BACHELOR THESIS & COLLOQUIUM – ME 184841

FORMAL SAFETY ASSESSMENT FOR SHIP COLLISION IN BALI STRAIT

DHANANG AJI PURNOMO
NRP 04211541000005

SUPERVISOR:
A.A. Bagus Dinariyana Dwi P., ST., MES., Ph.D
Prof. Dr. Ketut Buda Artana, ST., M.Sc

DOUBLE DEGREE PROGRAM
DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
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TUGAS AKHIR – ME 184841

FORMAL SAFETY ASSESSMENT UNTUK TUBRUKAN KAPAL DI SELAT BALI

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DEPARTEMEN TEKNIK SISTEM PERKAPALAN
FAKULTAS TEKNOLOGI KELAUTAN
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
SURABAYA
2019

APPROVAL FORM

FORMAL SAFETY ASSESSMENT FOR SHIP COLLISION IN BALI STRAIT

BACHELOR THESIS

Submitted to Comply One of The Requirement to Obtain a Bachelor Engineering Degree
On
Reliability, Availability, Management, and Safety (RAMS)
Bachelor Program Department of Marine Engineering
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember

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NRP	: 04211541000005
Bachelor Thesis Title	: Formal Safety Assessment for Ship Collision in Bali Strait
Department	: Marine Engineering

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Surabaya, 2019

Dhanang Aji Purnomo

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FORMAL SAFETY ASSESSMENT FOR SHIP COLLISION IN BALI STRAIT

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Abstract

The Bali Strait is one of the important straits in Indonesia due to the high density of ships that pass through the Bali Strait. With the high volume of ship traffic, especially passenger ships, with a total crossing of 190,820 trips per year in the Bali Strait, this has the possibility of ship accidents especially ship collisions. In this study, the analysis carried out for ship collision in the Bali Strait uses the Formal Safety Assessment (FSA) which consists of five steps of obtaining mitigation to reduce the level of risk. Hazard Identification is using the Brainstorming method from DNV. Risk analysis has two stages consists of frequency analysis carried out using IWRAP Theory where to obtain a causation probability from ship collision using Bayesian Network model and the consequence of analysis is by making modeling the distribution of oil spills from tankers due to ship collisions that occur using GNOME software. Risk Control Option (RCO) is a mitigation option to avoid collisions. The Cost-Benefit Assessment (CBA) purpose is to assess the RCO. Recommendation aims to make the best selection of several mitigations with consideration of CBA. Based on the ship collision scenario that has been made, the total results for head-on, overtaking, crossing collision frequencies are 0.78, 4.03×10^{-3}, 6.42×10^{-2}. As for the simulation results with two different time conditions from the consequences of oil spills with a volume of 5439.39 m^3, it can be seen that the distribution of oil which evaporated or dispersed, floating and beached. From the risk assessment, it can be seen that the risk value is based on the DNV risk matrix for head-on collision in tolerable level, crossing collision in unacceptable level, and the overtaking collision in unwanted level. The RCO produces mitigation which are AIS, ECDIS, and training navigators. The best option for mitigation that can be applied based on the cost benefit assessment is the installation of Automatic Identification System (AIS). This option give the most cost effective due to the lowest gross cost and net cost value. The benefits cost of impelementing AIS is IDR 28,189,470,772.00 and the reduction risk is 10%.

Keywords: Bali Strait, Bayesian Network, Formal Safety Assessment, GNOME, Ship Collision

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FORMAL SAFETY ASSESSMENT UNTUK TUBRUKAN KAPAL DI SELAT BALI

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Abstrak

Selat Bali merupakan salah satu selat yang penting di Indonesia dikarenakan tingginya densitas kapal yang melewati Selat Bali. Dengan tingginya volume lalu lintas kapal terutama kapal penumpang dengan jumlah penyebrangan sebanyak 190.820 *trip* per tahun yang berada di Selat Bali, maka hal tersebut memiliki kemungkinan untuk terjadinya kecelakaan kapal khususnya tubrukan kapal. Pada studi ini, analisa yang dilakukan untuk tubrukan kapal di Selat Bali menggunakan *Formal Safety Assessment* (FSA) yang terdiri dari lima tahapan mendapatkan mitigasi untuk menurunkan tingkat risiko. *Hazard Identification* dilakukan dengan menggunakan metode *brainstorming* dari DNV. *Risk Analysis* memiliki dua proses yang terdiri dari frekuensi analisis yang dilakukan menggunakan IWRAP *Theory* dimana untuk mendapatkan *causation probability* dari tubrukan kapal menggunakan *Bayesian Network* model dan konsekuensi analisis dilakukan dengan membuat permodelan persebaran tumpahan minyak dari kapal tanker akibat tubrukan kapal yang terjadi dengan menggunakan software GNOME. *Risk Control Option* (RCO) merupakan pilihan mitigasi untuk menghindari terjadinya tubrukan. *Cost-Benefit Assessment* (CBA) bertujuan untuk menilai RCO. *Recommendation* untuk melakukan pemilihan terbaik dari beberapa mitigasi dengan pertimbangan CBA. Berdasarkan skenario tubrukan kapal yang telah dibuat, hasil total untuk frekuensi *head-on, overtaking, crossing collision* adalah 0.78, 4.03×10^{-3}, 6.42×10^{-2}. Sedangkan untuk hasil simulasi dengan dua kondisi waktu berbeda dari konsekuensi tumpahan minyak dengan volume 5439.39 m^3 dapat diketahui distribusi persebaran minyak yang terevaporasi atau terdispersi, mengambang, dan mencemari daratan. Dari risk assessment, dapat dilihat bahwa nilai risiko berdasarkan risk matriks DNV untuk *head-on collision* di *tolerable level*, *crossing collision* berada pada *unacceptable level*, dan *overtaking collision* berada pada *unwanted level*. RCO menghasilkan mitigasi berupa AIS, ECDIS, dan *navigator training*. Pilihan terbaik untuk mitigasi yang dapat diaplikasikan yaitu *Automatic Identification System* (AIS). Pilihan ini merupakan biaya paling efektif dikarenakan nilai *Gross Cost* dan *Net Cost* terendah. Keuntungan biaya dari mengaplikasikan AIS sebesar IDR 28,189,470,772.00 dan penurunan nilai risiko yaitu 10%.

Kata Kunci: Bayesian Network, Formal Safety Assessment, GNOME, Tubrukan Kapal, Selat Bali

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PREFACE

Above all, the author gave thanks and praise to the Almighty God, Allah SWT and also Prophet Muhammad saw who has given me strength and wisdom so that the author can complete his studies and this bachelor thesis. Hopefully with the completion of this research study, authors gain more perspectives, information, and knowledge for the future career.

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The author concerns for the imperfection in this thesis. Therefore, any criticism and suggestion are expected. The author hoped this thesis will provide benefits primarily for the readers.

Surabaya, 2019

Dhanang Aji Purnomo

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CHAPTER 1
INTRODUCTION

1.1. Background

Indonesia is an archipelagic country which has a thousand islands. With such geographical conditions in Indonesia, sea transportation mode is needed to connect one island to another so that it can also have an impact on the economic and social distribution of the people that is evenly distributed. The number of passengers using sea transportation services is increasing, it needs followed by better quality of service to prospective passengers. On the other hand, safety is important to ensure hazards that can cause asset damage or fatalities can be avoided. Then, it requires more effort to avoid the accident that one of the losses can happen.

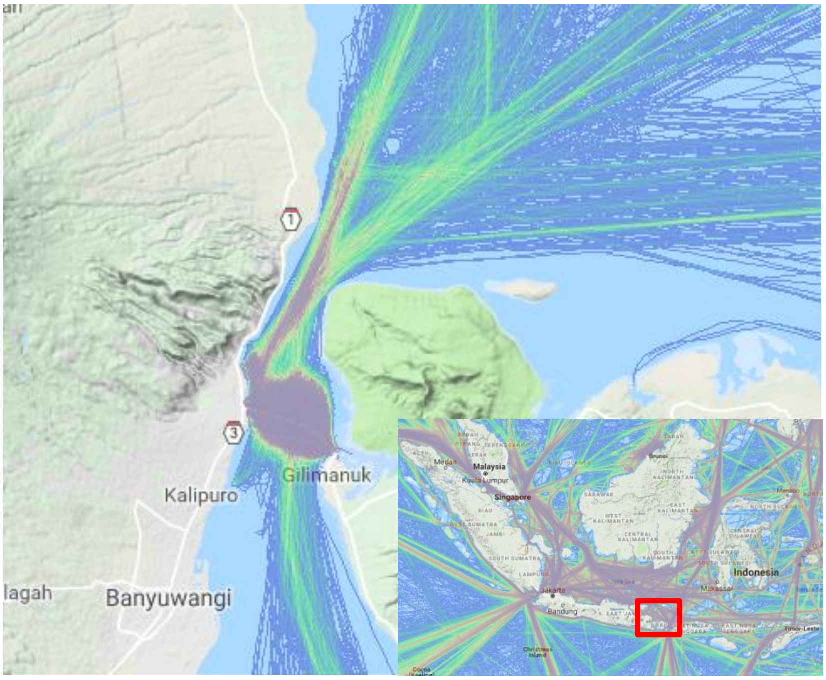

Figure 1. 1 Bali Strait
Source: marinetraffic.com

Bali Strait is a strait that separating Java and Bali while connecting the Indian Ocean and the Bali Sea. The coordinates of Bali Strait is -8° 05' 60.00" S and 114° 25' 29.99" E. The depth of sea level in Bali Strait is in the interval of 10 until 160 meters. This strait majority serves passenger ships which cross from Ketapang Port in Banyuwangi to Gilimanuk Port in Bali Island or vice versa. Also it has another port to accommodate cargo or tanker ship in Banyuwangi, named Tanjung Wangi Port.

According to the KNKT database, from 2010 to 2017 the number of accident every year almost increases. Ship accidents in Indonesia occurred mostly due to technical problems and human errors. Ship accidents due to technical problems is 51% and 49% due to human error. Therefore it is necessary to give recommendations to related parties to minimize the occurrence of marine transportation accidents, such as to port administration, classification bodies, ship operators, and crew members. In addition to the recommendations given to reduce the occurrence of accidents, the recommendations given can also be in the form of mitigation measures to minimize the occurrence of casualties when a ship accident occurs.

Table 1.1 Ship Accident Data of KNKT

NO	YEAR	TOTAL ACCIDENT	ACCIDENT TYPE					VICTIM	
			SINK ING	FIRES / EXPLOSION	COLLI SION	GROUN DING	ETC	DIED VICTIM	INJURED VICTIM
1	2010	5	1	1	3	0	0	15	85
2	2011	6	1	3	2	0	0	86	346
3	2012	4	0	2	2	0	0	13	10
4	2013	6	2	2	2	0	0	65	9
5	2014	7	2	3	2	0	0	11	4
6	2015	11	3	4	3	1	0	85	2
7	2016	18	6	4	3	1	2	46	18
8	2017	34	6	14	6	2	2	42	2

Based on ASDP data, the number of passenger ship which operated in the Bali Strait in 2018 was 52 ships. According to data from ASDP, the number of ships crossing in 2018 is 95,658 from Ketapang to Gilimanuk. These numbers is increased 94,962 ships in 2017. It can be seen from graphic below, that from 2011 to 2018 the number of ship crossing is increase 20%.

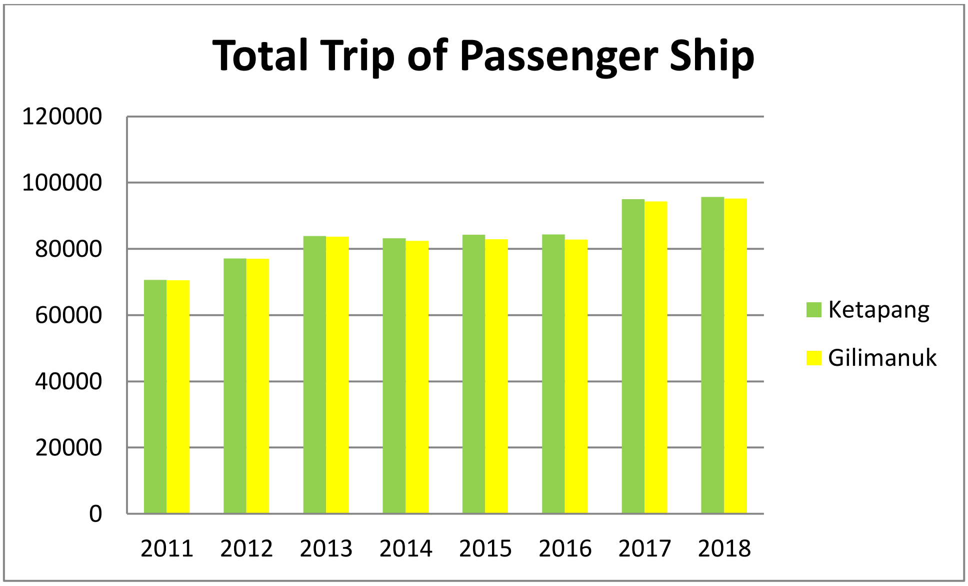

Figure 1. 2 Total Trip Data in Ketapang Port and Gilimanuk Port

The large number of roro vessels operating in the Bali Strait is followed by an increase in the number of crossing shipping, so that the Bali Strait has a risk of possible ship accidents. As an example in the case of the KMP Rafelia 2 accident that sank in the Bali Strait. The ship accident was caused by the ship experiencing overload so that the ship's load experienced an excess of 0.6 m or 559 tons which caused the ship's stability to not be good. Another type of ship accident in Bali Strait from 2010 to 2018 can be seen in the table below:

Table 1. 2 Ship Accident in Bali Strait Data 2010-2018

Year	Classification	Description
2010	Collision	Ship Collision between KM Shinpo 18 and KM Bosowa VI
2013	Grounding	Ship Accident of KMP Rafelia 2 in the entry channel of Padangbai, Bali
	Grounding	Ship Grounding KMP Citra Mandala Sakti around Red Bouy, Gilimanuk port
	Sinking	LCT Pancar Indah sinking due to bad ship condition and bad weather
2013	Collision	Ship Collision between KMP Gilimanuk with pile of Ketapang port, Banyuwangi
2015	Collision	LCT Perkasa Prima 05 collided with LCT Arjuna due to bad weather
2016	Sinking	KMP Rafelia 2 sinking in Bali Strait, 4 March 2016
2017	Collision	KMP Munic VII and KMP Tunu Pratama involved in a collision with cargo ship in Bali Strait
	Grounding	KMP Karya Maritim III grounding in Gilimanuk
2018	Collision	KMP Dharma Rosala collided with KMP Munic V

The problems that will be analyzed in this bachelor thesis are possibilities that can occur and the consequences that can lead to passenger ship accidents in Bali Strait. In order to improve navigation safety in the Bali Strait. This bachelor thesis estimates the frequency ship collision in the Bali Strait using the Bayesian Network method to determine the causation factor probability. The Bayesian Network model will be implemented using NETICA software. There are several consequences that can happen during ship collision. Beside the passenger vessel that crossing Bali Strait, also there are tanker ship that accommodate crude oil to Tanjung Wangi port. It has the possibility to collide with other vessel due to crossing line. From the accident, it can cause leaks in the tanker’s hull so the oil spills into the sea.

Based on the background, the author want to raise the topic of bachelor thesis “Formal Safety Assessment for Ship Collision in Bali Strait”. From the analysis will be generate recommendations to be able to minimize the accident rate, especially in the Bali Strait.

1.2. Statement of Problems

According to description above the statements of problems of this bachelor thesis are:

1. How to determine variables that potentially can affect ship collision in Bali Straits?
2. How to analyze the frequency so that the collisions of vessel in Bali Straits happen?
3. What are the consequences that can be generated from ship collision?
4. What is the mitigation recommendation that can be applied to preventing ship accident?

1.3. Constraints

For this research to be more focused and organized, there are some limitations on the problem which are:

1. The object of this research is about crossing vessel that operating in Bali Strait.
2. Causation probability analysis of ship collision using Bayesian Network method to determine frequency of ship collision in Bali Strait.
3. The consequence of ship collision is conducting the simulation of oil spill.

1.4. Objectives

Based on the problems mention above, the objectives of this research are:

1. Identify hazards from determining variables that can cause ship accidents in Bali Strait
2. To conduct of frequency analysis for determining the causation probability of ship collision using Bayesian Network method in Bali Strait
3. To determine the consequence of oil spill generated from ship collision
4. To minimize level of risk that consist of recommendation and mitigation to acceptable risks

1.5. Benefits

The several benefits of this bachelor thesis are:

1. The calculations and modeling can be additional information for relevant parties involved in operational in Bali Strait, so it can be used to preventing risk.
2. The research provided can be additional advice in making decision on shipping operations in the Bali Strait.

CHAPTER 2
STUDY LITERATURE

2.1. Formal Safety Assessment

Formal Safety Assessment (FSA) is a methodology that can be used as a tool to help in the evaluation in making a comparison between existing and possibly improved regulations with a view between the various technical and operational issues. By using risk analysis and cost-benefit assessment, the methodology aims to improve protection of life, health, the marine environment and property.

FSA consists of five steps:

1. Identification of hazards (a list of all relevant accident scenarios with potential causes and outcomes);
2. Assessment of risks (evaluation of risk factors);
3. Risk control options (devising regulatory measures to control and reduce the identified risks);
4. Cost benefit assessment (determining cost effectiveness of each risk control option); and
5. Recommendations for decision-making (information about the hazards, their associated risks and the cost effectiveness of alternative risk control options is provided).

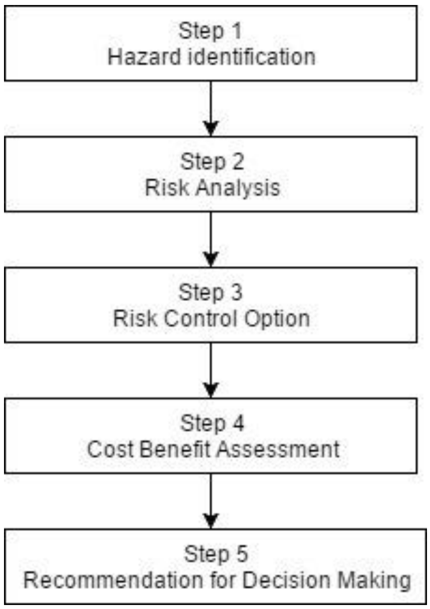

Figure 2. 1 FSA Process

2.1.1. Hazard Identification

This purpose is achieved by the use of standard techniques to identify hazards which can contribute to accidents. Hazard identification can be used with historical data

or expert judgments. It must be recognized that the modeling was proposed as an alternative to the FSA IMO guidelines, and various formal methods, such as Fault Trees, Event Trees, Influence Diagrams, Human Reliability Analysis (HRA), Human Element Analysis Process (HEAP), and possibly others, were proposed.
Hazard Identification can be done using this following method:
1. Literature Search
2. What-if review
3. Safety Audit
4. Walk-Through
5. Checklist
6. Brainstorming
7. Hazard and Operability (HAZOP)
8. Failure Mode and Effect Analysis (FMEA)

2.1.2. Risk Analysis

The purpose of the risk analysis is a detailed investigation of the causes and initiating events by frequency analysis and consequences analysis of the accident scenarios identified in hazard identification. This can be achieved by the use of suitable techniques that model the risk. This allows attention to be focused upon high-risk areas and to identify and evaluate the factors which influence the level of risk.

Risk analysis means analyzing two things, namely, frequency and consequences. Frequency means how often the undesirable event happens, the frequency can be analyzed by:
1. Historical Data;
2. Fault Tree Analysis;
3. Event Tree Analysis;
4. Human Reliability Analysis;
5. Common Cause Failure Analysis; and
6. Bayesian Network

While consequence is the effect arising from a hazard that occurs. The consequence can be analyzed by:
1. Source Term Model;
2. Atmospheric Dispersion Model;
3. Mitigation Models;
4. Effect Models;
5. Computer Model;

2.1.3. Risk Control Option

According to the FSA Guidelines, the purpose of step 3 is:

"To propose effective and practical Risk Control Options (RCOs) comprising the following four principal stages:
1. focusing on risk areas needing control;
2. identifying potential risk control measures (RCMs);
3. evaluating the effectiveness of the RCMs in reducing risk by re-evaluating step 2; and
4. grouping RCMs into practical regulatory options."

This third step is to bring up risk control options, both risks from hazards that have already occurred, as well as risks that have never happened but have been identified in the previous step. In this third step will produce various steps to prevent the risk of a hazard from happening.

The purpose of focusing risks is to screen the output of step 2 so that the effort is focused on the areas most needing risk control. The main aspects of making this assessment are to review:

a. risk levels, by considering the frequency of occurrence together with the severity of outcomes. Accidents with an unacceptable risk level become the primary focus;
b. probability, by identifying the areas of the risk model that have the highest probability of occurrence. These should be addressed irrespective of the severity of the outcome;
c. severity, by identifying the areas of the risk model that contribute to the highest severity outcomes. These should be addressed irrespective of their probability; and
d. confidence, by identifying areas where the risk model has considerable uncertainty either in risk, severity or probability. These uncertain areas should be addressed.

In this step, there is also the so-called Risk Control Measure which is a way of controlling one element of risk. If the Risk Control Measure is combined, it can be said as a Risk Control Option. Because it provides many options for controlling these risks, a combination of Risk Control Measure is called Risk Control Option. In doing this third step, there are several things that need to be underlined, namely the Attributes of Risk Control Measure which consists of 3 attributes, namely:

1. Category A Attributes
2. Category B Attributes
3. Category C Attributes

The purpose of making this attribute is to facilitate the user in determining the Risk Control Measure with a structured owner, in order to understand how RCM works, how RCM is implemented and also how RCM operates. Attributes can also be used as a guide to classify the type of RCM itself.

The purpose of RCM itself is as follows

1. reducing the frequency of failures through better design, procedures, organizational policies, training, etc.;
2. mitigating the effect of failures, in order to prevent accidents;
3. alleviating the circumstances in which failures may occur, and
4. mitigating the consequences of accidents.

2.1.4. Cost-Benefit Assessment

The purpose of step 4 is to identify and compare benefits and costs associated with the implementation of each RCO identified and defined in step 3. A cost-benefit assessment may consist of the following stages:

1. consider the risks assessed in step 2, both in terms of frequency and consequence, in order to define the base case in terms of risk levels of the situation under consideration;
2. arrange the RCOs, defined in step 3, as a way to facilitate understanding of the costs and benefits resulting from the adoption of an RCO;
3. estimate the pertinent costs and benefits for all RCOs;

4. estimate and compare the cost-effectiveness of each option, in terms of the cost per unit risk reduction by dividing the net cost by the risk reduction achieved as a result of implementing the option; and
5. rank the RCOs from a cost-benefit perspective in order to facilitate the decision-making recommendations in step 5 (e.g. to screen those which are not cost-effective or impractical).

2.1.5. Recommendation for Decision Making

The final Step of FSA aims at giving recommendations to the relevant decision makers for safety improvement taking into consideration the findings of all four previous steps.

The purpose of step 5 is to define recommendations which should be presented to the relevant decision-makers in an auditable and traceable manner. The recommendations would be based upon the comparison and ranking of all hazards and their underlying causes; the comparison and ranking of risk control options as a function of associated costs and benefits; and the identification of those risk control options which keep risks as low as reasonably practicable.

The RCOs that are being recommended should

1. Reduce Risk to the “desired level”.
2. Be Cost Effective

2.2. Bali Strait

Bali Strait is a strait that separates Java Island to Bali Island, so the strait is used as a shipping lane to connect both island. Ketapang as a port in the Java Island and Gilimanuk as a port in Bali Island. Ketapang Port is located in Banyuwangi District, East Java. Ketapang port is under the management of ASDP Indonesia Ferry (Persero) which is responsible to Ministry of Transportation. The port only serving passenger and land transportation by ferry, there is an average of 288 trips a day to Gilimanuk port utilizing 32 ferries equipped with 6 docking berths. This is an important gateway linking the islands of Bali and Java. Gilimanuk is the primary port for passenger ferries and Roll on Roll off (RoRo) cargo from Surabaya in Java. The length of the voyage from Ketapang Port to Gilimanuk Port is 3 miles for 54 minutes by ferry in operation. Other than that, there is Tanjung Wangi Port in Banyuwangi to service the cargo and tanker ships which do the loading and unloading process.

Figure 2. 2 Bali Strait
Source: Google Maps

Bali Strait in certain months has sea currents, winds and waves in scale of moderate. Flow in the strait of Bali besides having a fairly large speed, the direction is always changing. The current speed can reach 6-7 knots, even reached 8 knots. The direction of the flow in the afternoon towards the South, while in the afternoon day to the north. During the East season (April - October) the most amount comes from Southeast with an average speed of 3-16 knots, but never reached more than 20 knots. During the West season (December - March) the largest wind frequency is recorded from Southeast, with variations from South to Southeast. In July and August there is a big beach wave in Ketapang.

(a)

(b)

(c)

Figure 2. 3 (a) Ketapang Port, (b) Gilimanuk Port, (c) Tanjung Wangi Port
Source: *Google Maps*

2.3. Ship Collision

Collision between two ships at sea is always a serious incident and depending on the extent of the impact, the ships involved in a collision may or may not sink. The striking ship will normally not be in any great danger of sinking, as it will receive the impact of the collision at the bow, and the bow in front of the collision bulkhead will normally receive all the collision energy. Damages restricted to this part of the ship will normally not affect the stability of the ship. The struck ship, however, if receiving a blow to its side, has a high risk of loosing its stability and will thus be in danger of sinking. If the struck ship is a passenger ship with many people on board, effective and orderly evacuation of these people will be crucial to the outcome of the incident .

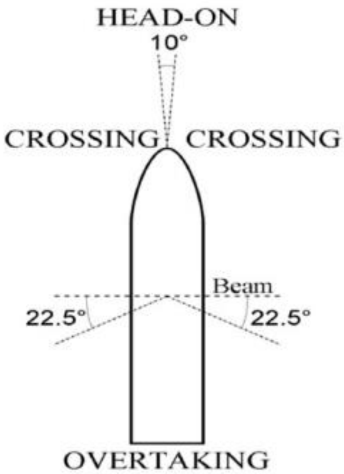

Figure 2. 4 Encounter types according to COLREG

Based on a Guide to Quantitative Risk Assessment for Offshore Installations, collisions are the impact on installations of ships or other marine buildings that include buildings on the sea floor and platforms that work near the installation. There are also types of collision ships can be divided into:

2.3.1. Head-on Situation

It is a condition where two ships move in opposite directions and collide on the bow. This event has the potential to occur in the Malacca Strait where the shipping traffic in and out is very dense.

2.3.2. Crossing Situation

It is a condition where two ships move in a direction that intersects and one of the ships collides with another in the midship section. To avoid this situation one of the ships must signal the other ship to pass first. This event could potentially occur if a ship cuts another ship's lane.

2.3.3. Overtaking Situation

It is a condition where two ships move in the same direction but at different speeds so that collisions occur because ships that are faster want to overtake a slower ship. To avoid this situation, slower vessels must give way to faster vessels to avoid collisions. This event can occur in a crowded shipping area without safe speed recommendations.

2.4. Factors on Ship Accident

There are different internal and external factors that affect on both probabilities. Internal factors are those that are related to the ship, herself; and external factors are those that will appear depend on who navigate the ship and also on the environmental situations related to the location of the ship.

The affecting factors can be divided into five major categories:

1. Human factors

2. Vessel specifications
3. Route characteristics
4. Atmospheric factors or weather conditions
5. Situational factors

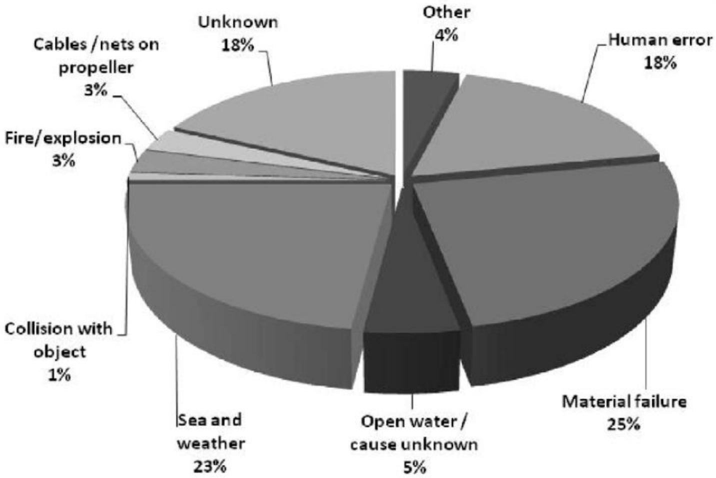

Figure 2. 5 Causes of the accidents (N = 857)
Source: (Gouveia et al.2007).

These all have been explained in more detail below.

2.4.1. Human Factors

Human factors are all those factors related to human and his interactions with the vessel. Human factors can cause human errors and human errors may end up with an accident like collision. As (Hänninen,2012) mentioned in her report, recently group and organizational factors contributions in human errors together with individual factors are being considered as human factors for risk analyzing in safety issues.
The collected human factors can be divided into three main categories:

1. Mind concern issues
2. Composition, competence and attitude of the ship’s crew
3. Company and organizational factors

2.4.2. Vessel Specifications

Vessel specifications are those factors that are directly connected to the vessel, like her dimensions and her abilities. They can be listed as below:

1. Length, breadth, and draught
2. Size
3. Wind exposure area of the ship; it has effect on wind drift force affecting the ship
4. Trim, list and heel angles
5. Type of the ship
6. Maneuverability; believes that the maneuverability of a ship is related to her draught and also the depth of the waterway.

7. Nationality or the flag state, it can be used as a proxy for human factor or it can be considered as a proxy for safety culture of the flag state
8. Age of the vessel
9. Onboard navigational aids, like GPS, ECDIS, etc.
10. Nautical Charts; availability and quality
11. Bridge design; for instance in older ships the steering, radar and charts were located separately in different places of the bridge, which made the bridge officer to leave his position in order to check the position or make any changes in the charts. Nowadays mostly they are located in one place, which makes the bridge officer to steer the ship while he has full control on charts and radar etc.

2.4.3. Route Characteristics

Route characteristics are the factors connected to the fairway, like its dimensions, and presence and type of navigational aids along the waterway. They can be listed as below:

1. Length, depth and width of the waterway
2. Depth uncertainty, it can be mentioned in the Nautical Charts
3. Number of changing courses and their level of difficulties
4. Traffic volume or density
5. Location of the vessel; if the vessel is navigating in Open sea, Offshore area, Coastal area, Inner coastal area or Port area
6. Composition and consistency of the sea bed
7. Slope of the sea floor
8. VTS (Vessel Traffic Service) zone

2.4.4. Atmospheric Factors or Weather Conditions

The following factors are included in this category:

1. Wind; speed and direction
2. Current; speed and direction
3. Wave; height and direction
4. Swell
5. Tide
6. Visibility
7. Ice condition (in arctic regions)
8. Time of the day; (Fujii, 1974) has mentioned that the risk of maritime accidents would be increased during the night time and darkness.
9. Availability of weather forecast
10. Differences between forecasted and seen weather conditions. (How reliable the forecast would be in that specific region.)

2.4.5. Situational Factors

Situational factors are those factors that will be presented according to different situations and cannot be categorized in above categories, like presence or absence of pilot on the bridge. Some may argue that this category can be split up into above categories. However, the author believes that having this category will help us later to have a clear view about different affecting factors and then lead us to find more accurate geometrical model or causation probabilities.

1. Availability and quality of pilot's assistance
2. Availability and quality of tug assistant
3. Loading conditions; for instance (Fowler and Sørgård,2000) believe that being in ballast condition will make the drift speed higher than normal.

2.5. Bayesian Network

Bayesian Network (BN), often known as Bayesian Network or Bayesian Nets for short, is a directed acyclic graph (DAG) and belongs to the family of graphical models (GMs). The detailed definition and features of BBN will be discussed as follows. Usually Bayesian Network is used to analyze the probability of events, this is achieved by combining probability distributions or functions of different parameters and revising their probabilities when new information/data is obtained.

A classical BBN structure is composed of nodes and arcs. The value of the nodes may be discrete or continuous, and the most widely used are the discrete nodes. There are mainly three types of discrete node: Boolean nodes, ordered values and integral values, depending on the number of values they may take. The values of Boolean nodes are binary, being either 'True' or 'False'. The ordered value nodes may take several values. For instance, the node 'Pollution' may take the value of 'high', 'medium', or 'low'. Integral values, in contrast, may take more than a hundred values (Kjrc´ ulff and Madsen, 2013). Arcs represent the influence of one node on another. The nodes connected by an arc are called the parent nodes and child nodes respectively. One child node may have several parent nodes, meaning this node is affected by several factors. Similarly, a parent node could have several child nodes, meaning that this factor may have influences on several other factors.

The nodes represent the variables of a problem and the links identify conditional probabilities existing between two or more variables. Bayes's theorem states that given two variables X1 and X2, the relationship that exists between the two is as follows:

$$P(X_2|X_1) = \frac{P(X_1|X_2).P(X_2)}{P(X_1)} \qquad (2.1)$$

This represents the probability of event X_2, which is known once the probability of X_1 is established. By generalizing, a Bayesian Network is obtained, which is determined by a set G = {V, E} of variables and relationships of conditioned probability, or respectively by a set of variables V = { X_1, X_2, ..., X_n} and arcs E ⊆ V ×V; the direct and acyclic links between variables define the graphic representation of the Bayesian network (Picture 2.6)

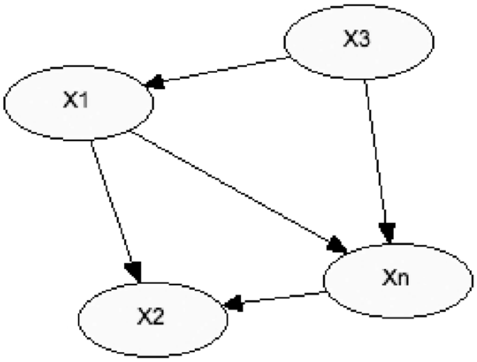

Figure 2. 6 Example of a Bayesian Belief Network (BBN)

In fact, there are three types of probabilities data in a BBN: prior probability, conditional probability and posterior probability. Prior probabilities are the probability distribution before taking into consideration of any evidence. Conditional probabilities are the probabilities that reflect the degree of influence of the parent nodes on the child node. For BBNs with discrete nodes, the probabilistic dependence is often represented via a table called a Conditional Probability Table (CPT).

Table 2. 1 Example of a Conditional Probability Table (CPT)

	$\boldsymbol{X_1}$			
	y		n	
	X_2		X_2	
$\boldsymbol{X_3}$	y	n	y	n
y	p1	p2	p3	p4
n	1-p1	1-p2	1-p3	1-p4

To obtain the CPT, we should first find out the possible combination values of the parent nodes, called an instantiation. For each instantiation, the probability that the child node will take a possible value is the conditional probability. They could be calculated using statistical or computational methods or elicited from domain experts. For a node with i states and k parent nodes and if each parent node has n states, i x n^k conditional probability values are required while (i - 1) x n^k values need to be elicited (Knochenhauer et al., 2013). The demand of a large number of CPTs is one of the biggest problems often criticized of BBN. The sheer number of probabilities would not only lead to heavy elicitation loads but will also cause inconsistency of the judgement (Coutts).

When new evidence (observation) is obtained, inferences could be made, i.e. posterior probabilities could be calculated. Making inferences is also called probability propagation, conditioning or belief updating. The evidence may take several forms, like specific evidence (X = x), negative evidence (Y – y1, and virtual evidence or likelihood evidence (P(X = x) = p). The inference may or may not follow the same direction of the arcs. Any node can be the evidence node and, similarly, the query node. Several rules govern the inference, namely the joint probability (1), the Bayesian rule (2) and the marginalization rule (3).

The application of BBN includes two parts: the development of the topology or the structure, which is the qualitative part, and the parameterization, which is the quantitative part. Both the structures and the parameters could be obtained through either subjective domain experts' judgment or data driven learning.

a. Some of the good reasons to choose BBN for modeling are listed as follows:
b. Explicit presentation of causal relationships.
c. Making both forward and backward inferences.
d. Combination of experts' knowledge and empirical data.
e. Power to deal with uncertainty.
f. Making updates with new information/observation.

Some common challenges for application of BBN include the difficulty of discretization of continuous variables, collecting and structuring expert knowledge and so on.

2.5.1. Establish nodes with dependencies

In order to construct a BN, the first step is to specify the graphical representation of the nodes (i.e. the structure). The structure may be defined by using prior information, by means of an estimate made from the data or by a combination of the two. The nodes with edges directed into them are called 'child' nodes, and the nodes with edges departing from them are called 'parent' nodes.

An influence diagram (ID) is a BN that is augmented with decision and utility nodes. An ID is used for modelling decision processes and for computing the utilities of available strategies. So as to make the best possible decisions, the utilities are associated with the state of the ID. These utilities are represented by utility nodes, and each utility node has a utility function. Once the decisions are made, the probabilities of the configurations of the network are fixed. The expected utility of each decision can then be computed. Based on the maximum expected utility principle, the highest expected utility can be chosen.

2.5.2. Create a CPT and prior probabilities for each node

Having established the influencing nodes, together with their dependencies, a CPT can be developed for each node or event. Theoretically, the CPT may be formulated using historical data, expert judgements or a combination of the two.

In this research, a binary logistic regression method is used to provide the conditional probability (Pi) of a ship involved in a casualty. In a binary regression, the dependent variable yi is binominal, and is modelled with a value of 1 for 'accident' and 0 for 'no accident'. Discrete-dependent variable is specified in the form of unobserved but continuous variable yi , this being mapped onto the binominal variable yi by the rule:

yi = 1 accident, if yi* > 0,

yi = 1 no accident, if yi* > 0,

where yi* $\in (-\infty, +\infty)$.

Consider a random m-dimensional variable $X_i = (x_{il}, \ldots, x_{im})$. Defining the unobserved variable yi* as a function of

$$\text{yi} *= \sum_{j=1}^{m} \beta_j X_i + \varepsilon_i, \quad (2.2)$$

where β_i represents a column vector of the coefficients describing the magnitude of the contribution of each risk factor, while ε_i represents an unobservable stochastic component.

Using binary logistic regression, the estimate probability can therefore be written in the form:

$$P_i = e^{\sum_{j=1}^{m} \frac{\beta_j x_i}{\sum_j^m \beta_j x_i}} \quad (2.3)$$

The binary logistic regression provides the estimate coefficient β_i. Given a subset X_i of variables x_{ij}, the conditional probability $P\left(Y = y_j \middle| X_i = x_{ij}\right)$ can be calculated using Equation (2). $P\left(X_i = x_{ij}\right)$ is obtained from the database. So the joint probability (Equation (3)), the marginalisation rule (Equation (4)) and the Bayesian rule (Equation (5)) can be calculated.

2.5.3. Generate posterior probabilities

A BN can be used to estimate how the probabilities of each node are affected by both prior and posterior knowledge. Once the structure and parameters have been determined from the available data, the BN is ready to draw inferences.

Using the following three equations, the probabilities of interest can be calculated.

The joint probability

$$P\left(Y = y_j, X_i = x_{ij}\right) = P\left(X_i = x_{ij}\right) \times P(Y = y_j \middle| X_i = x_{ij}) \quad (2.4)$$

The marginalization rule

$$P\left(Y = y_j\right) = \sum_j^m P\left(X_i = x_{ij}\right) \times P(Y = y_j \middle| X_i = x_{ij}) \quad (2.5)$$

The Bayesian rule

$$P\left(X_i = x_{ij} \middle| Y = y_j\right) = \frac{P\left(X_i = x_{ij}\right) \times P\left(Y = y_j \middle| X_i = x_{ij}\right)}{P\left(Y = y_j\right)} \quad (2.6)$$

2.5.4. Validation of the constructed model

Validation is an important aspect of this methodology, as it provides a reasonable amount of confidence in the results produced. In this study, a sensitivity analysis for validation of the model has been developed, and the following two axioms should at least be satisfied:

Axiom 1: A slight increase/decrease in the prior subjective probabilities of each parent node should without doubt cause a relative increase/decrease in the posterior probabilities of the child node.

Axiom 2: The total influence magnitudes of the combination of the probability variations from x attributes (evidence) on the values should always be greater than the one from the set of $x - y(y \in x)$ attributes (sub-evidence).

2.6. IWRAP Mk II

IWARP Mk II is a software for calculating the frequency of collision, whether Head-On, Overtaking or Crossing Collision. IWRAP also be able to calculate a collision frequency on every determined part. The conceptual procedure for calculation of the frequency of collisions or groundings follows the conceptual principles formulated by (Fujii,1974). The procedure first involves the calculation of the geometric number of collision or grounding candidates, N_G , which subsequently is multiplied by the causation factor, P_C. Hence the frequency of collisions, λ_{Col} , (or groundings, λ_{Grnd}) become,

$$\lambda_{Col} = P_C \,.\, N_G \qquad (2.7)$$

2.6.1. Head-on Collision

For head-on collisions the number of geometric collision candidates for ships sailing along the route segment can be expressed as,

$$N_G{}^{head-on} = Lw \sum \text{i, j}\, P_{Gi,j}{}^{head-on}, \frac{Vij}{Vi,Vj}\,(QiQj) \qquad (2.8)$$

Where,
N_G = number of collision candidate
L_W = the length segment
P_G = possibility collision occur
Vi = velocity vessel in route i
Vj = velocity vessel in route j
Vij = relative velocity
Qi = vessel frequency each year in route i
Qj = vessel frequency each year in route j

To determine the $P_{Gi,j}{}^{head-on}$ can be calculated use formula as below:

$$P_{Gi,j}{}^{head-on} = \Phi\left(\frac{B_{ij}-\mu_{ij}}{\sigma_{ij}}\right) - \Phi\left(-\frac{B_{ij}+\mu_{ij}}{\sigma_{ij}}\right) \qquad (2.9)$$

Where,
P_G = possibility collision occur
Φ = the standard normal distribution function
μ = vessel distance
μ_{ij} = $\mu_i + \mu_j$; is the mean sailing distance between the two vessels
σ_{ij} = $\sqrt{\sigma_i^2 + \sigma_j^2}$; is the standard deviation of the joint distribution
Bij = $\frac{B_i - B_j}{2}$; is the average vessel breadth

2.6.2. Overtaking Collision

For overtaking collisions the number of geometric collision candidates for ships sailing along the route segment is expressed by eq. (2.7) using the relative speed *Vij = Vi + Vj, Vij* > 0. If *Vij* < 0 then vessel will obviously not be able to overtake another vessel. In the practical implementation the absolute value of *Vij* is used and struck and striking vessel are registered. The geometric probability of meeting, eq. (2.8) becomes,

$$P_{Gi,j}{}^{overtaking} = P\left[y_i - y_j < \frac{B_i - B_j}{\sigma_{ij}}\right] - P\left[y_i - y_j < \frac{B_i - B_j}{\sigma_{ij}}\right] \quad (2.10)$$

2.6.3. Crossing Collision

In calculating frequency of crossing collision, angel becomes thing that must be considered. To calculate the geometric number of crossing collision for angel $10^o < \theta < 170^o$ use formula as written below:

$$N_G{}^{crossing} = \sum i,j \; \frac{QiQj}{ViVj} D_{ij} \, V_{ij} \frac{1}{\sin\theta} \quad (2.11)$$

Where,

N_G	= number of collision candidate
θ	= collision angel
Dij	= crossing collision diameter
Vi	= velocity vessel in route i
Vj	= velocity vessel in route j
Vij	= relative velocity
Qi	= vessel frequency each year in route i
Qj	= vessel frequency each year in route j

Where Vij is the relative speed between the vessels and Dij defines the apparent collision diameter, see Figure 2.7. The sinus term stems from the variable transformation when integrating over the area of the joint probability distribution, see Figure 2.8. Note that contrary to head-on and overtaking collisions the distribution of the traffic spread is not relevant for crossing collisions, except for the sinus term of course. It is seen that when the crossing angle goes to zero the length of the crossing (or the time of the crossing) goes to infinity and hence does the number of collisions. For practical reasons it is therefore necessary to limit the crossing angle to an interval of, say, 10 to 170 degrees.

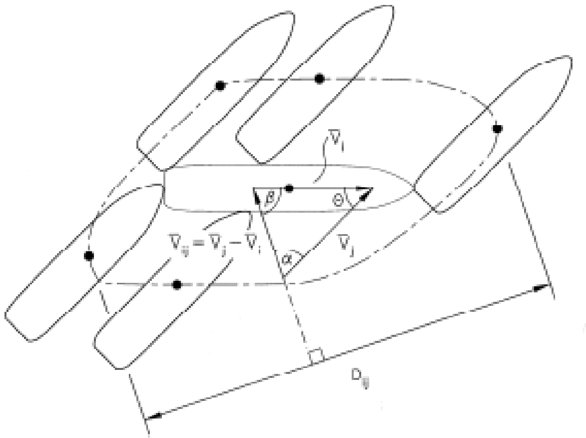

Figure 2. 7 Definition of geometrical collision diameter

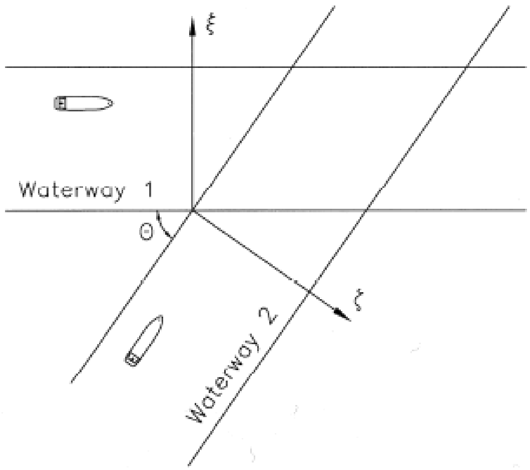

Figure 2. 8 Basic layout of the simulated crossings

Vij can be calculated use formula as below:

$$V_{ij} = \sqrt{V_i^2 + V_i^2 - 2V_i} \qquad (2.12)$$

To determine the value of Dij can be calculated use formula as below:

$$D_{ij} = \frac{L_i V_j + L_j V_i}{Vij} \sin\theta + B_j \left\{ 1 - (\sin\theta (\frac{V_i}{V_{ij}})^2 \right\} + B_i \left\{ 1 - (\sin\theta (\frac{V_i}{V_{ij}})^2 \right\} \qquad (2.13)$$

Where,
Li = vessel length in route i
Lj = vessel length in route j
θ = collision angel
Vi = velocity vessel in route i

Vj	= velocity vessel in route j
Vij	= relative velocity
Bi	= vessel breadth i
Bj	= vessel breadth j

2.7. GNOME Software

When a collision happen, the ship has the possibility of hull leakage, so the oil can spill from the tank of tanker. Then, modeling needs to be done to find out the distribution of oil spilled.

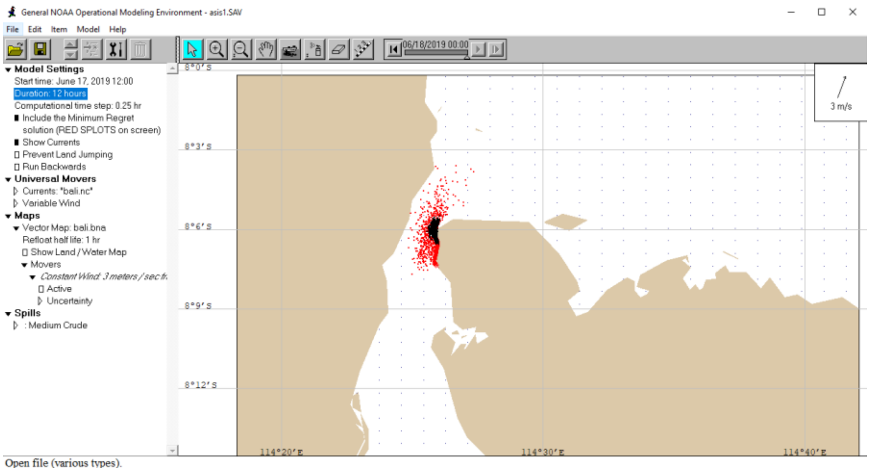

Figure 2.9 GNOME Software

GNOME software is oil spill trajectory model that simulates oil movement due to winds, currents, tides, and spreading. GNOME was developed by the Hazardous Materials Response Division (HAZMAT) of the National Oceanic and Atmospheric Administration Office of Response and Restoration (NOAA OR&R). It response to calculate a “best guess” of a spill’s trajectory and the associated uncertainty in that trajectory.

CHAPTER 3
METHODOLOGY

3.1. Flowchart

This research method is made as a reference in conducting research to identify risks, analyze the risks of obtaining the magnitude of risk, risk control option, make a cost-benefit assessment to produce recommendations that could be done, each step that will be carried out in this research is written in a research framework that could be seen in the figures 3.1 below:

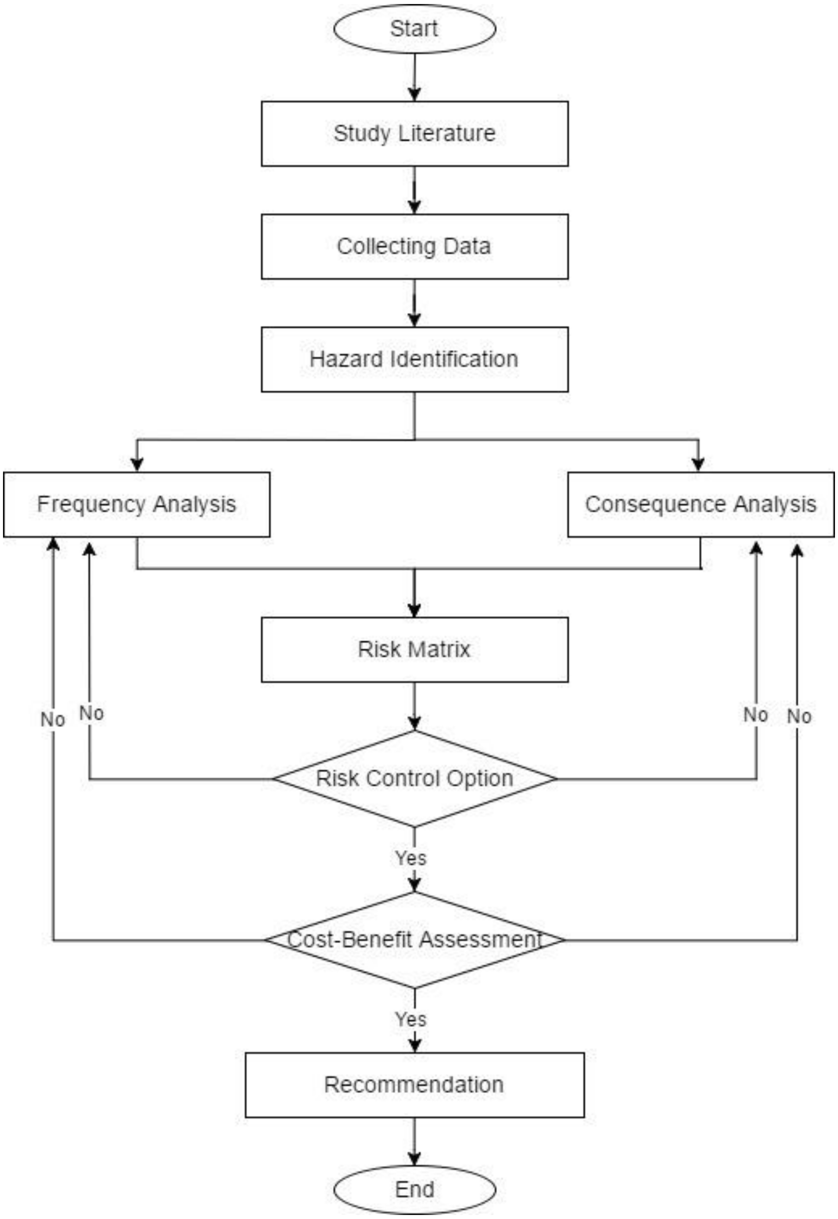

Figure 3. 1 FSA Flowchart

3.2. Study Literature

The study literature is an early stage to learning basic theories to be discussed of this case in bachelor thesis. Basic theory sources are from books, papers, journals and previous bachelor thesis. Literature-related issues can be used as a reference to understand the problem.

3.3. Collecting Data

After conducting a literature study, then the data collection related to collision problem. Data collection is used to support the problem solving of bachelor thesis. These data from port authority, PT ASDP Indonesia Ferry located in Bali Strait and BMKG (Badan Meteorologi, Klimatologi dan Geofisika) and other related data that influencing the occurrence likelihood of ship accident factors.

3.4. Hazard identification

The purpose of hazard identification step is to identify the hazards related to a specific problem area and generate a list of them, according to the likelihood of occurrence and the severity of their consequence. This step is developed based on the database of the accidents that happened in Bali Strait**.** There are several factors that cause of ship accident such as human error, environment, and route characteristics and from vessel itself that indirectly causes of accident.

3.5. Risk Assessment

The purpose of the risk assessment in this step is to investigate in detail the causes and consequences of the scenarios.

3.5.1. Frequency Analysis

Frequency analysis is done by doing the calculation from historical data or from the previous research about the likelihood of accident. In this bachelor thesis, the author will use Bayesian Network to analyze the probability of accident in term of frequency data exist.

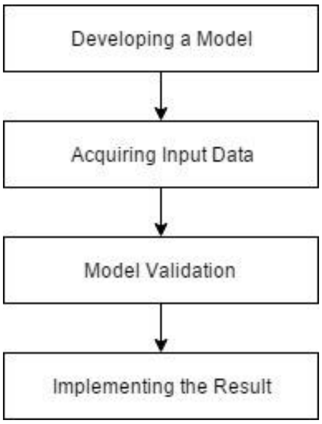

Figure 3. 2 Bayesian Network (BN) Process

From the flowchart of Bayesian Network process, it can describe as:

1. Developing a Model

To develop a modeling, the variable needs to be determining according to existing data that can cause a ship accident. All the nodes will be analyzed to determine relationships of nodes from the root cause to the effect of event. The software that will use to simulating Bayesian network structure is NETICA software by Norsys.

2. Acquiring Input Data

For BN with discrete nodes, the probabilistic dependence is often represented via a table called a Conditional Probability Table (CPT). All collected data of frequencies from historical data must be calculated with Conditional Probability Table (CPT).Conditional probabilities are the probabilities that reflect the degree of influence of the parent nodes on the child node.

3. Model Validation

In model validation stage, this step will be used sensitivity analysis to provide a degree of confidence that the model has been built correctly and is working as intended using NETICA software.

4. Implementing the Result

Based on the project result, the value of probability is implementing to analyze the next step. This model will be part of based risk analysis due to ship collision.

3.5.2. Consequence Analysis

Consequence analysis is very necessary to do in this method because as we know that to determine the value of a risk, it must have a value of consequence. So it is very necessary to carry out the consequences analysis in conducting a risk assessment using the Formal Safety Assessment method. In this stage, the writer will calculate oil spill from tanker ship due to ship collision.

3.6. Risk Matrix

After analyzing the frequency and consequences calculation, the step that needs to be done is conduct an assessment by mapping the combination results of consequence and frequency into the risk matrix. The risk matrix based on the standard of DNV-GL which can be seen in the figure below:

The risk matrix is combination of frequency and consequence. The frequency is divided into eight categories:

1. More than 10 years per year
2. 1-10 accident per year
3. 1 accident in ten years
4. 1 accident in hundred years
5. 1 accident in thousand years
6. 1 accident in ten thousand years
7. 1 accident in hundred thousand years

8. 1 accident more than hundred thousand years

The consequences of environment are grouped into six categories:

1. None / negligible
2. Minor environmental damages. Restored within days
3. Serious environmental damages. Restored within weeks
4. Serious environmental damages. Oil spill larger than 3 tons
5. Critical environmental damages. Oil spill larger than 30 tons
6. Catastrophic environmental damages. Oil spill larger than 300 tons

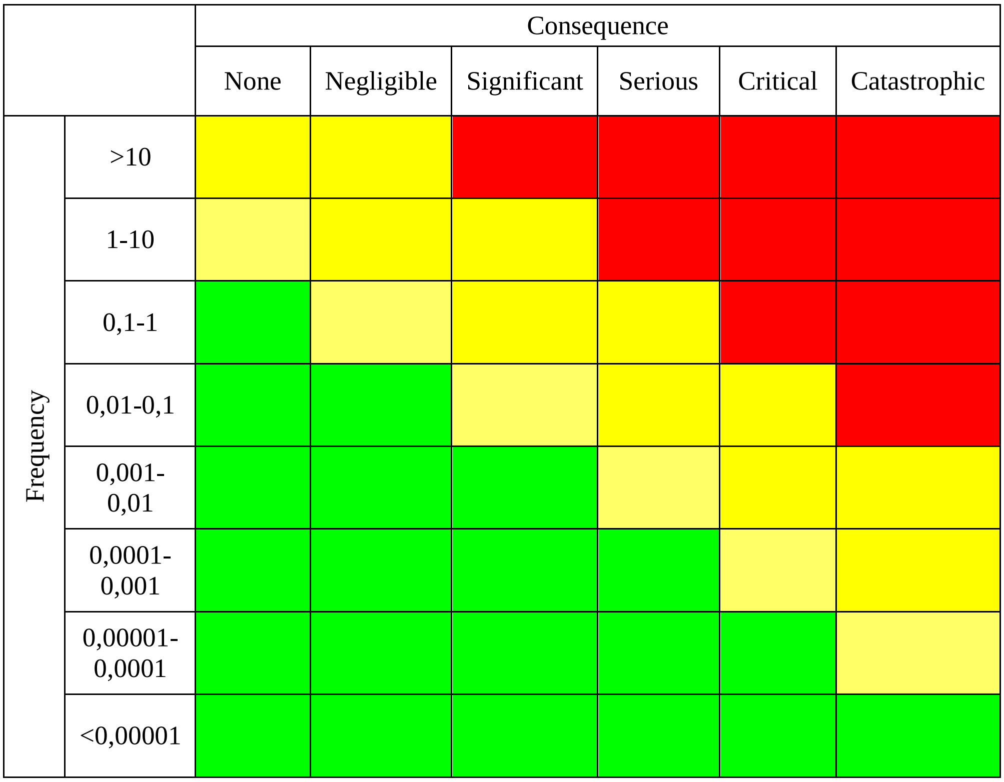

Figure 3. 3. Risk Matrix
Source: DNV-GL

3.7. Risk Control Option

The purpose of the step is to propose effective and practical risk control options (RCO) through the following four steps:

a. Focus on requiring control risk, to filter outputs from step 2, so that the focus is only areas that most need risk control.
b. Identifying actions to control potential risks (risk control measures = RCMs).
c. Evaluating the effectiveness of RCMs in reducing risk by re-evaluating step 2.
d. Classify RCMs into practical risks.

3.8. Cost and Benefit Assessment

The purpose of cost and benefit assessment is to identify and compare the benefits and costs of implementing each RCOs that have been identified in the third step.

Costs must be stated in the life cycle cost, which includes the initial period, operating, training, inspection, and certification decommission, etc. Whereas benefits can include a reduction in fatalities, injuries, casualties, environmental damage and cleaning (environmental damage & clean-up), indemnity by responsible third parties. And an increase in the average life of the ship. The output from this step consists of:

a. Costs and benefits for each RCO identified
b. Costs and benefits for the entities of concern (those most affected by the problem).

3.9. Decision Making Recommendation

The purpose of decision making and recommendation step is to define recommendations which should be presented to the relevant decision makers in an auditable and traceable manner. The recommendations would be based upon the comparison and ranking of all hazards and their underlying causes; the comparison and ranking of risk control options as a function of associated costs and benefits; and the identification of those risk control options which keep risks as low as reasonably practicable.

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CHAPTER 4
RESULTS AND DISCUSSION

4.1. General Description

Formal Safety Assessment in this bachelor thesis discusses about ship collisions in the Bali Strait. Bali Strait is one of the busiest strait in Indonesia which separates Java Island and Bali Island while connects the Indian Ocean and Bali Sea. This strait provide a passenger sea transportation to accommodate people who want to crossing over Bali Strait. In 2018 total trip for passenger ship which crossing Bali Strait is 190.820 trip. Then, it is very possible for ship accidents especially ship collision.

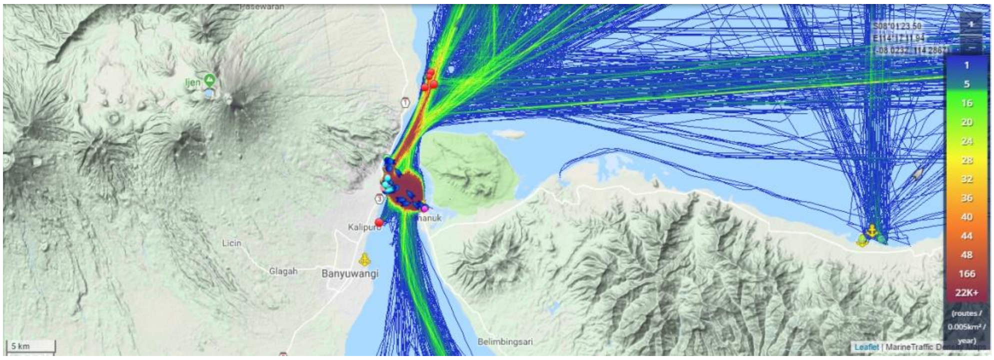


Figure 4. 1. Ship Density in Bali Strait
Source: marinetraffic.com

Formal Safety Assessment consists of five steps, such as:

1. Hazard Identification
2. Risk Assessment
3. Risk Control Option
4. Cost and Benefit Assessment
5. Recommendation

To make risk assessment, there will be two analyzes will be conducted, namely frequency analysis and consequences analysis. In order to estimate the frequency of collision, the number of collision candidates which carried out by manual calculation method based on the IWRAP theory is then multiplied by the probability of collisions using Bayesian Network model for estimating the causation probability. Then, to do the consequences analysis will be calculated the economical loss of oil spills by using GNOME software due to ship collision.

4.2. Data Processing

In this bachelor thesis an analysis of three types of collisions will be carried out, namely, Head-on, Overtaking and Crossing. To get the results of the frequency the general formula will be used as written below,

$$\lambda = P_C \ x \ N_G \qquad (2.7)$$

Where,
λ = the frequency of collisions
P_C = the causation factor
N_G = the geometric number of collision candidates

For the analysis is that the ship traffic has been grouped into a number of different ship classes according to vessel type, and vessel size. And that the number of vessels per time unit has been registered for each waterway. To get the value of the frequency, we need to find the geometric number of collision candidates. To find the geometric number of collision candidates (N_G) where each type of accident has a different formula. The formula to be used is in accordance with the types of accidents that exist, namely:

1. Head-On Collision

Head on Collision is one of the collision scenarios in which collisions occur in the bow side between two ships in opposite directions. The illustration of head on collision can be seen in Figure 4.2.

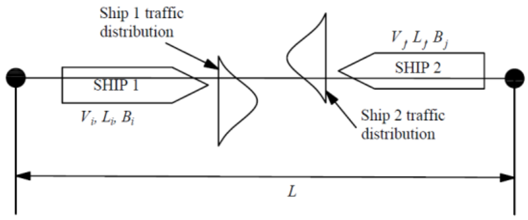


Figure 4. 2 Head On Collision Illustration

$$N_G{}^{head-on} = Lw \sum \mathrm{i,j}\, P_{Gi,j}{}^{head-on}, \frac{Vij}{Vi,Vj}(QiQj) \quad (2.8)$$

Where,
N_G = number of collision candidate
L_W = the length segment
P_G = possibility collision occurs
Vi = velocity vessel in route i
Vj = velocity vessel in route j
Vij = relative velocity
Qi = vessel frequency each year in route i
Qj = vessel frequency each year in route j

To determine the $P_{Gi,j}{}^{head-on}$ can be calculated use formula as below:

$$P_{Gi,j}{}^{head-on} = \Phi\left(\frac{B_{ij}-\mu_{ij}}{\sigma_{ij}}\right) - \Phi\left(-\frac{B_{ij}+\mu_{ij}}{\sigma_{ij}}\right) \quad (2.9)$$

Where,
P_G = possibility collision occurs
Φ = the standard normal distribution function

μ = vessel distance
μ_{ij} = $\mu_i + \mu_j$; is the mean sailing distance between the two vessels
σ_{ij} = $\sqrt{\sigma_i^2 + \sigma_j^2}$; is the standard deviation of the joint distribution
Bij = $\frac{B_i - B_j}{2}$; is the average vessel breadth

2. Overtaking Collision

Overtaking Collision is a collision scenario between two ships moving on one track in the same direction, and can occur when a ship that has a higher speed wants to overtake another ship. The illustrate of overtaking collision is shown in below in Figure 4.3.

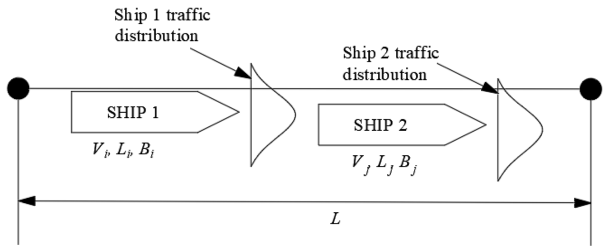


Figure 4. 3 Overtaking Collision Illustration

$$N_G{}^{overtaking} = Lw \sum \text{i, j}\, P_{Gi,j}{}^{overtaking}, \frac{Vij}{Vi, Vj}(QiQj) \qquad (2.8)$$

Where,
N_G = number of collision candidate
L_W = the length segment
P_G = possibility collision occurs
Vi = velocity vessel in route i
Vj = velocity vessel in route j
Vij = relative velocity
Qi = vessel frequency each year in route i
Qj = vessel frequency each year in route j

To determine the $P_{Gi,j}{}^{overtaking}$ can be calculated use formula as below:

$$P_{Gi,j}{}^{overtaking} = P\left[y_i - y_j < \frac{B_i - B_j}{\sigma_{ij}}\right] - P\left[y_i - y_j < \frac{B_i - B_j}{\sigma_{ij}}\right] \qquad (2.10)$$

3. Crossing Collision

Crossing collision is a collision scenario where two ships that have a direction of motion intersect with another ship's path at a collision intersection. Crossing collision is influenced by the angle formed between two paths at an intersection.

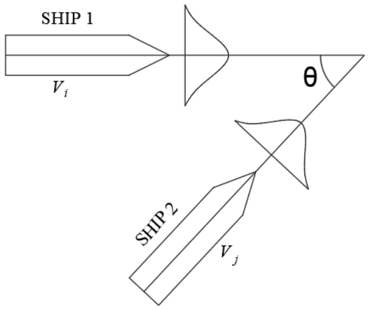


Figure 4. 4 Crossing Collision Illustration

$$N_G{}^{crossing} = \sum i, j \, \frac{QiQj}{ViVj} D_{ij} \, V_{ij} \frac{1}{\sin\theta} \tag{2.11}$$

Where,

N_G = number of collision candidate
θ = collision angel
Dij = crossing collision diameter
Vi = velocity vessel in route i
Vj = velocity vessel in route j
Vij = relative velocity
Qi = vessel frequency each year in route i
Qj = vessel frequency each year in route j

While Vij can be calculated use formula as below:

$$V_{ij} = \sqrt{V_i^2 + V_i^2 - 2V_i} \tag{2.12}$$

To determine the value of Dij can be calculated use formula as below:

$$D_{ij} = \frac{L_iV_j + L_jV_i}{Vij} \sin\theta + B_j \left\{ 1 - (\sin\theta (\frac{V_i}{V_{ij}})^2 \right\} + B_i \left\{ 1 - (\sin\theta (\frac{V_i}{V_{ij}})^2 \right\} \tag{2.13}$$

Where,

Li = vessel length in route i
Lj = vessel length in route j
θ = collision angel
Vi = velocity vessel in route i
Vj = velocity vessel in route j
Vij = relative velocity
Bi = vessel breadth i
Bj = vessel breadth j

According to the formulas above, there are some data needed to calculate the collision frequency of ships using the IWRAP method, the data needed are as follows:

a. Density of the leg in a year
b. Length of the ship

c. Breadth of the ship
d. Velocity of the ship
e. Angel

1. Traffic Distribution in Bali Strait

The data is collected from KSOP and ASDP as the input to conduct risk analysis. Data obtained in the form of the number of ship which crossed in the Bali Strait in a certain period of time. Based on the data obtained from the local port authority. The data are classified based on the length and the type of the vessels.

Table 4. 1 Ship Traffic Distribution in Bali Strait

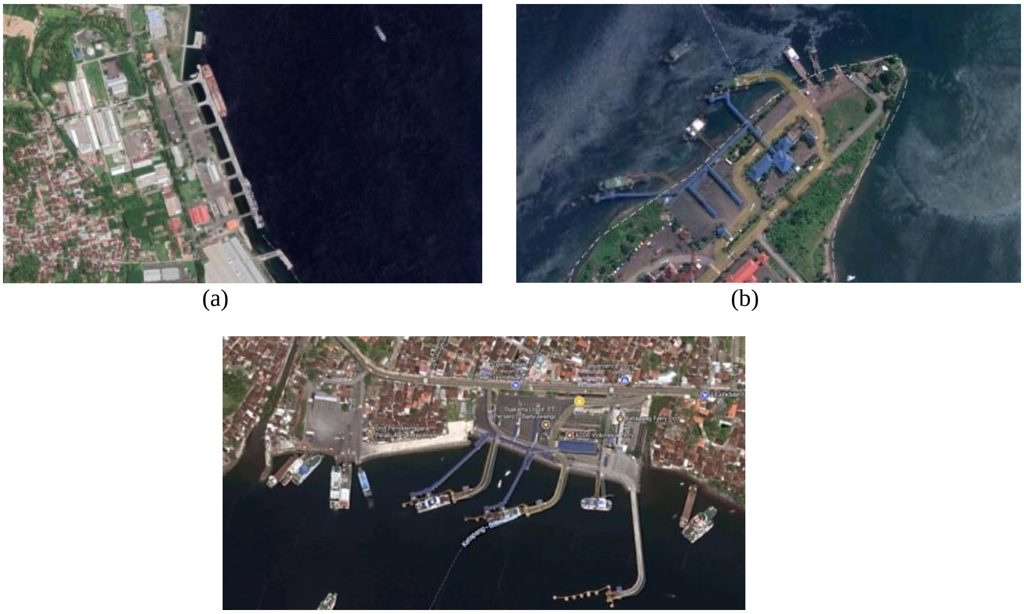
	Crude oil tanker	**Oil products tanker**	**Chemical tanker**	**Gas tanker**	**General cargo ship**	**Bulk carrier**
0-25	0	0	0	0	0	0
25-50	0	17	16	0	0	0
50-75	0	90	4	0	34	4
75-100	0	130	18	0	21	23
100-125	0	37	10	0	6	66
125-150	3	8	21	0	0	2
150-175	1	55	2	42	1	4
175-200	2	4	4	0	6	10

Table continue to the next table below

Table continue from Table 4.1

	Ro-Ro cargo ship	**Passenger ship**	**Support ship**	**Fishing ship**	**Sum**
0-25	0	0	10	16	26
25-50	23	21	121	145	343
50-75	32	23	67	6	260
75-100	0	24	32	0	248
100-125	0	0	0	0	119
125-150	0	0	0	0	34
150-175	0	0	0	0	105
175-200	0	0	0	0	26
				Total	1161

There are three ports located in the Bali Strait where 2 ports as crossing ports for passenger vessels called Ketapang and Gilimanuk Port and the other one is the cargo port called Tanjung Wangi Port. Tanjung Wangi Port located in the north west of Bali Strait. It is used to service bulk loading and unloading process, especially for bulk fertilizer, cement and fuel oil. Table 4.1 represents the number of vessels carrying out loading and unloading at Tanjung Wangi Port and the number of ships crossing the Bali Strait in 2018.



(a) (b) (c)

Figure 4. 5 (a) Tanjung Wangi Port, (b) Gilimanuk Port, (c) Ketapang Port
Source: googlemaps.com

Based on the ship data of passenger ship, the total trip of vessel increased every year and also it followed with the increasing of total passenger who crossing Bali Strait. In 2016 total trip of passenger vessels from Ketapang Port is 84338 and total trip of passenger vessels from Gilimanuk Port is 82775. In 2018 the total trip of passenger vessels from Ketapang Port is 95658 and from Gilimanuk Port is 95162. Ketapang Port and Gilimanuk Port facilitated with 5 jetty which consist of Pontoon, Moveable Bridge I, Moveable Bridge II, and Moveable Bridge III and Beaching/LCM. Based on the Table 4.2, the number of passenger vessel that cross Bali Strait increased every year from 2011 to 2018.

Table 4. 2 Passenger Ship Traffic in Bali Strait

Year	**Trip**		**Total**
	Ketapang	**Gilimanuk**	
2011	70640	70518	141158
2012	77157	77033	154190
2013	83874	83678	167552
2014	83235	82459	165694
2015	84266	82917	167183

Year	Trip		Total
	Ketapang	**Gilimanuk**	
2016	84338	82775	167113
2017	94962	94329	189291
2018	95658	95162	190820

In operating, the ship used to accommodate passenger or transportation from Java Island to Bali Island or vice versa in a day is 32 units of ships. Where 20 ships operate in Pontoon, Moveable Bridge (MB) I, Moveable Bridge (MB) II, Moveable Bridge (MB) III. In a day total trip for one unit of ship is 9 trips or 18 trips back and forth. While 12 ships operate in 3 LCM beaching which has the same trip with Pontoon, MB I, MB II and MB III. So that the total operating vessels in a day is 288 vessels. From Table 4.3 below, the total trip of ships from MB and Pontoon per day which the 32 units operating is 180 trips and total trip of ship per day in LCM is 108 trips where 20 units of ship operating.

Table 4. 3 Ship Operational in Ketapang-Gilimanuk

Total ship in MB/Ponton	32	units
Ship operation	20	units
Total ship per jetty	5	units
Trip per unit per day	9	trips
Total trip ships per day in MB/Pontoon	180	trips
Total ship in LCM	20	units
Ship operation	12	units
Total ship per jetty	4	units
Trip per unit per day	9	trips
Total trip ships per day in LCM	108	trips

2. Chronology of the Collision

The chronology of ship collision will be used as a verification to create Bayesian Network model. Variable of causes of the collision will be listed based on chronology reports. The chronology of ship collision is gathered from KSOP, KNKT and Mahkamah Pelayaran. Table 4.4 presents the example of chronology data of ship collision that happened in Bali. In detail the explanation of other ship collision chronology will be present in attachment.

Table 4. 4 Chronology of ship Collision

Accident	Date	Time	Cronological
Collision	28-Dec-18	12.45 WITA	Collisions between ships in the Bali Strait between KMP Munic and KMP Dharma Kosala. KMP Munic hit the stern of KMP Dharma Kosala. When KMP Munic is driving towards the port and in the front

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Accident	Date	Time	Cronological
			position there is the KMP Dharma Kosala which is not operating. Because the KMP Dharma Kosala was off, no crew members were watching while the crew of the KMP Munic V tried to contact KMP Dharma Kosala officers via Marine VHF radio but there was no response. But the KMP Munic captain was late responding and high waves with strong currents came and KMP Munic could not avoid a collision that hit the stern of the KMP Dharma Kosala. There was damage to the bow of the KMP Dharma Kosala and the lifeboat that fell to the bottom deck of the KMP Dharma Kosala. Whereas the damage that occurs in KMP Munic is dent on the hull of the ship. There were no fatalities due to a ship accident.

4.3. Hazard Identification

Hazard identification is a process of determining what hazards can cause an accident. The method of hazard identification is using brainstorming from *Formal Safety Assessment – Large Passenger Ships Research Report by DNV*. The process made the basis for a list of 45 scenarios or type of failures, later grouped into five categories. Five categories of hazard is culture, navigator, procedures, technical systems, user interface and others. The hazard identification aims to identify all relevant hazards, including giving suggestions to create Bayesian Network model for ship collision and also it important as the input to the rest of this bachelor thesis. For the detail explanation of hazard identification of ship collision can be seen in Table 4.5.

Table 4. 5 Hazard Identification of Ship Collision

CULTURE	NAVIGATOR	PROCEDURES
1. OOW distractions	12. Unfamiliar with vessel/bridge	19. Communication between navigators, misunderstandings
2. Insufficient manning	13. Dependence on technology	20. Communication with pilot (linguistic problems, etc.)
3. Cost cutting pressure	14. Incapacitation	21. Heavy traffic, many simultaneous situations
4. Time pressure – keep schedule	15. Incorrect use of equipment	22. Interaction, minor/leisure traffic
5. Tired, pressure, not sufficient rest	16. Misjudgment when approaching quay, in narrow waters,	23. Nav. rules not known

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6. Policy, responsibility of officers, etc.	17. Underestimate weather conditions (distance to hurricanes, poor training for these	24. “GPS assisted”/ “Radar assisted” collision
7. “We have 1st priority” attitude	situations, etc.)	25. Too many company procedures to follow / paperwork
8. Insufficient simulator training	18. Misjudgment of traffic situations	26. Checklists are not used as a tool, but are a goal in itself
9. High operational speed		27. Insufficient/wrong procedures
10. Company policy/culture		
11. Not optimized training		
TECHNICAL SYSTEMS	**USER INTERFACE**	**OTHER**
28. Insufficient radar functionality	39. Poor bridge design, physical work conditions	45. Sabotage (spoofing of GPS signals, lead/force vessel on ground…)
29. Quality of equipment (ECDIS (update), etc.)	40. Too much information (AIS, etc.)	
30. Technical failure (power supply)	41. Barriers regarding poor user interface	
31. Communication equipment failure	42. Alarm confusion	
32. Large vessels, difficult to maneuver	43. Local conditions (poor quay, marking, anchoring conditions, …)	
33. INS/IBS (Integrated Nav. System/Integrated Bridge System) failure (incl. software)	44. Complex operating procedures compensating for poor technical system	
34. GPS malfunction		
35. GPS jumps		
36. Gyro failure		
37. Autopilot malfunction		
38. Hard rudder as a result of loss of rudder feedback system		

Based on the Hazard identification above by DNV, the following hazards as the most important to the industry:

1. Level of distractions when the OOW is performing his tasks.
2. INS/IBS (Integrated Navigational System/Integrated Bridge System) failure (including software).
3. Poor bridge design and physical work conditions.
4. Misjudgment of traffic situations.
5. The OOW is unfamiliar with vessel/bridge.

4.4. Risk Assessment

The purpose of risk assessment is to analyze the frequency and consequences to determine the value of risk. The method to determine frequency analysis is used Bayesian Network model to estimate the probability of causation factor and manual calculation to calculate the number collision candidates, then to do the consequences analysis will use *GNOME software* to analyze oil spills of the ship affected by collision.

4.4.1. Frequency Analysis

Calculation of frequency analysis carried out using the IWRAP method. IWRAP itself is a theory published by Peter Friis-Hansen in 2007 (Technical University of Denmark) and made into a software developed by the International Association on Lighthouse Authorities (IALA) to calculate the frequency of ship accidents annually in certain areas.

In this bachelor thesis will calculate the frequency of collisions from Head-On, Overtaking and Crossing that occur in the Bali Strait. To calculate the frequency it needs causation of probability by using Bayesian Network probability distribution and geometric number of ship collision candidates with calculation manually.

4.4.1.1. Conceptual Bayesian Network Model

The next step is to make the structure of bayesian network or causal network which is the relationship of cause and effect between variables either direct or indirect. The relationship between factors that affecting ship collision obtained from studi literature, accident report and interview.

1. Relationship factor of weather to visibility

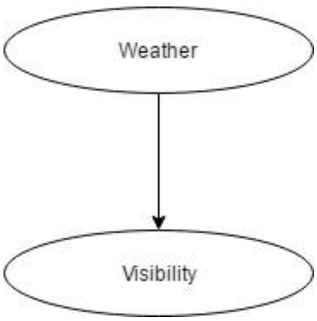


Figure 4. 6 Weather and Visibility relationship

One of the factors that can cause a ship accident is weather factor. The node describes the condition of weather in the region at certain times. The weather condition can influences the visibility of officer on watch when the ship operation. The condition of weather in Bali Strait is unpredictable because the Bali Strait itself connects directly to Indian Ocean and Java Sea. If the weather condition is clear or cloudy, it will not disturb the visibility but if the condition of weather is bad cause of the rain, then it will decrease the visibility of officer on the watch.

2. Relationship factors between visibility, time, conditional of crew towards human performance

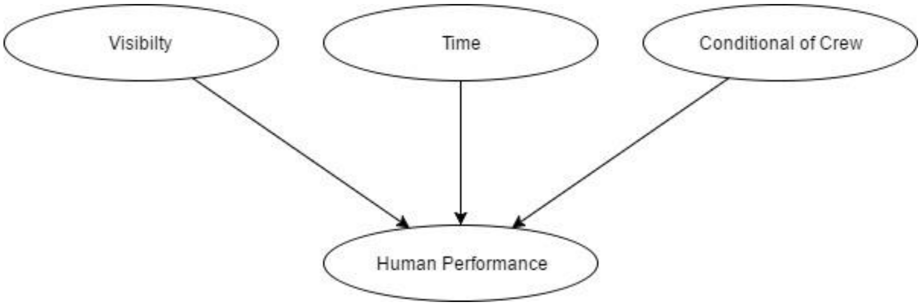


Figure 4. 7 Visibility, Time, Conditional of crew and Human performance relationship

Human failure has been commonly stated as the most typical cause group of marine traffic accidents. Ship collision can be caused by the performance of ship crew which not good to perform his tasks. This factor can be influenced by the visibility of officer on watch when navigating a ship, time distribution describing the probability of a ship navigating in the dark and conditional of crew is used as the indication of how well it performs its tasks as navigator in the vessel that can caused by tired.

3. Relationship factors between vigilance, human performance, steering failure towards loss of control

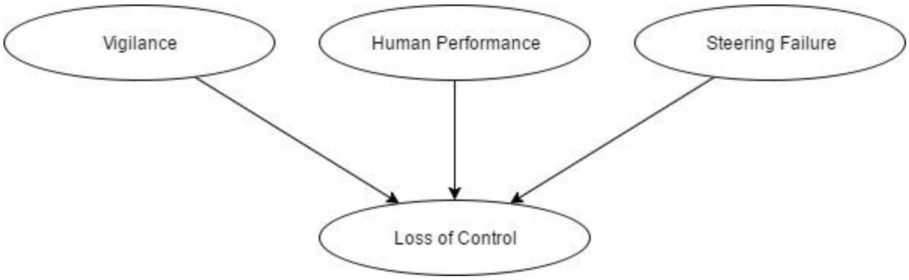


Figure 4. 8 Vigilance, Human performance, Steering failure and loss of control relationship

If the control is lost, nothing can prevent the ship from continuing towards the danger to the collision course. The factors that can affecting to the loss of control are no function steering gear system due to lack of maintenance routine of ship that make the technical failure, human performance factor that make the officer on watch did not perform his tasks well, and vigilance which influenced by the function of second officer, vessel traffic service and the communication level of navigation if there is no vigilance in shipping line then there is no control system to watch vessel traffic.

4. Relationship factors between loss of control and give way towards collision

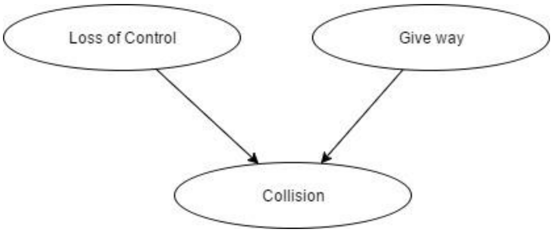


Figure 4. 9 Loss of control, Give way and Collision relationship

The incident of ship collision not only caused by one factor but a result of a combination of several factors. Navigational or technical failures, which cause loss of control on one of the vessels, will cause collision if the other vessel is not able to prevent the collision and give way situation where the vessel situation supposed or not supposed to change it course when own ship interact with the other ship.

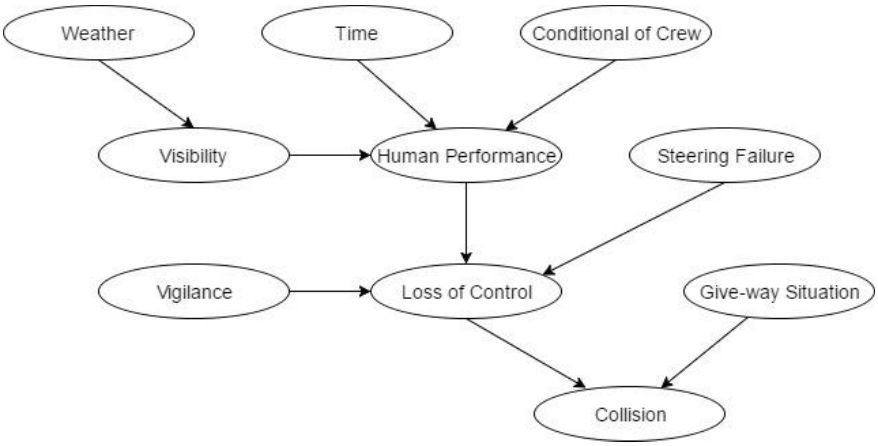


Figure 4. 10 Ship collision with all variables relationship

4.4.1.2. Probability Value Process

The next step to conduct Bayesian Network model is calculate the probability of nodes. The value of probability distribution has a range from 0 to 1. Which if each states is added up in the same node then the total value of probability is 1. To create the value of probability for states in each node will be explained in detail above. Also, the data of probability is obtained from the report of ship accident from KSOP in Bali Strait, and Mahkamah Pelayaran.

Table 4. 6 Node Description

Node Type	Node Description	Symbol	States	Symbol	Proceeding Node	Following Node
Parent	Weather	W	Good/ Rain	WG WR	-	V
Child	Visibility	V	Good/ Poor	VG VP	W	HP
Parent	Time	T	Day/ Night	TD TN	-	HP
Parent	Conditional of Crew	C	Fit/ Unfit	CF CU	-	HP
Child	Human Performance	HP	Excellent/ Poor	HPE HPP	V,T,C	L
Parent	Vigilance	I	Yes/ No	IY IN	-	L
Parent	Steering Failure	S	Function/ No Function	SF SN	-	L
Child	Loss of Control	L	Loss/ No Loss	LL LN	I,HP,S	C
Parent	Give way	G	Change/ No Change	GC GN	-	C
Child	Collision	C	Yes/ No	CY CN	L,G	-

1. Weather

The node describes the condition of weather in the region at certain times. The weather condition can influences the visibility of officer on watch when the ship operation. The condition of weather in Bali Strait is unpredictable because the Bali Strait itself connects directly to Indian Ocean and Java Sea. Based on the historical weather that obtained from accuweather.com and weather.com to know and estimate the condition of weather that happen in Bali Strait area that can influence ship collision.

The states defined for this node are “Good” where the weather condition is clear or cloudy and did not disturb the visibility with the probability value 0.641096 and state “Rain” where the bad condition cause of the rain that decrease the visibility with the probability value 0.358904.

2. Time

The node describe the operational of vessel in Bali Strait though its passenger ship or merchant ship. The operational of passenger vessel in Bali Strait for 24 hours. The differences of time ship operational also can influence the performance of ship crew. The states for this node are “Day” and “Night”. The data obtained from marinetraffic.com based on time operational of ship in Bali Strait. The probability value for state day where the operational of ships from 06.00 a.m. to 06.00 p.m. is 0.491 and state night from 06.00 p.m. to 06.00 a.m. is 0.509.

3. Conditional of Crew

The node of conditional of crew is divided into 2 states which fit and unfit. The data of conditional of crew based on the time of crew tired. The assumptions are made with the 56 ships operation in Bali Strait with the total crew officer work is two persons in one ship. In previous bachelor thesis explained that the time crew experience tired and sleepy is around 12.00 p.m. to 16.00 p.m. and 01.00 a.m. and 05.00 a.m. Then to find the probability value of conditional of crew is using the combination of tired and sleepy probability. The probability value of state fit is 0.713 and the probability value of state unfit is 0.287.

4. Steering Failure

The node indicates the reliability of the steering gear system that influenced by maintenance routines. Steering failure is divided into state function and not function. The data based on generic data from DNV. For the probability value of steering in function is 0.9904 and the probability value of steering gear failure is 0.0096.

5. Vigilance

The node describes about the performance of officer on watch or officer 2 or VTS that can detect danger. The states for this node are “Yes” where the officer can detect another ship with the probability value of yes state is 0.9375 and “No” where the officer cannot detect another ship that has the possibility to approaching to the ship with the probability value is 0.0625.

6. Give way

These nodes describe the give way situations that the vessel can experience. Give way category is divided into 2 states which “Change” and “Not Change”. The probability for this node is obtained from an analysis report analysis. Based on the analysis, it was found that 0.714 probability value of vessels will change it course and 0.286 probability value of vessels will not change it course.

4.4.1.3. Conditional Probability Table

In this process, addition of CPT is done to determine the probability of each state that depends on each parent node. Each parent variable and every possible state variable, there is a line in CPT that describes the probability of a child node consisting of several states (McCabe, dkk, 1998; Olmus dan Erbas, 2004). There are several methods to create Conditional Probability Table, in this bachelor thesis is using Weighted Sum Alghoritm. This method of calculation is an equation derived from paper called Generating Conditional Probabilities for Bayesian Network: Easing the Knowledge Acquisition Problem (Das, 2004). This method is used due to the required Conditional Probability Table (CPT) required by software used in this research study (NETICA Software) are a simplified CPT.

To start the calculation for Conditional Probability Table for the below parent nodes with more than 2 parent nodes such as Human Performance, Loss of Control and

Collision each parent nodes were weighted equally. For Conditional Probability Table of Visibility which influenced by Weather nodes is based on the DNV that explained if when in rain condition, the visibility decrease 30% to poor visibility which less than 1 nautical mile.

Table 4. 7 Conditional Probability Table of Visibility Node

VISIBILITY		
WEATHER	Good	Poor
Good	1	0
Rain	0.7	0.3

The calculation of Human Performance is used as an example with each parent nodes will weighted equally. According to Figure 4.5 Human Performance consists of 3 parent nodes which Visibility, Time and Conditional of Crew with the relative weights 1/3 for each node. Based on the software used, it specifies the Conditional Probability Table is 8x2 configurations due to combination for states of each node. After that continue the next step to add up the weighted nodes to get the probability result. The example of the calculation is presented in equation below.

$$P\ (Excellent|Day, Fit, Good) = \frac{Day}{3} + \frac{Fit}{3} + \frac{Good}{3}$$

$$P\ (Excellent|Day, Fit, Good) = \frac{0.491}{3} + \frac{0.713}{3} + \frac{0.892}{3}$$

$$P\ (Excellent|Day, Fit, Good) = 0.698667$$

Table 4. 8 Conditional Probability Table of Human Performance

HUMAN PERFORMANCE				
TIME	CONDITIONAL OF CREW	VISIBILITY	Excellent	Poor
Day	Fit	Good	0.698667	0.301333
Day	Fit	Poor	0.562667	0.437333
Day	Unfit	Good	0.556667	0.443333
Day	Unfit	Poor	0.295333	0.704667
Night	Fit	Good	0.704667	0.295333
Night	Fit	Poor	0.556667	0.443333
Night	Unfit	Good	0.562667	0.437333
Night	Unfit	Poor	0.301333	0.698667

In using the same methods calculations, Conditional Probability Table (CPT) for Loss of Control and Collision were obtained. The result of Conditional Probability Table (CPT) calculation of Loss of Control and Collision node presented in Table 4.8 and Table 4.9.

Table 4. 9 Conditional Probability Table of Loss of Control Node

LOSS OF CONTROL				
HUMAN PERFORMANCE	VIGILANCE	STEERING FAILURE	Loss	No Loss
Excellent	Yes	Function	0.397044	0.602956
Excellent	Yes	Not Function	0.529867	0.470133
Excellent	No	Function	0.4352	0.5648
Excellent	No	Not Function	0.762133	0.237867
Poor	Yes	Function	0.237867	0.762133
Poor	Yes	Not Function	0.4352	0.5648
Poor	No	Function	0.470133	0.529867
Poor	No	Not Function	0.8568	0.1432

Table 4. 10 Conditional Probability Table of Collision Node

COLLISION			
LOSS OF CONTROL	GIVE-WAY SITUATION	Yes	No
Loss	Change	0.469	0.531
Loss	Not Change	0.683	0.317
No Loss	Change	0.317	0.683
No Loss	Not Change	0.469	0.531

4.4.1.4. Causal Probability

A Bayesian network consists of a directed acyclic graph whose nodes are variables in the domain of interest, together with the probability distribution of each variable conditional on its parents in the graph (or its unconditional distribution if the variable has no parents).

From the picture, it explains about the cause of ship collision by several factors. To modeling the Bayesian network using NETICA software by input the probability value of parent nodes and conditional probability for child nodes in each state. Then to find the causal probability for each condition of ship collision. It needs to make the assumptions of scenario to determine the value of head on, overtaking, and crossing collision causation probability

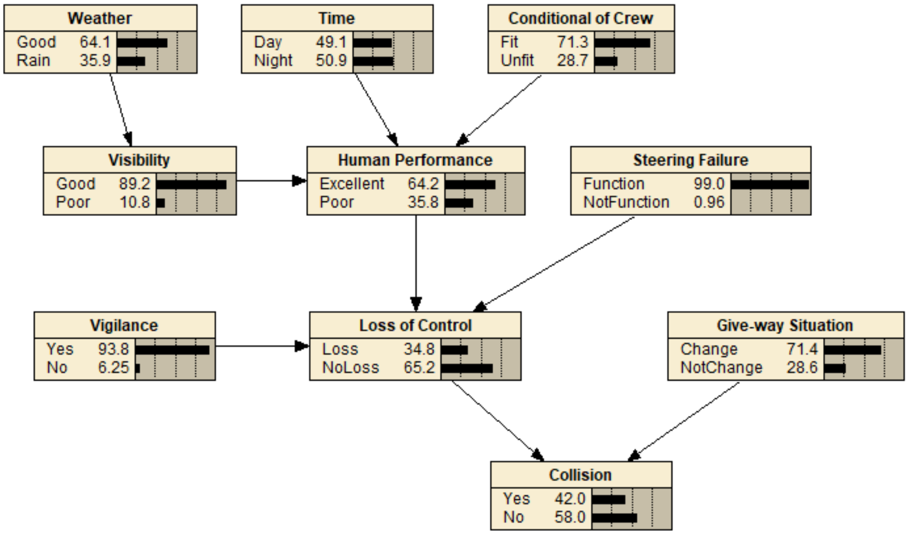


Figure 4. 11 Bayesian Network Model of Ship Collision

The mathematics equation joint probabilities (P) of ship collision model are:

1. Head On Probability

To calculate the causal probability of head on collision, several scenarios are needed that make the collision can occur. In this scenario that cause of a ship collision is caused by bad weather that decreased the visibility when the operational of vessel in daytime. The condition of crew in poor condition resulting in poor performance to carrying out their duties. The steering gear system is known to be in a good condition and also has a good vigilance by internal or external parties. The collision was caused by the loss of control so that the ship could not avoid collision even though the crew had maneuvered.

Table 4. 11 Causation Probability of Head On Collision

NODE	STATE	SYMBOL	PROBABILITY
Weather	Rain	(WR)	0.359
Visibility	Poor	(VP)	0.300
Time	Day	(TD)	0.491
Conditional of Crew	Unfit	(CU)	0.287
Human Performance	Poor	(HPP)	0.705
Steering Failure	Function	(SF)	0.990
Vigilance	Yes	(IY)	0.938
Loss of Control	Loss	(LL)	0.238
Give way	Change	(GC)	0.714
Collision	Yes	(CY)	0.469

After conduct the scenario, the next step is determine causal probability of ship collision by the probability value of each node using joint probability to calculate causation probability that explained below,

P(WR,VP,TD,CU,HPP,SF,IY,GC,LL,CY) =
P(WR)*P(VP|WR)*P(TD)*P(CU)*P(HPP|VP,TD,CU)*P(SF)*P(IY)*P(LL|SF,IY,HPP)*P(GC)*P(CY|LL,GC) =
0.358904*0.3*0.491*0.287*0.705*0.9904*0.9375*0.2378*0.714285*0.469 =
0.000791207

2. Overtaking Probability

Same as like head on condition, for a causation probability of overtaking collision. Scenario is carried out to determine the probability of ship accidents where weather conditions are quite good which can affect visibility for officer of watch. Although the ship operational time is at night but the conditions of crew in charge tend to be fit. Crew condition also affect to the performance for officer on the watch. The steering gear system is failure to function which causes the ship unable to maneuver so that it can cause the ship to collide with other vessel. The vigilance is carried out quite well even though there has been a failure in operating the ship even though the ship has attempted to maneuverings ships which can cause ship collisions.

Table 4. 12 Causation Probability of Overtaking Collision

NODE	**STATE**	**SYMBOL**	**PROBABILITY**
Weather	Good	(WG)	0.641
Visibility	Good	(VG)	1
Time	Night	(TN)	0.509
Conditional of Crew	Fit	(CF)	0.713
Human Performance	Excellent	(HPE)	0.557
Steering Failure	No Function	(SN)	0.010
Vigilance	Yes	(IY)	0.938
Loss of Control	Loss	(LL)	0.530
Give way	Change	(GC)	0.714
Collision	Yes	(CY)	0.469

After conduct the scenario, the next step is determine causal probability of ship collision by the probability value of each node using joint probability to calculate causation probability that explained below,

P(WG,VG,TN,CF,HPE,SN,IY,GC,LL,CY) =
P(WG)*P(VG|WG)*P(TN)*P(CF)*P(HPE|VG,TN,CF)*P(SN)*P(IY)*P(LL|SN,IY,HPE)*P(GC)*P(CY|LL,GC) =
0.641096*1*0.509*0.713*0.557*0.0096*0.9375*0.5298*0.714285*0.469 = 0.000207

3. Crossing Probability

To conduct causation probability of crossing collision, a scenario is created where an accident is caused by the absence of vigilance by the 2nd officer. Another factor for good weather and good visibility. Ships operate in night conditions and the condition of the crew is in good condition but the performance is in poor condition. There is no failure in the function of the steering gear system.

Table 4. 13 Causation Probability of Crossing Collision

N ODE	STATE	SYMBOL	PROBABILITY
Weather	Good	(WG)	0.641
Visibility	Good	(VG)	1
Time	Night	(TN)	0.509
Conditional of Crew	Fit	(CF)	0.713
Human Performance	Poor	(HPP)	0.295
Steering Failure	Function	(SF)	0.990
Vigilance	No	(IN)	0.063
Loss of Control	No Loss	(LN)	0.530
Give way	Change	(GC)	0.714
Collision	Yes	(CY)	0.317

After conduct the scenario, the next step is determine causal probability of ship collision by the probability value of each node using joint probability to calculate causation probability that explained below,

P(WG,VG,TN,CF,HPP,SF,IN,GC,LN,CY) =
P(WG)*P(VG|WG)*P(TN)*P(CF)*P(HPP|VG,TN,CF)*P(SF)*P(IN)*P(LN|SF,IN,HPP)*P(GC)*P(CY|LN,GC) =
0.641096*1*0.509*0.713*0.295*0.9904*0.0625*0.5299*0.714285*0.317 = 0.00051

4.4.1.5. Head On Collision Analysis

In head on collision analysis, there will be 4 legs used. Where each leg has a different number of ship densities and different length of leg.

Data for each leg for length of leg and ship densities is as follows:

Table 4. 14 Data for Calculation

Leg	Length of Leg	Ship Density	Standard Deviation
1	2000	95660	300
2	5900	1102	900
3	2300	95164	300
4	12600	350	900

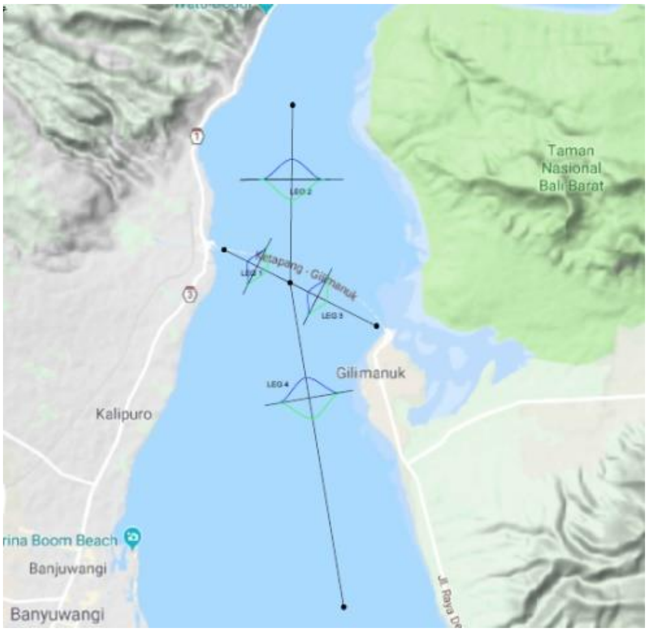


Figure 4. 12 Collision Scenario

This case study to conduct head on collision analysis is KMP Dharma Rucitra and KMP Trisila Bhakti 2 which in leg. Where leg 1 is crossing line of passenger ships that cross Bali Strait from or to Ketapang Port. The length of leg 1 is 2300 meters. The length of leg is measured from the port of Ketapang to the intersection of ships passing through the Bali Strait from north to south or vice versa. The value of a frequency is influenced by several factors, which shown in Table 4.15:

Table 4. 15 Data for Calculation

Description	Value
Length of leg	2000 m
Ships in each direction i	2028
Ships in each direction j	2140
Length of ships i	48 m
Length of ships j	50 m
Breadth of ships i	12.4 m
Breadth of ships j	13.5 m
Speed of ships i	7.5 m/s
Speed of ships j	7.3 m/s
Traffic distribution	Norm dist
Mean position from leg	290
Standard deviation	300
Causation factor	0.000791

After some of the data needed has been fulfilled, the calculation of frequency collision are divided into seven steps, which the following steps are:

1. Calculate relative speed between the vessels, the value of relative speed can be find with formula:
   $Vij = Vi + Vj$
   $Vij = 7.5 + 7.3$
   $Vij = 14.8\ m/s$

2. Average vessel breadth, according to the following equation:
   $Bij = \frac{Bi + Bj}{2}$
   $Bij = \frac{12.4 + 13.5}{2}$
   $Bij = 12.95\ m$

3. Mean Sailing distance between the two vessels,
   $\mu ij = \mu i + \mu j$
   $\mu ij = 290 + 290$
   $\mu ij = 580$

4. Standard deviation of joint distribution,
   $\sigma ij = \sqrt{\sigma i^2 + \sigma j^2}$
   $\sigma ij = \sqrt{300^2 + 300^2}$
   $\sigma ij = 424.26$

5. Collision probability,
   $P_{Gi,j}{}^{head-on} = \Phi\left(\frac{Bij - \mu ij}{\sigma ij}\right) - \Phi\left(-\frac{Bij + \mu ij}{\sigma ij}\right)$
   $P_{Gi,j}{}^{head-on} = \Phi\left(\frac{12.95 - 580}{424.26}\right) - \Phi\left(-\frac{12.95 + 580}{424.26}\right)$
   $P_{Gi,j}{}^{head-on} = 0.0094$

6. Number of geometric collision candidates for head-on collision,
   $N_G{}^{head-on} = Lw \sum_{i,j} PGi,j^{head-on} \frac{Vij}{ViVj}(QiQj)$
   $N_G{}^{head-on} = 2000\ x\ 5.46E - 06\ x\ \frac{14.8}{7.5\ x\ 7.3}\ x\ \left(\frac{2028\ x\ 2140}{365\ x\ 24\ x\ 3600}\right)$
   $N_G{}^{head-on} = 1.039$

7. Frequency of head-on collision,
   $\lambda = P_C\ x\ N_G$
   $\lambda = 0.00079\ x\ 1.039$
   $\lambda = 8.2E - 04$

For the example calculation of head-on collision frequency is 8.2 x $10^{-4.}$ By doing the same calculation method above, for the head on collision for merchant vessels in leg 2 and leg 4 in Bali Strait is 1.75 x 10^{-5}. Then, the total of head on collision frequency, on all determined leg with all vessels in the clustering data is 0.78.

4.4.1.6. Overtaking Collision Analysis

Same as head on collision, overtaking collision use leg 1 as a case study for calculating collision frequency. Overtaking collision can occur in a plot where ships move in the same direction, so the calculation of accident frequency is only viewed from ships moving eastward in leg 1. The calculation of overtaking collision has the same step as when calculating the head on collision frequency. Table below described about the data needed for the calculation of overtaking collision.

Table 4. 16 Data for Calculation

Description	Value
Length of leg	2000
Ships in each direction i	2028
Ships in each direction j	2140
Length of ships i	48
Length of ships j	50
Breadth of ships i	12.4
Breadth of ships j	13.5
Speed of ships i	7.5
Speed of ships j	7.3
Traffic distribution	Norm dist
Mean position from leg	290
Standard deviation	300
Causation factor	0.00021

In this case, the frequency of collision between KMP Dharma Rucitra and KMP Trisila Bhakti 2 will be calculated. The following steps to calculate overtaking collision are:

1. Calculate relative speed between the vessels, the value of relative speed can be find with formula:
   $Vij = Vi + Vj$
   $Vij = 7.5 - 7.3$
   $Vij = 0.2\ m/s$

2. Average vessel breadth, as follows:
   $$Bij = \frac{Bi + Bj}{2}$$

$$Bij = \frac{12.4 + 13.5}{2}$$
$$Bij = 12.95\, m$$

3. Mean Sailing distance between the two vessels,
$$\mu ij = \mu i - \mu j$$
$$\mu ij = 290 - 290$$
$$\mu ij = 0$$

4. Standard deviation of joint distribution,
$$\sigma ij = \sqrt{\sigma i^2 + \sigma j^2}$$
$$\sigma ij = \sqrt{300^2 + 300^2}$$
$$\sigma ij = 424.26$$

5. Collision probability,
$$PGi,j^{overtaking} = \Phi\left(\frac{Bij - \mu ij}{\sigma ij}\right) - \Phi\left(-\frac{Bij + \mu ij}{\sigma ij}\right)$$
$$PGi,j^{overtaking} = \Phi\left(\frac{12.95 - 0}{113.14}\right) - \Phi\left(-\frac{12.95 + 0}{113.14}\right)$$
$$PGi,j^{overtaking} = 0.024$$

6. Number of geometric collision candidates for overtaking collision,
$$NG^{overtaking} = Lw \sum_{i,j} PGi,j^{overtaking} \frac{Vij}{ViVj}(QiQj)$$
$$NG^{overtaking} = 2000\, x\, 0.091\, x\, \frac{0.2}{7.5\, x\, 7.3}\, x\, \left(\frac{2028\, x\, 2140}{365\, x\, 24\, x\, 3600}\right)$$
$$NG^{overtaking} = 0.024$$

7. Frequency of overtaking collision
$$\lambda = Pc\, x\, NG$$
$$\lambda = 0.00021\, x\, 0.024$$
$$\lambda = 5.1E - 06$$

For the example calculation of overtaking frequency generate 5.1 x 10^{-6} collision per year. The frequency of overtaking collision for merchant vessels is 2.4 x 10^{-9}. Then for all vessels in the clustering route segment in Bali Strait is 4.03 x 10^{-3}.

4.4.1.7. Crossing Collision Analysis

Crossing collision can occur at the intersection between two shipping line where there are 2 ships that move crossed and form a certain angle (θ). The crossing collision analysis in this case study use leg 1 with leg 2 which intersect each other in the Bali Strait which has the possibility of crossing collision. In this scenario, the first vessel is MT Elisabet Satu from the south to north and the second vessel, KMP Jambo

IX, which sails from west to east. The data needed, to calculate the frequency of collision is in the table below:

Table 4. 17 Data for Calculation

Ships North Going	66
Ships East Going	1630
Length of ship i	90
Length of ship j	68
Breadth of ship i	15
Breadth of ship j	15.2
Speed of ship i	8.9
Speed of ship j	7.3
Traffic Distribution	Normal dist.
Angle between legs	42
Causation factors	0.000207

To calculate the crossing collision analysis, it will be done into several steps which the following steps are:

1. Relative speed between vessels,

$$Vij = \sqrt{Vi^2 + Vj^2 - 2ViVjcos\theta}$$

$$Vij = \sqrt{8.9^2 + 7.3^2 - 2\ x\ 8.9\ x\ 7.3\ x\ \cos(42)}$$

$$Vij = 5.99 \text{ m/s}$$

2. Geometrical Collision Diameter,

$$Dij = \frac{LiVj + LjVi}{Vij} sin\theta + Bj\left\{1 - \left(sin\theta \frac{Vj}{Vij}\right)^2\right\}^{1/2} + Bi\left\{1 - \left(sin\theta \frac{Vi}{Vij}\right)^2\right\}^{1/2}$$

$$Dij = \frac{90\ x\ 7.3 + 68\ x\ 8.9}{5.99} \sin(42) + 15.2\left\{1 - \left(\sin(42) \frac{7.3}{5.99}\right)^2\right\}^{1/2} + 15\left\{1 - \left(\sin(42) \frac{8.9}{5.99}\right)^2\right\}^{1/2}$$

$$Dij = 151.49$$

3. Geometric number as candidates of crossing collision,

$$NG^{crossing} = \sum i,j \frac{QiQj}{ViVj} DijVij \frac{1}{sin\theta}$$

$$NG^{crossing} = \sum i,j \frac{66\ x\ 1630}{8.9\ x\ 7.3} Dij\ x\ 5.99 \frac{1}{\sin(42)}$$

$$NG^{crossing} = 1.82$$

4. Frequency of crossing collision

$\lambda = Pc * NG$

$\lambda = 0.000207 * 1.82$

$\lambda = 0.000378$

For the example calculation above, the crossing collision between MT Elisabet Satu and KMP Jambo IX generate the crossing collision 3.78 x 10^{-4}. The crossing collision frequency in Bali Strait collision scenario is 1.55 x 10^{-2}. Crossing collision analysis is also carried out in the port area where each port has 4 different piers consisting of Pontoon, Moveable Bridge I, Moveable Bridge II, and Moveable Bridge III. Then, the scenario is made to find out the possibility of a crossing collision that can occur in the port area.

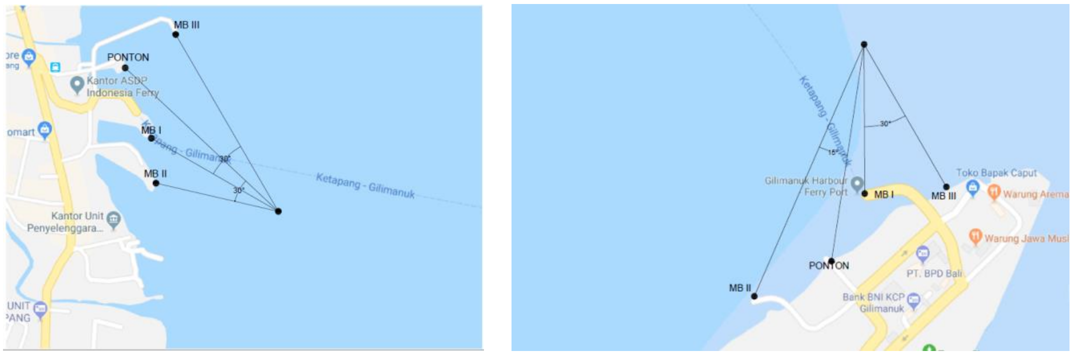


Figure 4. 13 Ketapang and Gilimanuk Port Crossing Collision Scenario

In figure 4.13, there are 4 scenario of crossing collision with different angles of crossing route. After done the calculations of crossing collision in port area. It can be seen that the value to the result of crossing collision frequency for 30^{o} such as between Moveable Bridge I and Moveable Bridge III in Ketapang Port area and for 15^{o} in the Gilimanuk Port area between Pontoon and Moveable Bridge II is 4.87 x 10^{-2}. So, for the total of crossing collision in Bali Strait is 6.42 x 10^{-2}.

4.4.2. Consequence Analysis

Consequence analysis that will be conduct in this bachelor thesis is about the modeling of oil spill when tanker vessel experienced collision with another ship. The simulation to modeling oil spill is using GNOME software from NOAA (National Oceanic and Atmospheric Administration). To simulate oil spill some data needed as input values in GNOME software, as it follows:

a. Determine ship specifications and oil spill.

The ship that will be used in the simulation is a double hull tanker with the following dimensions of vessel:

Table 4. 18 Ship Dimension

Hull Type	Double Hull	
Length	190.5	m
Breadth	29.26	m
Draught	10.58	m
DWT	40000	metric tons
Displacement	47.448	metric tons

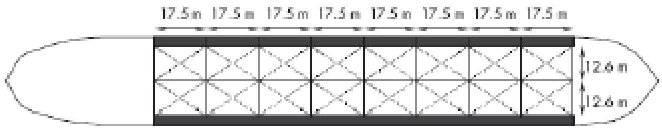


Figure 4. 14 Tank Plan of Ship Model

Ship that will be used based on previous researches which have a payload capacity of one compartment is 2825.3 m^3. In previous research, the ship that analyzed was collided which caused two compartments to leak causing the oil to spill with a volume of 5439.39 $m^{3.}$

b. Input location map

In process of map that will be used as locations to conduct the simulations is done on the NOAA website by determining which part of the area will be analyzed, the map to be used at this bachelor thesis in the northern part of the Bali Strait.

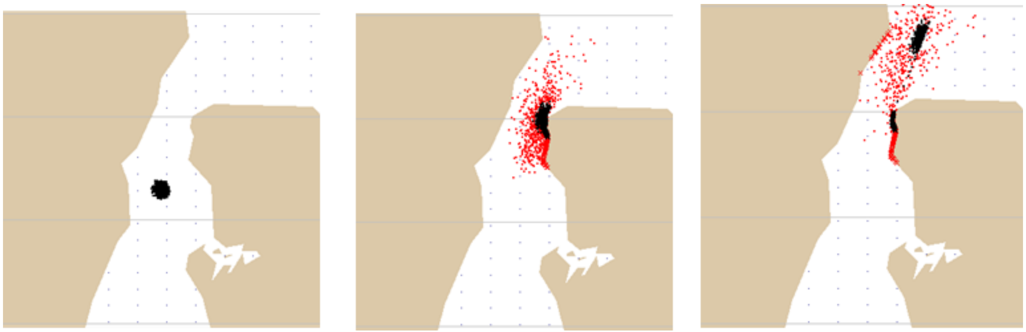
c. Determine coordinates

The coordinate point is done to determine the point of occurrence of oil spills due to the collision that has been screened before. The point of the collision is at coordinates 8° 08' 09" S and 114° 24' 59" E.

d. Wind and current velocity

To get current velocity in the location of the incident can be obtained from GNOME Online Oceanographic Data Server (GOODS) web same as location map. In software modeling, the input wind speed move from Southwest to the Northeast Bali Strait at a speed of 3 m/s.

After the required data is inputted into GNOME software, the nest step is run a simulation of oil distribution. Oil spills will be simulated in 12 hours and 24 hours to determine the oil distribution. The results of the simulations in the scenario are:



(a) (b) (c)

Figure 4. 15 Oil Spill Distribution
(a) Initial Condition, (b) After 12 hours, (c) After 24 hours

Based on the simulation results, it can be seen that after 12 hours the oil has spread to the coastal part in the west of Bali Island and after 24 hours of oil spill, oil continues to move towards to the Bali Sea in the north of Bali Island and also has hit the eastern part of Java namely Banyuwangi.

Table 4. 19 Oil spill volume in 12 hours and 24 hours

Condition	Oil Volume (m^3)	
	12 hours	24 hours
Released	5439	5439
Evaporated/Dispersed	723	1082
Beached	1817	1784
Floating	2899	2573

From the simulation results, it can be seen that the volume of oil spilled into the sea. There were 1082 m^3 of oil evaporated or dispersed at 24 hours, this amount increased where at 12 hours the amount of oil evaporated and dispersed was 723 m^3. This can be caused by oil which has been split into smaller particles which can be dispersed by seawater or evaporate by the sun's heat. The volume of oil that reaches the beach at 12 hours is 1817 m^3 then after 24 hours the amount of oil on the beach decreases to 1784 m^3, this can occur because the oil can be carried by the waves into the sea or evaporate. Whereas for the amount of oil still floats in the sea after 12 hours is 2899 m^3 and after 24 hours the amount of oil is reduced by 2573 m^3.

The volume of oil spill is 5,439.39 liters where for 1 liter crude oil is IDR 5,180.00. Then, the total loss for oil spill is IDR 28,176,064,000.00. In addition, the parties have a responsibility to cleaning the environment as a result of oil leaks that occur at sea. To estimate cleanup cost, it can be done with the following formula based on previous research "*Worldwide Analysis of Marine Oil Spill Cleanup Cost Factors*":

$$C_{li} = r_i l_i C_n \tag{4.1}$$

$$C_{li} = 0.161$$

$$C_{ui} = C_{li}\, t_i o_i m_i s_i \tag{4.2}$$

$C_{ui} = 0.001$

$$C_{ei} = C_{ui}A_i \quad (4.3)$$

$C_{ei} = 5982$ USD

C_{ei} = IDR 83,750,778.00

Where,

C_{ui} = response cost per unit for scenario
C_{li} = cost per unit spilled for scenario
C_n = general cost per unit spilled in nation, *0.35 USD/liter cost in Asia*
C_{ei} = estimated total response cost for scenario
t_i = oil type modifier factor for scenario, *crude oil type*
o_i = shoreline oiling modifier factor for scenario, *8-15 km*
m_i = cleanup methodology modifier factor for scenario, *dispersants method*
s_i = spill size modifier factor for scenario, *3,400-34,000 tonnes oil spill*
r_i = regional location modifier factor for scenario, *in Asia*
l_i = local location modifier for scenario, *in offshore*
A_i = specified spill amount for scenario, *5439,39 liters*

Based on the results of the cleanup cost estimation calculation, the cost needed to clean up the oil spill is IDR 83,750,660.00. So, the total cost of oil spill and cleanup cost is IDR 28,259,826,000.00.

4.5. Risk Matrix

After analyzing the frequency and consequences of each ship collision scenario, then the next step is rate the result by combining frequency and consequence into the risk matrix. For the frequency that will be used is related to the tanker shipping lane that has the consequence of oil spill. The risk matrix according to DNV standards and the results can be carried out as can be seen in Table 4.19.

4.5.1. Head-on Collision Risk Matrix

Based on the results of the frequency calculation, the value for head-on collision is 1.75×10^{-5}, which means there are more than 1 accident in 1 year. For the value of consequence, based on the volume of oil spill is 5439 m^3 or equal to 4677.54 metric ton where the explanation of catastrophic level is oil spill larger than 300 tons. The conclusion of head-on collision in risk matrix is in tolerable level.

4.5.2. Overtaking Collision Risk Matrix

For the result of overtaking collision frequency is 2.4×10^{-9}, it means there will be 4 accident in thousand years. For the value of consequence, based on the volume of oil spill is 5439 m^3 or equal to 4677.54 metric ton where the explanation of catastrophic level is oil spill larger than 300 tons. The conclusion of head-on collision in risk matrix is in negligible level.

4.5.3. Crossing Collision Risk Matrix

According to the result the frequency of crossing collision is 1.55×10^{-2}, it means there will be 8 accidents in hundred years. For the value of consequence, based on the volume of oil spill is 5439 m^3 or equal to 4677.54 metric ton where the explanation of catastrophic level is oil spill larger than 300 tons. The conclusion of head-on collision in risk matrix is in unacceptable level.

Table 4. 20 Head On, Overtaking, Crossing Collision Risk Matrix

		Consequence					
		None	Negligible	Significant	Serious	Critical	Catastrophic
Frequency	>10						
	1-10						
	0,1-1						
	0,01-0,1						**Crossing**
	0,001-0,01						
	0,0001-0,001						
	0,00001-0,0001						**Head-on**
	<0,00001						**Overtaking**

Legends:

Negligible
Tolerable
Unwanted
Unacceptable

4.6. Risk Control Option

According to the results of risk assessment, the value of head-on and crossing collision frequency is at the unacceptable level and overtaking at the unwanted level. Therefore, the mitigation is needed to avoid the occurrence of ship accidents. There are several mitigation options that will be explain in the list below:

1. Automatic Identification System (AIS)

AIS can improve the navigator's ability or the operator in ship traffic control to know the traffic condition and avoid potential collisions.

2. Electronic Chart Display and Information System (ECDIS)

ECDIS can be used to plan and display the ship's route, so the officer can detect vessel's position in relation to possible unseen hazards. Also it helpful for navigating officer to reduce the workload.

3. Navigator Training

The navigator need the certification of Standards of Training, Certification and Watch-keeping for Seafarers (STCW) which the requirements for basic navigational skills. The training will improved the safety level of the vessel and the capability of navigator that can be done in simulator to give a real life experience of the given situations.

4.7. Cost Benefit Assessment

The purpose of Cost Benefit Assessment is to determine of every RCO that have been determine before. After calculating the total cost of RCO, it will be compare with the benefit because of the risk reduction. The value will be useful to choose the best option to give the recommendation of mitigation.

4.7.1. Cost

This step will discuss about the cost estimation for every Risk Control Option (RCO) mentioned before. The purpose is to estimate the total cost needs to reduce the risk.

1. Automatic Identification System (AIS)

The cost needed about the installation of AIS equipment to install in vessel or ship traffic control to monitoring traffic condition in Bali Strait, the total price will expain in table 4.21 for the specification of equipment and its price, as it follows:

Table 4. 21 Automatic Identification System (AIS) Cost

Item	Specification	Price
GPS	GPA017 S/S GPS Antenna Without Cable (Shielded/IMO Compliant)	IDR 1,470,000.00
AIS Transponder	FA1701 AIS Transponder Unit	IDR 39,130,000.00
AIS Display	FA1702 FA170 Display Unit	IDR 15,330,000.00
Cable	INTERCONNECT CBL 10M FA170	IDR 1,750,000.00
	Antenna Cable Assembly, 2 x TNC-P, 15 Meters	IDR 1,190,000.00
Antenna	CX4-3 VHF WHIP ANTENNA CX4-3/FEC	IDR 5,600,000.00
Pilot Plug	FA1703 PILOT PLUG UNIT FA170	IDR 5,880,000.00
Total		IDR 70,350,000.00

2. Electronic Chart Display and Information System (ECDIS)

The cost needed to do the installment of Electronic Chart Display and Information System (ECDIS) to reduce the workload of navigator, as it follows:

Table 4. 22 Electronic Chart Display and Information System (ECDIS) Cost

Item	Specification	Price
Monitor	MU 190 19" Color LCD Monitor without bracket	IDR 62,930,000.00
Mounting	FAR-190-BKT MU190 MOUNTING BRACKET	IDR 12,250,000.00
Processor Unit	EC3000 PROCESSOR UNIT FMD3200	IDR 154,630,000.00
Keyboard/Trackball	RCU024/5 Keyboard/Trackball Control Unit w/5 meter Cable	IDR 27,300,000.00
Cable	CBL 6TPSH-XH12X2 20M RCU026	IDR 9,310,000.00
Total		IDR 266,420,000.00

3. Navigator Training

The cost of navigator training needed to accommodate the navigator who will join the training, the total cost in table below as it follows:

Table 4. 23 Navigator Training Cost

Item	Description	Price
Course fee	20 person for 5 days	IDR 316,400,000.00
Board and lodging		IDR 84,000,000.00
Travel expenses		IDR 28,000,000.00
Total		IDR 428,400,000.00

4.7.2. Benefit

The implementation of a RCO might have benefits to reducing the number of consequence or frequency. The table below is explain about the cost of RCO implementation cost comparing to the reduction based on total cost of consequence that might be happen, as it follows:

Table 4. 24 Risk Control Option Benefit

Risk Control Option	Implementation	Reduction	Benefit
AIS	IDR 70,350,000.00	IDR 28,259,820,772.19	IDR 28,189,470,772.19
ECDIS	IDR 266,420,000.00	IDR 28,259,820,772.19	IDR 27,993,400,772.19
Navigator Training	IDR 428,400,000.00	IDR 28,259,820,772.19	IDR 27,831,420,772.19

The table below describes the expected risk reduction due to the implementation of risk control option (RCO). The numbers of percentage based on the reducing causation factors of collision probability. In example, the implementation of AIS is reducing head-on, overtaking, and crossing collision probability.

Table 4. 25 Risk Reduction Collision

Risk Control Option	Risk Reduction
AIS	10%
ECDIS	27%
Navigator training	35%

4.8. Recommendation

The purpose of recommendation for decision making to improve the reduction risk. To determine the best option from several RCO is choosing the RCO that has highest cost-effectives which is benefit comparing to the risk reduction. Gross cost determines a cost-effectiveness of the risk control option to the reduction in probability of collision averted. Net cost determines a cost-effectiveness accounting for the economic benefits of the risk control option to the reduction in probability of collision averted. The definitions are:

$$\text{Gross Cost of Averting Collision} = \frac{\Delta C}{\Delta R} \tag{4.4}$$

$$\text{Net Cost of Averting Collision} = \frac{\Delta C - \Delta B}{\Delta R} \tag{4.5}$$

Where,

ΔC = cost of the implementation of the risk control option
ΔB = economic benefit resulting the implementation of the risk control option
ΔR = risk reduction

Table 4. 26 Recommendation

Risk Control Option	Gross Cost of Averting Collision	Net Cost of Averting Collision
AIS	IDR 739,747,634.00	IDR (296,419,251,022.00)
ECDIS	IDR 993,733,681.00	IDR (104,414,027,498.00)
Navigator training	IDR 1,208,803,611.00	IDR (78,531,096,987.00)

Based on the table above, the results shows that Automatic Identification System (AIS) is the most cost effective measures in this evaluation. The Gross Cost and Net Cost values are low. A negative Net Cost indicates that the RCO is beneficial in itself due to the cost of implementing the RCO is less than the the economical benefit of implementing it.

CHAPTER 5
CONCLUSION

5.1. Conclusion

According to the research of Formal Safety Assessment (FSA) for Ship Collision in Bali Strait, it can conclude that:

1. The result of frequency calculation for each scenario are:
   a. Total head-on collision is 0.78; it means there 1 accident in 1 year
   b. Total overtaking collision is 4.03 x 10^{-3}; it means there will be 4 accident in thousand years
   c. Total crossing collision is 6.42 x 10^{-2}; it means there will be 6 accident in hundred years.
2. The result of oil spill simulation with the total volume of oil leak is 5439.39 m^3. In scenario, oil spill is divided into two conditions which are 12 hours and 24 hours. There were 1082 m3 of oil evaporated or dispersed at 24 hours, this amount increased where at 12 hours the amount of oil evaporated and dispersed was 723 m3. The volume of oil that reaches the beach at 12 hours is 1817 m3 then after 24 hours the amount of oil on the beach decreases to 1784 m3. Whereas for the amount of oil still floats in the sea after 12 hours is 2899 m3 and after 24 hours the amount of oil is reduced by 2573 m3.
3. The best option for mitigation that can be applied based on the cost benefit assessment is the installation of Automatic Identification System (AIS). This option gives the most cost effective due to the lowest gross cost and net cost value. The benefits cost of implementing AIS is IDR 28,189,470,772.19 and the reduction risk is 10%.

5.2. Suggestion

After conducting research with the title of Formal Safety Assessment for Ship Collision in Bali Strait, there are several things that need to be considered, which are:

1. The use of IWRAP software is helpful during the process of ship collision frequency calculation.
2. In process of data collecting, the author has difficulty to conduct the probability using Bayesian Network method, because not all accident is being reported.
3. In determining the volume of oil spill, further research is needed to determine other factors that can affect the hull leak according to real time conditions, so the results are more accurate.

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ATTACHMENT

Tabel 1 Ship Collision Chronology

Accident	Date	Time	Cronological
Collision	02-Jun-10	04.30 WITA	Officer on watch of the KM Shinpo 18 saw the suspected lamp was the stern light of another ship on the left. The distance between the two ships in front of KM Bosowa VI is about 4 nautical mile. The Officer on watch in KM Bosowa VI carrying out VHF radio communications but were not responded by the crew in KM Shinpo 18. The posistion of the two ships were getting closer, the officer on watch KM Bosowa VI ordered the helmsman to change course by maneuvered to the left. The position of the two ships already in collision position. Officer on watch KM Shinpo 18 ordered the helmsman to maneuvered the ship to the right. However the turnaround in the KM Shinpo 18 with the right maneuver could not prevent the two ships from colliding danger. As a result of collisions between KM Bosowa VI and KM Shinpo 18, resulting in the right bulwark in front of the KM Bosowa VI collapsed 20 meters and the right hull below the water line dented. While KM Shinpo 18 is have severe damage to the left bow which resulted theship being severely damaged and leaking then sinking.
	25-Dec-13	10.36 WITA	KMP Gilimanuk, GT 733, departing from Ketapang Port towards Gilimanuk Port, crew of people, with 180 passengers, and cargo in the form of small vehicles with 25 units, motorbikes 40 units. When the ship moved, a strong wind and strong currents came from the south to the north, when the ship exits the dock, the bow is turned to the right but is unable, and the ship is dragged and finally hits the new dock pile.

	15-Feb-15	16.30 WITA	LCT Perkasa Prima 05 with LCT Arjuna experienced collisions and sticked for about 15 minutes. LCT Perkasa Prima V which contains 3 small trucks on the LCM dock in Gilimanuk Port leading to Ketapang Port, Banyuwangi. When LCT Perkasa Prima V was about to get out of the port suddenly there was a heavy current which resulted in LCT Perkasa Prima V being dragged and crashing into the LCT Arjuna ship which was speeding into the port of Gilimanuk Port. Ramp door of the LCT Arjuna ship is caught in the LCT Perkasa Prima V railing section. There are no fatalities. There is damage to the railing of LCT Perkasa Prima V and damaged on the hull of the ship. Monitored the wave height around Gilimanuk port reaching 1 meter. Wind speed is 15-20 knots per hour. However, there is potential for Cumulonimbus (CB) clouds. These clouds can cause an increase in wind speed and have an impact on wave heights and heavy ocean currents.
	28-Dec-18	12.45 WITA	Collisions between ships in the Bali Strait between KMP Munic and KMP Dharma Kosala. KMP Munic hit the stern of KMP Dharma Kosala. When KMP Munic is driving towards the port and in the front position there is the KMP Dharma Kosala which is not operating. Because the KMP Dharma Kosala was off, no crew members were watching while the crew of the KMP Munic V tried to contact KMP Dharma Kosala officers via Marine VHF radio but there was no response. But the KMP Munic captain was late responding and high waves with strong currents came and KMP Munic could not avoid a collision that hit the stern of the KMP Dharma Kosala. There was damage to the bow of the KMP Dharma Kosala and the lifeboat that fell to the bottom deck of the KMP Dharma Kosala. Whereas the damage that occurs in KMP Munic is dent on the hull of the ship. There were no fatalities due to a ship accident.

Tabel 2 Head On Collision

Head-on Collision	Crude oil tanker	Oil products tanker	Chemical tanker	Gas tanker	General cargo ship
Crude oil tanker	4.28E-12	2.19E-10	2.79E-11	2.15E-11	6.13E-11
Oil products tanker	2.01E-10	9.74E-09	1.24E-09	1.02E-09	2.70E-09
Chemical tanker	5.42E-11	2.61E-09	3.45E-10	2.93E-10	7.04E-10
Gas tanker	2.48E-11	1.27E-09	1.89E-10	1.53E-10	3.27E-10
General cargo ship	2.92E-11	1.40E-09	1.59E-10	1.25E-10	4.10E-10
Bulk carrier	4.34E-11	2.09E-09	3.09E-10	2.70E-10	5.30E-10
Ro-Ro cargo ship	0	0	0	0	0
Passenger ship	3.91E-11	1.87E-09	2.26E-10	1.86E-10	5.26E-10
Support ship	1.05E-10	4.80E-09	7.01E-10	6.42E-10	1.21E-09
Fishing ship	1.50E-10	6.68E-09	6.89E-10	5.49E-10	2.01E-09
Total	6.51E-10	3.07E-08	3.89E-09	3.26E-09	8.47E-09

Continue from Table 1

Head-on Collision	Bulk carrier	Ro-Ro cargo ship	Passenger ship	Support ship	Fishing ship
Crude oil tanker	6.15E-11	0	3.18E-11	9.32E-11	7.98E-11
Oil products tanker	2.79E-09	0	1.40E-09	4.06E-09	3.35E-09
Chemical tanker	7.89E-10	0	3.75E-10	1.15E-09	8.47E-10
Gas tanker	4.32E-10	0	1.89E-10	6.77E-10	3.74E-10
General cargo ship	3.46E-10	0	1.99E-10	4.84E-10	5.44E-10
Bulk carrier	7.21E-10	0	3.06E-10	1.08E-09	5.74E-10
Ro-Ro cargo ship	0	7.90E-01	0	1.31E-05	0.00E+00
Passenger ship	5.08E-10	0.00E+00	2.62E-10	7.15E-10	6.65E-10
Support ship	1.66E-09	0.00E+00	6.89E-10	2.38E-09	1.26E-09
Fishing ship	1.48E-09	2.60E-05	9.31E-10	2.34E-09	2.56E-09
Total	8.79E-09	7.90E-01	4.39E-09	1.31E-05	1.03E-08

Tabel 3 Overtaking Collision

Overtaking Collision	Crude oil tanker	Oil products tanker	Chemical tanker	Gas tanker	General cargo ship
Crude oil tanker	2.00E-14	6.05E-12	1.37E-12	7.81E-13	1.64E-12
Oil products tanker	6.05E-12	2.50E-10	6.90E-11	7.41E-11	5.58E-11
Chemical tanker	1.37E-12	6.90E-11	1.83E-11	1.54E-11	1.32E-11
Gas tanker	7.81E-13	7.41E-11	1.54E-11	0	1.65E-11
General cargo ship	1.64E-12	5.58E-11	1.32E-11	1.65E-11	1.07E-11
Bulk carrier	1.38E-12	6.09E-11	1.73E-11	2.02E-11	1.54E-11
Ro-Ro cargo ship	0	0	0	0	0
Passenger ship	6.15E-13	6.41E-11	1.34E-11	3.73E-12	1.50E-11
Support ship	2.02E-12	1.06E-10	3.23E-11	3.57E-11	2.78E-11
Fishing ship	3.61E-12	9.92E-11	3.14E-11	4.06E-11	1.42E-11
Total	1.75E-11	7.85E-10	2.12E-10	2.07E-10	1.70E-10

Continue form Table 2

	Bulk carrier	Ro-Ro cargo ship	Passenger ship	Support ship	Fishing ship
Crude oil tanker	1.42E-12	0	6.15E-13	2.02E-12	3.61E-12
Oil products tanker	7.17E-11	0	6.41E-11	1.06E-10	9.92E-11
Chemical tanker	2.02E-11	0	1.34E-11	3.23E-11	3.14E-11
Gas tanker	2.15E-11	0	3.73E-12	3.57E-11	4.06E-11
General cargo ship	1.80E-11	0	1.50E-11	2.78E-11	1.42E-11
Bulk carrier	1.18E-11	0	1.73E-11	1.38E-11	2.45E-11
Ro-Ro cargo ship	0	4.03E-03	0	7.24E-10	1.53E-07
Passenger ship	1.8274E-11	0	3.87E-12	2.70E-11	3.32E-11
Support ship	1.8041E-11	7.24E-10	2.70E-11	1.47E-11	5.29E-11
Fishing ship	3.2145E-11	1.53E-07	3.32E-11	5.29E-11	8.73E-12
Total	2.13E-10	4.03E-03	1.8E-10	1.04E-09	1.53E-07

Tabel 4 Crossing Collision

Crossing Collision	Ro-Ro cargo ship	Support ship	Fishing ship
Crude oil tanker	2.71E-04	7.43E-10	3.16E-09
Oil products tanker	1.20E-02	3.17E-08	1.31E-07
Chemical tanker	1.96E-03	4.89E-09	2.23E-08
Gas tanker	1.30E-03	4.53E-09	1.27E-08
General cargo ship	2.99E-03	7.92E-09	3.24E-08
Bulk carrier	3.43E-03	1.16E-08	3.38E-08
Passenger ship	1.87E-03	3.79E-09	2.04E-08
Support ship	4.18E-03	1.20E-08	3.71E-08
Fishing ship	5.40E-03	6.26E-09	6.37E-08
Total	3.34E-02	8.34E-08	3.57E-07

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