A Comparative Study of Maritime Quantitative Risk Assessment Models Using Automatic Identification System Data

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Abstract

Ship collision is a matter of major concern all over the world. A significant number of studies have been published regarding the assessment of ship collision risk. This paper studies ship collision risk assessment models and investigates the characteristics of the models with the aid of the Automatic Identification System (AIS) from Chattogram Port and Singapore Port area. A comparison of the results are shown and facts associated with ship collisions are highlighted together with possible solutions.

Keywords: Quantitative Risk Analysis, Head-on Collision, Crossing, and Overtaking.

Introduction

Ship collisions are not rare by any means and often such collisions are catastrophic. Therefore, there is a growing interest among researchers from multiple disciplines in the field of maritime risk assessment. Quantitative risk assessment (QRA) model for shipping waterways, thus far, has enjoyed a growing interest in the past years.

Quantitative risk analysis of ship collision and grounding is a systematic approach to evaluate the level of safety of marine transportation with recommendations from Risk Control Options (RCOs) that incorporates both frequency and consequence estimation. The risk of ship accidents has increased drastically in the past few decades due to an increase in freight transportation all over the world. Pedersen (2010) have specified that more than 1.5% of all ships are involved in severe and costly accidents annually, resulting in loss of lives, property, and environment.

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It is necessary to mention that marine transportation is the primary means of freight transportation all over the world. Economic growths, as well as ever-growing consumption of commodities, have drastically increased global trade in the last few decades in international, territorial and inland waterways. An increase in the freight requires an increase in the number of vessels to carry them, which in turn imposes greater risk and unbearable loss. For sustainable economic growth, countries like Singapore, Bangladesh, and many others depend heavily on commercial shipping. For example, in Bangladesh, the Chattogram Port is the primary seaport of the country, which handles over 90% of the country’s total maritime trade (Khaled and Kawamura, 2015). Singapore, one of the highly developed free-market economy country in the world, highly depends on its ports to run the economy at full swing. Any major accident in the port area of the country affects its economy as a whole. Therefore, the problem of ship accidents around the port area is severe and study on accident characteristics is crucial for generating preventive measures. With this perspective in mind, the following sections highlight the collision risk problem.

The Problem of Concern

Ship accident can be of many types. Among them, collision, adverse weather, overloading, stability failure, excessive current and bottom damage are common causes of ship accidents. Figure 1 shows the percentage of different categories of ship accidents in Bangladesh (Uddin and Awal, 2017). The research suggests that collision accidents are about 60.3% of the total number of accidents, which is quite significant and so denotes that collision is the most frequent type of waterway accident in Bangladesh. Other modes of accidents comprise little percentage compared to ship collision such as 8.7% of accidents due to adverse weather, 6.1% accidents due to overloading, 4.8% accidents due to stability failure, 4.8% of accidents for excessive current and others. A study by Awal (2007) on maritime accidents also suggests that collision has been one of the leading types of ship accidents in Bangladesh since 1995.

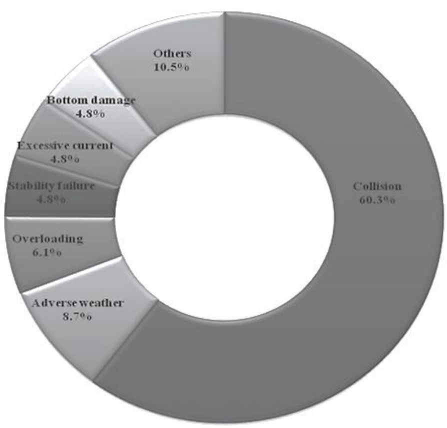

Figure 1: Percentage of different types of maritime accidents in Bangladesh (Uddin and Awal, 2017).

Accident Scenario

Khaled et al (2018) conducted a study on the trend of annual accident rates. The findings were quite alarming. In the case of Chattogram Port, a statistical summary is shown (Table 1) for the years between 2007 and 2017. The vessels handled by Chattogram Port Authority (CPA) are gradually increasing and collisions per 1000 no. of the handled vessel have been very high, e.g. in 3 collisions on average with an exception in the fiscal year 2013-14 when as many as 7 collisions were recorded. In the case of grounding, five new accidents were reported in 2014-2017 and 3 of those were in Karnafully river channel.

Table 1: Collision per 1000 handled vessels in Chattogram port

Year	No. of vessels handled	No. of collisions	Collision per 1000 no. of handled vessels
2007-08	2074	2	0.964
2008-09	2088	0	0
2009-10	2203	4	1.815
2010-11	2308	5	2.166
2011-12	2079	7	3.367
2012-13	2136	5	2.341
2013-14	2294	17	7.410
2014-15	2566	9	3.507
2015-16	2875	7	2.435
2016-17	3092	8	2.587

The study also dug deep into various categories of collision accidents. For example, in year 2013, accidents in different collision scenario is shown in Table 2.

Table 2: Collisions per year for the year 2013 (excluding 0-25m wooden vessels).

Collision scenario	Overtaking	Head-on	Crossing	Bend
Modified Model Collision/year	2	1	0.5	4

As a matter of national interest in trade and economic development, a focus on Singapore port is considered vital. A significant amount of international trade takes place between Singapore and Bangladesh, therefore, most Bangladeshi government and commercial vessels ply between these two ports. A study by Weng et. al (2012) reveals that the accepted collision frequency of Singapore port, as shown in Table 3 estimates collision frequency, 1.75 per year, and it is quite close to the average actual frequency of 1.80 per year. The study considers historical accident records for the Singapore Strait between the years of 1997 and 2002.

Table 3: Vessel collision frequency in the Singapore Strait

Collision Type	Causation Probability	No. of conflicts (per year)	Collision Frequency (per year)
Overtaking	4.90×10^{-5}	12,168	5.48×10^{-1}
Head-on	4.90×10^{-5}	5,292	2.38×10^{-1}
Crossing	1.30×10^{-5}	7,440	9.67×10^{-1}
Total		24,900	1.75

Further study on the collision probability reveals that there exists commonly accepted probability values which help different policymakers to conduct quantitative risk analysis (QRA) to generate better policies. For example, causation probabilities, P_c (overtaking) = $1.30{\times}10^{-4}$, P_c (head-on) = $4.90{\times}10^{-5}$, and P_c (crossing) = $4.90{\times}10^{-5}$ are commonly accepted globally (Pedersen, 2002; Otto et al., 2002; Kujala et al., 2009). Therefore, studying the collision causation probability of different ports using different techniques will help understand the collision risk of different ports and also allow one to understand the advantages and disadvantages of different risk evaluation techniques. Hence, the study focuses on the following objectives:

I. To study different QRA models.
II. To predict the collision risk of Chattogram port and other ports of national interest by QRA models using AIS data.
III. To compare the variation of collision risk of different ports using different QRA models and discuss facts related to ship collision.

Literature Review

Over the years, several research works addressed various types of quantitative risk assessment models. For example, Wang et al. (2002) summarized published literature for assessing the shipping damage and oil outflow after a collision and grounding to develop a standard for design against accidents. Fujii and Tanaka (1971) studied marine traffic capacity in light of estimating the frequency and consequence of collision and grounding accidents. Wang and Foinikis (2001) explored the formal safety assessment (FSA) of containerships. In this study, they used fault tree analysis (FTA) for hazard identification and risk evaluation. Zaman et al. (2015) examined the formal safety assessment in the Malacca Strait using AIS data. Finally, a comprehensive review work by Li et. al (2012) on quantitative risk assessment model summarizes the development so far.

Methodology

This study analyses contemporary quantitative risk analysis (QRA) models. It attempts to classify the models to comprehend their relative merits and demerits. The study finds that QRA models for maritime risk assessment are of two types: accident probability (or frequency) estimation models and consequence evaluation models. Accident probability estimation has two subgroups, which are ship collision/grounding models and ship fire/explosion models. For ship collision/grounding there are two types of models, which are causation probability (P_c) models and geometrical probability (P_a) models. Based on this discussion, a classification of QRA models is drawn and shown in Figure

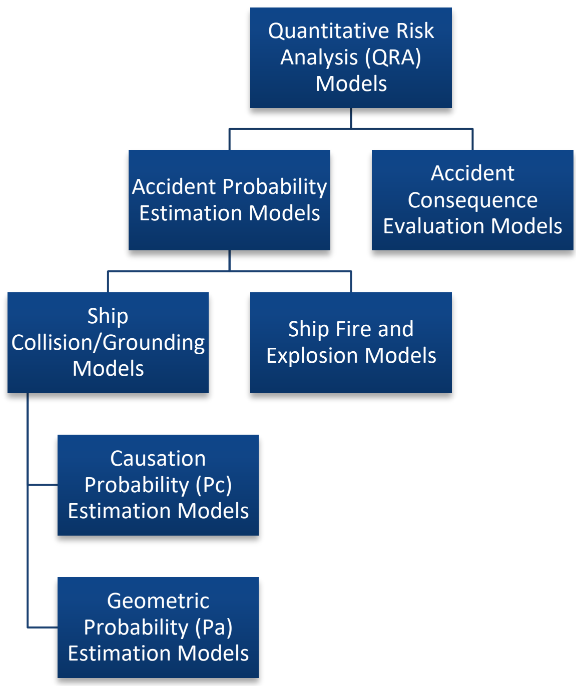

Figure 2: Classification of Quantitative Risk Assessment (QRA) models.

Accident Probability Estimation

It is a general practice that ship collision (or grounding) frequency is calculated from historical records for a specific water area. Hence, the probability of an accident and henceforth the analysis applies to that particular area only. With this view in mind, the following subsections discuss the methodology in detail.

Ship Collision and Grounding Models

The ship collision and grounding model in its simplest form is expressed as,

$$P = P_c \times P_a \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (1)$$

Here, P is the probability that a vessel is involved in a collision accident during its journey passing through a particular water area. P_c is the causation probability, which is the conditional probability that a collision occurs in an accidental scenario. P_a is the geometrical probability of a vessel encountering accidental scenarios, namely, the collision probability if no aversive measures are made. Numerous researchers have contributed their efforts on causation and geometrical probability estimations, which is introduced in following sub-sections.

Causation Probability Estimation

The causation probability is determined by mariners' operational skills, the vessel maneuverability under accidental scenarios and similar other parameters. In practice, in most works of literature, causation probabilities for distinct water areas are considered time static for a particular accident scenario. Therefore, the causation probability can be estimated based on historical data collected in different locations and then applied in the area of interest (Pedersen, 2010). The estimated causation probabilities can be applied in collision (or grounding) frequency estimation in other water areas with distinct geometrical characteristics and traffic volumes. The causation probabilities can also be applied to predict the collision (or grounding) frequency when the traffic volume changes in future. This is because the causation probability reflects the ability of vessels to address various types of accident scenarios and independent of traffic and geometrical characteristics. Several methods have been used to estimate the value of the causation probability. These are:

I. Historical Accident Statistics
II. Fault Tree Analysis (Bayesian Network Approach)
III. Expert Judgment Elicitation.
IV. Others

The simplest way is to use historical accidents statistics to calibrate the causation probability *Pc*. This approach heavily relies on the availability of historical accident records. Hence, it is a useful and efficacious method if historical data is available for a particular region. The limitations of this method are not able to reflect the insightful understanding of the causes of the accidents. Accordingly, it would not provide supports to decision-makers to apply risk reduction solutions.

Often, fault tree analysis method is used to estimate the causation probability. By using the fault tree, the error related to human performance and the error related to incapacitation can be modelled. Bayesian network approach, as an improvement over the fault tree analysis, can also be used to estimate causation probability. Through a carefully constructed Bayesian Network, expert judgement and historical statistics can be incorporated, in order to model the human error, human behavior and mechanical failure etc. The Bayesian network is constructed by nodes and arcs. The nodes are variables that could have several different values and each value with some probability.

Geometrical Probability Estimation

The geometrical probability, which is dependent on the geometric parameters of the water area, vessel size, traffic volume, vessel speed over ground (SOG), course over ground (COG), and others. Following are the methods that can be used to estimate the geometrical probability:

I. Fujii and Tanaka (1971) model.
II. Macduff (1974) model.
III. Pedersen (1995) model.
IV. Kaneko (2002) model.
V. Zaman et al (2015) model.

In this research, Fujii and Tanaka (1971) model and Zaman et. al (2015) model will be used for analysis. The reason for considering these two models is because of the availability of data or input variables from AIS data and also these two models have the least limitations. A brief literature review and comparison of all the cited geometrical probability is given below.

Table 4: Summary of different geometrical probability models.

Models	Model Equation	Description
Fuji and Tanaka (1971)	$\int_{entrance}^{exit} (\rho D_e V_{rel}/V)dx$	ρ = Ship Density (No. of Ships/Area) D_e = Dia. of evasion V_{rel} = Relative Speed
Macduff (1974)	$P_a = \frac{XL}{D^2}\frac{\sin(\theta/2)}{925}$	X = Actual Length of Path to be considered L = Average Vessel Length D= Average Distance between Ships Θ = Approaching Ship Angle
Pedersen (1995)	$N_a = \sum_i \sum_j \int_{\Omega(Z_i Z_j)} \frac{Q_i^{(1)} Q_j^{(2)}}{V_i^{(1)} V_j^{(2)}} f_i^{(1)}(z_i) f_j^{(2)}(z_j) V_{ij} D_{ij} dA\Delta t$	A = Considered Sea Area V_{ij}= Relative Velocity D_{ij}= Collision Diameter $Q_{i\ or\ j}$ = Number of movements of ship class i or j per unit time z = Distance from the centreline of the waterway f = Lateral distribution of the ship routes
Kaneko (2002)	$\lambda_c = \frac{4\rho VrT}{\pi}(1+\alpha)E\left(\frac{2\sqrt{\alpha}}{1+\alpha}\right),$	ρ = Average Number of sailing ships in the area V= Velocity of other

	$\lambda_c = \rho V 2rT\sqrt{1+\alpha^2+2\alpha\cos\theta}$	ships V_o= Velocity of own ship α = V/ V_o θ =Angle between the directions of own ship and other ships
Zaman et. al (2015)	$N_i = \frac{N_m}{D_C}\left(\frac{4}{\pi}L + 2B\right)$ $N_a = P_a \times \left(365 \times \frac{24}{T}\right)$	N_i = Geometrical Probability P_c = Causation Probability D= Width of channel N_a = No. of collisions/year

Model of Zaman et. al (2015)

This method estimates probabilities based on AIS data and hazards analysis. The factors analyzed in assessing the ship collision probability are the head-on situation, crossing situation, overtaking situation, and traffic density, based on AIS and GIS (Geographic Information System) data. The traffic density can be determined as:

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

Here, N_m is the number of ships using the channel, D_c is the channel length, and W_c is the channel width. A particular area is selected for ship collision probability calculation, based on AIS and GIS data.

The ship collision probability per passage can be expressed as:

$$P_a = N_i \times P_c \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

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

$$P_c = \mu_c \times T \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

Where $\boldsymbol{\mu_c}$ in the failures per hour and T is the time taken per passage. The probability number of collisions in the head-on and overtaking condition per passage can be expressed by the following equation, assuming that four groups of ships have identical characteristics such as head on, overtaking, left and right-side crossing:

$$N_i = \frac{\boldsymbol{N_m}}{\boldsymbol{D}} \times \left(\frac{\boldsymbol{4L}}{\boldsymbol{\pi}} + \boldsymbol{2B}\right) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

In these Equations (2 to 5), *B* is the mean beam of meeting (m), *L* is the mean length of meeting (m), and *D* is the sailing passage distance, and *Nm* is arrival frequency of meeting ships (ship/time).

The number of collisions per year then be determined as:

$$\boldsymbol{N_a} = \boldsymbol{P_a} \times (365 \times 24 / T) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

These above equation models are used for the calculation of ship collision probability in the Chattogram port and Singapore port areas, based on AIS data and GIS.

Consequence Assessment

The consequence analysis for each scenario can be categorized using Zaman et al., (2015). Five categories comprise the risk level by using a risk matrix. Table 5 shows the probability index and the consequence categories. The consequence analysis is classified as the following:

Table 5: Probability index and consequence categories

Probability Index	Description	Probability
Very unlikely	Less than once per 1000 years	P<1/1000
Remote	Once per 100-1000 years	P<1/100
Occasional	Once per 10-100 years	P<1/10
Probable	Once per 1-10 years	P<1
Frequent	More than once per year	P = 1

Study Area

Two of the main study areas of this paper are Chattogram port and Singapore port. Figure 3 and Figure 4 shows the study area of Chattogram port. In order to extract data a circle of 35 kilometers radius is considered (Figure 4) which is in the latitude and longitude of 22.113606 degrees north and 91.6627459 degrees east respectively.

Figure 3: Study area of Chattogram port (www.google.com/maps)

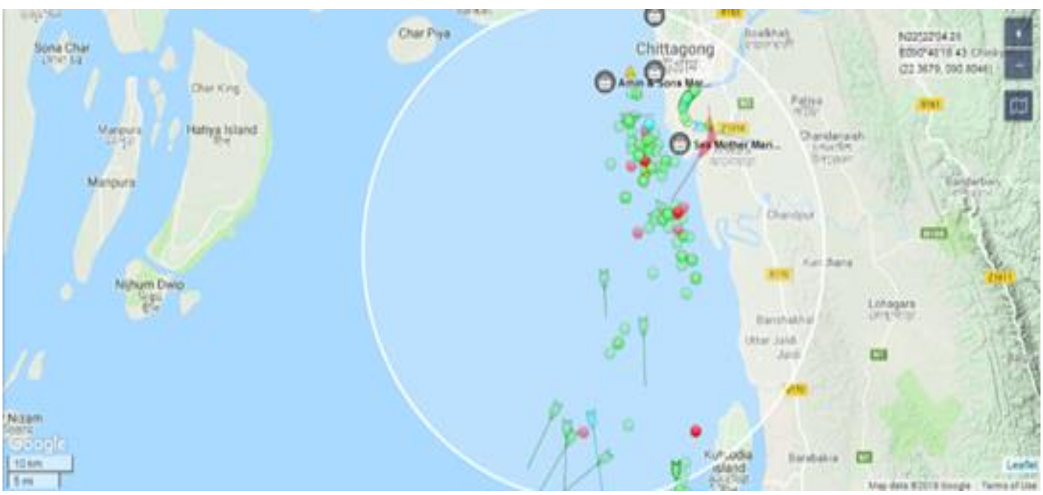

Figure 4: Study area of Chattogram port (www.marinetraffic.com)

Figure 5 and Figure 6 shows the study area of Singapore port. In order to extract data a circle of 3 kilometers radius is considered (Figure 6) which is in the latitude and longitude of 1.2478314 degrees north and 103.7721295 degrees east respectively.

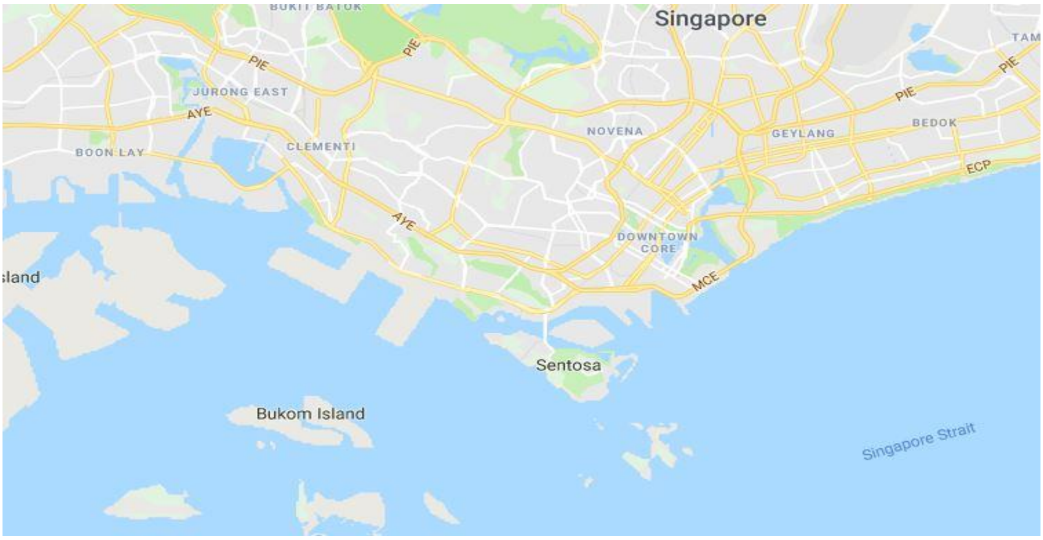

Figure 5: Study area of Singapore port (www.google.com/maps).

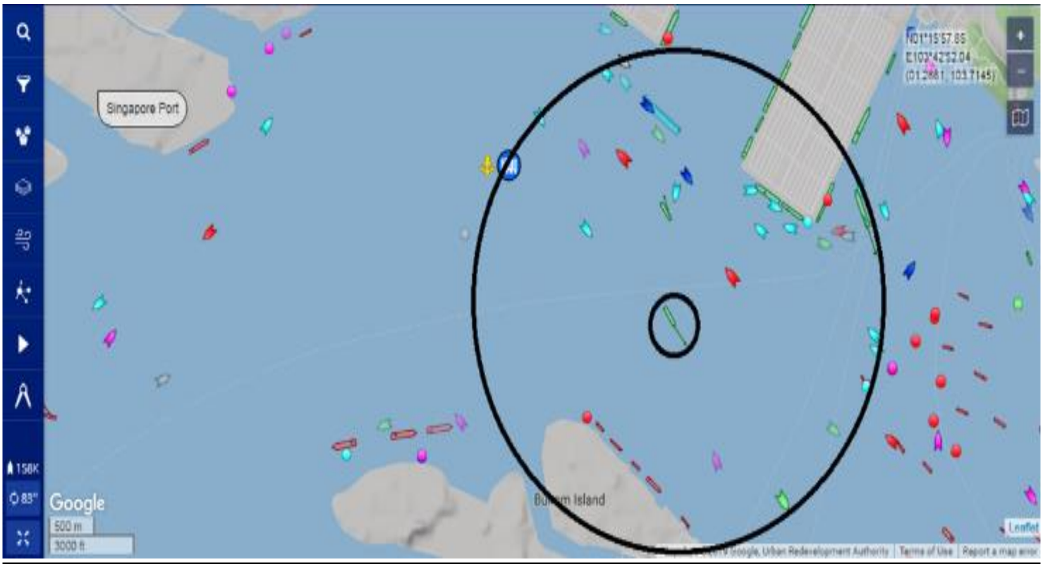

Figure 6: Study area of Singapore port with traffic information (www.marinetraffic.com).

Calculation and Result for Particular Date

A calculation of probability of collisions conducted using sample data for 10th December 2018 from Chattogram port. The head-on and overtaking conditions are shown in Figure 7. The crossing condition is observed in Figure 8 (www.marinetraffic.com).

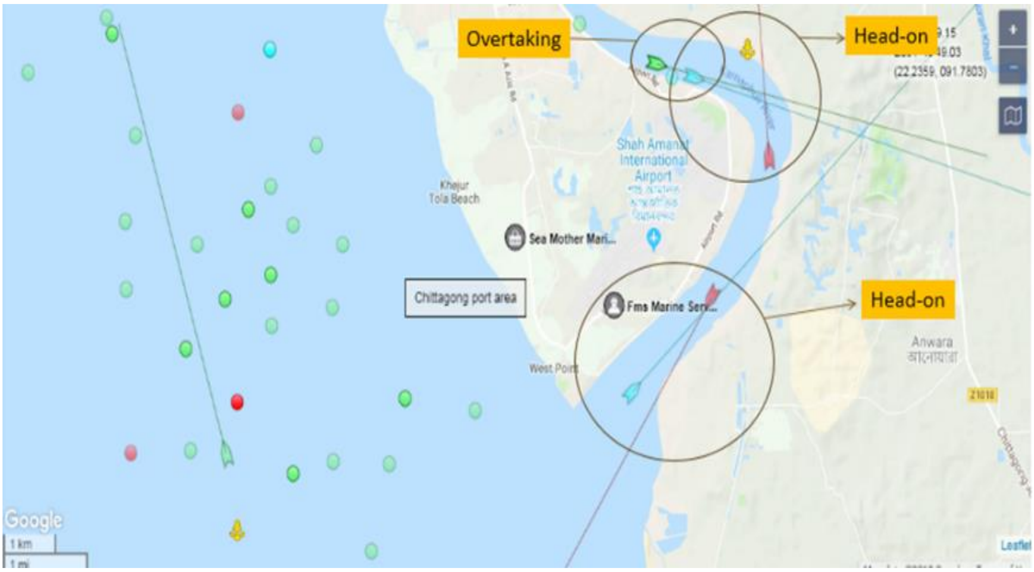

Figure 7: Head-on and overtaking conditions on 10 December 2018.

Figure 8: Crossing conditions on 10/12/18.

Table 6 demonstrates the calculation of collision probability for Chattogram port on 10th December 2018.

Table 6: Collision probability calculation for 10/12/18

10/12/18 (1hr-day)											
Collision Scenario	Nm	Ni	μc	Dc (m)	L (m)	B (m)	T (hr)	Pc	Pan	Pa	Class
Head-on	2	0.015132	7.31E-04	35000	164	28	1	0.00073059	1.10553E-05	0.48	**Probable**
Overtaking	2	0.015132	7.31E-04					0.00073059	1.10553E-05		
Crossing	6	0.0453961	7.31E-04					0.00073059	3.3166E-05		
	10								5.52766E-05		

Sample Calculation:

For Head-on condition,

N_m=2, L=164 m, B = 28 m

$$N_i = \frac{N_m}{D_c} \times (\frac{4}{\pi} L + 2B) = \frac{2}{35000} \times (\frac{4}{\pi} \times 164 + 2 \times 28) = 0.01513$$

μ_c(failures per hour) = 7.31exp-4 (constant as taken from historical analysis)

$P_a = N_i \times P_c$=0.01513 × 7.31exp-4 = 1.1055exp-5

Similarly, for over-taking, P_a=1.1055 exp-5

Similarly, for crossing, P_a=3.3166 exp-5

Total P_a = 1.1055exp-5+1.1055 exp-5+3.3166 exp-5 = 5.5276 exp-5

Finally, N_a = 5.5276exp-5× $365 \times 24/1$=0.48422 (which is <1; so, in probable region)

Hence, calculations for different dates of different months for both Chattogram and Singapore port were carried out. The probability of Chattogram port with respect to different months are shown in Figure 9, Figure 10 and Figure 11.

December	
Date	Probability
10.12.18	0.4844
14.12.18	0.4879
23.12.18	0.3134
25.12.18	0.5574
27.12.18	0.4975
31.12.18	0.2578

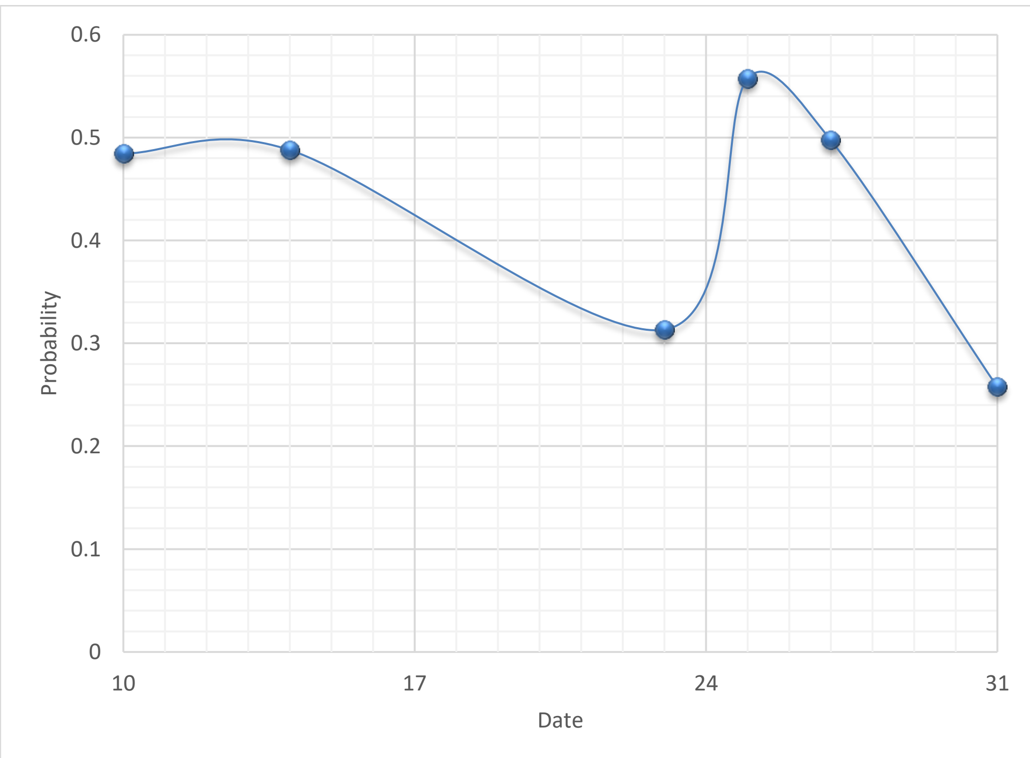

Figure 9: Probability for December 2018.

January 2019	
Date	Probability
03.01.19	0.1928
09.01.19	0.2589
10.01.19	0.2063
12.01.19	0.1672
15.01.19	0.4915
16.01.19	0.2824
23.01.19	0.3079
24.01.19	0.2416

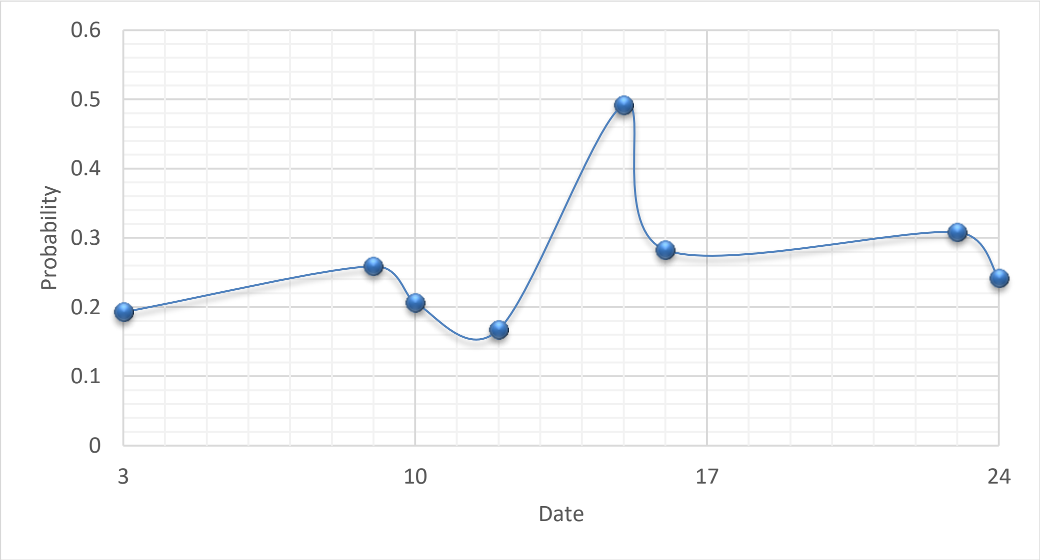

Figure 10: Probability for January 2019.

April 2019	
Date	Probability
15.04.19	0.4845
16.04.19	0.4881
17.04.19	0.4719
18.04.19	0.4826
19.04.19	0.5473
20.04.19	0.3891

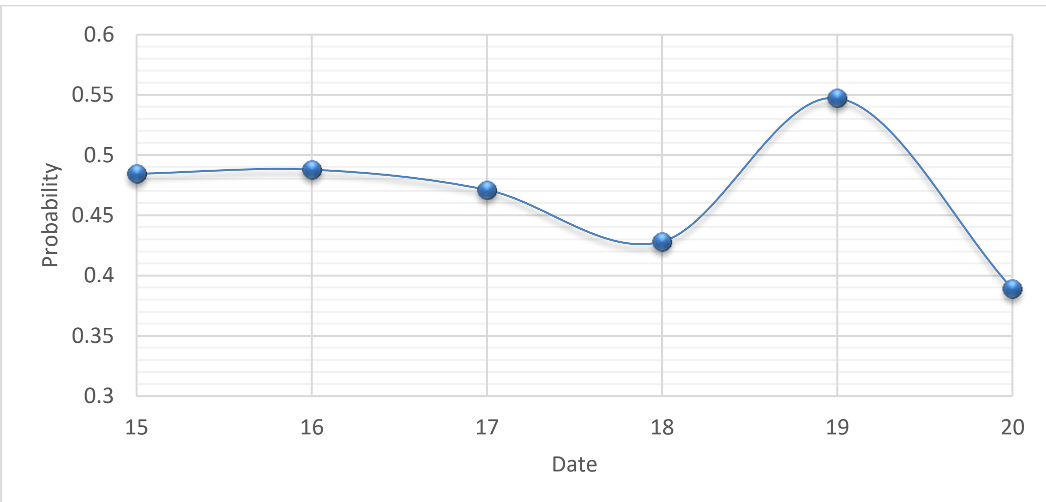

Figure 11: Probability for April 2019.

From the above analysis for Chattogram port it is observed that there is decreasing tendency in probability in the middle of the month and increase in probability at the end of the month. The graph is more likely of a heartbeat shape and the collision risk is mostly in the probable region. The probability for January 2019 and April 2019 of Singapore port is given in Figure 12 and Figure 13.

January 2019	
Date	Probability
08.01.19	0.0219
19.01.19	0.1492
21.01.19	0.0216
24.01.19	0.0321
31.01.19	0.0171

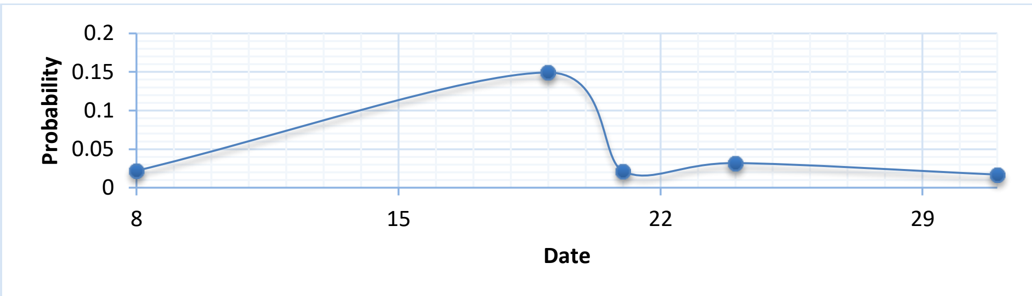

Figure 12: Probability for January 2019.

April 2019	
Date	Probability
15.04.19	0.0235
16.04.19	0.1791
17.04.19	0.0144
18.04.19	0.0448
19.04.19	0.0171
20.04.19	0.0339

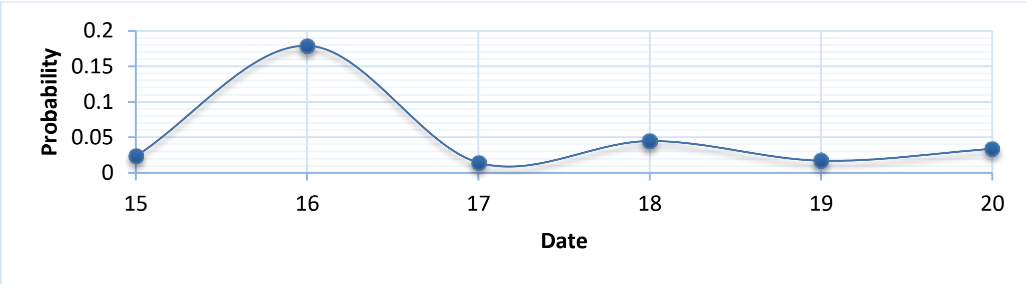

Figure 13: Probability for April 2019

Model of Fujii and Tanaka (1971)

Fujii and Tanaka (1971) proposed a model to estimate the average number of evasive actions by a ship passing through an area as:

$$\int_{entrance}^{exit} \left(\frac{\rho D_e V_{rel}}{V}\right) dx \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

Where ρ is the ship density (number of ships per unit area), D is the diameter of e evasion, V_{rel} is the relative speed, and V is the speed of the passing ship. The model is developed based on geometry and laws of motion. The diameter varies from 9.5 to 16.3 times of ship length according to Fujii-Yamanouchi and Mizuki (1974). The assumptions of this model is more reasonable compared to Macduff (1974) model. Following the pioneering work of Fujii and Tanaka (1971), the concept of a ship domain was proposed and widely applied in navigational safety studies. Various types of ship domains of distinct shapes and sizes are defined by Goodwin (1975), Davis et. al (1982) and Coldwell (1983). Jingsong et. al (1993) commented the existing ship domains mentioned above and proposed the concept of fuzzy ship domains. Since then, the fuzzy ship domains have been developed and applied in estimating frequencies of ship collisions. Szlapczynski (2006) proposed a unified measure of collision risk based on the concept of ship domain.

Calculation and Results for Particular Dates

Analysis using the Fuji and Tanaka (1971) model are shown in Figure 14 and Table 7 followed by sample calculations. Figure 14 shows the snapshot of traffic data which is used for calculation. Table 7 shows the collision risk for Singapore port on 08 January 2019 as “Occasional”.

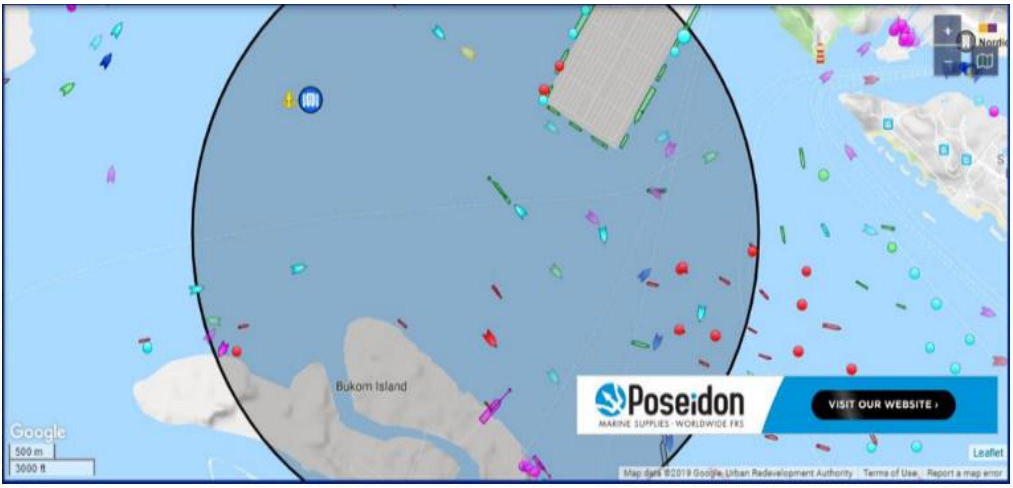

Figure 14: Calculation of Collision Probability on 8 January 2019.

Table 7: Collision Probability calculation on 08 January 2019.

No. of Ships	Diameter of evasion (m)	Area (m^2)	Ship Density	Ship Speed (knot)	No. (enter)	Speed (knot)	Calculated Probability	Geometrical Prob.	Pc	Pa	P	Class
17	2000	3141600	5.41126-06	11.3	1	4.1	0.0068958	0.046833737	4.90E-05	2.29E-06	2.01E-02	**Occasional**
					2	10.2	0.001054					
					3	7.8	0.0033521					
					4	20.1	-0.0084282					
					5	8.2	0.002969					
					6	20	-0.0083324					
					7	20	-0.0083324					

					8	6.2	0.0048845					
					9	9.5	0.0017239					
						Sum	-0.0042					
					No. (exit)							
					1	13.6	-0.0022028					
					2	8.3	0.0028732					
					3	4.1	0.0068958					
					4	7.9	0.0032563					
					5	7.4	0.0037352					
					6	0.7	0.0101521					
					7	1.5	0.0093859					
					8	2.4	0.0085239					
						Sum	0.04262					

Sample calculation:

No. of ships in the risk zone = 17

Diameter of evasion = 2000m

Area = $\frac{\pi}{4} \times 2000^2$ = 3141600 m^2

Ship Density = $\frac{17}{3141600}$ = $5.4113 \times 10^{-6}\ m^{-2}$

Own Ship Speed = 11.3 knots

Relative Velocity for entering ship 1 = 11.3 - 4.1 = 7.2 knots

$\frac{\rho D_e V_{rel}}{V} = \frac{5.4113 \times 10^{-6} \times 2000 \times 7.2}{11.3}$ = 0.00689577

Similarly adding up for all the ships entering the risk zone we get = -0.00421408

And after adding up for all the ships exiting the risk zone we get = 0.04261966

Now for Geometrical probability = 0.04261966 - (-0.00421408) = 0.046833737

We take P_c as 0.000049. So we get P as = (0.000049×0.046833737) =

2.29×10^{-6}

Finally, P_a is obtained as $2.29\times 10^{-6} \times 365 \times 24 = 2.01 \times 10^{-2}$ (which is < 0.1; so, in occasional region)

Graphical Representation

The analysis of collision probability of Singapore port for the months of January 2019 and April 2019 are demonstrated in Figure 15 and Figure 16. The representations show the fluctuations of risk values along the days of the months. In January 2019, the collision probability reached a peak of 0.23. On the other hand, in April 2019, the probability reached a peak of 0.1, which is significantly lower than January 2019.

Collision probability for January 2019	
Date	Probability
08.01.19	2.01E-02
19. 01.19	0.028825
21. 01.19	0.05589
24. 01.19	0.229
31. 01.19	0.148

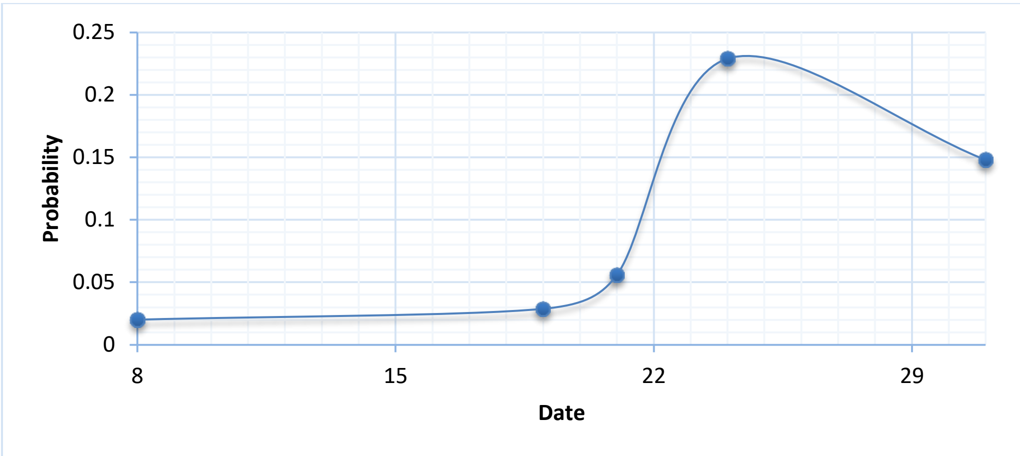

Figure 15: Variation of collision risk for Singapore port in January 2019.

Collision Probability Data for April Month	
Date	Probability
15.04.19	0.1005
16.04.19	0.0310
17.04.19	0.0208
18.04.19	0.0206
19.04.19	0.0055
20.04.19	0.0140

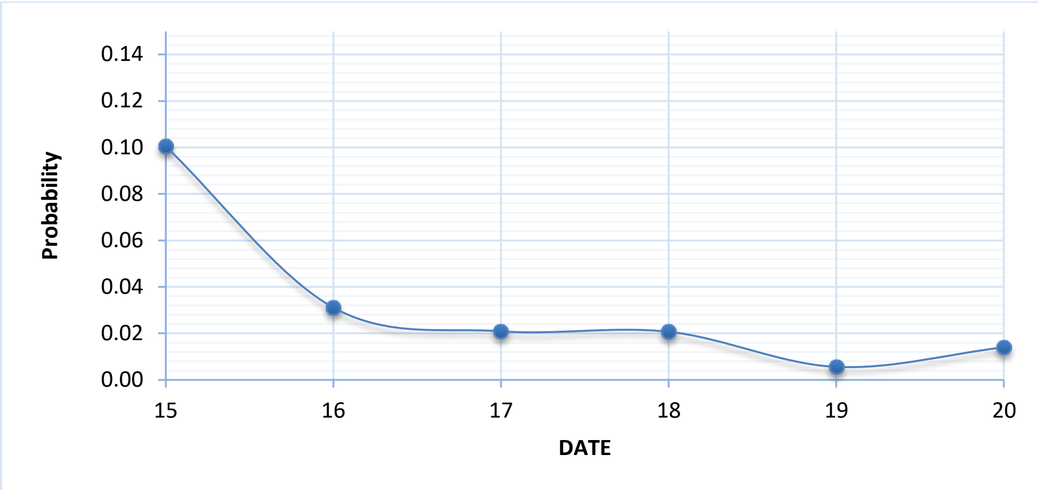

Figure 16: Variation of collision risk for Singapore port in April 2019 (mostly occasional, sometimes probable)

From the graphs of collision risk probability vs. date, it can be seen that the collision risk for Singapore port in the month of January gradually increases until 20 January 2019. There is a sudden increase/spike in the risk values in between 20 January 2019 and 25 January 2019 and thereafter it decreases for the remaining days in that month. The risk value remained in the remote region during the beginning (until 20th) but entered the occasional region because of the spike in the middle and persisted in that region (20th to 30th of April 2019).

For April 2019, the collision risk starts to decrease from 15th upto18th and increase slightly from there. This risk remains in the occasional region for most of the time. But for the date 18th, 19th, and 20th April 2019 it belonged to the remote region.

Comparison of Models

A comparison according to the probability index for the two models can be shown in Figure 17, Figure 18, Figure 19 and Figure 20 for January 2019 and April 2019.

Comparison of January 2019

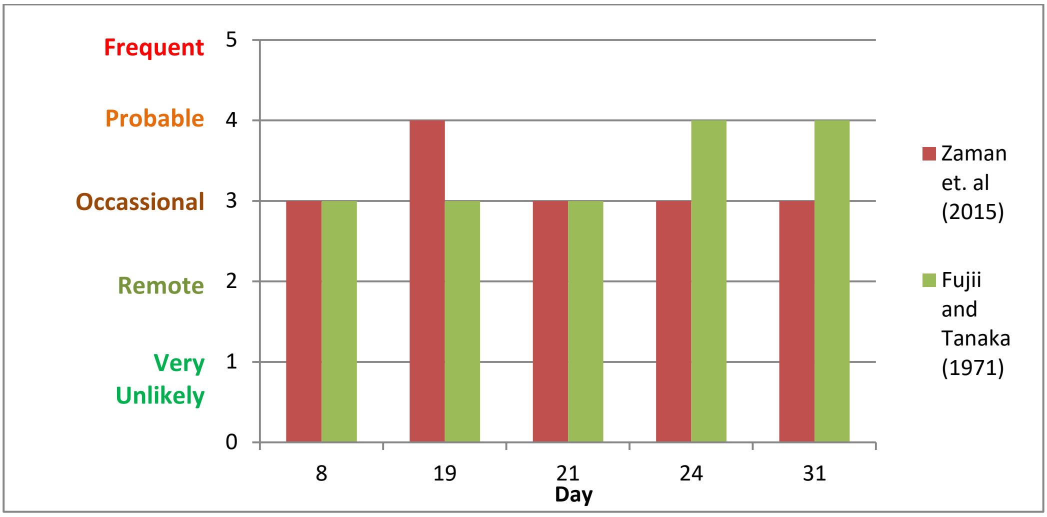

Figure 17: A comparison between Zaman et. al (2015) model vs Fujii and Tanaka (2015) model using Probability Index for January 2019

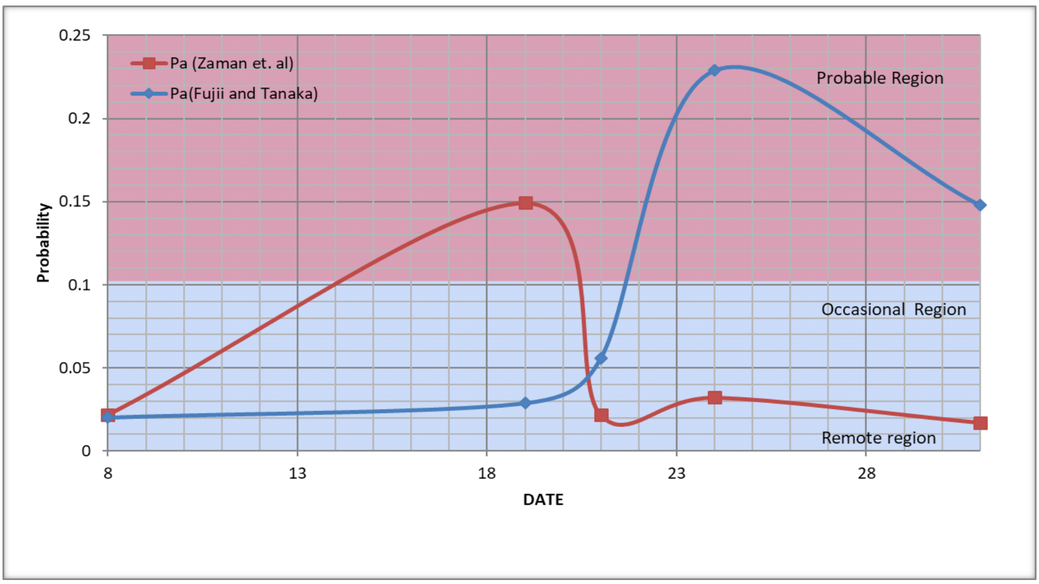

Figure 18: A combined risk curves of between Zaman et. al (2015) model and Fujii and Tanaka (1971) model using Probability Index for January.

Comparison of April 2019

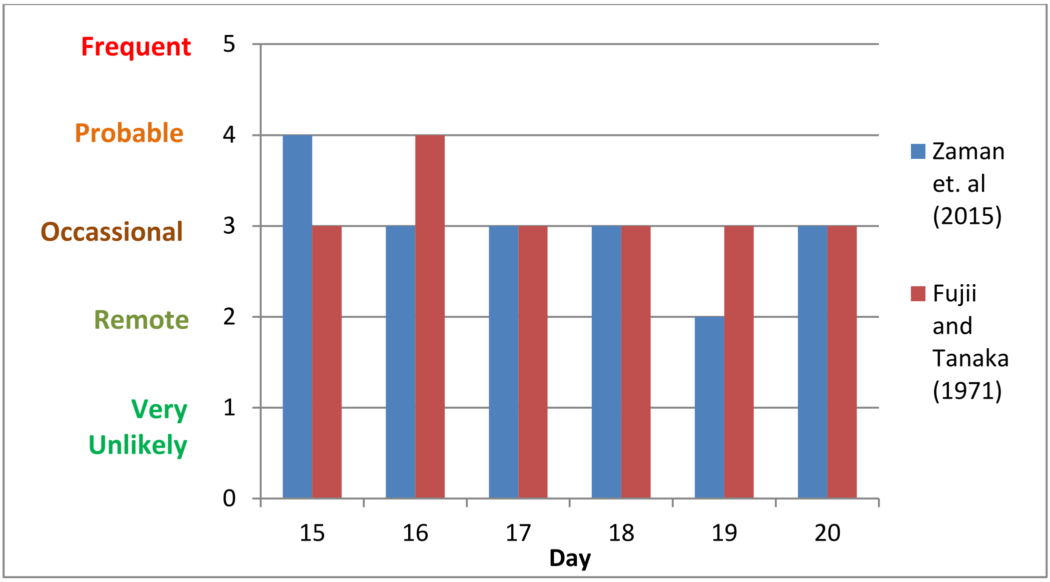

Figure 19: A comparison of probability index for April

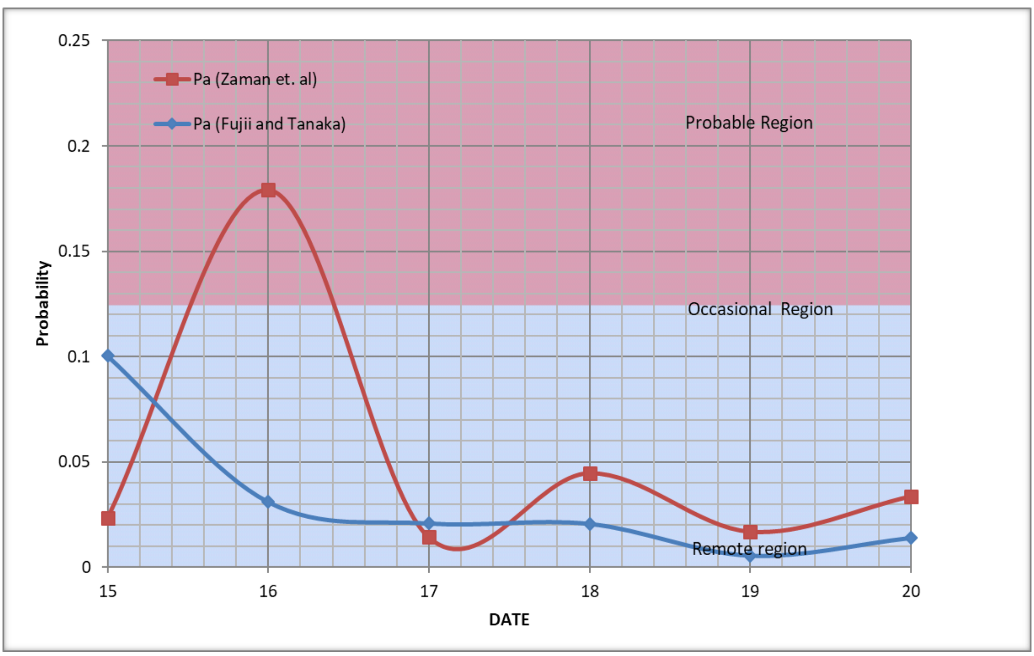

Figure 20: A combined risk curves of Probability Index for April 2019.

Comparison Table

A comparison between the two methods that are considered in this paper is shown in Table 8 below where various topics and particulars are described.

Table 8: Model comparison Fujii and Tanaka (1971) vs. Zaman et. al (2015).

No.	Topic	Model of Fujii and Tanaka (1971)	Model of Zaman et. al (2015)
1.	Required parameters	Velocity of the ships are required	Velocity is not needed, only vessel length and breadth are required.
2.	Area Size	Varies between 9.5 to 16.3 times of ship length	Not fixed
3.	Zone/Area of study	Area of study is selected around a single ship depending on the density of the ships	Any random area/port can be selected for probability analysis
4.	Collision scenario	Ships are considered as entering or exiting	3 situations are considered I. Head-on II. Crossing III. Overtaking
5.	Time dependency	More time dependent	Less time dependent

Conclusion

Based on the investigation the following conclusions can be drawn:

1. From the probability index and consequence categories it can be stated that the collision risk for the Chittagong port for different months is more likely a heartbeat shape and in the probable region (once per 1-10 years). Using more advanced techniques can make the time shorter.
2. Head on, Crossing, overtaking; these three situations are found to be the most frequently occurred situations for all the ports.

3. There are limitations for Fujii's method which is because of:
    a. Evasive action is quite conservative (diameter of evasion taken randomly)
    b. Random vessel is taken for calculation where other random vessels could have also been taken.
4. For the study zone Zaman et. al (2015) method gives higher risk probability and Fuji and Tanaka (1971) method gives comparatively lower risk probability.
5. Zaman et al (2015) method results in less fluctuation compared to Fujii and Tanaka (1971).

Recommendation

The following recommendations are made for future research and developments:

1. Increasing the sample size may produce an overall status of ship collision risk. Also, live automatic identification system (AIS) data may be used to produce real-time risk scenario.
2. Deep learning or machine learning technique may be used to identify potential risk candidates. Such a development may be useful in practically applicable automated risk control systems.
3. For future studies, other models of risk evaluation may be considered and their merits/demerits may be investigated.
4. Automatic Radar Plotting Aid (ARPA) can be incorporated in future research to evaluate collision probabilities. Using artificial intelligence with ARPA, smart ships may evaluate their own risk and suggest/conduct safe maneuvers in confined water areas.

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