ASSESSMENT OF COLLISION & GROUNDING RISK at CHITTAGONG PORT, BANGLADESH

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ABSTRACT

Analysis of an updated waterway accident database from 1981-2013 in Bangladesh shows 57.96% accidents were due to collision and grounding, which were 76.92% at Chittagong Port (CP). Ever growing traffic along with increment in maximum permissible length and depth at CP will increase the risk of collision & grounding in future. In this study, previous risk analysis of collision accidents by authors is rectified firstly by inclusion of recently installed Vessel Traffic & Management Information System (VTMIS) in Chittagong Port Authority (CPA) in prediction of collision frequency by IWRAP MK2 software. Secondly, grounding Causation Probability at CP is evaluated for the first time by a localized Bayesian Belief Network (BBN) on Hugin Researcher software. Both recent and future risk scenarios are modeled intending to help in future decisions on upgrading safety standards. The proximity between the historical database and IWRAP value has been found regarding collision accident frequency. Causation Probability of grounding has been found to be 0.000934. An insight on how to propose Risk Control Options (RCOs) has been provided by “Most likely situation” analysis. Such analyses can be carried out on different ports and channels worldwide to calculate collision or grounding risk and ensure safety.

Keywords: Risk Analysis, Collision, Grounding, BBN Model, IWRAP

1.0 INTRODUCTION

Risk Analysis is a systematic approach to evaluate the level of safety of a system with recommendations on Risk Control Options (RCOs) that incorporates both frequency and consequence estimation. The risk of ship accidents has increased drastically in the past few decades for increasing freight transportation all over the world. Pedersen et al. have specified that more than 1.5% of all ships are involved in a severe and costly accident annually, resulting in loss of lives, property, and environment [11]. Marine transportation is the primary means for freight transportation all over the world. Economic growths, as well as ever-growing consumption, have

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drastically increased vessel movement in last few decades in international, territorial and inland waterways all around the world. An increase in the freight requires more vessels to carry them and impose greater risk and loss. Major structural damage, loss of life or property and pollution are the consequences of collision and grounding accidents. Collision and grounding accidents are considered as the main ways to cause large oil spills from ships. Ship grounding accounts for about one-third of commercial ship accidents [4,8]. The scenario is not much different in Bangladesh. In our previous study, we reported the trend in marine accidents of Bangladesh as well as Chittagong port (CP) from an updated database [6,7]. Being the primary seaport in Bangladesh, CP handles over 90% of the total maritime trade [7]. With recent decision on increasing the allowable draft in already a shallow Karnafully river channel will make it more prone to grounding accident. The present allowable draft and length is 9.5 m and 190 m respectively.

In this study, the recent accident information has been collected from the Chittagong Port Authority (CPA), and the accident database has been updated. The prediction from the IWRAP Mk2 model on Karnafully river has been evaluated based on the actual collision accident frequency. The effect of the inclusion of Vessel Traffic & Management Information System (VTMIS) in CP has been evaluated regarding a separate model in IWRAP Mk2 software using the already reported causation probability [7]. Moreover, a systematic way to propose risk control options have been investigated in which the most influential states are considered in the evaluation of causation probability using the Bayesian Belief Network (BBN) model.

2.0 ACCIDENT SCENARIO

Hansen et al. [2] mentioned that the causes of marine accidents are divided into four groups namely as due to maneuvering, incapacitation of personnel, technical problems and environmental causes. Merging the first two groups into one, the groups can be renamed as the Human error, Technical error and Environmental facto. In the reference [6], the authors have developed accident database in Bangladesh based on the data from 1981 to 2013 and the results are summarized in Table 1. It is found that Human error causes around 62% of accidents that occur all over Bangladesh. The second most significant factor is the Environmental factor with 33% causation percentage. In case of all accidents in Chittagong Port, Human error causation percentage rises to 75% and Technical error is the second significant one instead of the Environmental factor.

The percentage of causes of collision in Chittagong Port can be also found from Table 1, which is evaluated from 33 collisions recorded in Chittagong Port since 1981. While Human error is involved in 80% of all navigational accidents in the world according to Hansen et al. [2], Human error is 87.87% in case of collision accidents in Chittagong Port. Actually, a few accidents are caused by anchor dragging in Chittagong Port which is due to Human error as well as excessive current. Those accidents are taken both as Human error and Environmental factor. Except Human error involved in anchor dragging, the percentage of Human error becomes 57.57% for collision type of accidents in Chittagong Port as shown in Table 1.

Table 1: Factors of accidents in Bangladesh (1981-2013)

<table>
<thead>
<tr>
<th>Factors</th>
<th>In all Accidents in Bangladesh</th>
<th>In all Accidents at CP</th>
<th>In Collisions at CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Error</td>
<td>62%</td>
<td>75.36%</td>
<td>57.57% (87.87%)</td>
</tr>
<tr>
<td>Environmental Factor</td>
<td>33%</td>
<td>8.7%</td>
<td>33.33%</td>
</tr>
<tr>
<td>Technical Factor</td>
<td>5%</td>
<td>15.94%</td>
<td>9.09%</td>
</tr>
</tbody>
</table>
In this study, we updated the accident database to understand the recent accident trends in Chittagong Port Bangladesh. Collision accident data of the last four years have been obtained from Chittagong Port Authority and listed in Table 2. It can be seen that the vessels handled by CPA are gradually increasing. On the other hand, collision/1000 handled vessels have an approximate value of 2-3 with an exception in the fiscal year 2013-14. In case of grounding, five new accidents were reported in the last four years and 3 of those were in Karnafully river channel.

Table 2: Collision per 1000 handled vessels in Chittagong port

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

3.0 INFLUENCE of VTMIS on COLLISION FREQUENCY

In collision and ground risk analysis we have used both Hugin researcher and IWRAP Mk2 software. Causation probability ($P_C$) in the equation proposed by Fuji et al. [3] and Macduff et al. [9] has been calculated by Hugin researcher for both collision and grounding, whereas the collision frequency is calculated by creating collision models in IWRAP Mk2 software. IWRAP models to calculate collision frequency in Chittagong Port has been constructed to simulate four different situations at present and in future. The different situations are:

1) Collision Frequency Calculation Model 2013: This model calculates collision frequency based on the traffic frequency and Causation Probability data of 2013.
2) Collision Frequency Calculation Model 2014: This model calculates collision frequency based on the modified traffic frequency and Causation Probability data of 2014. Causation Probability for 2014 is found from VTMIS inclusion in BBN.
3) Collision Frequency Calculation Model 2020a: This model calculates collision frequency in Chittagong Port based on the modified traffic frequency for 2020 calculated from vessel growth rate but unchanged Causation Probability of 2014.
4) Collision Frequency Calculation Model 2020b: This model calculates collision frequency in Chittagong Port based on the modified traffic frequency for 2020 calculated from vessel growth rate and changed Causation Probability for the inclusion of VTMIS (=working) observation.

It has been found that VTMIS inclusion changes collision Causation Probability ($P_C$) to 1.515E-04 from 2.014E-04 [7]. So, VTMIS reduces $P_C$ by 24.74% in Chittagong Port. Total collision probability that includes the geometrical probability of collision apart from Causation Probability will be reduced more than 30% as VTMIS ensures a better traffic distribution that aids to less collision. If we assign an observation as VTMIS (=working) to be 100, which means all the vessels are aided with VTMIS receiver, $P_C$ becomes 1.081E-04. So, VTMIS installation in all the vessels will result in a reduction of Causation Probability by 46.33% [7].
A thorough understanding of causation probability can help to understand critical situations in an accident. The magnitude of different types of Causation Probabilities in IWRAP Mk2 software has default values that are adapted from the work of Fujii et al. and were initially defined for Japanese Waters [10]. The Values are given in Table 3.

<table>
<thead>
<tr>
<th>Types of Encounter</th>
<th>Causation Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head-on</td>
<td>$0.5 \times 10^{-4}$</td>
</tr>
<tr>
<td>Overtaking</td>
<td>$1.1 \times 10^{-4}$</td>
</tr>
<tr>
<td>Crossing</td>
<td>$1.3 \times 10^{-4}$</td>
</tr>
<tr>
<td>Bend</td>
<td>$1.3 \times 10^{-4}$</td>
</tr>
<tr>
<td>Merging</td>
<td>$1.3 \times 10^{-4}$</td>
</tr>
<tr>
<td>Grounding</td>
<td>$1.6 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

In this study, the default IWRAP Causation Probability values given in Table 3 are substituted by the Causation Probability value found from the BBN model used by Khaled et al. for CP [7]. For different give way situations (= head-on, overtaking, crossing, bending) scenarios, causation reduction factors are estimated which indicate the change of the specified causation factors for a particular state such as Place(=Straight Channel), Place(=Outer Anchorage), Place(=Bend) and Place(=River Mouth). These factors are calculated for all the four different models separately. Cause reduction factors for collision frequency for the model 2013 can be found from the primary BBN network without VTMIS [7]. On the other hand, causation reduction factors for collision frequency calculation model 2014 as well as collision frequency calculation model 2020a are found from the BBN model with VTMIS. Moreover, Causation reduction factors for collision frequency calculation model 2020b are calculated from the BBN model with VTMIS for an observation VTMIS (=working) and given in Table 4. For instance, Causation Probability for give way situation (=overtaking) is $2.65E-04$ and for observation of place (=straight channel), the Causation Probability will be $2.61E-04$. So, causation reduction factor for place (=straight channel) is $1.014$ in Table 4 and can be found by simply dividing the former by the latter.

<table>
<thead>
<tr>
<th>Give Way Situation</th>
<th>Head-on $(\times 10^{-4})$</th>
<th>Overtaking $(\times 10^{-4})$</th>
<th>Crossing $(\times 10^{-4})$</th>
<th>Bending $(\times 10^{-4})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified Causation Probability</td>
<td>0.2138</td>
<td>2.6512</td>
<td>1.1053</td>
<td>0.9472</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Place</th>
<th>Causation Reduction Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight Channel</td>
<td>0.9160</td>
</tr>
<tr>
<td>Outer Anchorage</td>
<td>1.203</td>
</tr>
<tr>
<td>Bend</td>
<td>1.049</td>
</tr>
<tr>
<td>River Mouth</td>
<td>1.2113</td>
</tr>
</tbody>
</table>

IWRAP Mk2 model requires information on route, waypoints, legs and traffic distribution. Most of this information is obtained from the hydrographic chart and maps from Bangladesh Navy. However, traffic distribution in Chittagong Port channel is assumed as a normal distribution. Karlsson et al. have specified the deviation in the Gaussian distribution is taken as 40% of the width
of the navigational channel [5]. They have also found the geometrical distribution of Oresund between Denmark and Sweden to be composed of 98% Gaussian and a 2% uniform distribution, which has been taken as reference for standard deviation for all straight channel, bend, and outer anchorage legs. Figure 1 shows waypoint 6 to 13 in the IWRAP model.

![Figure 1: IWRAP model, waypoint 6 to 13](image)

Collision frequency results are shown in Table 4. It was found that the total number of accidents predicted by the model was 15 and 12 respectively in 2013 and 2014, whereas the actual collision frequency was 5 and 17 (Table 2). Hence, the sensitivity of the model is well justified in the context of CP. Later, we have also modeled two scenarios namely as 2020a and 2020b by taking into account the gradual increment of handled vessels and VTMIS installation. The number of accidents predicted by these two models is 15 and 11 respectively, which indicates that VTMIS usage in all vessels will be able to reduce four accidents per year. A further look in the results also shows that not turning in time (bend) in Karnafully river channel (mostly at the bends) remain the most severe cause for collision.

### Table 4: Predicted Collision Frequency in Chittagong Port

<table>
<thead>
<tr>
<th>Collision Scenario</th>
<th>Model 2013</th>
<th>Acc. /Year</th>
<th>Model 2014</th>
<th>Acc. /Year</th>
<th>Model 2020a</th>
<th>Acc. /Year</th>
<th>Model 2020b</th>
<th>Acc. /Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overtaking</td>
<td>0.2816</td>
<td>3</td>
<td>0.4218</td>
<td>2</td>
<td>0.3172</td>
<td>3</td>
<td>0.4366</td>
<td>2</td>
</tr>
<tr>
<td>Head-on</td>
<td>0.4887</td>
<td>2</td>
<td>0.4995</td>
<td>2</td>
<td>0.3837</td>
<td>2</td>
<td>0.5658</td>
<td>2</td>
</tr>
<tr>
<td>Crossing</td>
<td>0.9406</td>
<td>1</td>
<td>1.078</td>
<td>1</td>
<td>0.8152</td>
<td>1</td>
<td>1.168</td>
<td>1</td>
</tr>
<tr>
<td>Bend</td>
<td>0.1124</td>
<td>9</td>
<td>0.144</td>
<td>7</td>
<td>0.1111</td>
<td>9</td>
<td>0.1561</td>
<td>6</td>
</tr>
<tr>
<td>Total Collision</td>
<td>0.06427</td>
<td>15</td>
<td>0.08168</td>
<td>12</td>
<td>0.06254</td>
<td>15</td>
<td>0.08835</td>
<td>11</td>
</tr>
</tbody>
</table>

### 4.0 MOST INFLUENTIAL STATES

The BBN model for evaluation of causation probability has been developed using HUGIN Researcher software [7], which allows to evaluate the influence of different states on Collision (=yes) state. In order to suggest risk control option, an index with those states causing maximum Causation Probability should be constructed. In the software, if we input evidence of a certain state in a node, i.e., assigning the evidence/observation as 100%, it changes the probability of Collision. The upgraded probability can be assigned the probability of Collision (=yes) state for a certain observation.
A comparative study of Figure 2 a) and Figure 2 b) indicates the change in collision (=yes) evidence for a change in the evidence of give Way (= neither ship change direction) with a certain observation. The value of collision (=yes) changes from 0.020142% to 25% for an observation of give Way (= neither ship change direction). So, it can be concluded that neither ship give way situation increases the probability of collision to 25%. Such, nodes with maximum influence on collision (=yes) state are included in Table 5. The same operation was carried out for all other nodes.

Table 5: Maximum Influential Nodes on Collision (=yes) state.

<table>
<thead>
<tr>
<th>Node</th>
<th>State</th>
<th>Conditional Probability of Collision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Give Way</td>
<td>Neither Ship Give Way</td>
<td>0.25</td>
</tr>
<tr>
<td>Technical Error</td>
<td>Occur</td>
<td>0.0766</td>
</tr>
<tr>
<td>Loss of Control</td>
<td>Yes</td>
<td>0.7456</td>
</tr>
<tr>
<td>Human Error</td>
<td>Occur</td>
<td>0.0744</td>
</tr>
<tr>
<td>Environmental Error</td>
<td>Unsafe</td>
<td>0.0738</td>
</tr>
<tr>
<td>Maneuvering Assessment</td>
<td>No Assessment</td>
<td>0.007513</td>
</tr>
<tr>
<td>Vigilance</td>
<td>Not Available</td>
<td>0.007513</td>
</tr>
<tr>
<td>Proper Manning</td>
<td>No man</td>
<td>0.00948</td>
</tr>
</tbody>
</table>

From Table 5, we can find that Technical Error, Human Error, and Environmental Error are among the top five influential nodes on collision (=yes) state. In the BBN model, the above three nodes are included as the accumulation of those factors that cause loss of control. The nodes are influential on collision (=yes) state as those are only three arc distance from the node collision in the BBN model used for collision [7]. Moreover, the primary reason to carry out this analysis is to find the most influential nodes in the BBN model and propose some Risk Control Option (RCO) against them. Because, proposing common RCO for decreasing Human Error and others are extremely tough as many variables are included in those, a further analysis was carried out to find out the influencing nodes on Human Error, Technical Error, and Environmental Factor separately.

In the case of Human Error, the top seven states and nodes are given in Table 6. Also, the most influential states and nodes on Technical Error and on Environmental Factor are given in Table 7 and Table 8 respectively.
<table>
<thead>
<tr>
<th>Node</th>
<th>State</th>
<th>Conditional Probability of Human Error</th>
<th>Conditional Probability of Collision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maneuvering Assessment</td>
<td>No assessment</td>
<td>0.10</td>
<td>0.0075</td>
</tr>
<tr>
<td>Vigilance</td>
<td>Not available</td>
<td>0.10</td>
<td>0.0075</td>
</tr>
<tr>
<td>Proper Manning Turn</td>
<td>No man</td>
<td>0.011</td>
<td>0.00095</td>
</tr>
<tr>
<td>Turn</td>
<td>Don’t need to turn but turn</td>
<td>0.0034</td>
<td>0.000309</td>
</tr>
<tr>
<td>Performance</td>
<td>Poor</td>
<td>0.0032</td>
<td>0.0003064</td>
</tr>
<tr>
<td>Competence</td>
<td>Low</td>
<td>0.0028</td>
<td>0.003064</td>
</tr>
<tr>
<td>Personnel Condition</td>
<td>Unfit</td>
<td>0.00873</td>
<td>0.00061770</td>
</tr>
</tbody>
</table>

Table 7: Most Influential nodes on Technical Error

<table>
<thead>
<tr>
<th>Node</th>
<th>State</th>
<th>Conditional Probability of Technical Error</th>
<th>Conditional Probability of Collision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship Type</td>
<td>Trawler</td>
<td>0.000994</td>
<td>0.0004794</td>
</tr>
<tr>
<td>Communication Equipment</td>
<td>Not Available</td>
<td>0.00081885</td>
<td>0.00052876</td>
</tr>
<tr>
<td>RADAR Function</td>
<td>Not Available</td>
<td>0.00081885</td>
<td>0.00047212</td>
</tr>
<tr>
<td>Steering Gear</td>
<td>Not Capable</td>
<td>0.00074573</td>
<td>0.00070313</td>
</tr>
<tr>
<td>Engine Condition Place</td>
<td>Straight Channel</td>
<td>0.00030216</td>
<td>0.00039926</td>
</tr>
<tr>
<td>Country of Origin</td>
<td>Local</td>
<td>0.00029393</td>
<td>0.00044177</td>
</tr>
</tbody>
</table>

Table 8 Most Influential nodes on Environmental Factor

<table>
<thead>
<tr>
<th>Nodes</th>
<th>State</th>
<th>Environmental Factor</th>
<th>Causation Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current &amp; Wind</td>
<td>Excessive</td>
<td>0.00109124</td>
<td>0.00044058</td>
</tr>
<tr>
<td>Weather</td>
<td>Stormy</td>
<td>0.00101697</td>
<td>0.00043601</td>
</tr>
<tr>
<td>Turbulence</td>
<td>Present</td>
<td>0.00082885</td>
<td>0.00041940</td>
</tr>
</tbody>
</table>

The above nodes are most influential on collision as well as on Human Error, Technical Error, and Environmental Factor. To decrease collision in CP, it will be a good idea to take care of the above nodes first and propose RCO based on these.

5.0 GROUNDING CAUSATION PROBABILITY

In this study, a BBN model to estimate grounding Causation Probability for CP has been developed as well. This model has 45 nodes. Values of the BBN nodes are generally obtained from the historical data source, subjective measurements, and expert opinions. In order to obtain practical knowledge about the data type, DNV (2003) model was analyzed thoroughly and reproduced by HUGIN [1]. Conditional Probability Tables (CPT) in DNV (2003) grounding model are used as the reference in several nodes of the localized BBN model for CP. Accident database, Chittagong Port Authority (CPA) website, Bangladesh meteorological society website, etc. were used as historical data source. Expert opinions were obtained from CPA personnel, DOS personnel, and a container vessel’s captain by asking questionnaire. Figure 3 depicts the grounding BBN model.

45 nodes in the BBN for CP have been divided into several categories. The categories are:
1. Visual detection: weather, visibility, daylight, local familiarization.
2. Navigational aid detection: radar function, ECDIS, Paper chart, communication equipment, detection, maneuvering path, buoy.
3. Human factors: duties, non-navigational task, other distractions, distraction level, tired, stress level, incapacitated, personnel condition, competence, performance, maneuvering assessment, training.
5. Support: pilot vigilance, proper manning, lookout, vigilance, communication.
6. Overall: loss of control.
9. Other: ship types, place, country of origin, turn, grounding.

Figure 3: Grounding BBN model for CP

As a localized waterway accident problem is analysed in this study taking into account different local factors, which are included in category 7. Figure 3 shows all nodes and interconnections. The probability of different states can also be found in adjacent monitor windows. The leaf or output
node for this BBN model is “Grounding” that has two states ‘yes’ and ‘no’. The probability of Grounding (=yes) state will give us $P_{C,\text{grounding}}$ for CP. The monitor windows for all the nodes are shown in Figure 4. $P_{C,\text{grounding}}$ is found to be 0.000934 in the developed BBN model, while $P(\text{Grounding}=\text{yes}) = 0.000015$ in the DNV model [1]. It should be noted that DNV model has only calculated power grounding probability and drifting type of grounding was excluded from there. Causation Probability for Chittagong should be higher taking into regard both power and drifting type of grounding as well as the narrow channel.

Figure 4: Grounding BBN model for CP with monitor windows
6.0 CONCLUSIONS
The conclusions of this study can be summarized as follows.
(1) In this study, we updated the accident database to understand the recent accident trends in Chittagong Port Bangladesh. It has been found that approximately 2-3 collision accidents are occurring per thousand handled vessels.
(2) By using the developed BBN model to estimate the causation probability of collision, a careful study has been done to check the positive effect of using VTMIS. It has been found that VTMIS will help to reduce four accidents per year in Karnafully river channel.
(3) In this study, a systematic approach has been proposed to obtain useful insight on Risk Control Options (RCOs) by "Most likely situation" analysis on the BBN model. The factors having the maximum influence on accident (collision/grounding) should be handled to avoid any unfortunate event and loss of life.
(4) A BBN model to estimate grounding Causation Probability for CP has been developed in this study. Though grounding accidents are not that severe compared to the collision, there is always a high chance of grounding accident at the shallow Karnafully river channel. A primary study on the grounding accident with a localized BBN model gave a grounding causation probability of 0.000934, which means there is a probability of grounding accident on every 1000 handled vessels.
(5) Further analysis on the grounding trend and evaluation of collision frequency along with using a modified traffic distribution from the Automatic Identification System (AIS) will be beneficial in a more reliable prediction.

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