., 2014. *Risk of Ship Collision in the Barents Sea in 2030*, Master Thesis, The Arctic University of Norway (UiT).
14. Zaman M.B., Kobayashi E., Wakabayashi N. and Maimun A., 2015. Development of Risk

Based Collision (RBC) Model for Tanker Ship Using AIS Data in the Malacca Straits, *Procedia Earth Planet. Sci.*, 14: 128–135.

15. Hänninen M. and Kujala P., 2014. Bayesian Network Modeling of Port State Control Inspection Findings and Ship Accident Involvement, *Expert Syst. Appl.*, 41(4): Part 2, 1632–1646.

16. Mou J.M., Chen P.F., He Y.X., Yip T.L., Li W.H., Tang J. and Zhang H.Z., 2019. Vessel Traffic Safety in Busy Waterways: A Case Study of Accidents in Western Shenzhen Port, *Accident Analysis & Prevention*, 123: 461-468.

17. *Revised Guidelines for Formal Safety Assessment (FSA) for Use in the IMO Rule-Making Process*, MSC-MEPC.2/Circ.12/Rev.2, http://www.imo.org/en/OurWork/Safety /SafetyTopics/Pages/FormalSafetyAssessment.aspx, [Accessed: August 2019].
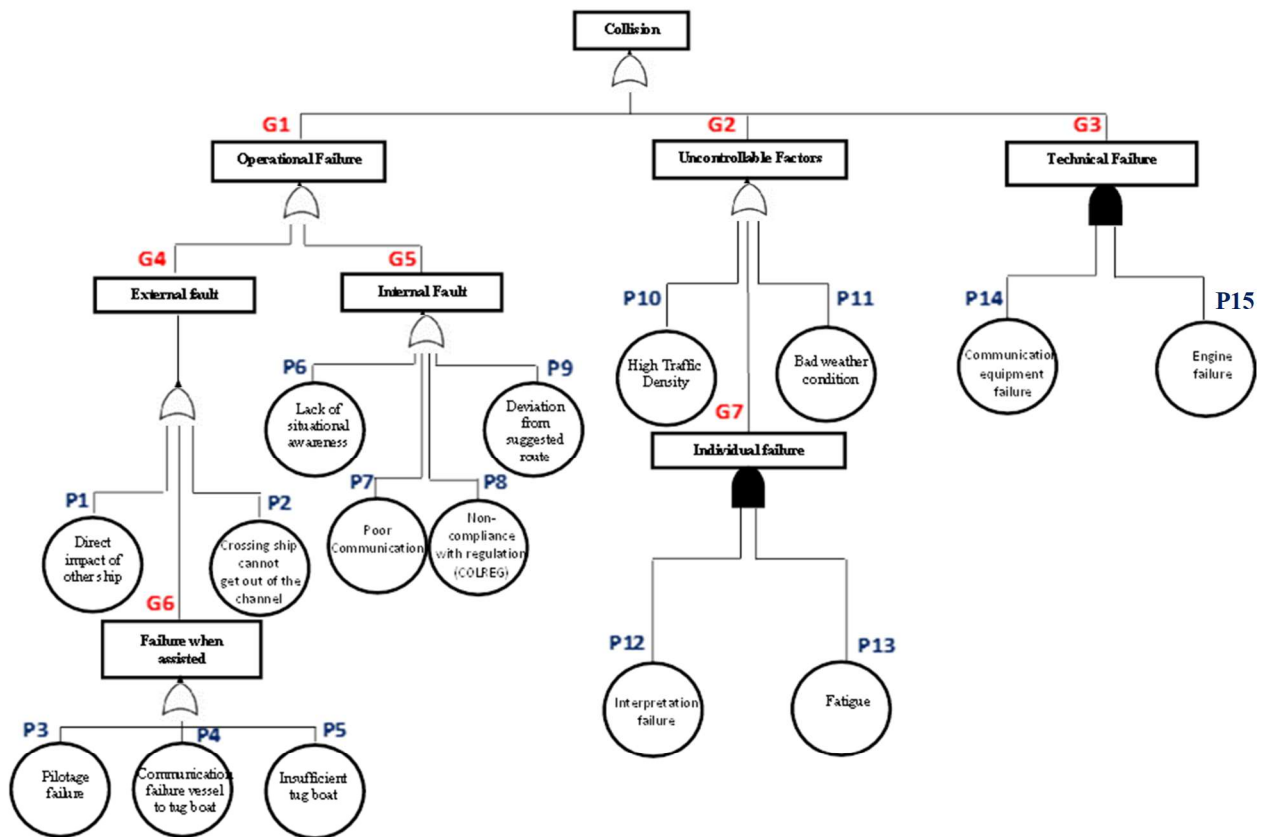
APPENDIX

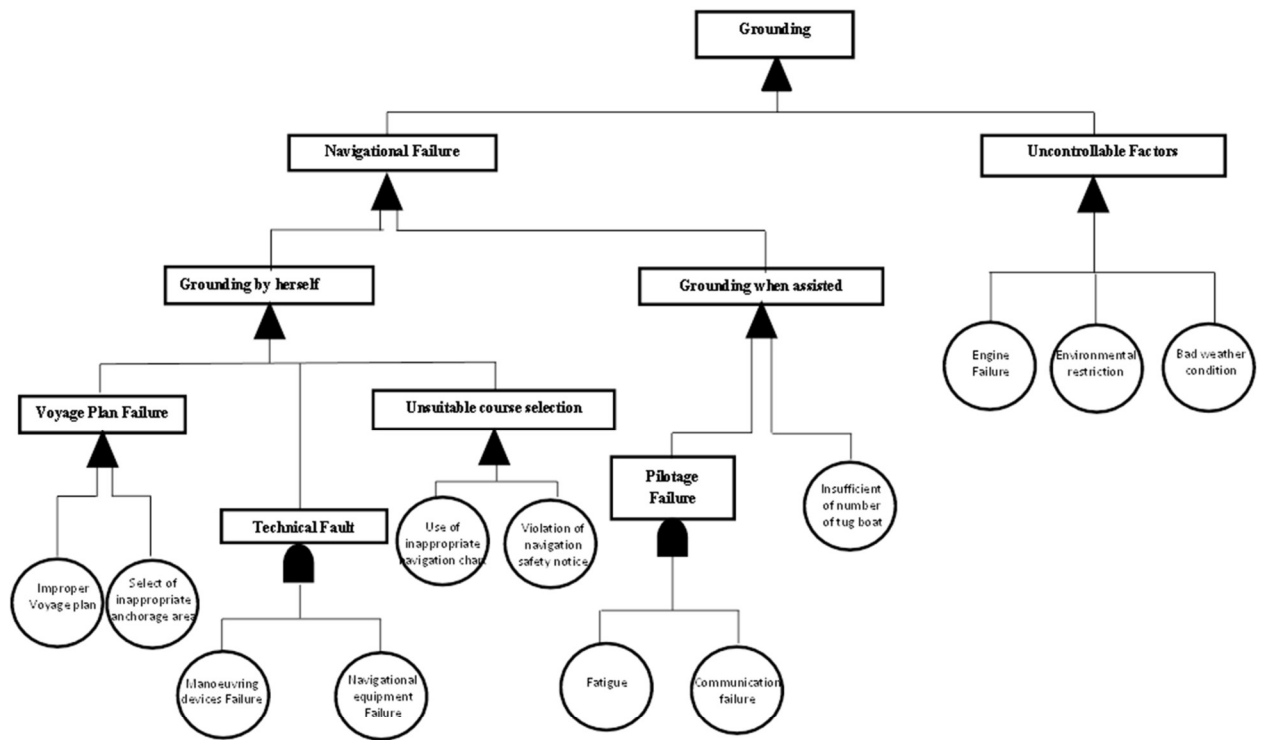**Figure A1**: Fault Tree for collision accident

Figure A2: Fault Tree for grounding accident