Framework of a Bow-Tie Based Quantitative Risk Assessment on an Offshore Oil and Gas Processing Unit

by

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Dissertation submitted in partial fulfilment of

the requirement for the

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CERTIFICATION OF APPROVAL

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Approved by,

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January 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(AWANG MUHAMMAD NASUHA BIN AWANG NAZARUDIN)

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ABSTRACT

The study presents the proposal for a framework of a bow-tie based quantitative risk assessment (QRA) on a system of an offshore oil and gas platform. Offshore operations such as drilling or production are associated with a high level of risk because they typically operate in a dynamic and tough environment, especially at the deep-water region. The necessity of having an integrated methodology or a framework of risk analysis will provide a supportive infrastructure for engineers in making decisions for the purposes of risk mitigation and risk prevention during the new or operating installations.

The subject of the study is to create a generic framework of quantitative risk assessment (QRA) which is based on bow-tie method. The paper will start by proposing on how the bow-tie based QRA will be done. Then, the paper will continue by defining a system of an offshore oil and gas platform to be studied in the 'System Definition' phase in which a case study using the proposed QRA will follow.

The framework will start by defining the system and a Fault Tree Analysis (FTA) will be developed based on the simplified Process Flow Diagram (PFD). From the top event of the Fault Tree Analysis, the top event will be used as the Initiating Event for the development of Event Tree Analysis (ETA) which is proposed by the bow-tie method. The consequences of the failure will be presented in the ETA.

In order to complete the risk equation, the probability of occurrence from the ETA will be multiplied with its Impact or Consequences using Risk Matrix Analysis that is proposed in ISO 17776 to rank the risks according to their risk levels.

The result of this QRA will be that when the highest risk of the systems has been identified, it will be useful for the process or mechanical piping engineer to provide improvement to the design or devise a risk mitigation plan for that particular occurrence.

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CHAPTER 1
INTRODUCTION

1. INTRODUCTION

Risk assessment is a technique for identifying, quantifying and evaluating hazards. It is widely used in the oil and gas industries to support risk mitigation, prevention and maintenance. Apart from that, oil and gas industries are constantly exposed to high risk levels due to the dynamic and rough working environment. Quantitative risk assessment includes estimating the likelihood (frequencies) and consequences of hazard occurrence. After the risk has been quantified, appropriate risk-management options can be planned and devised.

1.1. Background of Study

1.1.1. The History of Risk Assessment on Offshore Installations

Oil and gas industries are the major source of world's source of energy. Throughout the years of exploration and production development, new technological advancement has pushed all oil custodians in the whole world towards the limit of exploring new fields such as deep-water. In 1970s, when offshore drilling and production platform was complemented with living quarters, Norwegian Petroleum Directorate (NPD) issued regulations in demanding risk evaluation to be performed. It was the first regulatory requirement for proper Quantitative Risk Analysis (QRA), as it is known today.

Before the incident of Piper Alpha in July 1988, there was no regulatory practice was in place especially for risk assessment [1]. The Piper Alpha accident in 1988 provided a tragic validation that major accidents can be predicted and prevented using risk analyses and QRA specifically could be useful to reduce the risk [2].

Figure 1: Piper Alpha on fire (taken from: http://www.mirror.co.uk/news/real-life-stories/piper-alpha-25-years-on-2031040)

Right after the incident, the observation regarding the risk analysis is that, risk analysis activities were performed rapidly for new installations by 1992, which was due to the newly made regulations by Health and Safety Executive (HSE).

1.2. Problem Statement

Despite having positive technological development in the oil and gas industries, a rising awareness has stimulated oil custodians to consider various types of risk analysis in order to prevent or to mitigate the possible hazards due to the high-risk activities in the oil and gas industries especially involving offshore operations and activities.

Due to the availability of various tools for risk assessments, the hypothesis that can be made is that there is no unifying framework which combines these risk assessment tools together to perform a risk assessment study. By combining several risk assessment tools together, it is expected to benefit from the advantages of those specific tools.

1.3. Objectives

The research focuses on THREE (3) main objectives, which are:

1. To apply the generic framework of the proposed bow-tie based Quantitative Risk Assessment (QRA) on a particular engineering operation involving offshore oil and gas operation.
2. To develop a fault and event tree analysis in order to calculate the probability of the top event.
3. To develop a bow-tie model for risk assessment purposes.

1.4. Scope of Study

The scope of study outlines the boundary and the limits of the study.

The scope of study will commence from the beginning of the typical QRA which is from defining the system under study. Then it will go through the cycle of the proposed methodology of bow-tie based QRA within the limit of conceptual design or simplified design of a system, not a detailed one. The study would only like to prove that a generic theoretical methodology can be carried out. The scope of work is divided into three very essential stages;

The first stage will involve the system definition and literature review regarding the bow-tie based Quantitative Risk Assessment (QRA) particularly on the offshore oil and gas installations. The system definition is very essential in this study because it is the foundation for the subsequent analyses.

The second stage of this study will involve the application of Fault Tree Analysis and Event Tree Analysis. These analyses will be performed based on the system that has been identified during the earlier stage of this study. The failure data and hazards identified during the first stage will also be useful for the analyses.

The last stage of the study is to complete the equation of risk by multiplying the probability of occurrence with the impact of the consequences found after completing the ETA using Risk Matrix approach. The risk(s) will be rank according to its risk levels.

CHAPTER 2
LITERATURE REVIEW

2. LITERATURE REVIEW

2.1. Introduction to Risk Assessment

Oil and gas exploration and production activities have many hazards associated with them.

Different tools and techniques can be used to identify and assess hazards and risk, and it is important that the appropriate approach is selected.

Physical situations that possess potential to cause danger or harm are known hazard. Therefore, an oil tanker is a hazard because it has the potential to start a fire. Exploration drilling or wildcat drilling activities are exposed to hazards because these activities have the potential to cause blowouts [3].

Accidents are the realisation of a hazard [3].

Risk is the combination of the likelihood and consequence of such accidents. It is further defined as the probability of adverse event. The likelihood can be expressed either as frequency which is the rate of events per unit time or a probability. The consequence is the degree of harm or impact caused by the event [3] [4].

Risk assessment is a process through which the frequency of a hazardous event and impact of the consequence is measured or calculated. Risk assessment measures the intensity of a hazard to a system [4] [5].The intensity is measured in the perspective of the severity or the magnitude of the outcomes of the hazards and usually, it is measured in terms of the possible loss of life or injury that personnel are exposed to. Risk assessment consists of two distinct stages which are qualitatively identify and characterize the hazard and the later stage is to quantify the risk [5].

For new installations or activities in oil and gas exploration and production, it is essential to identify hazards as early as possible in order to provide engineers enough time to organize a study and evaluation of the hazard before any installations are made or activities are carried out [6].

2.2. Quantitative vs. Qualitative Risk Assessment

Risk assessment is defined as a function of the probability and consequence of an accident or potential hazard. Risk assessment maybe be performed or implemented on a qualitative or quantitative basis.

The qualitative method assesses risk by using an index system which is based on the basic data of a system such as pipeline lengths, flow rate etc. The basic data will be assessed by experienced professionals, producing a qualitative set of judgement of possible constituted risks [7]

The quantitative method assesses risk by numerical simulation, including a quantitative calculation of possibilities and consequences of different accidents. Typically, the outcomes of quantitative method are individual risk and social risk [7].

Qualitative approach can be adequate for risk assessments of a simple system or a simple facility or operation. However, the application of quantitative methods is considered when [7];

- Several risk reduction options are available in which relative effectiveness is not apparent
- The exposure of risk to the workforce, public, environment or asset is assumed to be high
- The equipment spacing allows significant risk of escalation
- New technology is involved resulting in a perceived high level of risk which no historical data is available
- Demonstration of relative risk levels and their risk levels and their causes to the workforce is needed to make them more conscious of the risk
- Demonstration within the operation unit and to third parties, including the regulating authorities, that risk are as low as reasonably practicable (ALARP) is required.

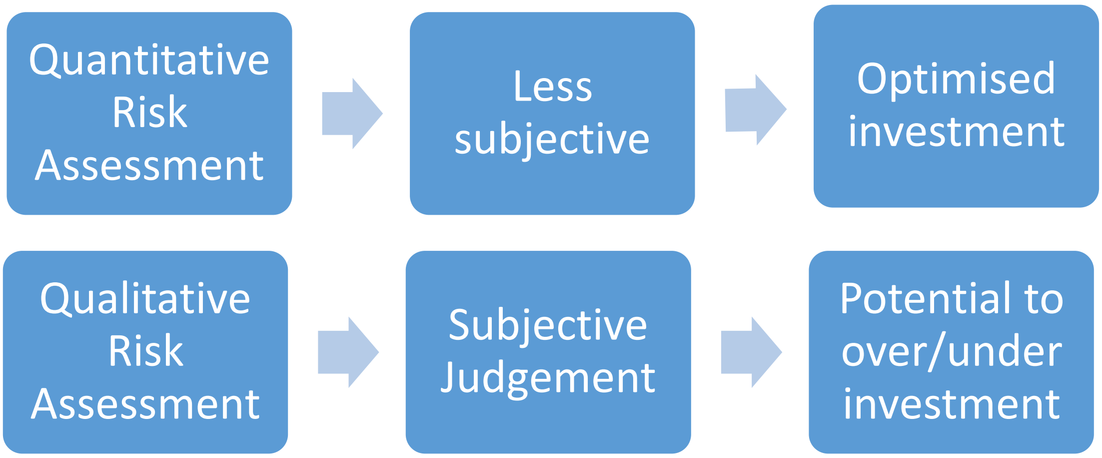


Figure 2: Quantitative versus qualitative assessment [8]

Quantitative assessment estimates practical values for consequences and their probabilities and produces values of the level of risk in specific units defined. Full quantitative assessment may not always be possible due to lack of historical data [8].

2.3. Purpose of Quantitative Risk Assessment

The purposes of a QRA may include [3]:

- Estimating risk levels and assessing their significance in order to decide whether the risks need to be reduced
- Identifying the main contributors to the risk in order to comprehend the nature of the hazards and to suggest risk reduction measures
- Defining design accident scenarios to be used as design basis for installations
- Comparing design options
- Evaluating risk reduction measures
- Demonstrating acceptability to regulators to show whether risks have been made as low as reasonably practicable (ALARP)
- Identifying safety-critical procedures and equipment to minimise risk during operation
- Identifying accident precursors which may be monitored during operation to provide warning of adverse trends in accidents.

Quantitative risk assessment has been proven in providing engineers to monitor risks and to provide guidance in decision-making about safety issues especially in oil and gas industries.

2.4. Components of Quantitative Risk Assessment

2.4.1. System Definition

The first stage of QRA is system definition whereby the installation or the activity of whose risks to be analysed is defined.

This stage determines the scope of work for the QRA and it defines the boundaries for the study in which it identifies the activities that are included and which are excluded [3].

2.4.2. Hazard Identification

The second component of QRA is to identify the initiators or basic events of accidental sequences.

Hazard identification consists of a qualitative review of accidents that may occur, based on previous accident experience. In QRA, hazard identification is a technique to select a list of possible failure cases that are suitable for quantitative modelling [3].

Hazard identification is the most essential part of QRA because if the hazards have not been identified, the hazards cannot be mitigated [2].

The process of hazard identification includes identifying hazards by cause, location, consequence or impact grouping. The objective is to specify failure cases or starting conditions for accidents to be modelled.

There are several techniques to identify hazards [2]:

1. Hazard review – a qualitative review of the installation to identify the hazards that are present.
2. Hazard checklist – a review of the installation against a list of hazards that have been identified in previous hazard assessments.
3. Hazard and operability study (HAZOP) – a systematic review of the process plant design. It is a method to identify hazards that might affect safety and operability based on the use of guidewords.
4. Procedural HAZOP – a version of HAZOP applied to safety-critical operations such as drilling, rig-moves, heavy lifts etc.
5. What-If Analysis – a flexible review technique which can be applied to any installation, operation or process, to identify hazards.

6. SWIFT – The Structured What-If Checklist technique combines the relatively unstructured What-If technique with the more organised and thorough aspects of the HAZOP technique.
7. HAZID – a systematic review of the possible causes and consequences of hazardous events.
8. Failure modes, effects and criticality analysis (FMECA) – a systematic review of a mechanical system, to evaluate the effects of failures of individual components.
9. Emergency Systems Survivability Analysis – a systematic review of the ability of emergency systems to withstand accident conditions.
10. Safety inspections and audits – visual examinations of an existing installation and its operating procedures to identify potential safety hazards.

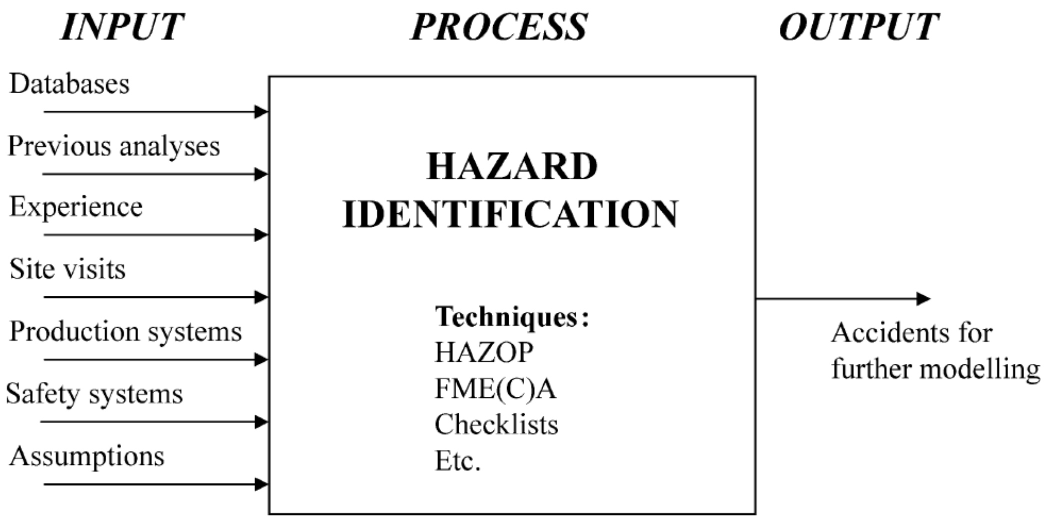


Figure 3: Hazard Identification Process [2]

2.4.3. Frequency Analysis

Frequency analysis estimates how likely it is for the accidents to occur. The frequencies are usually obtained from analysis of previous accident experience [3].

Sometimes the likelihood estimates are generated from a detailed analysis of past experience and available historical data and sometimes they are judgemental estimates based on specialist or expert’s view of the event.

In most risk assessment, the frequency or the likelihood is also expressed in term of the probability of the event. A frequency per year or per event in units of time may be used [5].

The terms “probability” and “frequency” are often used in regards to risk.

“Probability” is the ratio of the number of chances that a particular event may occur to the total number of chances. It is expressed as a number in the range 0 to 1, zero being the certainty that the event will not occur, and 1 the certainty that the event will occur.

“Frequency” is a rate which expresses how often a particular event occurs within a stated time period. It is often expressed in terms such as 1 per 1 000 years.

The difference between “frequency” and “probability” is clearly demonstrated by noting that an event has a frequency of occurrence of 4 per year whereas the probability of the event occurring in on year is less than 1 [6].

The main approach for frequency analysis are [3];

- Historical accident data.
- Fault Tree analysis which involves estimating the frequency of each component from a combination of historical data.
- Theoretical modelling.
- Event tree analysis is used to extend the initiating event frequency estimated into a failure case frequency combining with the consequence models.
- Human reliability analysis.
- Judgement evaluation.
- Bayesian analysis.

2.4.4. Consequence Analysis

Consequence analysis evaluates the effects or harm caused by the accidents and their effects on employees involved, environment or assets of the business. Estimation of consequence is most often in the form of computer modelling but it can also be based on accident experience or expert’s judgements [3].

When the frequencies and consequences of the event has been estimated, they can be combined to form overall risk.

Calculating a total expected risk value R from [5];

$$R = \Sigma P_i \times C_i$$

Whereas P_i is the likelihood or frequency of the event and C_i is the consequence of the event [5].

Consequence analysis can involve [8];

- Consider existing controls or barriers to treat the consequences
- Relating the consequences of the risk to the original objectives
- Considering immediate consequences and those that may arise after a certain time has passed
- Considering secondary consequences for instance those impacting upon associate activities or equipment.

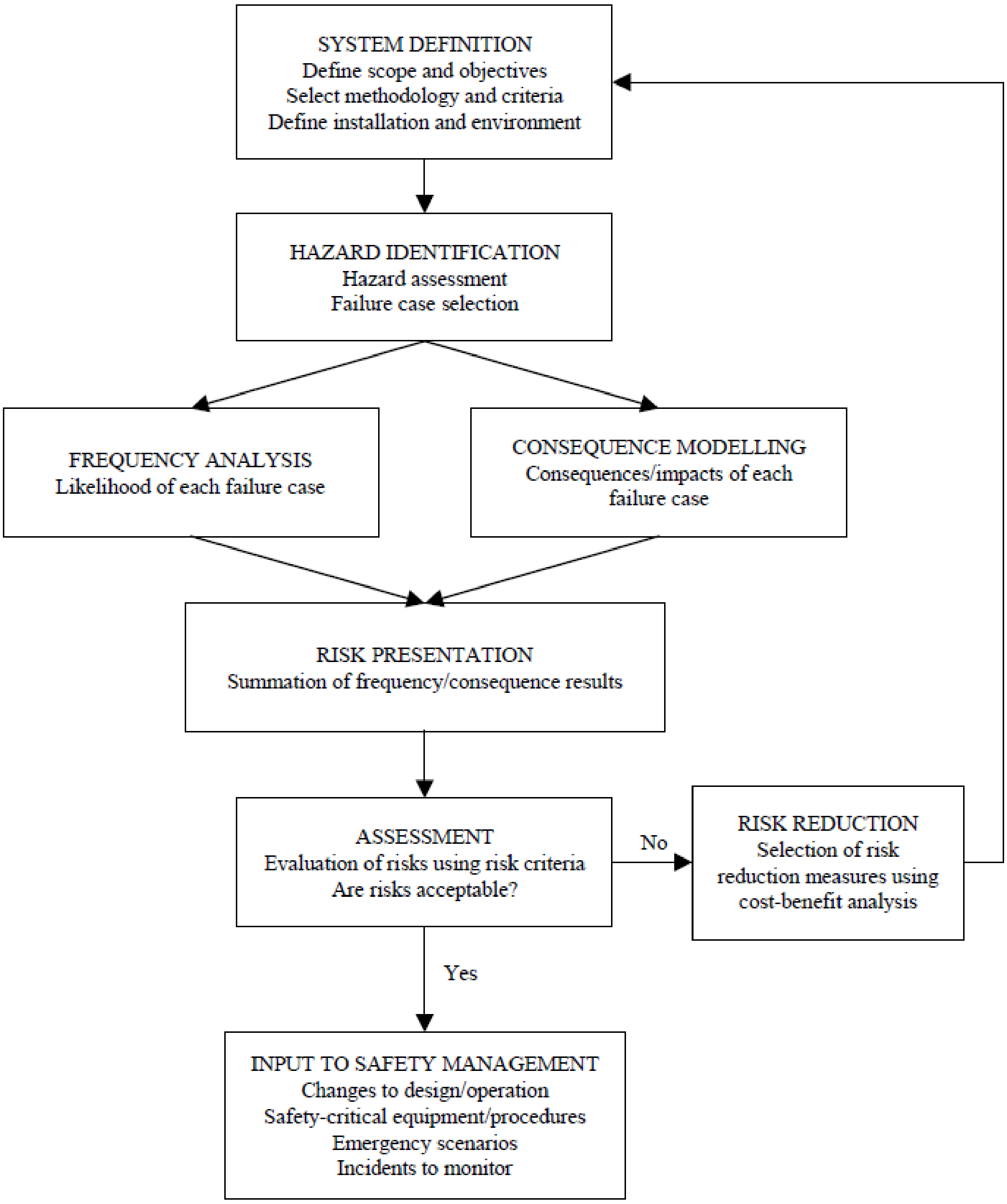


Figure 4: Flow diagram of QRA [3]

2.5. Tools for QRA

2.5.1. Fault Tree Analysis

Fault Tree Analysis (FTA) is an evaluation technique that can be used to determine or estimate the various causes of a predicted hazardous event. FTA is used to identify causes of equipment failure and was used primarily used as a tool in reliability and availability assessment.

The fault tree is a graphical model displaying the various combinations of individual equipment failures of the system under study that can result in the happening of the hazardous event expected, usually referred to as the top event [6].

A variety of information is provided by FTA to assist decision-making. Some of the roles of FTA in decision-making are [9];

1. To provide a visual, logic model of the basic causes and intermediate events leading to the top event.
2. To prioritize the contributors to the top event.
3. To use FTA to identify vulnerable areas in a system to prevent the top event.
4. To monitor the performance of the system.
5. To minimize and optimize resources.
6. To assist in evaluating design alternatives and establish performance-based design requirements.
7. To diagnose, identify and correct causes of the top event.

A typical fault tree is composed of a number of symbols as shown in Figure 5 [9].

An example fault tree is shown below;

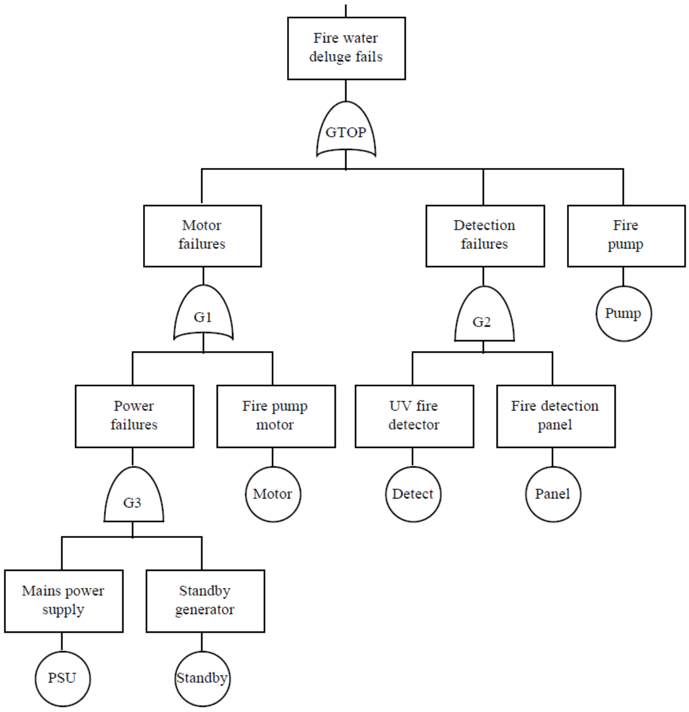


Figure 5: Fault Tree Analysis example [3]

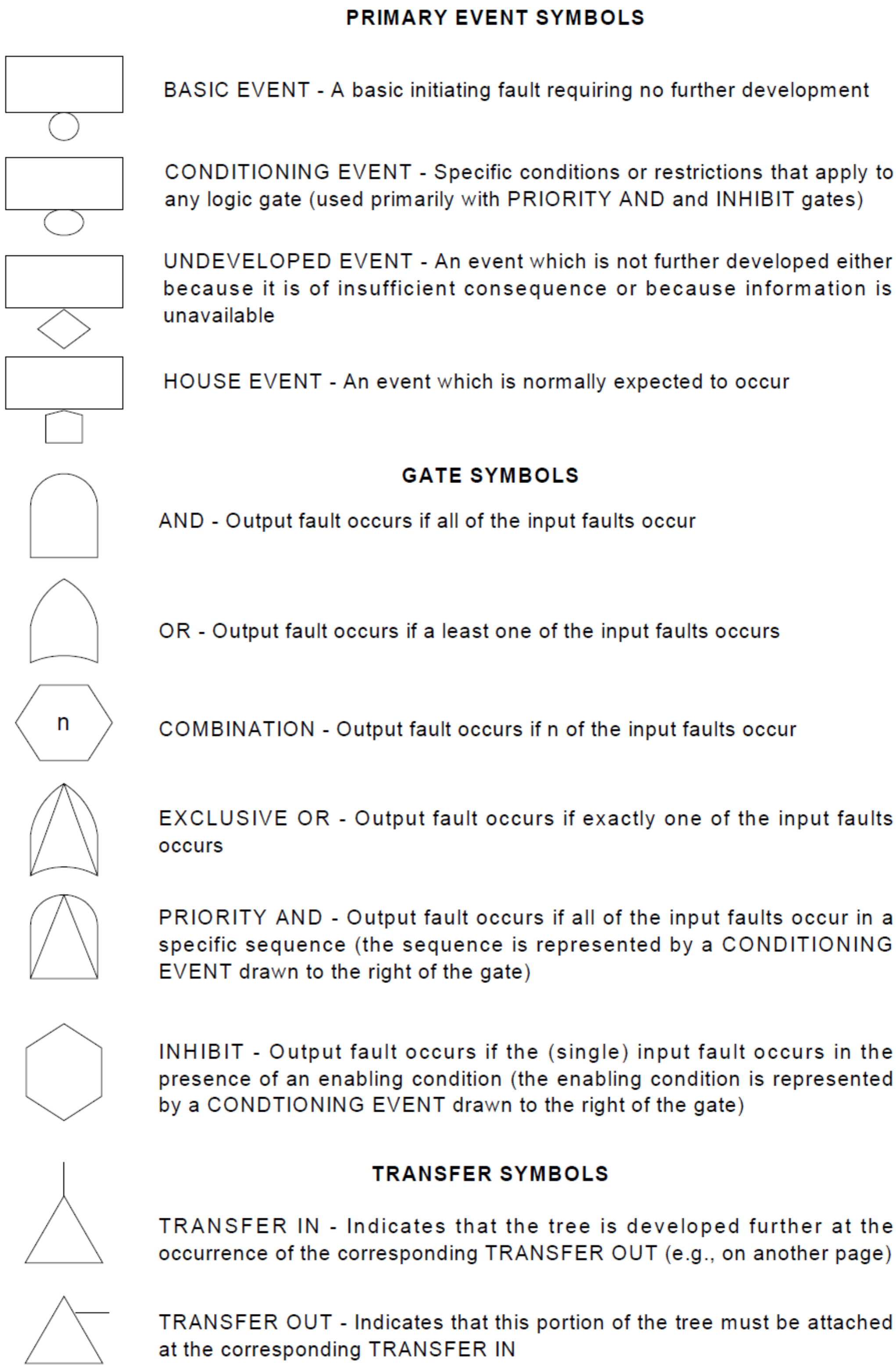


Figure 6: Fault Tree symbols [9]

Simple fault trees can be analysed using a gate-by-gate approach to determine the top event probability. The OR and AND gates are evaluated as follows [3];

OR gate:

$$P(A) = \sum_{i=1}^{N} P(Bi)$$

AND gate:

$$P(A) = \prod_{i=1}^{N} P(B_i)$$

Where:

P (A) = Output event probability

P (B_i) = Input event probabilities

N = Number of input events

$\sum$ = Sum

$\prod$ = Product

2.5.2. Event Tree Analysis

An event tree analysis (ETA) is a graphical way of showing the possible outcomes of a hazardous event, such as a failure of equipment. ETA involves determining the responses of systems and operators to the hazardous event in order to determine all possible alternative outcomes.

Event trees are used to identify the escalation paths of an event. Accident sequences provided by ETA is represented by logical AND combinations of events [6].

ETA can be used to brainstorm potential scenarios or sequences of events following an initiating event and how outcomes are affected by various treatments, barriers or control to mitigated undesired outcomes [8].

The output of an ETA is the quantitative estimates of event frequencies or probabilities of various failure sequences and outcomes.

There are two main ways in which event trees are used:

- Pre-incident applications – identifying the barriers or protective devices that could allow an incident precursor to develop into an actual failure.
- Post-incident applications – exhibiting the various outcome that may result from a failure.

An example of event tree used using failure probability of the protective device is shown below;

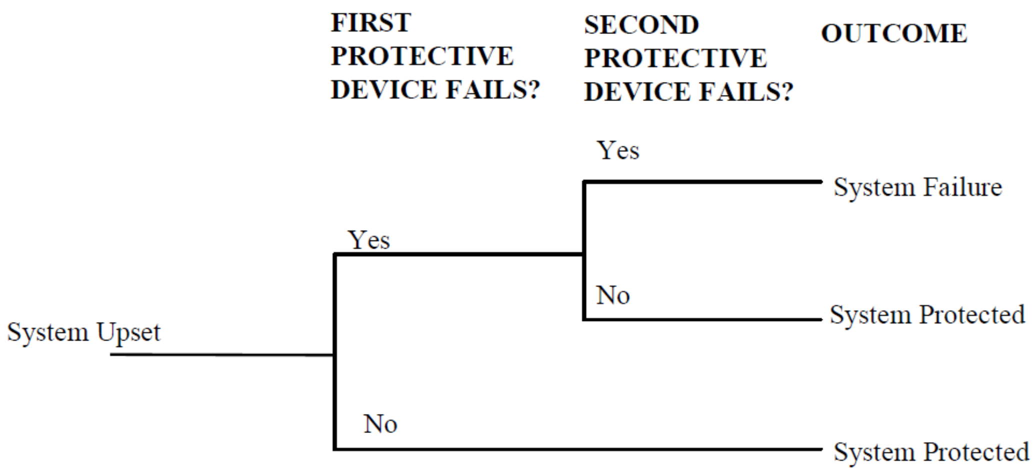


Figure 7: Event Tree example [3]

The quantification of an event tree can be used using spreadsheets or computer models. A probability is associated with each branch. In each case, the sum of the probabilities of each branch must be unity. The probabilities of each outcome are the products of the probabilities each branch leading to them [3];

$$P(A) = \prod_{i=1}^{N} P(B_i)$$

Where:

P (A) = Outcome probability

P (B_i) = Branch probabilities on route to outcome

N = number of branches on route to outcome

$\prod$ = Product

2.5.3. Risk Matrix

The ISO 17776 Risk Matrix is a detailed matrix that has been designed for ranking and evaluation of risks in petroleum and natural gas industries. The ISO risk matrix is a 5x5 matrix combining various categories of consequence and likelihood.

The consequences are divided into four categories: people, assets, environment and reputation.

Consequence					Increasing probability			
Severity rating	People	Assets	Environ-ment	Reputation	A	B	C	D
					Has occurred in E&P industry	Has occurred in operating company	Occurred several times a year in operating company	Occurred several times a year in location
0	Zero injury	Zero damage	Zero effect	Zero impact				
1	Slight injury	Slight damage	Slight effect	Slight impact	Manage for continued improvement			
2	Minor injury	Minor damage	Minor effect	Limited impact				
3	Major injury	Local damage	Local effect	Considerable impact				
4	Single fatality	Major damage	Major effect	Major national impact	Incorporate risk-reducing measures		Fail to meet screening criteria	
5	Multiple fatalities	Extensive damage	Massive effect	Major international impact				

Figure 8: ISO 17776 Risk Matrix [6]

Numerical definitions for Risk Matrix [3];

1. Frequency
   - Frequent (Frequency>10)
   - Probable (1<Frequency<10)
   - Remote (0.1<Frequency<1)
   - Not likely (0.01<Frequency<0.1)
   - Improbable (Frequency<0.01)
2. Consequence
   - Severe = Multiple fatalities
   - Very serious = A Fatality
   - Serious = Disabling

- Moderate = Medical treatment

CHAPTER 3
METHODOLOGY

3. METHODOLOGY

In order to achieve the objectives of this study, a study methodology is taken into consideration. The suitable methods are implemented in order to obtain the desired outcome.

3.1. Project Activities

There are SEVEN (7) project activities in performing this study which comprises of;

1. Define the system of the case study.
2. Draw simplified process flow diagram of the system under study.
3. Identify the hazards related to the overall system and its sub-systems.
4. Perform the Fault Tree Analysis (FTA) based on the identified basic events.
5. Perform the Event Tree Analysis (ETA) with the continuation from the top event of the developed FTA.
6. Calculate the probabilities of occurrence.
7. Complete the overall risk equation using Risk Matrix Approach and rank the risk(s) according to their risk level.

3.2. Project Flowchart

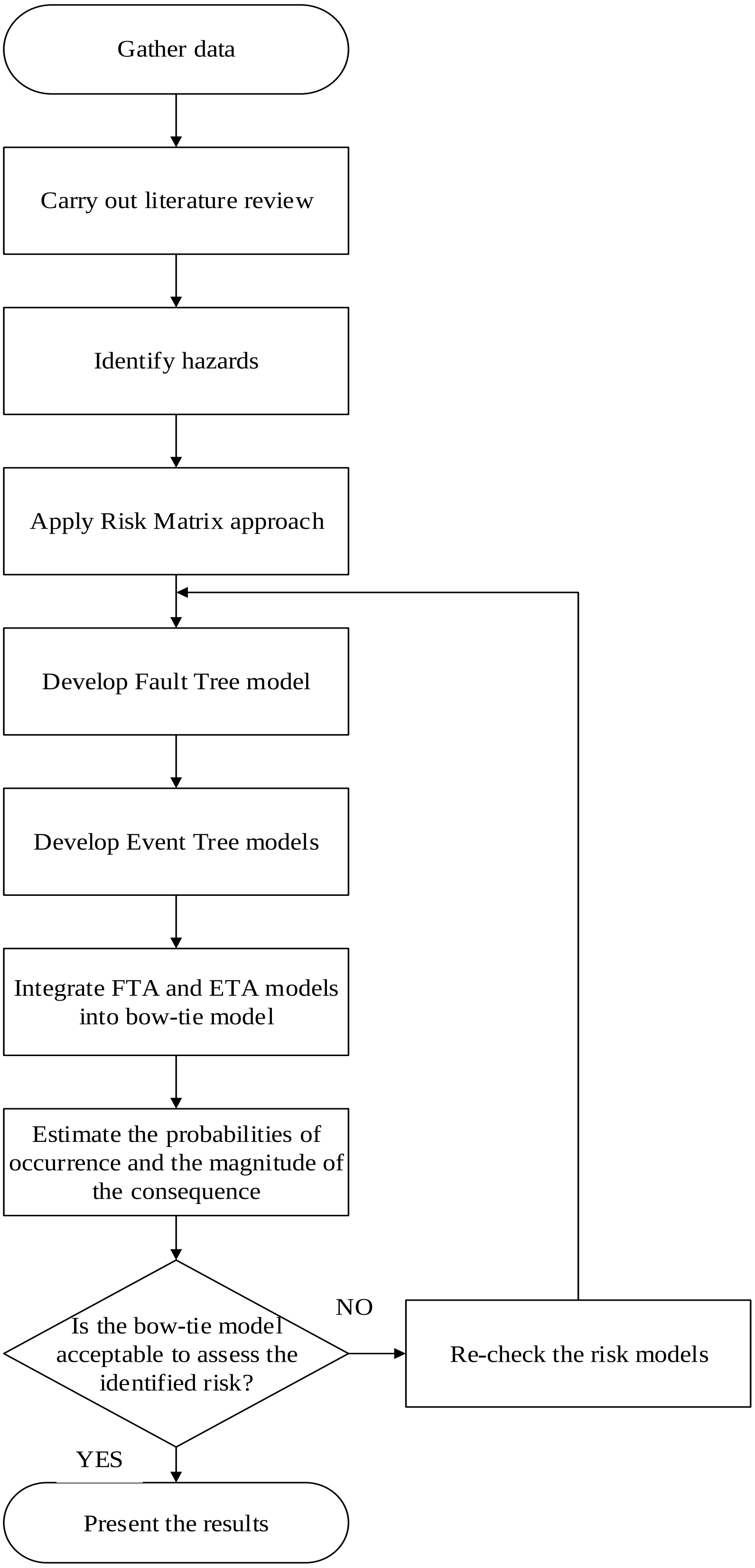


Figure 9: Project flowchart

3.3. Project Milestone

Below are the key milestones in order to assist the completion of the methodology of the study as well as to achieve the objectives of the project.

Table 1: Key Milestones of the Study

No.	Activity	FYP	Week
1	Selection of project topic	1	Week 1
2	Submission of extended proposal		Week 6
3	Proposal defence		Week 8 - 9
4	Completion of literature review and collection of data		Week 12
5	Submission of interim report draft		Week 12
6	Submission of interim report		Week 14
7	Analyzing data for hazard identification	2	Week 1
8	Completion of fault tree model		Week 3
9	Completion of event tree models		Week 6
10	Submission of progress report		Week 8
11	Completion of bow-tie model		Week 9
12	Completion of risk assessment		Week 11
13	Submission of final report draft		Week 12
14	Submission of technical paper		Week 13
15	Oral presentation		Week 14
16	Submission of project dissertation		Week 15

3.4. Project Gantt chart

Please refer to Appendix 1 - Gantt chart for FYP 2013.

3.5. Bow-tie based QRA Flow Chart

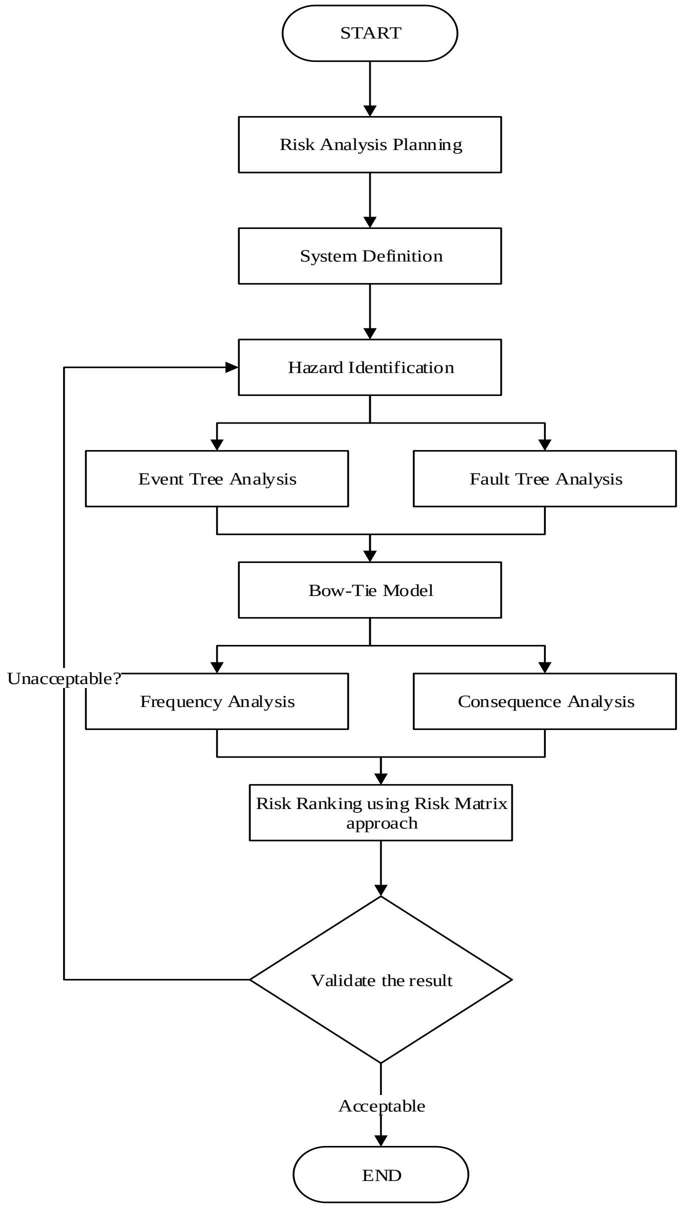


Figure 10: Bow-tie based QRA Flow Chart

3.6. Constructing Fault Tree Analysis

In order to construct a FTA, it is necessary to identify the basic events leading to the top event.

Simple fault trees can be analysed using a gate-by-gate approach to determine the top event probability. The OR and AND gates are evaluated as follows [3];

OR gate:

$$P(A) = \sum_{i=1}^{N} P(Bi)$$

AND gate:

$$P(A) = \prod_{i=1}^{N} P(B_i)$$

Where:

P (A) = Output event probability

P (B_i) = Input event probabilities

N = Number of input events

∑ = Sum

∏ = Product

3.7. Constructing Event Tree Analysis

An event tree analysis requires an Initiating Event (IE) to begin with. In the case of a bow-tie based QRA, the Initiating Event is taken from the top event constructed in FTA together with its frequency.

A probability is associated with each branch. In each case, the sum of the probabilities of each branch must be unity. The probabilities of each outcome are the products of the probabilities each branch leading to them [3];

$$P(A) = \prod_{i=1}^{N} P(B_i)$$

Where:

P (A) = Outcome probability

P (B_i) = Branch probabilities on route to outcome

N = number of branches on route to outcome

∏ = Product

3.8. Bow-tie based risk analysis

Bow tie analysis is a diagrammatic way of describing and analysing the route of risk from causes to consequences.

It can be considered to be a combination of a fault tree which analyses the cause of an event (represented by the knot of a bow tie) and an event tree analysing the consequences [8].

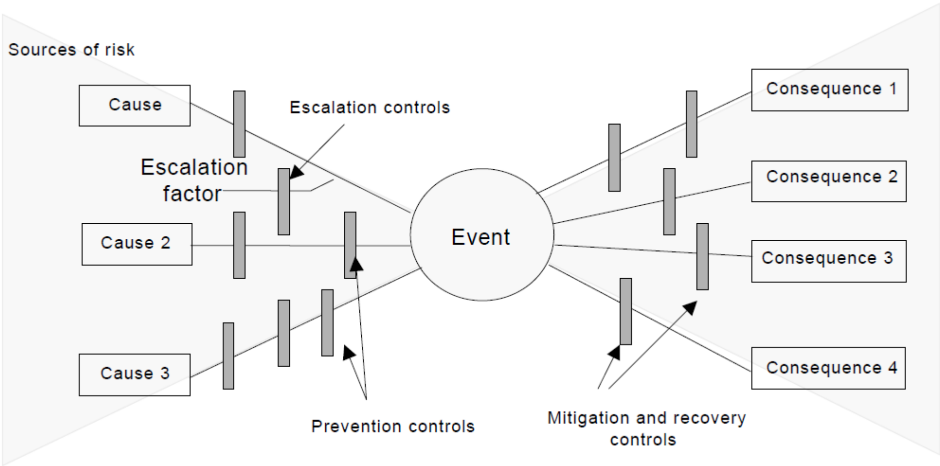


Figure 11: Representation of a bow tie analysis [8]

Bow tie is used to display a risk showing a range of possible causes and consequences. It is very beneficial in showing the independent pathways leading to failure.

The strengths of bow tie analysis:

- It gives a clear pictorial representation of the problem.
- It focuses attention on controls of both prevention and mitigation and their effectiveness.
- It can be used for wanted consequences.
- It does not require a high level of expertise to use.

Bow tie diagram consists of five basic elements

- Basic events
- Fault Tree
- Top Event

- Event Tree
- Output events

Fault Tree is placed on the left side of the diagram and it starts with the basic events and diverges until intermediate events leading to the top event.

Event Tree is placed on the right side of the bow tie diagram which begins from the top event as the initiating event and follows by the sequence of events leading to possible multiple outcomes.

Once the bow tie diagram is constructed, quantitative analyses can be executed using the conventional assumptions and mathematical operations of FTA and ETA [10]

An example of a bow-tie diagram of oil and gas pipeline failure is as shown below;

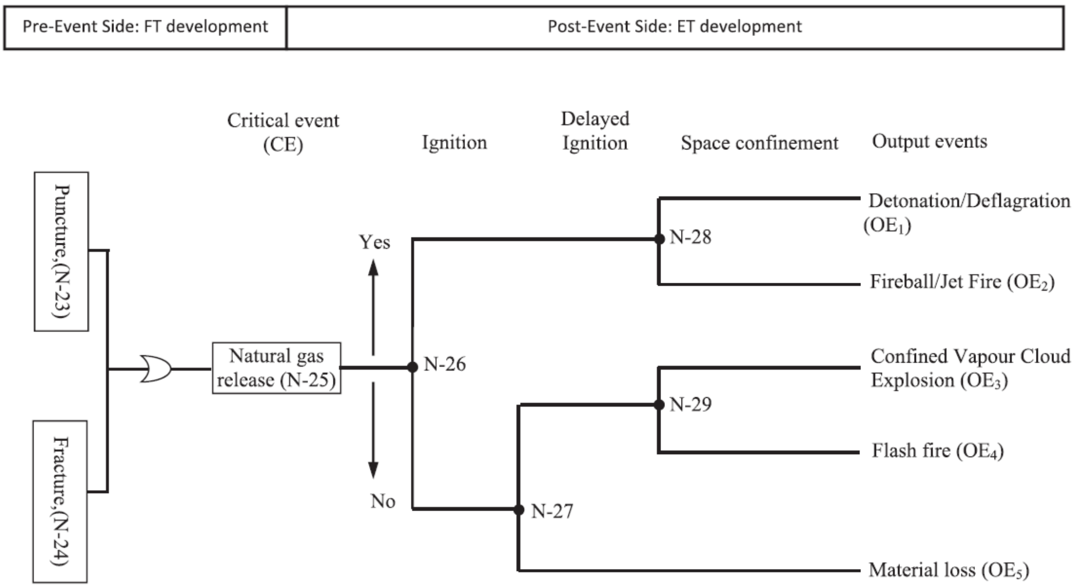


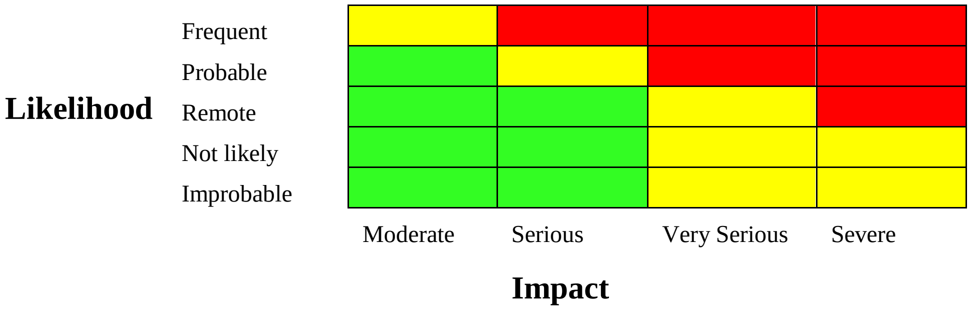
Figure 12: Bow tie diagram of natural gas pipeline failure [10]

3.9. Risk Matrix Approach – Ranking the risks

After the frequency of the outcomes based on the ETA constructed, risk matrix approach is utilized in order to complete the equation of the risk which is to multiply it with the impact or magnitude of the consequences or outcomes.

The rating of the risk is based on Table 2;

Table 2: Risk matrix table



CHAPTER 4
RESULT AND DISCUSSION

4. RESULT AND DISCUSSION

4.1. Overview

This section will attempt to provide an overview of a case study of the implementation the proposed framework of the bow-tie based quantitative risk assessment (QRA) on a particular system of an offshore oil and gas platform.

4.2. Case study – Implementation of the proposed bow-tie based QRA on the Erb West Field Platform

Based on the proposed flowchart in the Chapter 3: Methodology, the case study will be executed on the equipment/unit level of the offshore oil and gas platform.

Erb West Field is about 125 km offshore Kota Kinabalu, Sabah in 210 feet water depth and it is owned by PETRONAS Carigali Sdn. Bhd. (PCSB). The field was discovered in 1971 [11].

The Erb West facilities consist of Erb West Drilling Platform (EWDP-A), Erb West Drilling Platform B (EWDP-B), Erb West Production Platform A (EWP-A), Erb West Gas Platform A (EWG-A), Erb West Living Quarters A (EWQ-A), Erb West Venting A (EWV-A) and Erb West Venting Flare (EWV-AA) [11].

Figure 13: A picture of the Erb-West Complex, offshore Sabah (credits: http://blog.daum.net/yong1927/5553392)

4.2.1. System Definition

The proposed bow-tie based quantitative risk assessment is applied to various sub-systems of an offshore processing unit (OPU) which is referred to in this paper as the overall system. The offshore processing unit (OPU) under study was taken from a simplified Process Flow Diagram (PFD) of the Erb West Production Platform A (EWP-A). These sub-systems include the separators (oil and condensate), compressors, a flash drum as well as a scrubber.

The purpose of the production platform is to operate the wells and to separate the fluid from the wells into oil, gas condensate and water.

At the terminal of the production platform, oil, gas and condensate and gas will be pumped and compressed to the onshore facility using pipelines or offloaded to the shuttle tanker.

The processing unit typically has 3 main parts which are the wellhead, separators and several gas compressions.

A typical layout of the offshore processing unit is depicted in Figure 14. Production lines from the wells end at the wellhead. The well fluid passes through a manifold and is withdrawn at a production separator. The main hazard possess by the well is possible blow. However, this case study will not include possible hazards from the wellhead but mainly focuses on the other major parts of the processing unit which are separation and gas compression.

4.2.2. Process Description

The Erb-West Production Platform simplified PFD is further minimized to simplify for the purpose of the QRA. The layout of the separators and compressors are arranged with the assistance from the paper which has done a risk assessment study of a similar layout of equipment [12]. The layout had been redrawn using Microsoft Visio and the proposed simplified system has only 2 separators (for oil and gas-condensate), 2 gas compressors, a flash drum and a scrubber.

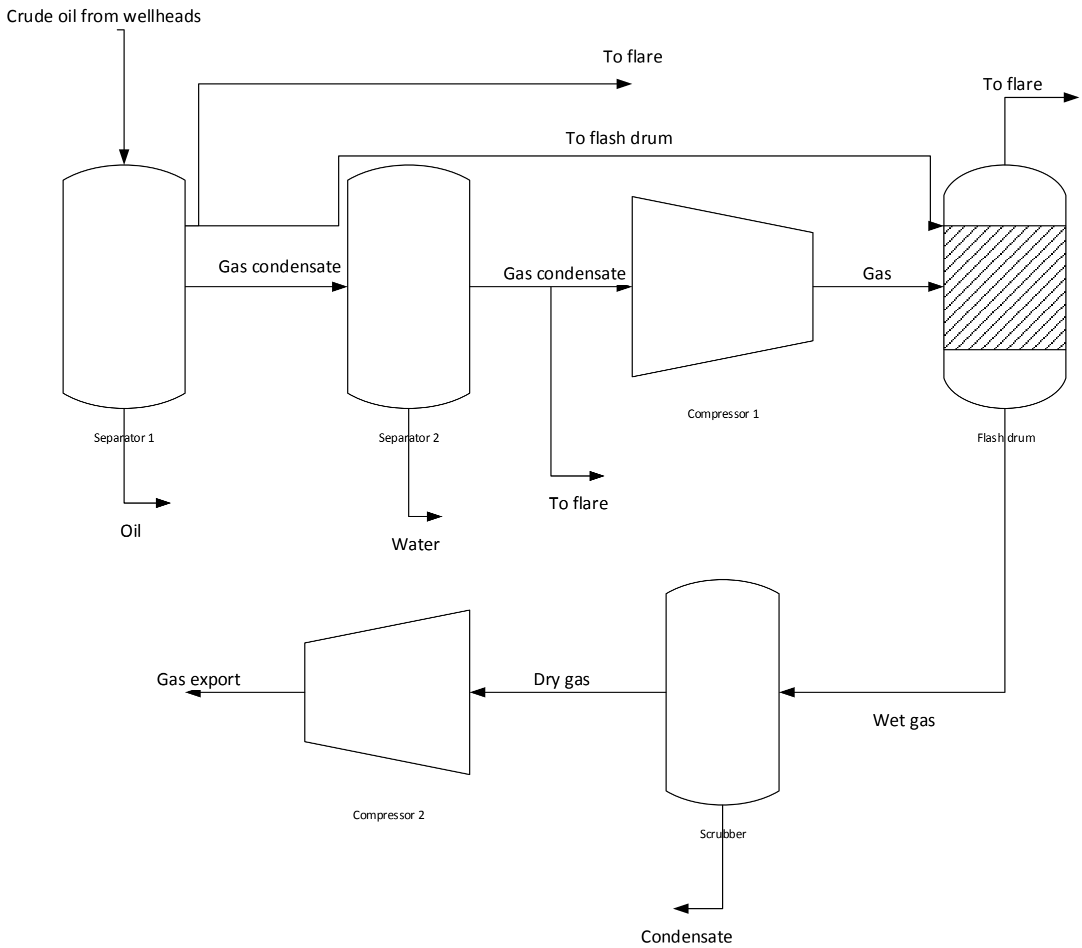


Figure 14: Simplified Process Flow Diagram of Offshore Processing Unit

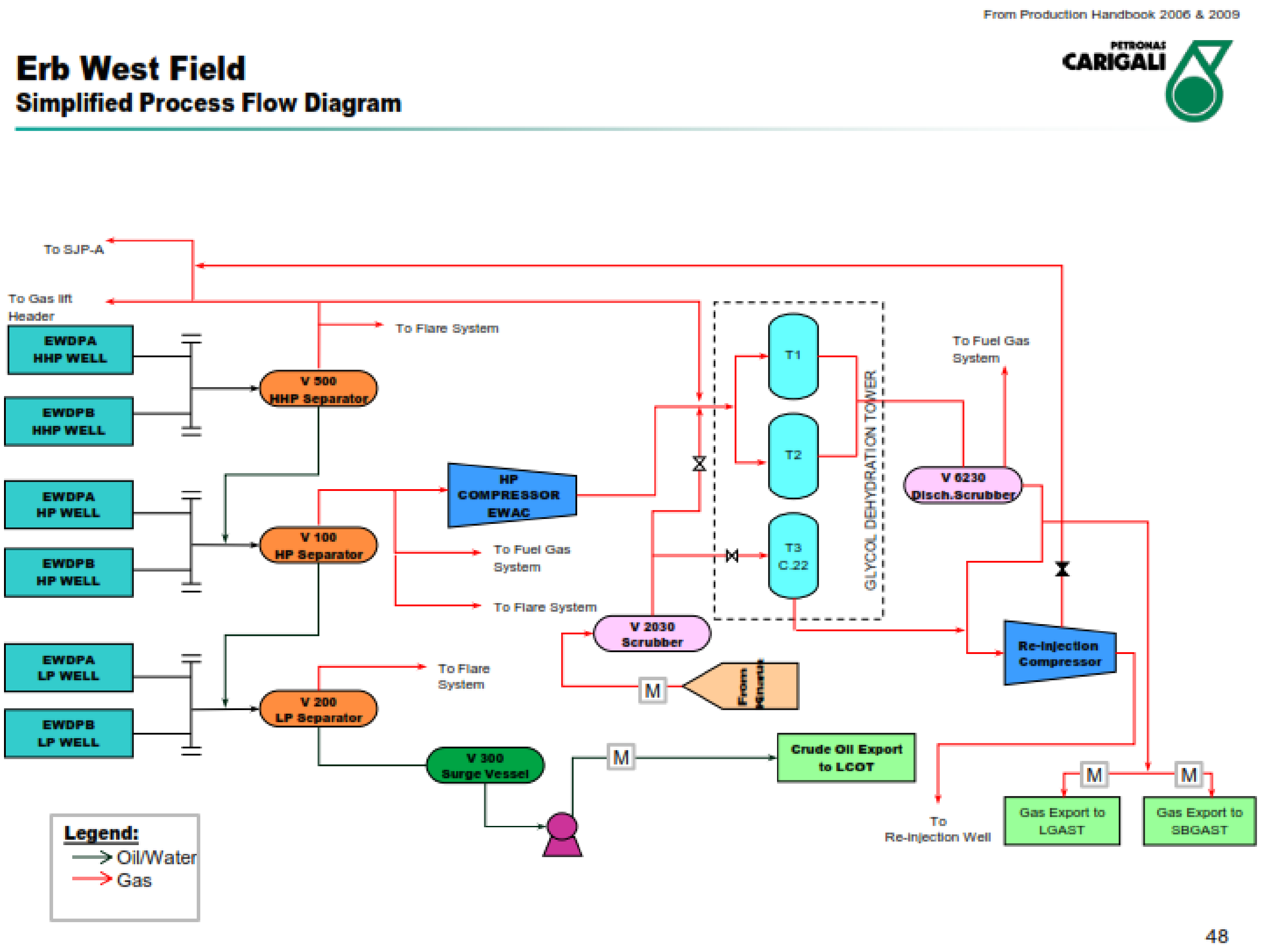


Figure 15: Simplified Process Flow Diagram of the Processing Unit taken from [12]

The well fluid passes through separators where the fluid is separated into oil, gas-condensate, gas and water. In this layout, the oil passes through 2 separators and transported to the oil terminal as depicted on the simplified PFD of the production platform of Erb West Complex which in its case, to Labuan Crude Oil Terminal (LCOT).

Gas is compressed using compressors and subsequently passed through the flash drum where the temperature is reduced, condensate formed and separated out. The gas is subsequently dried and purified and further compressed to high-high pressure through compressors. Part of the gas is used for gas reinjection and small amount are being flared.

4.2.3. Hazard Identification

The historical data of accidents and incidents recorded over the past period of time are gathered to generate the necessary input to conduct a quantitative risk assessment. The failure data has been reviewed and the equipment of the processing unit are grouped into 6 major hazard groups.

According to the fire and explosion hazard index carried out on the similar processing unit, it is noted that Separator 1 has the highest index among the remaining hazard groups which indicated that it posed the highest level of risk.

This has simplified the case study and subsequent procedures depicted by the proposed framework of the QRA can be continued which is followed by the Fault Tree Analysis.

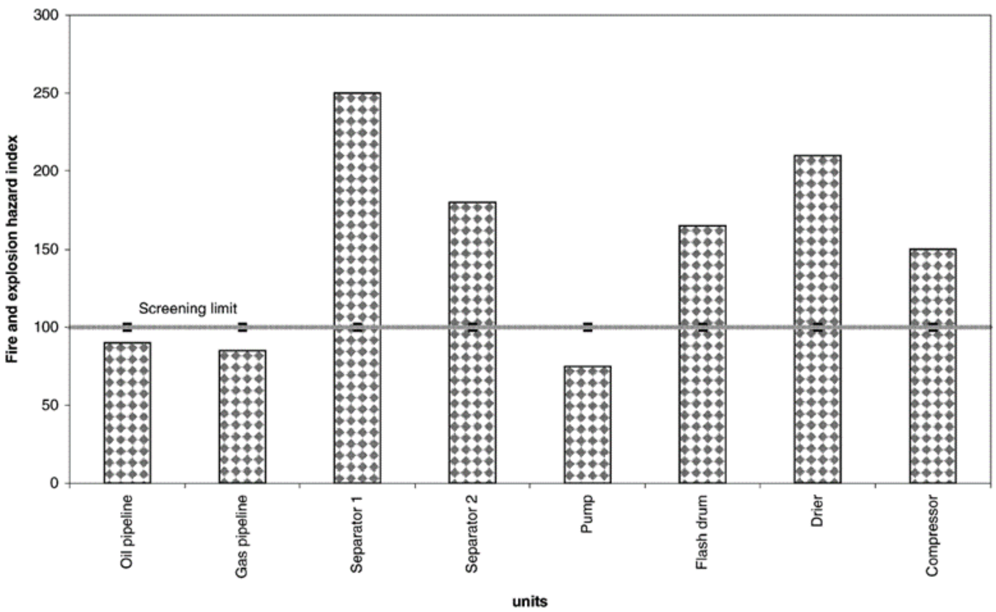


Figure 16: Fire and Explosion Hazard Index for 6 equipment of processing unit as well as oil and gas pipeline [12]

After identifying the most hazard group which is the Separator 1 of the offshore processing unit, the basic events pertaining to the possible failures of the Separator 1 are listed.

In the case of Separator 1, the development of high-pressure in the separator causes the sub-system to fail as BLEVE (Boiling liquid expanding vapour explosion). This will become the top event for the Fault Tree Analysis.

There are 21 basic events which will lead to the development of BLEVE to happen in Separator 1. The basic events are tabulated with its individual failure frequency per year which had been retrieved from the database of Worldwide Offshore Accident Databank (WOAD).

Table 3: Basic events for a probable accident in Separator 1

Failure Number	Type of Failure	Failure Frequency (per year)
1	Flow control valve failed	0.0250
2	Level indicator failed	0.0200
3	Excess flow at upstream	0.0800
4	Impurities causing exothermic reaction	0.0030
5	Sudden change in pressure	0.0170
6	Temperature controller failed	0.0200
7	High-pressure upstream line	0.0700

8	Upstream pressure controller failed	0.0250
9	Condensate line chocked	0.0021
10	Oil pipeline choked	0.0075
11	Gas pipeline or valve choked	0.0015
12	Safety valve undersize	0.0500
13	Pressure release valve choked or could not function on demand	0.0015
14	External heating	0.0150
15	Exothermic reaction in vessel	0.0030
16	Temperature controller failed	0.0020
17	Pressure controller system of separator failed	0.0020
18	Pressure of safety release inadequate	0.0015
19	Ignition due to explosion energy	0.1500
20	Ignition due to heat from surroundings	0.2000
21	Electric spark as source of ignition	0.2500

4.3. Fault Tree Analysis

Based on the basic events identified and listed in the Hazard Identification section previously, the Fault Tree Analysis has been performed using a non-commercial licenced software entitled Logan Fault and Event Tree Analysis [13].

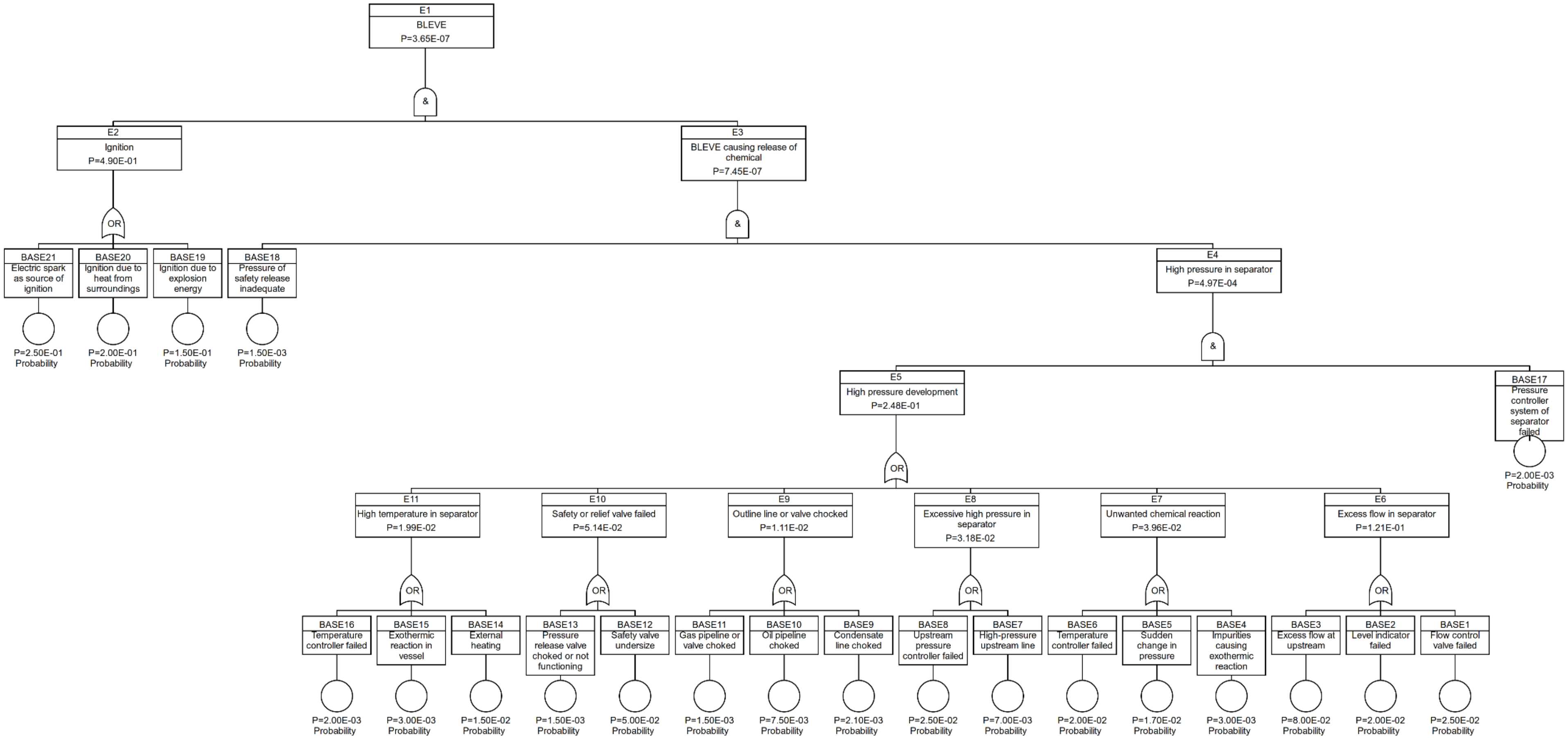


Figure 17: Fault Tree Analysis of Separator 1

4.4. Event Tree Analysis

After developing the Fault Tree Analysis (FTA), the Top Event of the FTA was used as the Initiating Event (IE) and integrated in performing the Event Tree Analysis (ETA). The ETA was developed using the same non-commercial licenced software, Logan Fault and Event Tree Analysis software [13].

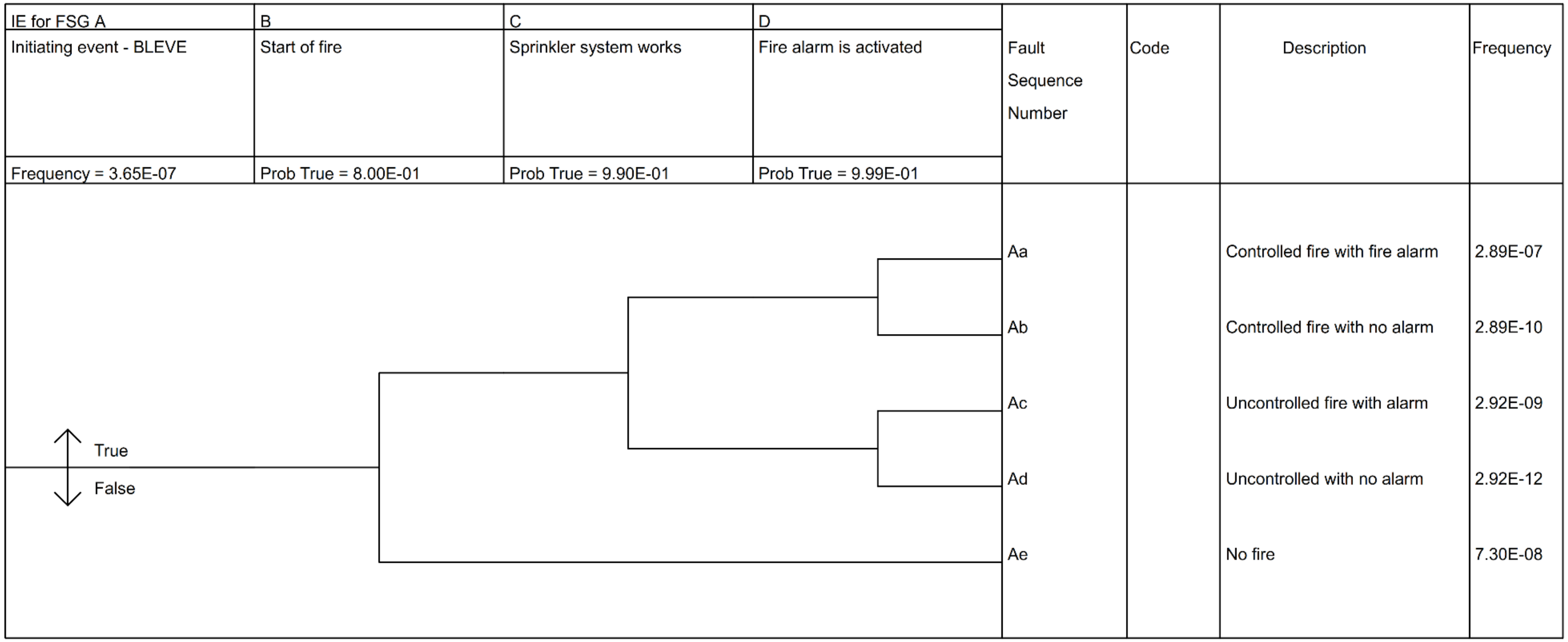


Figure 18: Event Tree Analysis of BLEVE

4.4.1. Bow Tie Diagram

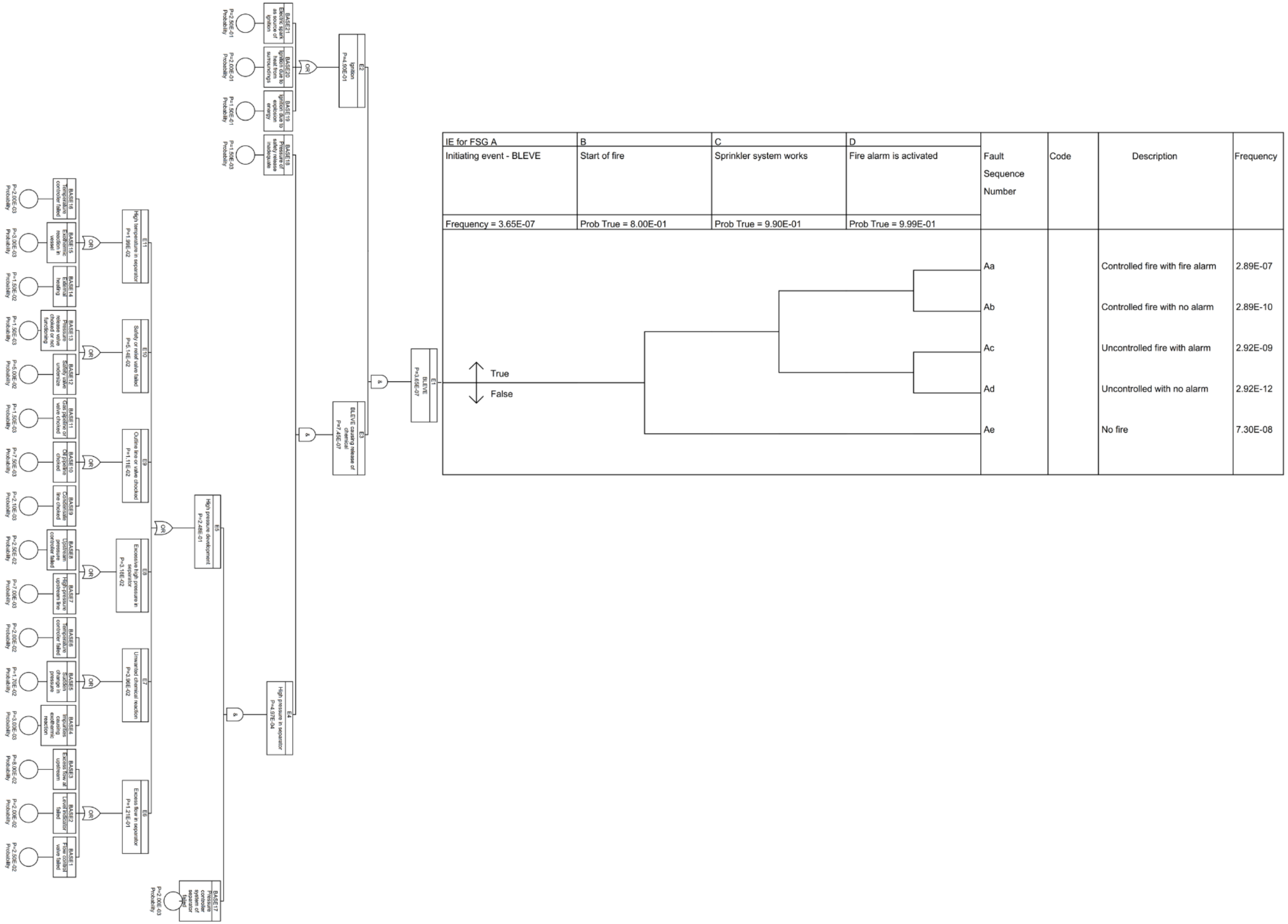


Figure 19: Bow Tie Diagram of Separator 1 hazards of Offshore Processing Unit

4.5. Risk Matrix Approach

It is desirable to rank the various possible hazard outcomes and screen the minor ones so as to concentrate the effort on the most hazardous one.

Therefore, the possible outcomes of the bow tie diagram is ranked using the risk matrix;

Numerical definitions for Risk Matrix [3];

1. Frequency
    - Frequent (Frequency>10)
    - Probable (1<Frequency<10)
    - Remote (0.1<Frequency<1)
    - Not likely (0.01<Frequency<0.1)
    - Improbable (Frequency<0.01)

Table 4: Rating table for Risk Matrix Approach

Fault Sequence Number	Risk event	Likelihood	Impact	Rating
Aa	Controlled fire with fire alarm	Improbable	Very Serious	**L**
Ab	Controlled fire with no alarm	Improbable	Very Serious	**L**
Ac	Uncontrolled fire with alarm	Improbable	Severe	**M**
Ad	Uncontrolled with no alarm	Improbable	Severe	**M**
Ae	No fire	Improbable	Serious	**L**

Based on Table 4, the possible outcomes are ranked and represented in the Risk Matrix as shown in Figure 20;

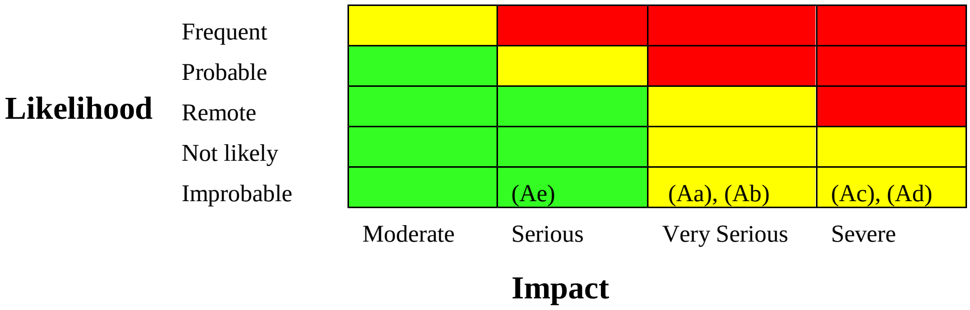


Figure 20: Risk Matrix of the Possible Outcome of BLEVE

4.6. Discussion

The deliverables of this study is to produce a working framework of a bow-tie based Quantitative Risk Assessment of an offshore installation or operation.

Using the case study of an Erb West Platform – Offshore Processing Unit, the framework has been proven to be able to identify the causes and the consequences of the most hazardous equipment of the system which is the Separator 1.

From the bow-tie diagram as well, the escalation path leading to failures as well as the respective barriers to prevent the possible outcomes have been identified and this will help in the decision-making activities for the engineering team.

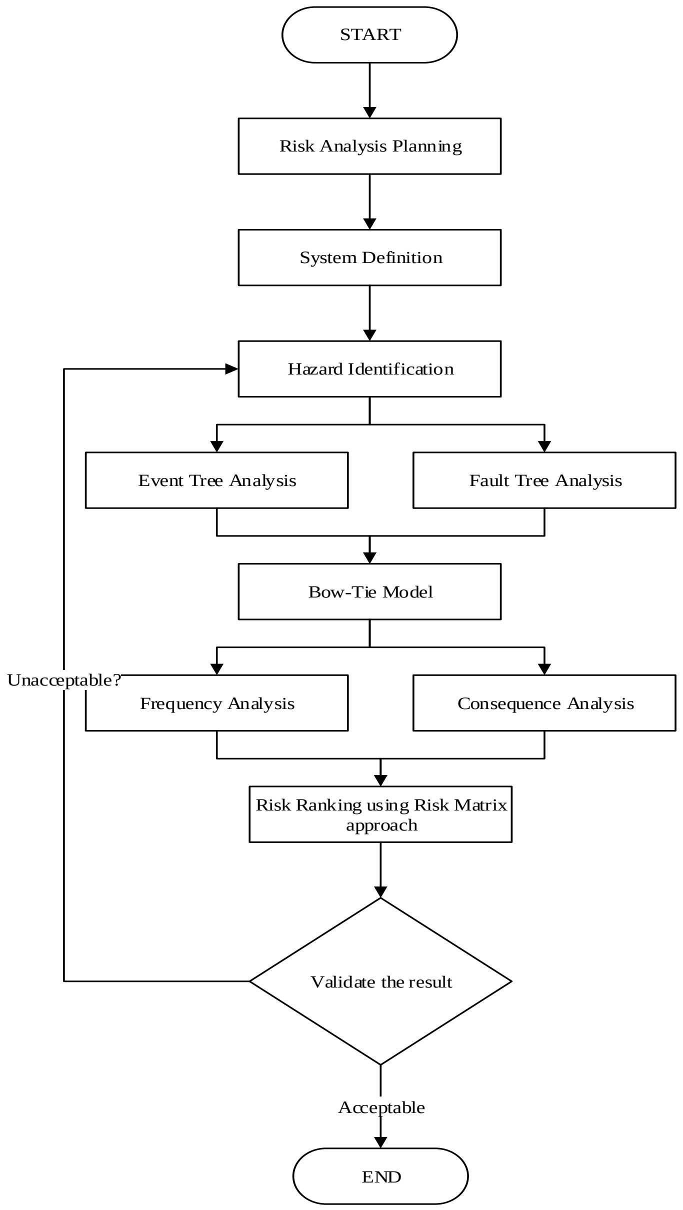


Figure 21: The Flowchart of the Bow-Tie Based QRA

CHAPTER 5
CONCLUSION

5. CONCLUSION

Understanding the risk assessment process is very essential in studying and managing risks. In this study, humble attempt has been made to provide an alternative approach in enhancing the field of risk management and methodology.

Numerous risk assessment frameworks and risk analysis techniques have been explored. The literature review showed that there many different risk analysis and techniques to choose from.

It is hoped that the content of this report will attempt to assist risk analysts, risk managers and engineers particularly in the oil and gas industries to make informed decisions. The content of this report serves as a theoretical platform for a generic framework of a bow-tie based quantitative risk assessment for readily application in the oil and gas industry.

There are several reasons of why bow-tie based risk assessment methodology has a greater advantage in comparison to the various methodologies and tools. One of them is that bow-tie based QRA enjoy the benefits of having the frequency of the causes of hazards analysed using Fault Tree Analysis as well as the probability of the consequences identified and quantitatively determined using Event Tree Analysis. The magnitude or the severity of the consequences or outcomes is also assessed and classified using Risk Matrix Approach. The consequences derived from bow-tie QRA will be attributed into decision problems for risk management which decisions taken will be reflected back towards the causes. It is also useful for analysing accidents where causes and consequences remain linked together [14].

5.1. Recommendations

In order to overcome the problems and disadvantages of the various types of risk assessment and methodology, the author has produced the recommendations for the overall study based on the observation and the result generated.

The recommendations are suggested for the benefits of this study such as ways to improve how the study is conducted to increase the reliability of the framework as well as steps that can be implemented by the oil and gas companies in improving the risk assessments and their methodology.

5.1.1. Central concepts of Risk Management

It is hoped that an enhanced central concepts in the field of risk management is to be developed for the benefit of all oil custodians around the world. This will benefit the industries in the way that knowledge and data sharing can be maximised as the individual companies will have the same concept of doing risk assessment.

5.1.2. Historical accident and incident data sharing

Not all companies can afford to handle the management of their accident and incident data sharing for the benefit of risk management applications. Certain companies are also limited in the historical database due to lack of funds and this will eventually limit their capability in executing their risk assessments. It is suggested that a common database with all essential terms and definitions are created in order for these historical accident and incident data can be efficiently managed and shared within the oil and gas industry.

5.1.3. Employ advanced risk assessment frameworks and techniques

Risk assessment and its methodology is generally a systematic scientific approach that is facilitated by frameworks. In this study, it has been shown that there is a wide range of risk assessment techniques have been developed and employed and some of the techniques are very advanced. Therefore, it is essential to employ only the most advanced risk assessment in addressing the risks within the oil and gas industry as a regulation as it would generate a higher degree of reliability and validity of the research results.

5.1.4. Introducing generic standard of risk assessments

Throughout the study, it is discovered that generic standard is limited with regard to offshore activities. By introducing a more widely accepted international standard on risk assessment framework, it would facilitate and promote the use of risk assessment in parts of the world where there is not accustomed to applying such techniques. The introduction of a generic standard may facilitate communication and sharing of risk assessment results which will also benefit the public in general.

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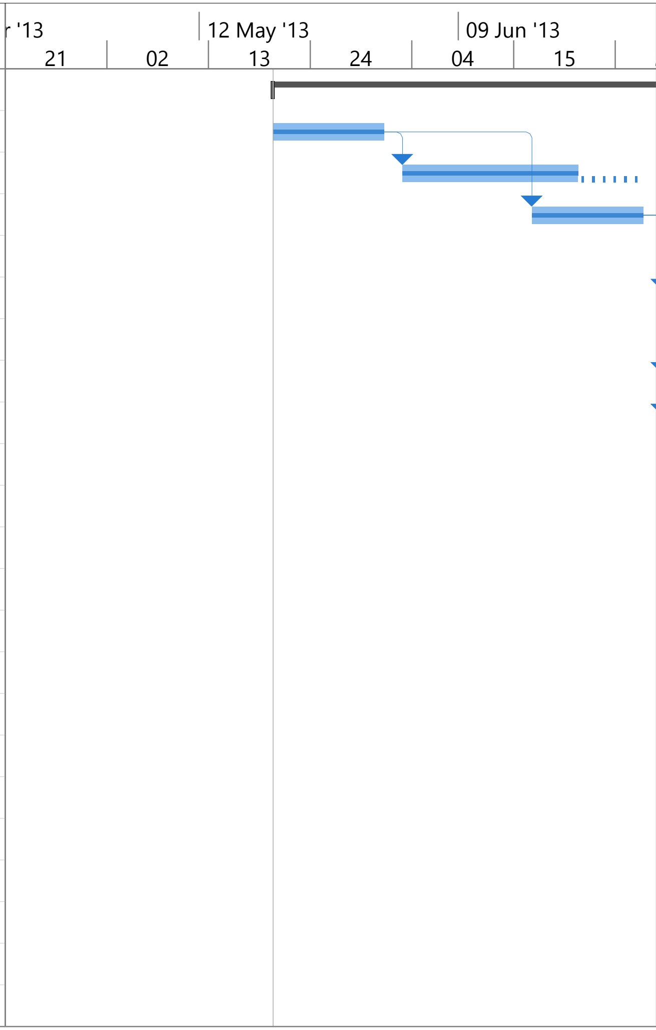
APPENDIX

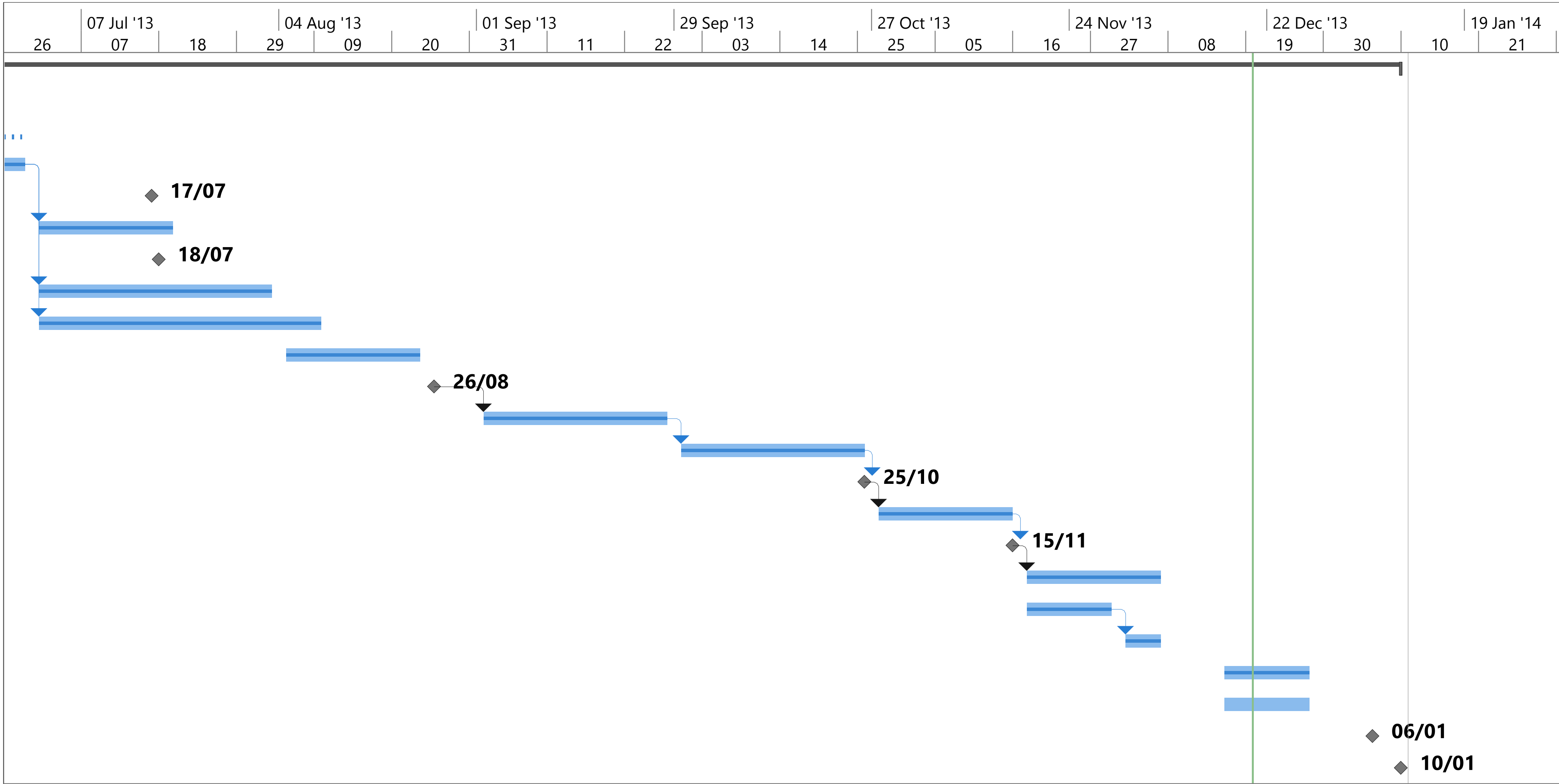
Appendix 1 - Gantt chart for FYP 2013.

ID		Task Mode	Task Name	Duration	Start	Finish
1			**QRA of FPSO System using Bow-Tie Model**	**169 days?**	**Mon 20/05/13**	**Fri 10/01/14**
2			Select project topics	10 days	Mon 20/05/13	Fri 31/05/13
3			Conduct preliminary research work	15 days	Mon 03/06/13	Fri 28/06/13
4			Prepare extended proposal	10 days	Mon 17/06/13	Fri 28/06/13
5			Submit extended proposal	0 days	Wed 17/07/13	Wed 17/07/13
6			Prepare proposal defence	15 days	Mon 01/07/13	Fri 19/07/13
7			Present proposal defence	0 days	Thu 18/07/13	Thu 18/07/13
8			Prepare extensive literature review	25 days	Mon 01/07/13	Fri 02/08/13
9			Gather guidelines for QRA	30 days	Mon 01/07/13	Fri 09/08/13
10			Prepare draft for interim report	15 days	Mon 05/08/13	Fri 23/08/13
11			Submit interim report	0 days	Mon 26/08/13	Mon 26/08/13
12			Perform hazard identification	20 days	Mon 02/09/13	Fri 27/09/13
13			Develop fault tree analysis	20 days	Mon 30/09/13	Fri 25/10/13
14			Complete fault tree analysis	0 days	Fri 25/10/13	Fri 25/10/13
15			Develop event tree models	15 days	Mon 28/10/13	Fri 15/11/13
16			Complete event tree analysis	0 days	Fri 15/11/13	Fri 15/11/13
17			Prepare progress report	15 days	Mon 18/11/13	Fri 06/12/13
18			Develop a bow-tie model	10 days?	Mon 18/11/13	Fri 29/11/13
19			Prepare Risk Matrix	5 days	Mon 02/12/13	Fri 06/12/13
20			Prepare final report draft	10 days	Mon 16/12/13	Fri 27/12/13
21			Prepare technical report	10 days	Mon 16/12/13	Fri 27/12/13
22			Oral presentation	0 days	Mon 06/01/14	Mon 06/01/14
23			Submit final report	0 days	Fri 10/01/14	Fri 10/01/14



Project: FYP - QRA of FPSO Sys
Date: Fri 20/12/13

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	



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Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
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Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	