Prediction of quantitative risk assessment and risk level criteria based on the data from oil tanker collision simulation at Kyauk Phyu Deep Sea Port, Myanmar

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Abstract. The rates of ship accidents in waterways have been massively increased by many reasons including ship to ship collision. Collisions of crude oil tankers threat the health, safety and marine environment to its related surroundings. This study presents the QRA for double hull crude oil tanker collision in Kyauk Phyu Deep Sea Port of Myanmar navigational waterway by following the FSA guide lines. In order to present the useful simplified risk assessment method, the risk is predicted including frequencies, consequences analysis with the virtual ship collision model which is constructed based on the local situations. Furthermore risk acceptance criteria are also illustrated by F-N, F-T and F-P curves. The maximum acceptable risk levels are also conducted for social risk (1*10^{-3} fatalities per year), environmental risk (0.7*10^{-3} spills per year) and property risk (4*10^{-1} USD per year) respectively. Ultimately, this paper aims to develop the IMO’s FSA into simplified method and hopes to assist the local authorities’ decision making process in case of tanker incident occurs in this area.

1. Introduction
Nowadays, the delivering of world trade is mostly used by waterborne transportation so that it is the vital signs of global economy. At the same time, the safety of life, cargo and ships at sea is one of the most important factors for maritime industry. However, it has a numerous number of legislation and guidelines for safety, many accidental issues are still rarely happened yet including the oil spill by tanker accidents. As a result, not only they have severe damage consequences to the health safety of its related human and living things but also have huge economic consequences for local resident. According to ITOPF record, figure 1 below shows that the causes of oil spill (> 7tons) incidents global record in percentage from 1970 to 2017 [1]. From this 47 years record, it is obvious that the most frequent cause of oil pollution from tanker ships is the ship collision. There are numerous negative impacts to many sectors after causing the ship to ship collision incident. When the ship collision was occurred, firstly it makes adverse impact to its related environment as well as the marine wildlife. Likewise, it injuries and dies the crew and passengers which are an irrecoverable losses in all of the losses. Reviewing the previous studies, Dong Y and Frangpol [2] presented the probabilistic ship collision risk and sustainability assessment into economic, societal and environmental matrices with the probability distribution using Monte Carlo Simulation. This study also assessed the expected utility related to different risks interval in different attitudes. Youssef and Ince [3] developed a quantitative risk assessment of double hull oil tanker ship collision model which is collided with 30 different ships by using LS-DYNA nonlinear finite element method in order to predict the structural damages of each collision condition. And also estimated the environmental consequences in terms of monetary value.
and finally the total risk are assessed. Vidmar and Perkovic [4] studied the safety assessment of crude oil tanker. This study systematically analyzed the overall risk management state and discussed the risk acceptance criteria for three risks: potential loss of life (PLL), potential loss of containment (PLC) and potential loss of property (PLL) in recent decades with F-N curves for different tanker sizes. The main objective of this study is to analyze the ship collision frequency, consequences and risk for deep sea port of Myanmar waterway area and conduct the risk standard level for this area based on the IMO’s FSA guidelines.

![Figure 1](image.png)

**Figure 1.** Significant causes of oil spill (>7 tons) incidents in percentage from 1970 to 2017 [1].

2. Material and methods

During this few years, China formally introduced the “Belt and Road Initiative” across Eurasia to connect China with Europe, the Middle East, and South Asia. With this project, Myanmar is also one of the integral components of the 21st century Maritime Silk Road and the Silk Road Economic Belt. Kyauk Phyu special economic zone project is one of the demonstrable evidence by Chinese investments which is located in the Rakhine State, western part of Myanmar [5]. The Kyauk Phyu deep sea port project include oil terminal, already operated since 2013, which handles the maximum 300,000 dwt crude oil tankers from Middle East and transport to Yuan province in China by passing through the crude oil pipeline that avoids the Malacca Straits and it would save about 5000 km sailing distance for sea going vessels to China. The deep sea port project will consist of the container terminal with on total 10 berths. It is planning to accommodate the maximum 6000 TEU containers and bulk carriers. This port will be one of the biggest infrastructure projects in Myanmar’s history and would be beneficial for the country’s economic growth. On the other hands, it needs to consider negative impact to local people and environment such that oil spill in its navigational waterway due to unexpected conditions [6]. That is why this paper is based on this local situation data and then identifies the virtual hazardous scenario to determine the risk in this port. In this study, the beginning step is to identify the hazardous scenario by the FSA approach [7]. So, the four different oil tankers model will be initially established and then ship to ship collision model will be simulated in the LS-DYNA nonlinear finite element. In the risk assessment study, the two data are needed to identify such as frequency and consequences. That is why the ship collision frequency calculation will be approached in the next step based on the local environmental and traffic input data of the study area by following the Pederson’s ship [8] model. Likewise, the ship collision consequences will also be derived in third step including environmental losses, property losses and societal losses in terms of monetary value. In order to calculate the economic losses, Monte Carlo simulation will be applied that taken 1000000 random number will be initialized and give the expected costs with the probability distribution for each matrices. Finally, F-N curve will be illustrated for three risks: PLL, PLC and PLP for each tanker class and the suitable risk acceptance standard will be conducted for the study area.

3. Collision hazardous identification

In this study, the four different double hull oil tankers namely as Panamax, Aframax, Suezmax and VLCC [9] are collided by the Container ship and Bulk carrier in each collision scenario. At the same time, the striking ships’ bow structure model will be chosen as 22328 dwt Container vessel and 24497 dwt Bulk Carrier respectively. By using these particulars of each vessel, the vessel hull form for each tanker and striking ship bow structure are created by the Solidwork engineering drawing software.
When the hull form is completed, each model are simulated by the LS-DYNA explicit dynamic from the ANSYS 14.0 software [9] in order to get the output of collision structural failure to inner and outer hull, penetration results and determine whether it will be spilled oil or not. In each simulation, the striking bow structures collide with 8.5 knots and 90° collision angle to struck ship oil tankers. The required input data for ship’s material and density are taken as program default values and the mesh size is set as 1.5m. The simulation output of Panamax and Container ship collision can be seen in the figure 2 which is selected from the 8 collision scenarios. From these collision simulations, the inner and outer hull of all collision models are breached with a speed of 8.5k knots so that is why the damaged area for inner and outer shell can be estimated and simultaneously it can be determined that each scenario either oil spill happens or not. The oil leakage amount for marine pollution considers as 10% of oil volume which carried in damaged tank [10]. Table.1 lists the resulted damaged area and oil leakage amount for each accidental case.

![Figure 2. Panamax and container ship collision simulation result.](image)

| Struck ship | Striking Ship | Spill amt (ton) | Std Deviation | Outer hull Area (m²) | Inner hull Area (m²) |
|-------------|---------------|----------------|---------------|----------------------|----------------------|
| Panamax     | Container     | 608.703        | 108.03        | 1155                 | 51                   |
| Panamax     | Bulk          | 608.703        | 108.03        | 1330.5               | 538.5                |
| Aframax     | Container     | 934.985        | 189.9         | 679.5                | 117                  |
| Aframax     | Bulk          | 934.985        | 189.9         | 618                  | 208.5                |
| Suezmax     | Container     | 1297.644       | 257.5         | 631.5                | 61.5                 |
| Suezmax     | Bulk          | 1297.644       | 257.5         | 471                  | 28.5                 |
| VLCC        | Container     | 1767.802       | 285.5         | 370.5                | 70.5                 |
| VLCC        | Bulk          | 1767.802       | 285.5         | 354.5                | 45.5                 |

4. Collision frequency analysis
Many researchers conducted the enormous models to compute the ship-ship collision accident frequency $F_{q_{collision}}$ [8,10,11]. It is obvious that ship collision accidents mostly occur in the crossing waterway area. Therefore, the Pedersen’s model [8] is applied in this study to determine number of possible ship-ship collisions ($N_a$) over the considered risk area. So, the ship-ship collision frequency can be calculated as;

$$F_{q_{collision}} = N_a \cdot P_c$$  (1)

The causation probability $P_c$ is the probability of accidents caused by human errors and technical faults. This parameter can be estimated from the accidental data from different locations and then extended to the required analyzed area. Another approach is to calculate the value of $P_c$ by analyzing the human mis-operation and external faults establishing with event tree. In this study, the first method
is used to get the causation probability $P_c$. Based on the collision statistics in Bay of Bangel waterways [12] has estimated that for $P_c$ value is $1.44E-04$. According to the specific navigation condition of the representative ships in the port area and above model, the number of collision between various ships can be computed and then the ship-ship collision frequency of the representative ships in this port area can be obtained [13].

Furthermore, another three kinds of frequencies namely oil spill frequency $F_{q,spill}$, hull damage frequency $F_{q,hull}$ and crew casualty frequency $F_{q,fat}$ are considered based on the collision accident frequency. At first, oil spill frequency is considered as the product of collision accident’s frequency and oil tanker spill probability in collision case. The probability of spill in collision is assumed as the value of 0.175 based on the report data from ITOPF, IMO, LMIS and MAIB such kinds of association [14]. As for the calculation of hull damage frequency, the hull breaching probability is initially derived by following the formula of hull damage penetration probability from MARPOL regulation 32 [15]

$$P_{ST} = 1 - \left[0.749 + \left\{5 - 44.4 (\frac{y}{B_s} - 0.05)\right\} (\frac{y}{B_s} - 0.05)\right]$$

(2)

In here, $P_{ST}$ means the probability of side damage penetration; $y$ is the distance between two side shell and $B_s$ denotes the ship’s breadth. The frequency of Ship’s crew fatalities is considered upon the COWI analysis [16] and the expected number of crew fatalities $N_{fat}$ rate during this analyzed year is 0.01 and then frequency of crew can be determined by equation (3). All of the estimated results are listed in the table 2.

$$F_{q,fat} = \frac{N_{fat}}{N_{crew}}$$

(3)

| Struck ship | $D_{ij}$ | $N_a$ | $P_c$ | $P_{ST}$ | $T_{fleet}$ | $F_{q, collision}$ | $F_{q, spill}$ | $F_{q, hull}$ | $F_{q, fat}$ |
|-------------|----------|-------|-------|----------|-------------|------------------|----------------|---------------|------------|
| Panamax     | 267.83   | 9.83E-03 | 1.44E-04 | 0.118   | 9786.81     | 1.42E-06       | 2.49E-07       | 2.66E-07     | 3.98E-04   |
| Aframax     | 288.70   | 1.04E-02 | 1.44E-04 | 0.247   | 17580.49    | 1.49E-06       | 2.61E-07       | 3.69E-07     | 3.57E-04   |
| Suezmax     | 314.68   | 1.16E-02 | 1.44E-04 | 0.241   | 10724.44    | 1.67E-06       | 2.92E-07       | 4.03E-07     | 3.13E-04   |
| VLCC        | 373.68   | 1.47E-02 | 1.44E-04 | 0.213   | 16046.47    | 2.12E-06       | 3.71E-07       | 4.51E-07     | 3.13E-04   |

5. Collision Consequences Analysis

The consequences analysis is the compulsory part in quantitative risk assessment. The costs for time variant consequences are considered as the equation (4) in which $FV$ defines the value at future time $t$, $PV$ means the value at present time $n$ and the interest rate is assumed as 2%. In this section, the consequences costs are mainly considered as environmental, property and crew casualty losses which monetary values are further elaborated into environmental clean-up cost, ship repair cost, cargo oil loss, operation time loss, crew injury loss and fatality.

$$FV = PV \times (1 + i)^{t-n}$$

(4)

Environmental damage costs $C_{ENV}$ due to oil pollution can be determined based on the amount of spilled oil volume for impacted area clean-up and compensation [17] which can be calculated as:

$$C_{ENV} = f_{env} \times f_{spill} \times 42301Q_{spill}^{0.7233}$$

(5)

Where, $Q_{spill}$ = amount of spilled oil in ton, $f_{env}$= environmental modelling factor (mean 1 and COV 0.2) and $f_{spill}$ = oil spill modelling factor (mean 0.3 and COV 0.2) [18]. Property damage costs are considered based on the three situations such as ship repair cost $C_{REP}$, oil cargo losses $C_{CARGO}$ and down time losses $C_{TIME}$. The approximate ship repair times compared to the damaged area are followed by the COWI analysis [16].

$$C_{REP} = f_{rep} \times A \times c_{rep}$$

(6)

$$C_{CARGO} = f_{cargo} \times f_{spill} \times Q_{spill} \times c_{oil}$$

(7)

$$C_{TIME} = f_{time} \times c_{time} \times Dt$$

(8)
From the above equations, \( A \) = struck ship damaged area, \( c_{\text{rep}} \) = ship repair cost per area, \( c_{\text{oil}} \) = oil price per ton, \( c_{\text{time}} \) = ship operation cost per day, \( D_t \) = down time, \( f_{\text{rep}}, f_{\text{cargo}}, f_{\text{time}} \) = modelling factor with mean 1 and COV 0.2. Every collision accidents, the cost of crew’s fatalities \( C_{\text{FAT}} \) and injury losses \( C_{\text{INJ}} \) should be mainly considered as one part by the equation (9) and equation (10). The input values for fatalities modelling factor \( f_{\text{fat}} \) and injury factor \( f_{\text{inj}} \) are assumed as the same value of the above modelling factor. Then, the expected number of crew fatalities \( N_{\text{fat}} \) rate in collision case is taken as 0.387 and 5.413 for injuries \( N_{\text{inj}} \) respectively [19]. Value of life \( V_{\text{life}} \), injury cost per person \( c_{\text{inj}} \) and others input data are described in the table 4.

\[
C_{\text{FAT}} = f_{\text{fat}} \times N_{\text{fat}} \times V_{\text{life}} \quad (9)
\]

\[
C_{\text{INJ}} = f_{\text{inj}} \times N_{\text{inj}} \times c_{\text{inj}} \quad (10)
\]

Finally, the total economic value \( \text{TEV} \) for ship collision will be calculated as equation (11). And table 3 summarizes the input value which used in the consequences calculation and each economic damage costs are computed by using the method of Monte Carlo simulation. The costs of each risk in every activity can be determined by this simulation which supposed the probability distribution function and finally through one simulation can determine the costs deviation. This study used the Monte Carlo simulation lognormal distribution with 100000 random variables and runs the simulation into 50 iterations. The estimated consequences costs for each scenario are finally listed in the table 4.

### Table 3. The input value used in the economic losses calculation.

| Variables                      | Mean (S) |
|--------------------------------|----------|
| Value of statistical life \( V_{\text{life}} \) [12] | 3000000  |
| Injury costs per person \( c_{\text{inj}} \) [13] | 50000    |
| Repair cost per m² \( c_{\text{rep}} \) [25]     | 216      |
| Crude oil price per ton \( c_{\text{oil}} \)     | 371      |
| Daily cost per day \( c_{\text{time}} \) [5]     | 20068    |
| Value of Panamax [12]          | 50000000 |
| Value of Afamax [12]           | 65000000 |
| Value of Suezmax [12]          | 85000000 |
| Value of VLCC [12]             | 130000000|

### Table 4. Results of collision consequences costs for each scenario.

| C_{\text{ENV}} | C_{\text{REP}} | C_{\text{TIME}} | C_{\text{CARGO}} | C_{\text{INJ}} | C_{\text{FAT}} |
|----------------|---------------|-----------------|-------------------|---------------|---------------|
| Pan&Con        | 1.41E+06      | 2.60E+05        | 4.20E+05          | 2.25E+05      | 2.70E+05      | 1.16E+06      |
| Pan&Bulk       | 1.41E+06      | 4.03E+05        | 4.20E+05          | 2.25E+05      | 2.70E+05      | 1.16E+06      |
| Af&C           | 1.92E+06      | 1.72E+05        | 4.20E+05          | 3.47E+05      | 2.70E+05      | 1.16E+06      |
| Af&B           | 1.92E+06      | 1.78E+05        | 4.20E+05          | 3.47E+05      | 2.70E+05      | 1.16E+06      |
| Sue&C          | 2.44E+06      | 1.49E+05        | 4.20E+05          | 4.80E+05      | 2.70E+05      | 1.16E+06      |
| Sue&B          | 2.44E+06      | 1.07E+05        | 4.20E+05          | 4.80E+05      | 2.70E+05      | 1.16E+06      |
| VLCC&C         | 3.05E+06      | 9.50E+05        | 4.20E+05          | 6.55E+05      | 2.70E+05      | 1.16E+06      |
| VLCC&B         | 3.05E+06      | 8.63E+05        | 4.20E+05          | 6.55E+05      | 2.70E+05      | 1.16E+06      

6. Risk assessment and risk acceptance criteria

In this portion, the final risks for each of the accident are assessed by the product of accident frequency and consequences. Moreover, others potential such as Potential Loss of Life (PLL), Potential Loss of Cargo (PLC) and Potential Loss of Property (PLP) are also computed in this part. The results are listed in the table 5. The risk control option is one of the important parts in the risk assessment study so that this paper considers the risk outputs into negligible, acceptable and intolerable region according to the ALARP principle [20-22]. Initially, the societal risks are presented.
by F-N curves which are the curves of the cumulative frequency (F) via number of crew fatalities and injuries of four oil tankers associated with the model incidents. Similarly, Frequency versus number of spill oil (F-T) and frequency versus loss of property in USD (F-P) plots are also illustrated to predict the level of risk for each different oil tanker. A benchmark FN criterion considers as the acceptable frequency (F) per ship year of accident exceeding N fatalities and it can be expressed as:

$$F(N) = F_{AN}^{-b}$$  \hfill (12)

Here, The FN criterion slope (b) could be varying from different places with the range between -1 and -2. For the marine based risk criterion, the slope line is set to be -1 by following the IMO guideline [23]. The acceptable frequency ($F_{1A}$) per ship year for the intercept with N=1 axis and maximum number of fatalities in one accident $N_T$ is expressed as:

$$F_{1A} = \frac{PLL_A}{\sum_{N=1}^{N_T} N}$$  \hfill (13)

| Struck ship | Striking Ship | Total risk ($/ship yr) | Potential Loss of Cargo (PLC) (ton/ship yr) | Potential Loss of Life (PLL) (fatalities/ship yr) | Potential Loss of Property (PLP) ($/ship yr) |
|-------------|---------------|------------------------|--------------------------------------------|-------------------------------------------------|---------------------------------------------|
| Panamax     | Container     | 5.3179                 | 1.52E-04                                   | 2.31E-04                                         | 0.69E-01                                    |
|             | Bulk          | 5.3804                 | 1.52E-04                                   | 2.31E-04                                         | 1.07E-01                                    |
| Aframax     | Container     | 6.3906                 | 2.44E-04                                   | 1.29E-04                                         | 0.64E-01                                    |
|             | Bulk          | 6.4                    | 2.44E-04                                   | 1.29E-04                                         | 0.66E-01                                    |
| Suezmax     | Container     | 8.2147                 | 3.79E-04                                   | 2.11E-04                                         | 0.60E-01                                    |
|             | Bulk          | 8.145                  | 3.79E-04                                   | 2.11E-04                                         | 0.43E-01                                    |
| VLCC        | Container     | 13.791                 | 6.55E-04                                   | 1.41E-04                                         | 4.29E-01                                    |
|             | Bulk          | 13.606                 | 6.55E-04                                   | 1.41E-04                                         | 3.89E-01                                    |

The value of potential loss of life $PLL_A$ are taken as the average value of four tankers simulation as 2.1*10^{-4}. The maximum number of fatalities in collision accident is assumed as 6. And then, the $F_{1A}$ value is given an output result of 1*10^{-4}. The next step is setting an ALARP border with upper and lower limits which centred on the acceptable frequency $F_{1A}$ benchmark [23]. The final risk criteria can be determined as:

- Upper criterion (intolerable risk) $F(N) > 10 F_{1A} N^{-1}$
- Lower criterion (negligible risk) $F(N) < 0.1 F_{1A} N^{-1}$

With the same approach for calculating of risk criteria for crew fatalities, oil pollution risk criteria are estimated with the mean value of potential loss of cargo oil PLC in collision accident is taken as 6.55*10^{-4}, maximum number of spill ton in one accident is about 1200 ton and final output of $F_{2A}$ is 0.7*10^{-4}. Similarly, the risk criteria for property loss can be computed as the above consideration. $F_{3A}$ value for property losses is computed as 4*10^{-2} with the mean potential loss of property PLP is 1.69*10^{-1} and maximum property losses is the value of 7*10^6 USD respectively. The estimated criteria for the above three categories are drawn on the figure 3.

7. Conclusion
This paper performed a QRA method for crude oil tankers collision with other vessels in Kyauk Phyu deep sea port of Myanmar territorial water. Following the FSA procedure, the double hull oil tankers full scale model is collided with bow structure of bulk and container vessels. Then, LS-DYNA explicit dynamic method in ANSYS 14 software was applied to determine the hull breaching area and oil leakage amount. The estimated collision frequency $F_{q_{collision}}$ in this model is slightly different with the IMO’s struck ship collision frequency because IMO refers only to the number of events between 1980 to 2007 period. The collision accident frequency for struck ships is gradually decreased in this recent decade. Most of the unit costs used in consequences analysis are based on the local exchange rates and economy rates and also input 100000 random variables. Thus it is the most suitable way to consider the consequences analysis. Later, the risk acceptance criteria was considered by following the ALARP
principle for potential loss of life, potential loss of cargo and potential loss of property which were illustrated in F-N, F-T and F-P curve. In here, The estimated risk standard for societal and property losses are nearly same as the Vidmar’s and IMO results [4,7]. However, the environmental risk level is quite different. Since, the oil spill amount in Vidmar’s model is taken as the global data with the range between 2000 ~ 15000 ton and then these values are used in the PLC calculation which gives the result of 1543 ton/ship year. But, the PLC value is based on the model oil spill amount (10% of damage tank) so that the result is obviously smaller than the Vidmar’s model. As a further research and next step in this area it should be consider the cost benefit analysis to identify and compare the risk reduction. The cost benefit analysis was not considered in this study because some input data are inconvenient to collect for this research area within the short time duration. As a final goal, this study conducted the simplified quantitative collision risk assessment model and modified the FSA procedure in methodology. This study hopes to assist the future oil tanker collision risk assessment study and to become guidance for the prediction of risk in the Kyauk Phyu Deep Sea Port for local authorities.

Figure 3. (a) F-N curve, (b) F-T curve and (c) F-P curve for collision accident

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