RISK ASSESSMENT AND RISK MANAGEMENT FOR SUBSEA RIGID SPOOL COMMISSIONING AND INSTALLATION OPERATIONS

By

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ABSTRACT

Today the newest frontier in oil & gas exploration, drilling and production industries is the Oil and Gas Subsea Industry. Oil and gas fields reside beneath many inland waters and offshore areas around the world. Subsea oil & gas production equipment and systems can range in complexity from a single satellite well with a flow-line linked to a fixed platform, FPSO or an onshore installation, to several wells on a template or clustered connected to a manifold via a rigid spool.

The proposed study focuses on developing a risk assessment and risk management tool that can be used by the decision maker in the field to address the risks involving the different subsea rigid spool operations. This includes site integration tests, different phases of the logistics operations to get these spools from their test facility to their offshore fields, and the deployment and installation operations carried out in their designated locations in the subsea fields.

This study attempts to identify and integrate the risks in each operational step and give a clear account of the consequences involved ,the effects of such risks on the project as whole showing the true cost of such risks and also gives the tools to reduce these risks to as low as reasonably practical.

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TABLE OF CONTENTS

ABSTRACT……………………………………………………………………......ii

ACKNOWLEDEGMENTS…………………………………………………….iii

TABLE OF CONTENTS……………………………………………………..iv

List of Tables……………………………………………………………………..vi

List of Figures…………………………………………………………………vii

List of Abbreviations……………………………………………………viii

CHAPTER 1: INTRODUCTION..1

1.1 Introduction to the Subsea Oil and Gas Industry 1

1.2 Hazards , Risks and Failure Consequences in Subsea Industry 3

1.3 Challenges Facing Accurate Subsea Risk Analysis 7

1.4 Scope of Research 9

1.5 Research Objectives 10

CHAPTER 2: LITERATURE REVIEW 12

2.1 Accident Modeling and Prevention 12

2.1.1 The Nature and Causes of Accidents 14

2.1.2 Subsea Assets integrity and Risk Analysis 15

2.1.3 Accident Prediction Models and Model Classification 19

2.2 Utilizing Accident Modeling in the Proposed Thesis 22

2.3 Site Integration Test (S.I.T)..24

2.4 Transportation and Logistics...34

2.5 Subsea Rigid Spool Offshore Installation and Commissioning Operations 39

CHAPTER 3: METHODOLOGY OF RISK ASSESSMENT AND MANAGEMENT 42

3.1 Methodology of Risk Assessment and Management 43

3.2 Steps of the Methodology 45

3.2.1 Description of Operational Sequence 46

3.2.2 Identifying the Hazards in Each Operational Step 46

3.2.3 Identifying the likelihood of occurrences for the risks and hazards associated with all three operational phases in the case study. 53

3.2.4 Consequence Assessments 59
3.2.5 An Engineered Risk Matrix for the study. 63
3.3 Control Tools Used to Prevent and/or Mitigate Hazards 67
3.5 Summary 72
CHAPTER 4: IMPLEMENTATION OF THE PROPOSED METHODOLOGY IN A CASE STUDY 73
4.1 Application of Thesis on Subsea Rigid Spool Operations. 73
4.2 Case study of a lifting accident involving a Subsea Rigid Spool at a Fabrication Facility on July 19, 2010 74
4.2.1 Incident Summary. 74
4.2.2 Incident Investigation Overview. 78
4.2.3 Incident Description. 78
4.2.4 Root Cause Analysis. 81
4.2.5 Corrective Action Recommendations. 84
4.2.6 Lessons Learned due to Incident as per the Oil Company's Final Report. 87
4.3 Appling the Research on Case Study Operation 89
4.3.1 Developing an Engineered Risk Matrix for the Operations of the Case Study. 90
4.3.2 Developing a hazard prevention and mitigation checklist for the case study. 95
4.3.3 Implementing the risk assessment and risk management study in this case study 99
CHAPTER 5 CONCLUSION AND FUTURE WORK 108
5.1 Summary 108
5.2 Future Work 109
5.2.1 Development of risk assessment and management systems for other subsea assets 109
5.2.2 Development of a computerized Subsea assets risk management system. 110
REFERENCES 112

List of Tables

Table 1 Likelihood Of Lifting Incident & Hazard Occurrence Checklist..58

Table 2 Risk Matrix 65

Table 3 Causal Factor #A 82

Table 4 Causal Factors #B 83

Table 5 Causal Factor #C...83

Table 6 Corrective Action Recommendations. 86

Table 7: Risk Matrix 94

Table 8 Lifting Incident Likelihood Of Occurrence. 97

List of Figures

Figure 1: Jack-up rig and production platforms…………………………………………..2

Figure 2: A Schematic Shows a Number of Floating Production Units……….……………3

Figure 3: Deepwater Horizon oil rig in flames fueled from the gushing subsea well……….3

Figure 4: Rigid Spool…………………………………………………………………..28

Figure 5: Typical Rigid Jumper Shape………………………………………………...29

Figure 6: Specific 4" Rigid Jumper Shape……………………………………………..29

Figure 7: Simple Subsea Rigid Spool ………………………………………………….32

Figure 8: Land Transportation of Rigged Spool……………………………………….37

Figure 9: Offshore Transportation Of The Rigged Spool…………………………………...39

Figure 10: A Lifting Incident/Hazard Check List……………………..………………….51

Figure 11: An Uncontrolled Pressure Release Check List…………………………………..52

Figure 12: Control Means To Reduce Potential Pressure Release Check List……………...68

Figure 13: Control Means to Reduce Potential Lifting Hazard Check……………………...69

Figure 14: Risk Assessment Flow Chart…………………………………………........71

Figure 15: Spool Diagram……………………………………………………………...76

Figure 16: Tipped Over Crane………………………………………………………….77

Figure 17: Tipped Over Rigged Spool………………………………………………….77

Figure 18: Potential Factors That Could Result in Lifting Incident…………………………96

Figure 19: Factors To Reduce Lifting Hazards……………………………………………98

List of Abbreviations

AEB	Accident Evaluation Barrier
ALARP	As Low As Reasonably Practicable
AEB	Accident Evaluation Barrier
BOE	Barrels of Equivalent
BAR	Pressure Unit
CCA	Cause Consequence Analysis
CWMS	Computerized Work Management System
CMMS	Computerized Maintenance Management System
CVC	Cameron Vertical Connection
CVCRT	Cameron Vertical Connection Running Tool
DP	Dynamic Positioning
ETA	Event Tree Analysis
FIG	Figure
FPSO	Floating Production, Storage and Offloading Unit
FTA	Fault Tree Analysis
GBq	Giga- Becquerel
HAZOP	Hazard and Operability Study
HRA	Human Reliability Analysis
HSE	Health Safety & Environment
JSA	Job Safety Analysis
M	Meter
MSDS	Material Safety Data Sheet
MPFM	Multi-Phase Flow Meter
NST	Newfoundland Standard Time

PHA	Preliminary Hazard Analysis
PRA	Probabilistic Risk Assessment
PRV	Pressure Relief Valve
PT	Pressure – Temperature
QC	Quality Control
QHSE	Quality Health Safety & Environment
QRA	Quantitative Risk analysis
R&D	Research and Development
ROV	Remotely Operated Vehicle
RT	Running Tool
SIT	Site Integration Test
SPAC	Standards , Policies and Admin, Controls
STAMP	System-Theoretic Accident Model and Processes
USD	United States Dollars
XMT	Christmas Tree

CHAPTER 1: INTRODUCTION

1.1 Introduction to the Subsea Oil and Gas Industry

On planet earth hydrocarbons, such as crude oil and natural gas, are the products of compression and heating of ancient organic materials, in the absence of oxygen over geological time. They are found in various deep and shallow underground zones in different locations all around the world. Such oil and gas zones are either found onshore, such as the ones processed in the deserts of the Middle East, Texas, Alberta, and in other land locations all around the world. These zones are utilized, and oil and gas are extracted. There are also oil and gas zones that are located offshore, where they are beneath the ground of the seabed.

The term Subsea in the Oil and Gas Industry relates to the exploration, drilling, and development operations of oil and gas fields conducted in underwater locations.

To distinguish between different facilities and approaches that are needed, subsea oil field developments are usually split into shallow water and deep-water categories.

The term shallow water is used for shallow water depths, where bottom-founded facilities like jack-up drilling rigs can be used during the drilling operations and fixed offshore structures during production operations. They are also used where saturation diving is feasible, and where in most cases all the main flow control equipment is located on the surface, such as the wellhead and the XMT that are on the production platforms and installations as shown in Figure 1 [by:- Jon Mainwaring , Rig-zone Staff 2012].

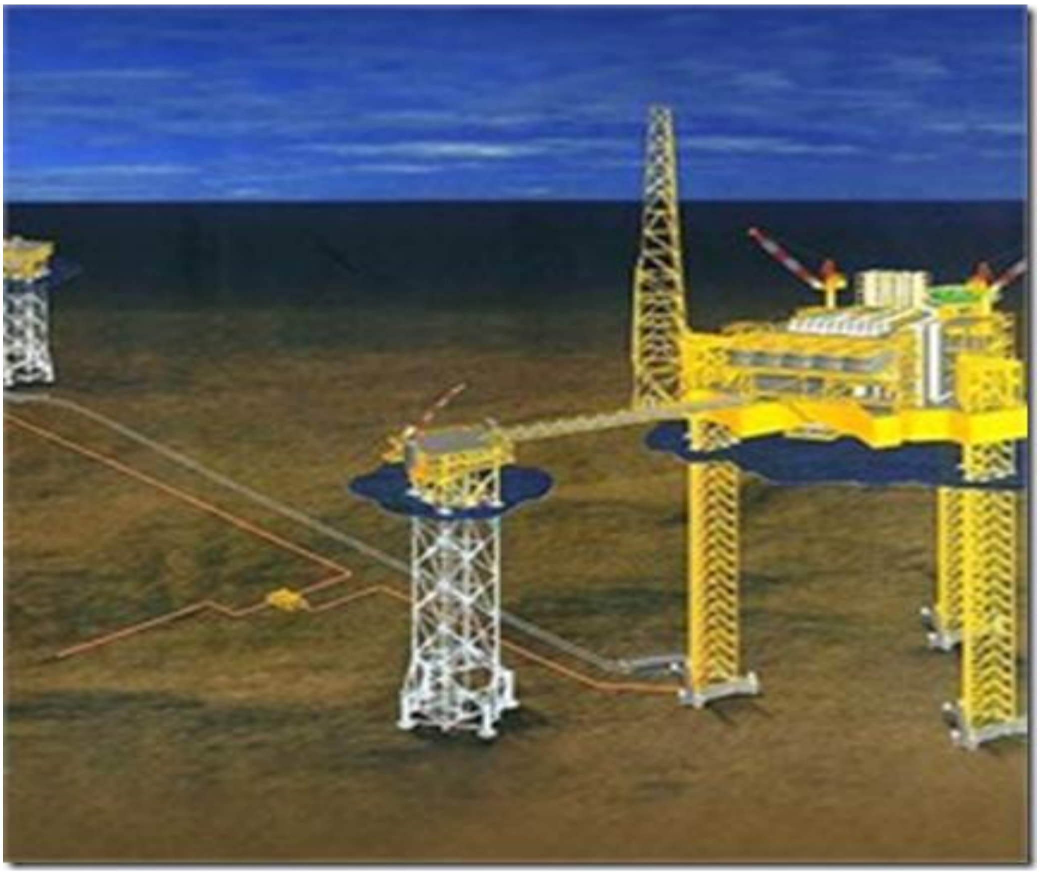


Figure 1: Jack-Up Rig And Production Platforms [by:- Jon Mainwaring , Rig-zone Staff 2012].

Deep-water is a term often used to refer to offshore projects located in water depths greater than 300 feet, where floating drilling vessels, whether semi sub drilling rigs or drill ships are used for drilling operations. They are also used for floating oil platforms during production operations. Deep water is where remotely operated underwater vehicles are required as manned diving is not practical.

In deep water operation, the term or prefix used to describe the assets and systems used in deep water drilling and production operations is referred to as subsea. As in subsea well, subsea XMT, subsea manifold, and subsea field, as per Figure 2 Source [FMC technology’s website Feb. 2014].

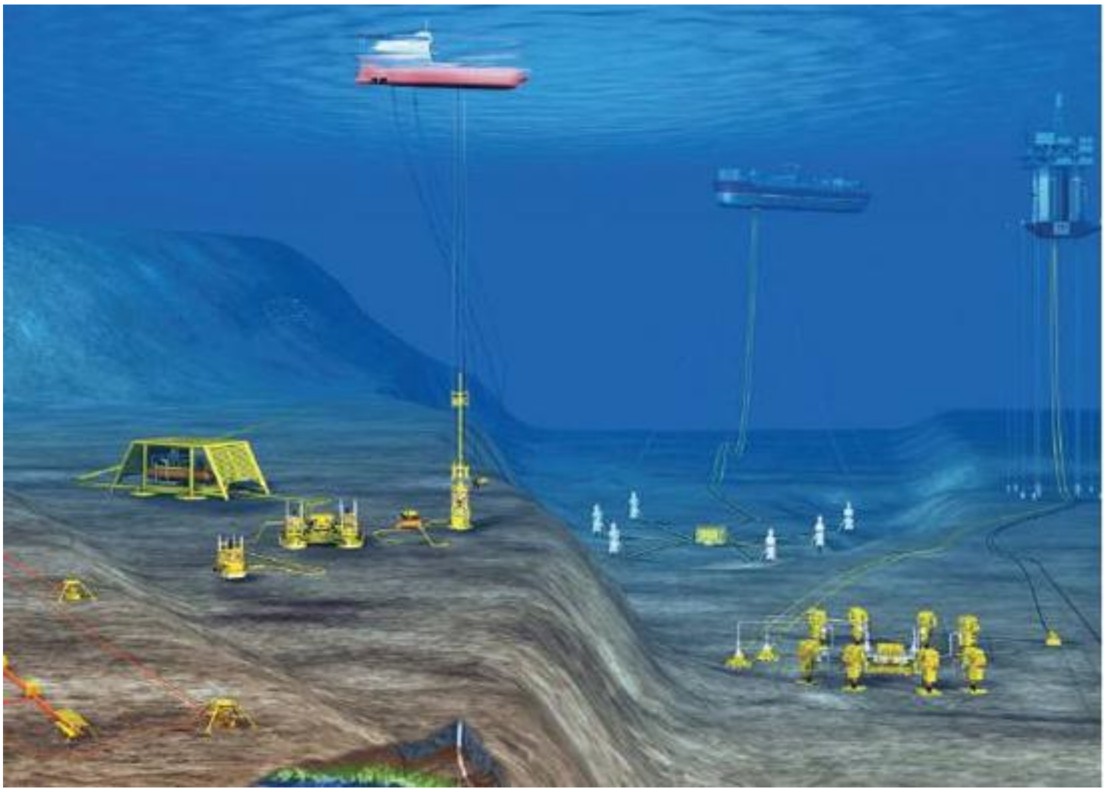


Figure 2: **A Schematic Shows a Number of Floating Production Units [FMC technology's website Feb. 2014].**

1.2 Hazards, Risks and Failure Consequences in Subsea Industry

Basic Terminology

Initiating Event: The start of an unplanned and unwanted event such as system or equipment failure or human error is the initiating event for the event tree.

Event: The event following and caused by the initiating event such as release of pressure (after valve failure), radioactive release (after equipment source damage) , dropping equipment (after human error) are also termed as precursor events.

Outcome Event: The possible effects, scenarios or outcomes of an initiating event are known as the outcome events, such as an oil spill, radioactive contamination, explosion or costly operational down time.

Subsea Risk Matrix: A subsea risk matrix is a matrix that is used during risk assessment of the different phases of the subsea process operation, from the manufacturing and testing phase to final commissioning in the offshore subsea spots. It is used to define the various levels of risk as the product of the hazard probability categories and hazard severity categories

Flowchart: A flowchart is a type of diagram that represents an algorithm or process, showing the steps as boxes, and their order by connecting them with arrows. This is used in analyzing, designing, and managing the risk analysis and risk management operations.

Safety engineering is a discipline which assures that engineered systems provide acceptable levels of safety. The primary goal of safety engineering is to manage risks by eliminating or reducing them to acceptable levels.

By understanding the existing hazards, risks, and failure consequences of any system, a realistic and suitable risk management system can be developed. This system would provide acceptable levels of safety to such a system or industrial entity.

Any unwanted or undesired occurrence during any operation is termed as an incident. Hazards generally refer to those events that have the potential to cause an incident or accident. An accident is a resulting outcome of an occurrence of a single incident or multiple incidents or events. Risk analysis is widely recognized as a systematic process to model the probable accident scenarios for the industrial facility, and quantify the losses and consequences in a measurement of risk (Daneshkhah, 2004). It has now become a common term which has various implications. It is usually defined as a combination of the likelihood of occurrence of an unwanted event (accident) and its consequences. Alternatively, it can also be defined with the following explanations:

Kaplan and Garrick (1981) define "risk as a set of scenarios (occurrences), each of which has a probability (likelihood) and consequences".

Kumamoto and Henley (1996) define "risk as collections of likelihoods and likely occurrences".

Aiche (2000) defines "risk as a combination of probability of the occurrence and its consequences".

Crowl and Louvar (2002) define "risk as a probability of a hazard resulting in an accident".

Ayyub (2003) defines "risk as a characteristic of an uncertain future and is neither a characteristic of the present nor past. It results from a hazardous event or sequence of hazardous events referred to as causes and if it occurs, results in different adverse consequences".

Bedford and Cook (2001) define "risk with two particular elements: hazard (a source of danger) and uncertainty (quantified by probability)."

Risk involved in a potential accident or incident is evaluated based on a systematic analysis, which usually comprises a number of steps including a detailed qualitative and quantitative evaluation (Modarres, 2006). A detailed risk analysis is always designed to answer three fundamental questions about an occurrence in a facility: (1) what can happen and why? (2) what are the likelihoods?, and (3) what are the consequences? (Modarres, 2006). Four major steps, namely: hazard identifications, consequence assessment, likelihood assessment, and risk characterization have to be conducted in a comprehensive risk analysis in order to get the answers to these questions (Ferdous, 2006).

The severity of the consequences resulting from a failure in an oil and gas subsea system can be overwhelming, with devastating environmental and economic results. Also, there is much more potential for human losses when compared to the consequences resulting from a failure in an oil and gas land fields; this is due to a number of reasons :-

- Most subsea wells are at deep water depths a few thousand feet below the sea surface, which makes the process of mitigation should an incident occur very complicated, very costly, and technically challenging to address.
- Most of these subsea fields are far away from the shore (most of the offshore subsea fields off Newfoundland-Canada are more than 300 Km from shore), adding a logistical challenge to get equipment and/or people to or from these fields in case of an incident and also increases the time before any outside help can arrive should an incident develop.
- The remoteness of these offshore subsea fields, the weather, and time of year are major negative factors that could delay or prevent any immediate response to a major incident occurring in a subsea field offshore.
- Subsea systems are a relatively new technology with limited historical occurrences of major incidents, which means there are no clear standard guidelines for how to address the different situations should a major incident take place.

An example of the above factors and severity of the consequences resulting from a subsea incident can be demonstrated by reviewing the Deep-water Horizon catastrophe and the oil spill incident that followed. Following the explosion and sinking of the Deep-water Horizon oil rig, which claimed 11 lives, a sea-floor oil gusher flowed unabated for three months in 2010. The gushing wellhead was not capped until 87 days later. The total discharge is estimated at 4.9 million barrels in the gulf of Mexico. The environmental cost was epic, as well as the financial liability and

Figure 3: Deepwater Horizon Oil Rig In Flames Fueled From The Gushing Subsea Well Spillius, Andrew The Telegraph (London). Retrieved 2010-06-18.

penalties that the oil company responsible had to pay. Some estimates suggested that the total liability could amount to as much as $100 billion USD by the conclusion of the disaster. Spillius, Andrew The Telegraph (London). Retrieved 2010-06-18.

1.3 Challenges Facing Accurate Subsea Risk Analysis

In process industries the integrated hazard identification, risk assessment, consequence analysis, and risk mitigation are provided via different formalized programs. These formalized programs are used in the general operations and facility operation, when carrying out critical routine operations and when handling hazardous materials. These programs show the methodology and aspects of detection, prevention, and mitigation of risks associated with processing, handling, and production during the different phases of any industrial process . Special attention is given to hazard identification and hazard assessment techniques, ranging from simple screening checklists to highly structured Hazard and Operability (HAZOP) analysis. This shows how to calculate potential consequences of identified hazards, quantify the likelihood of these events, and combine equipment failure rate data and human reliability analysis with hazard assessment.

However, when dealing with oil and gas subsea systems and subsea assets, the process to have a working system for hazard identification, risk assessment, consequence analysis, and risk mitigation systems effective and in place faces many challenges. These challenges are due to the complex nature of subsea assets, equipment, and the nature of operations carried out as follows:

- Subsea equipment and assets are custom-made products. For example, there is no production line to produce a Subsea Christmas tree (XMT) , subsea rigged spool, or subsea manifold. These subsea assets and equipment are built according to the customer’s (oil companies) field requirements, policies, and field development strategic planning. This results in the uniqueness of equipment ordered for each project. For example for a subsea rigged spool, such uniqueness would be in terms of different size , shape , weight , added accessories , materials used, methodology of testing, and the procedures and ways of commissioning it subsea. Therefore a standard risk assessment, consequence analysis, and risk mitigation system are not adequate or accurate to address the whole matter.

- Many subsea assets, such as subsea manifolds and spools, are manufactured in the countries and location near where they will be installed. This means there is no one facility or fixed set up when building the different subsea assets, unlike the consistency we see in other processing industries.
- The means of transportation both on land and via sea for these assets and tools from the fabrication and test facilities to the offshore locations also differs greatly depending on equipment nature, availability of transportation vessels and location and nature of offshore field.

As stated above, subsea systems are much more challenged to have an adequate or accurate standard risk assessment, consequence analysis, and risk mitigation system in place to address their custom built nature, whether this be in the final manufacturing and testing phases or for their transportation , installation and commissioning phases.

1.4 Scope of Research

The scope of this research is to address the hazard identification, risk assessment, consequence analysis, and risk mitigation challenges for subsea equipment and assets on the macro level, by developing a risk assessment and risk management system designed for the subsea rigid spool. A risk Matrix and operation flow chart is created for each individual subsea project, to be used as a tool to help the decision maker have a full understanding of the risks involved in every operational step and the visible means to reduce such risks to as low as reasonably practicable. In this study, the subsea rigged spool shall be the subsea asset of interest, starting from the testing and integration phase through the transportation and logistics phase, from test facilities to offshore destinations, to the final phase of installation and commissioning phase of the subsea assets (rigid spool) in its designated spot subsea.

1.5 Research Objectives

As the oil and gas industry moves towards the subsea fields in pursue of new untapped oil and gas reservoir sources to meet the global demand, a number of highly innovative and custom made subsea assets and equipment have been created. These enable industry to extract and develop hydrocarbons from these deep and remote subsea fields. With such new custom made newly innovated equipment and assets comes the challenge of new risks associated with the testing, the logistics, and the installation operations of this subsea equipment and assets, which cannot be addressed in the same manner as the traditional risks present in other process industry systems; nor can these risks be identified and managed in the same manner as those in the land based process industry systems. Therefore, the need to develop new approaches for subsea risk assessment and risk management was present.

The overall objectives for this research are as following:-

- To propose a system for risk assessment and risk management created for subsea assets [subsea rigged spool is the asset of interest in this study], where the commissioning and installation operations involve identification, assessment, and prioritization of risks. This is followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of any unfortunate events. Also, the intent is to maximize the realization of opportunities in an attempt to prevent such unfortunate events from occurring, and to have a mitigation plan should they happen.

- To develop a risk matrix for each individual custom made subsea assets, to suit the features of each subsea asset. Then this risk matrix would be utilized, to determine on flow charts the degree of the consequences and the likelihood of occurrence for all operations associated with the identified hazards, showing the different scenarios in which these hazards can occur.
- To empower the decision makers in the field during all phases of the operation of testing, moving and installing this subsea equipment and assets with a tool that shows the risks and their probability of occurring, and what's at stake should they occur. This tool also demonstrates what measures need to be taken to reduce the chance of such risks occurring.

The end result of this study is to have an easy to use and effective risk assessment and risk management system custom built for subsea assets [Rigid Spool in this study] that can be used by the field operational supervisor or QHSE officer.

CHAPTER 2: LITERATURE REVIEW

The purpose of this study is to develop a risk assessment and risk management tool, built specifically for the subsea rigid spool. This tool is developed to cover the operations which are carried out on the spool, from the time its fabrication is completed till it’s installed and commissioned in its subsea spot in its designated subsea field offshore. In order to develop such an accurate risk assessment and management tool, an overview of the different existing accident and prevention models that are in use today in industry is presented, and what this study used from these models and what it adds, also to be mentioned that due to the new nature of this industry vary little risk studies and publications are available on the subject.

2.1 Accident Modeling and Prevention

In most high technological industries today, such as the oil and gas subsea industry, the consequences of accidents, events, mishaps and near misses are so severe that they are simply unacceptable. Therefore, when such events happen a thorough investigation is carried out in order to learn from what has happened, how it happened, and to prevent future occurrences. From such investigations and studies accident modeling was developed. Most accidents can be traced to one or more than one of four levels of failure: Organizational influences, unsafe supervision, preconditions for unsafe acts, and the unsafe acts themselves. In these models, an organization's defenses against failure are modeled as a series of barriers, with individual weaknesses in individual parts of the system, and continually vary in size and position. The system as a whole produces failures when all individual barrier weaknesses align, permitting "a trajectory of accident opportunity", so that a hazard passes through all of the holes in all of the defenses, leading to a failure (Smith, D. R., Frazier, D., Reithmaier, L. W. and Miller, J. C. 2001 & Stranks, J. 2007).

Therefore, the main purpose of accident modeling is to understand and analyze different accidents and work on preventing them.

2.1.1 The Nature and Causes of an Accident

The term (Accident) has been used mainly as a common denominator for a set of phenomena that is of interest, which includes a critical accident, incidents, and mishaps which have in common two things: first, that they carry with them unwanted and undesirable outcomes , secondly, that they are unexpected .

The nature of any accident has a three-step sequence:-

- Initiation (the event that starts the accident).
- Propagation (the event or events that maintain the accident), and
- Termination (the event or events that stop the accident or diminish it in size).

Comprehending how accidents evolve from the initiating events, to their propagating effects, to the final consequences is paramount in designing safety into systems. (Hollnagel, E . 2004).

The main aim of accident modeling is to understand accidents, causes in order to prevent them from occurring.

Accidents cannot be attributed to a single cause, but are the result of a number of failures and mistakes that are caused by confluences of a whole chain of errors. Therefore, there is a tendency to consider the relationship between variables rather than causes.

However, it can be observed that accidents are mainly caused by three causal factors:

1st Unsafe acts: Any act that deviates from a generally recognized safe way or specified method of doing a job.

2nd Unsafe conditions: Any physical state which deviates from that which is acceptable, normal, or correct in terms of its past production or potential future production of personal injury and/or damage to property or systems. Any physical state which results in a reduction in the degree of safety normally present.

3rd Management and organizational failures which result from poor management of safety policy & decisions , inadequate safety programs , supervision , worker training or communication , leadership failure or inadequate management job knowledge.

It should be noted that accidents are invariably preceded by unsafe acts and/or unsafe conditions. Thus, unsafe acts and/or unsafe conditions are essential to the occurrence of an accident (Kjellen, U. 2000).

2.1.2 Subsea Assets integrity and Risk Analysis

Subsea asset integrity in this study is in regard to the integrity of the process. This starts from the manufacturing and testing phases of the subsea rigid spool, passing through transportation and logistics phases of transporting the subsea spool to its designated offshore field location and the integrity of commissioning and installation of the subsea spool in its final spot subsea. Subsea spool integrity here refers to the ability to have the work performed on the subsea spool in an effective and efficient way , whilst protecting the health and safety of the workers carrying out the work, protecting the equipment and assets, and protecting the environment. This is done via means of ensuring that the people, systems, processes and resources that deliver integrity are in place, in use, and perform as required.

Therefore, an Integrity Management tool is developed to address the quality at every stage of the subsea asset phases that have been mentioned above. This would cover the facilities in which the subsea rigid spool will be worked on, the work procedures while carrying out the different jobs on the spool, and means for handling , lifting and transporting these spools. The inspections, auditing/assurance, and overall quality processes are just some of the tools designed to make the subsea integrity management system effective.

The integrity of a subsea rigged spool as an asset during installation and commissioning is defined as its ability to perform its required function effectively and efficiently whilst protecting health, safety and environment (HSE UK, 2009). Failure of the management of offshore operations to adequately monitor the asset integrity during such operations often leads to poor decision making (Stephens et al., 1995).

The safety of any system can be defined as " Freedom from unacceptable risk" (Harold E. Roland, Brian Moriarty-1990). From such a definition one can grasp the importance of risk analysis in any system, and a subsea system is no exception. Since absolute safety where all risks are completely eliminated can never be achieved, we strive to reduce all risk to an acceptable level. Therefore, the goal is that all risk associated with the subsea system activity in this study, as in industry, is reduced to As Low As Reasonably Practicable or ALARP, and to reduce the frequency at which hazards may occur to tolerable limits.

In general risk analysis can be qualitative and quantitative. The analysis estimates and predicts the risks associated with unwanted events, measures societal risk, individual risk, potential loss of life, probability of an accident and reliability of a system. Qualitative evaluation is usually performed at each stage of the system or operation development to identify the possible hazards with relevant causes. Traditional qualitative evaluation methods like Safety Reviews, Functional Hazard Analysis, What-If Analysis, Relative Ranking, Preliminary Hazard Analysis (PHA), Checklist Analysis and Failure Modes & Effect Analysis are descriptive and generally used for identifying possible system hazards (Wang, 2004 & Modarres, 2006).

Normally these methods are used in preparation for consequence analysis or failure frequency analysis modeling of the risk analysis process, and also when a more detailed study is not required (Hauptmanns, 1988; Lees, 1996, 2005). After identifying the possible hazard scenarios of a system, the principal task of risk analysis is to determine the logical causes and consequences for the identified hazard scenarios and to evaluate the risk in a quantitative manner for the unwanted events.

Quantitative risk analysis (QRA) for a process system can either be deterministic or probabilistic (Wang, 2004). The deterministic methods focus on consequence assessment (such as worst-case scenario analysis), while the probabilistic approaches consider both frequency and consequence. The probabilistic approach of QRA evaluates risk for an industrial facility in terms of its numerical evaluation of consequences and frequencies of an accident or an incident. Probabilistic data and information about the possible hazard scenarios of an accident are the main required parameters of probabilistic QRA. The final outcome of QRA is a numerical evaluation of the overall facility in terms of calculating the probability of occurrences of potential hazards and their contributions to risk.

A variety of techniques and many formal methods are used to assess or to "measure" risk including Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause-Consequence Analysis (CCA), Human Reliability Analysis (HRA), and the latest technique, “Bow-tie” analysis, has been used in QRA to perform risk analysis (Badreddine and Amor, 2010).

Even when statistical estimates are available, in many cases risk is associated with rare failures of some kind, and data may be sparse. Often, the probability of a negative event is estimated by using the frequency of past similar events or by event tree methods, but probabilities for rare failures may be difficult to estimate if an event tree cannot be formulated. This makes risk assessment difficult in hazardous industries such as the subsea industry. In this industry the frequency of failures is rare, and harmful consequences of failure are numerous and severe. In addition to all the previous factors stated, general historical statistical data is limited in the subsea industry due to the fact it’s a new industry using new technologies.

In statistics, the notion of risk is often modeled as the expected value of an undesirable outcome. This combines the probabilities of various possible events and some assessment of the corresponding harm into a single value. The simplest case is a binary possibility of Accident or No accident. The associated formula for calculating risk is then:

Risk = Likelihood of a Hazard Occurring X Consequences resulting from These Hazards

Because the level of consequence severity that could result from a subsea system failure is extremely severe, as is the likelihood of occurrence for any defined hazard, these depend on the initiating events that lead such a hazard to happen, and also on the presence or absence of prevention layers of protection and procedures barriers to prevent the occurrence of such hazards.

2.1.3 Accident Prediction Models and Model Classification

It is important to understand the causes of accidents in complex industries such as the subsea oil & gas industry in order to enhance the safety of such industries and to develop preventive strategies to mitigate the occurrence of future similar accidents. Accident models provide a conceptualization of the characteristics of the accident, which typically show the relation between the causes and effects, explain why and how accidents occur, and are used as a technique for risk assessment during system development and to study the causes of the occurrences of an accident.

As stated before, in complex industries such as the deep subsea oil and gas industry accidents are not usually caused by a single failure or error but rather as a sequence of events initiated by the deviation from process parameters, failures or malfunctioning of one or more components.

Most traditional accident models use a linear notion of causality to analyze the accident process. Accident causation models are classified into three different types: sequential, epidemiological, and systemic (Hollnagel 2004).

1st Sequential accident models

The sequential accident models are the simplest types of accident models, where the occurrence of a preventable accident or injury is the natural culmination of a series of events or circumstances which invariably occur in a fixed and logical order. One of the earliest sequential accident models is the “Domino theory” proposed by Heinrich (Heinrich HW. 1931).

2nd Epidemiological accident models

This accident model describes an accident as an analogy to the spreading of a disease, i.e as the outcome of a combination of factors, some manifest and some latent , that happen to exist together in space and time, and the steps needed to create such models are the following steps :

1:collection and analysis of data, 2:examination of apparent relationships for other causative factors, 3:establishment of hypotheses regarding causation and testing them under controlled conditions, 4: developing control measures and testing them for effectiveness, 5: incorporation of these tested control methods into programs of accident prevention. The epidemiological models can be seen as more powerful ways of understanding an accident and differ from sequential accident models on four main points (Albert P. Iskrant Feb. 1960).

1. Performance deviations such as unsafe acts , unsafe conditions , a critical act or disturbance which could be called performance deviation, this model helps

in understanding how systems gradually deteriorate from a normal state into a state where an accident occurs.

2. Environmental conditions are the surrounding conditions that could lead to performance deviations.
3. Barriers: this feature of the model could prevent the unexpected consequences from occurring and could stop the development of an accident at the last moment.
4. Latent failure which could occur as a result of human error is a condition present within the system well before the onset of a recognizable accident sequence.

3rd Systemic accident models

Systemic models view accidents as emergent phenomena, which arise due to the complex interactions between system components that may lead to degradation of system performance, or result in an accident; an example of a systemic accident model is Leveson's STAMP (Systems-Theoretic Accident Model and Processes) model, a systemic model that considers the technical, human and organizational factors in complex socio-technical systems.

By reviewing these types of models we could summarize their characteristics. While both sequential and epidemiological models represent clear cause and effect links, these models view accidents as resultant phenomena, in the sense that the consequences are predictable, in contrast to that the systemic models which see accidents as emergent phenomena, as events that arise from the compelling of conditions but which cannot be predicted in a similar manner.

2.2 Utilizing Accident Modeling in the Proposed Thesis

The study here presents a risk assessment and risk management system for the subsea rigged spool. In order to determine a practical and accurate risk assessment it is essential to have an accurate accident model, because by utilizing a functional accident causation model we can identify the sources of such potential hazards or accidents and ultimately work on eliminating or reducing the probability of them occurring.

The selection process of a suitable accident causation model depends on the area of focus, causal factors, and the purpose of the model, different models focus on different aspects and are associated with different recommendations for improvement. As reviewed in the start of this chapter and mentioned in chapter 1, the aspects of the subsea oil and gas industry can be summarized as follows:

- The subsea oil and gas industry is a new industry with limited historical accident / incident logged data.
- The subsea oil and gas industry utilizes state of the art new technologies which in many cases are in their early R&D phase so there is no concrete understanding of their reliability nor is there an understanding of the full potential of harm they could cause if failure occurs .

- The subsea oil and gas industry is a very customized industry in every aspect so each subsea asset is custom built for a particular customer for a particular field; this custom criterion is present in the way each asset is manufactured and because of the different hazardous substances built into it, the way it is transported, the way it is submerged to its subsea slot and even in many cases in the way these assets are commissioned.

In this study it is proposed to utilize the methodology of a number of different accident causation models. This study creates a custom built risk assessment and management for the subsea rigged spool in all 3 phases from the end of manufacturing till commissioning operations in the subsea field, Therefore different accident models will be utilized in different areas where its determined that they best fit. For example in the subsea rigged spool (S.I.T) phase utilizing a sequential model such as the Accident Evaluation and Barrier (AEB) model in each potential hazard or accident scenario would be the most successful approach. During the logistical phase of transporting the spool it might be recommended to utilize the epidemiological accident model such as the “Swiss cheese” model proposed by Reason. As for the complex phases of the operations such as during offshore transportation, submarining and commissioning operations of the subsea rigged spool, more complex accident models are required to provide a conceptualization of the characteristics of the potential hazard/ accident that might occur. In these phases models such as Kujath’s Conceptual offshore oil and gas process accident model can be used. This model addresses and works to prevent accidents related to hydrocarbon release scenarios and any escalating events that follow, Kjellen, U.(2000).

An even more affective accident model that can be utilized in critical phases of the subsea rigged spool offshore operation is the latest approach to model the accident process. This model accommodates modeling of multiple risk factors considered in the system in which interaction and relationship of the system elements are complex and non-linear such as those present in the offshore logistics and transportation, submerging and commissioning of the rigid spool.

Together the above accident causation models explain the causation mechanisms of accidents, based on somewhat theoretical hypotheses (Panagiota Katsakiori 2008); therefore during the different phases and steps of the operations of the subsea rigged spool various accident models are utilized in this thesis to help determine the different risks and possible accidents that might occur and therefore work on eliminating or reducing them to as few as possible.

2.3 Site Integration Test S.I.T

The purpose of this review is to describe in a semi-detailed way the procedures required to carry out the S.I.T after full completion of spool fabrication, in order for the spool to perform its job. Only the S.I.T procedures for a simple spool will be displyed without any accessories such as acoustic sand detectors, flow meters, sensors,...etc. (BUR/PRJ/008/2011). Such accessories would also require a S.I.T before they are ready to be shipped for deployment subsea. The main step can be stated as follows :

- Cleaning the inner pipe body, the rigid spool & ROV panel piping.

- Rigid Spool body Hydro-Test and MEG or Water filling.
- Rigid Spool Connector Tubing pressure test.
- De-watering of the Rigid Spool.

1st Rigid Spool Cleaning task

Piping cleaning will be performed on spool [before the CVC connections are welded on] as follows:

Step 1:- Initial Status:

- Equipment visually inspected.
- All necessary equipment has been functionally tested.
- All fittings are of a suitable rating for operation.
- Crane / Forklift available for movement of equipment.
- All necessary personnel available.
- Rigid Spool pre shape horizontally mounted.

Then fill system supply tank with water, connect water supply tank to water pump and water disposal tank at pre-shaped end of the Rigid Spool.

Step 2:- Spool body piping flushing:

- Connect water supply tank to pumping system.

- Connect pump outlet with flushing spray nozzle to pre-shape piping at one end
- Water disposal tank at the other end.
- Insert flushing hose with spray nozzle into piping system (forwards and backwards).
- Visually check water coming out through piping end using clean bottle
- Continue pumping , checking till there is no debris observed

Step 3:- ROV panel piping tubing flushing:

- Tubing not connected to CVC, dummy stab removed and hot stab installed
- Connect TRANS AQUA supply tank to pumping system
- Connect pump outlet hose to hot stab
- Visually check trans aqua coming out through tubing end using clean bottle
- Continue pumping , checking till there is no debris observed

Completely disconnect the flushing system, empty water disposal tank and dewater the rigid spool [empty the water from the rigid spool].

Piping cleaning shall be performed for rigid spool for the verification of absence of any debris in the flow path.

2nd Hydro-test & Meg Filling Procedure for Rigid Spool.

The Spool Body Hydro test is in accordance with the spool design and fabrication limitations, to demonstrate that the spool main body piping has the strength required to meet the design conditions and to check the integrity of the spool body. The test medium for all Rigid Spool Hydro-Tests shall be MEG except for 4” Spools for which fresh water could be used.

Step 1: Hydro test equipment set up & function test:-

- Equipment visually has been inspected.
- All necessary equipment has been serviced ready for testing.
- All relevant documentation is in place for equipment.
- Fittings, hoses and instrumentation are ready.
- Instrumentation is calibrated and certificates available.
- All fittings are of a suitable rating for operation.
- Crane / Forklift is available for movement of equipment.
- Full certification is available for all equipment and hoses.
- PRV rated to hydro-test pressure is fitted.
- Equipment function test pressure shall be (1.1 * hydro test pressure).

Step 2: Place the Rigid Spool in the vertical position and start filling it with the MEG:-

1- Rigid Spool is in accordance with the final metrology, connectors are locked on the test hub without gaskets in the vertical position. See Figure 4 (BUR/PRJ/008/2011).

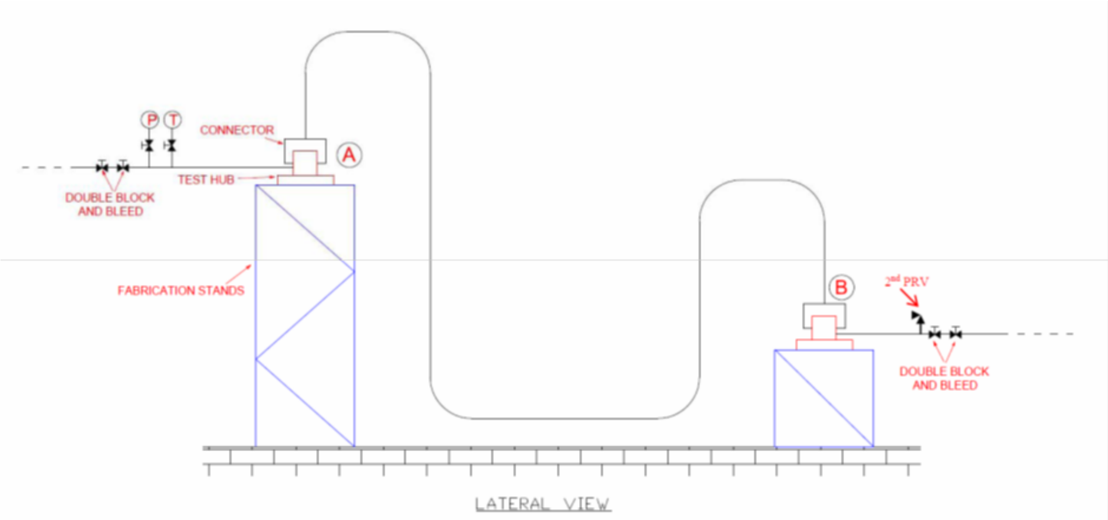


Figure 4: Rigid Spool

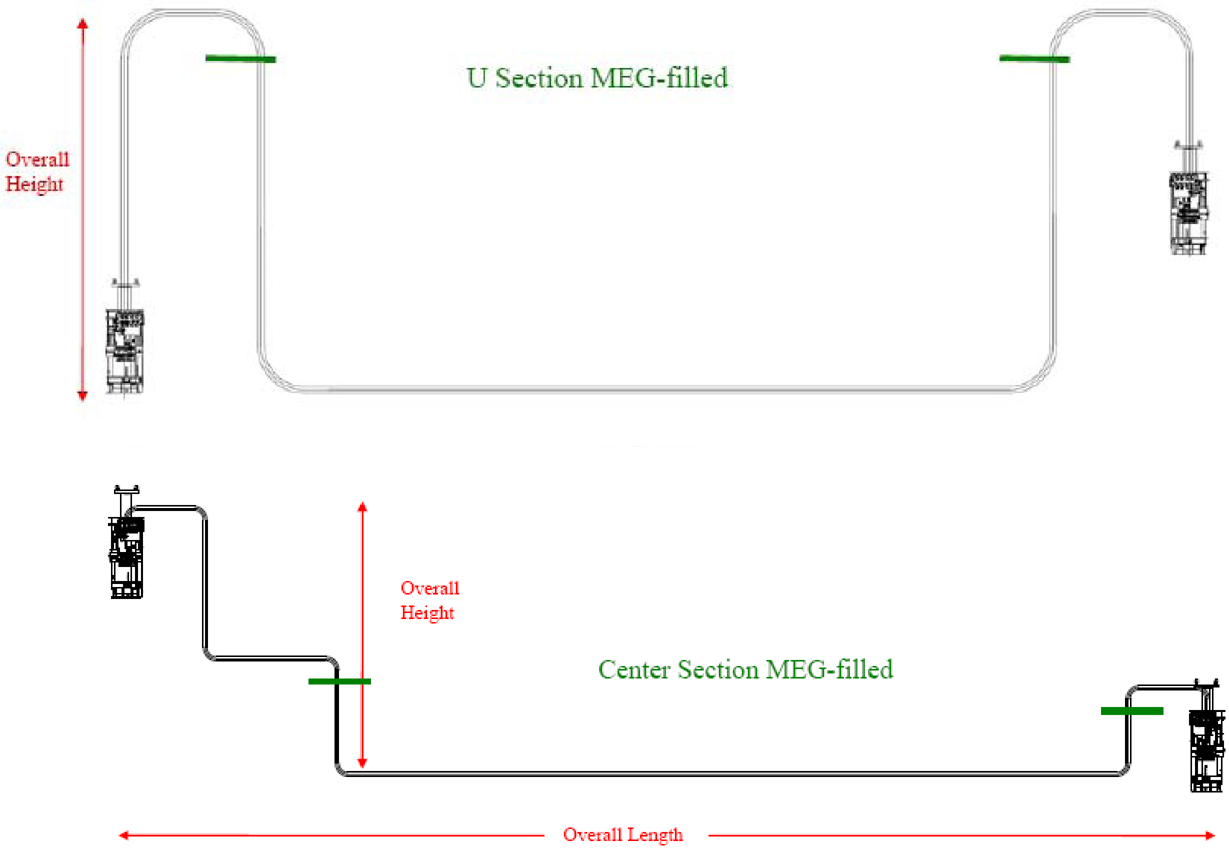
2- Connectors are unlocked and jumper is lifted (with RT) from Test/Fabrication Hubs; gaskets are mounted.

3- Pressure safety valves (2-off) are set at the required pressure.

4- Connector hubs are locked again on Test/Fabrication Hubs and the jumper is ready for the hydro-test.

5- MEG is pumped by the filling pump from test hub B "the lowest point”, Figure 5&6 (BUR/PRJ/008/2011).

Filling starts by pumping MEG from hub B and opening the valve at hub A for air venting. An estimation of MEG quantity for a rigid spool will depend on spool size and inner volume.



Specific 4" Rigid Jumper shape with CVC connectors

Figure5& 6: Specific 4" Rigid Jumper Shape

6- Pumping MEG will continue through Hub B till MEG is coming from hub A;

7- Close the valve at hub A; cycling is applied to get rid of any trapped air inside Rigid Spool Body as per following:

- Connect high pressure pump to spool body.
- Start slowly pumping, raising the pressure to 50 bar.
- Hold for 5 minutes.
- Pump up to 100 bar, slowly.
- Hold for 5 minutes.
- Release pressure down to 0 bar from venting point.
- Repeat the above steps a second time.

8- Hydro-test can start by pressurizing from test hub A. The test medium temperature relations with volumetric expansion and compressibility factor are shown in the charts and need to be reviewed before starting pressurization.

9- Pressure shall be increased at a steady rate, and due to the small volume of the piping, a pressure increase up to 7-10 bar/min is acceptable. Intermediate steps at 35%, 50%, 80% and 95% of the test pressure for leak visual checks shall be performed, and a hold period of 10 minutes shall be respected for each step. Pressure increase from 95% to 100% of the test pressure shall be performed decreasing the rate down to 1 bar per minute.

10- A stabilization period of 10 minutes shall be allowed for conformation of temperature and pressure stabilization before the test hold period begins.

11- When pressuring any test system, continuous attendance and supervision must be maintained at the test pump and pressure gauges shall be monitored at all times during the test by a QC engineer.

12- The test pressure shall be held for a minimum of 6 hours (test holding time). If, due to residual trapped air the pressure drops under the minimum required during the hold time it will be brought up and, after a new stabilization, the hold period we be reinitiated.

13- Mechanical connector shall be visually inspected for leaks during the pressure test.

14- Pressure and temperature shall be recorded during pressurization, stabilization and hold periods. Temperatures and pressure shall be recorded by a PT transducer/recorder. Pressure and temperature shall be recorded every 10 minutes during the stabilization and hold periods.

15- After satisfactory completion of the pressure test, the authority's representative shall witness the gradual release of pressure in a steady and controlled manner.

16- Open valves on hub A for gradual pressure release.

3rd Rigid Spool connector tubing pressure test.

Tubing Hydro- tests are carried out when weather conditions are stable and no sensible fluctuation of temperature is envisaged throughout the hold period. They are carried out to confirm the integrity of the spool tubing lines to perform their job under the designed pressures [tests here are 1.1 or 1.5 times their working pressure]. The S.I.T Tubing hydro-test for a simple subsea rigid spool as featured here would test items 1,3 and 4 as shown in Figure 7 (BUR/PRJ/008/2011) .

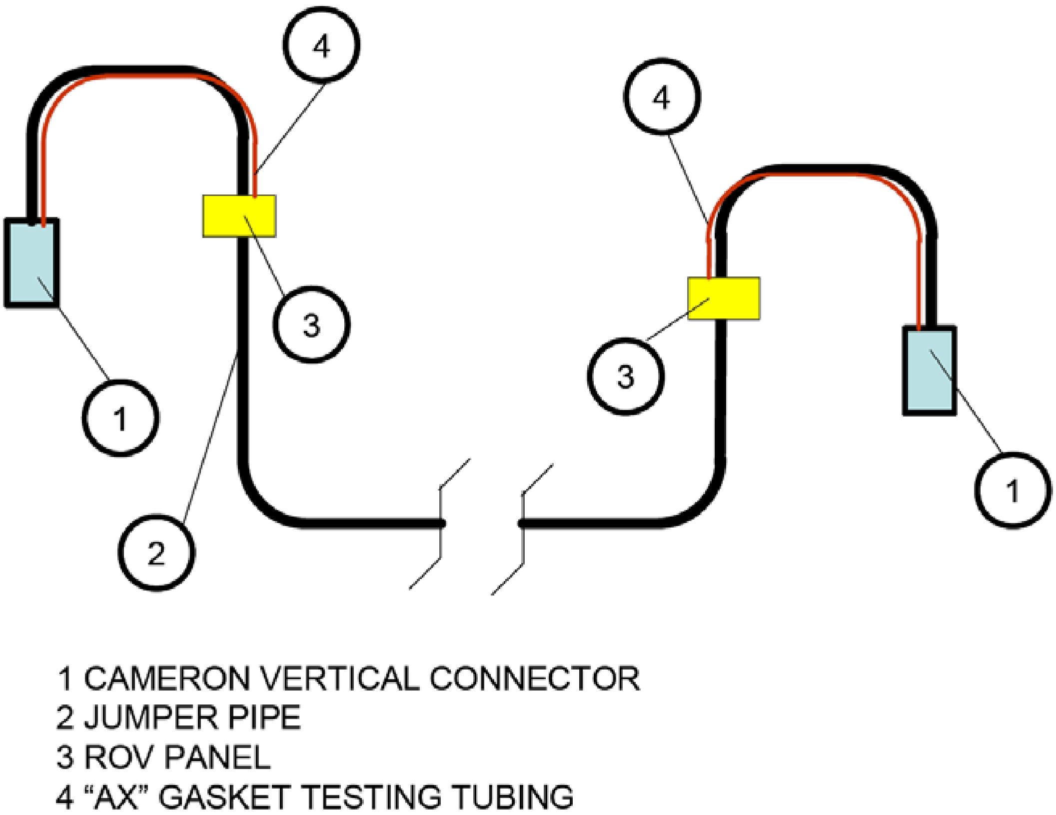


Figure 7: Simple Subsea Rigid Spool

Step 1: Initial Status

- Hydro-testing equipment set up and tested.
- PRV and check valve are installed, PRV is set at relevant bar.
- Tubing connected to CVC.

- Instrumentation and injection hose have been connected.
- Dummy stab removed and hot stab installed
- Flushing satisfactorily completed.

Step 2: Start hydro-test

- Connect hydro-test pump to hot stab.
- Start pressurization 0 bar to 35% of Test Pressure.
- Commence pressurization of the tubing to 35% of test pressure with controlled rate.
- Hold for 5 minutes and inspect for leak.
- Then restart pressurization from 35% to 50% Test Pressure, hold for 5 min. and inspect for any leak or pressure drop.
- Do the same as the last step for 50% to 80% Test Pressure, wait for 5 min. And inspect, then go to 95% of test pressure and also wait to see if all is well.
- Then go to 100% of the test pressure and after stabilization (wait for 5 min and inspect for leaks) start a 15 min test at 104 bar; a drop of up to 3% is acceptable .
- If test passes and is accepted then bleed down the pressure [but the ROV panel and tubing are left filled with test fluid].
- Take the hot stab out and put the dummy back in.

The test medium used is TRANSAQUA [a water based hydraulic fluid].

4th De-watering of the Rigid Spool.

This final step in the SIT will be carried out via a suction line fitted in from the high-end connection, and via suction pump the test medium fluid will be removed from the rigid spool, after which the rigid spool will be placed in the horizontal position [a support frame will be built to support the subsea rigid spool] and it will be ready to be transported to the port key side.

2.4 Transportation and Logistics

After the completion of the rigid spool. S.I.T at its fabrication facility, the second step is the transportation and the logistic activity associated with moving the rigid spool from its fabrication and test facility to the offshore location (BUR/PRJ/003/2010) over its field were it is submerged and installed in place connecting the two specific subsea assets it is built for, and to accomplish this there are two sub-steps as follows:

1st : The transportation operations via land to port:

After the SIT is done and the subsea rigged spool is ready, the next step is the safe transport of the spool via land and sea to its offshore field where it is to be installed. The challenges and risks here can be summarized as:-

Step 1: Dewatering the spool body and placement in horizontal position:

Dewatering the hydraulic test medium is the 1st operation carried out in preparation to safely move the rigged spool where we:-

- Bring, inspect and connect all involved equipment such as the suction pump, suction tank , all rated houses and fittings , and a containment system should a leak happen ..etc.

- MSDS present for the test fluid, job procedure present and all personnel involved in the dewatering operation present for a tool box talk to review the tasks for each individual.

- All related work and safety permits filled out.

Step 2: Lifting the subsea rigged spool from the vertical position (after dewatering operation is carried out) and placing and securing it in a transport frame in the horizontal position.

- All equipment involved in this operation (cranes, forklifts, rigging equipment...etc) must be inspected, certified and all must be working within their safe handling loads with a proper safety factor added.

- All procedures (especially the support structural design plans, drawings and metal support work) and work permits must be present and reviewed by the engineer in charge on site and must be understood by all personnel taking part in the job.

- The sequence of the operation needs to be understood by all especially during critical jobs such as during the lift, or during the supports welding operations when only essential personnel must be present.

Step 3: Rigid Spool road gurney management operations:

In this final step to move the rigged spool from its SIT location to the sea port, after the rigged spool has been dewatered and secured to a transportation frame in the horizontal position, the following steps will be taken:

- The road route needs to be mapped, studied and confirmed so that no rigid structural objects [bridges, electrical posts, trees ..etc] can become an obstacle in the way, and alternative routes are to be planned if necessary .

- All local authorities need to be informed and approval from them must be granted to proceed (local police, electrical company, city or town officials ,..etc) and in most cases the police need to escort the spool convey and even give approved times and dates for the move (in most cases the spool is a wide transport item that requires stopping traffic on 2 way roads.

- An operation meeting must be carried out with all involved parties, to review procedures, permits and the game plan, and there must be good communication at all times. ….

Example of logistics and land transportation operations as in Figure 8 (By Hassan Elfeki).

Figure 8 Land Transportation of Rigged Spool

2nd The transportation operations offshore to subsea field location:

At this point after the rigged spool has been successfully transported to the seaport we start the next phase which is the transportation of the rigged spool via sea vessel (boat or barge) to its offshore field location for deployment and installation. We follow the following steps:

Step 1: The spool to be re-oriented to the vertical position and secured on its support frame along with its lifting spreader beam and filled with its deployment fluid:

- All equipment (cranes, forklifts, rigging equipment..etc) inspected and certified and checked for being within safe load capacity.

- All procedures (especially lift planes) and permits are to be present and reviewed by all involved personnel.

- The spreader beam supports the entire spool during lifting and confirms the spool balance.

- The spool is then filled with its deployment fluid, after all the equipment used in this operation is inspected and certified. The deployment fluid is present with its MSDS and a contingency plan is in place should a spill occur, and all the relevant procedures and personnel involved are present.

Step 2: The spool to be secured on the barge or boat via sea designed support frame and the gurney plan to the field offshore:

- The spool to be secured on the barge or boat via sea designed support frame {strong back} and strapped down to the deck via the proper sea fasteners. All equipment used to be certified and inspected.

- The maritime specialists along with the weather experts to determine the acceptable weather timing; and sea conditions for the gurney to go to the field offshore.

- Vessels exiting the port and the planned route must be presented to all government and local authorities prior to the start of the gurney.

Example of offshore transportation on barges as in Figure 9 (by Hassan Elfeki).

Figure 9 Offshore Transportation Of The Rigged Spool.

2.5 Subsea Rigid Spool Offshore Installation and Commissioning Operations

The 3rd and last step in the Rigid Spool installation and commissioning operations after the SIT have been carried out and the Spool has been transported from the SIT facility to it location offshore is to pick up, submerge the Rigid Spool and lower it to its location on the sea bed or in the glory hole in the field, install and connect it, and then commission it by a series of tests before it enters its operational service. This will take place via the following sub step:-

Step 1: Submerging the Subsea Rigid Spool and landing it in its right hubs.

- Remove pressure caps from the asset hubs, clean hubs and place a debris cap in preparation to land rigid spool.

- Pick up the rigid spool via boat or barge crane and submerge over safe handling zone, about 10 to 15 meters above the depth of the subsea assets.

- Remove the debris caps off both hubs and slowly move over the assets and land the spool down on it proper hubs.

Step 2: Connect the rigid spool via CVC running tool to the hubs, locking them to hubs and pressure testing the connectors.

- Bring down one end of the rigid spool connector to 50% of soft land, then bring down the other end 100% and lock it to its hub, Then bring the 1st side down the remaining 50% and lock it to its hub.

- Before unlatching the 2 CVC running tools, conduct a connector pressure test to confirm the integrity of the gaskets and that is to be carried out on both connectors to the designated pressures (3000 , 5000 psi , ..etc) for the required time (10 , 15 min, ..etc) .

Step 3: Unlatch the two CVC running tools from both sides and retrieve them back to the vessel .

- Hydraulically unlatch both CVC running tools and slowly lift each of them one at a time to about 10 meters over the subsea assets.

- Once in the safe handling zone retrieve back to the surface and secure on the deck of the vessel to send them back to port.

It is important to note here that this is a very simple and straightforward subsea spool [Site Integration Test]. The spool here is just an underwater pipe connection, and although such simple spools are built and used, most subsea rigid spools would be built with other accessories such as sensors, flow meters , injection ports ..etc. which would require more tests carried out in the SIT phase for each component to confirm its integrity and functionality on the subsea rigid spool.

CHAPTER 3: METHODOLOGY OF RISK ASSESSMENT AND MANAGEMENT

Hydrocarbon production from conventional oil and gas fields, whether from onshore land fields or from offshore platform installations, are facing many challenges to keep up with the global demand for hydrocarbons.

Therefore, the exploration and development of new oil and gas fields continue to move towards deeper waters offshore known as subsea fields.

Such development of oil and gas subsea fields has helped in solving the hydrocarbon growing demand issue.

As technology improves, the contribution from subsea fields will grow and the subsea oil and gas production installations will become increasingly utilized to meet the growing global demand for hydrocarbons.

These subsea production systems can range in complexity from a single satellite well with a flow line linked to a fixed platform, FPSO or an onshore installation, to several wells on a template or clustered around a manifold, which are transferred to a fixed or floating facility, or directly to an onshore installation.

Subsea production systems can be used to develop reservoirs or parts of reservoirs, which require drilling of the wells from more than one location. Deep water conditions, or even ultra-deep water conditions, can inherently dictate the development of a field by means of a subsea production system, since traditional surface facilities such as a steel-piled jacket, might be either technically unfeasible or uneconomical due to the water depth.

The development of subsea oil and gas fields requires specialized equipment. The equipment must be reliable to safeguard the environment, and make the exploitation of the subsea hydrocarbons economically feasible. The deployment of such equipment requires specialized and expensive vessels, which need to be equipped with human diving capability for relatively shallow water depths (i.e. up to a few hundred feet depth of water at maximum), and robotic diving equipment such as "ROVs" for deeper water depths.

Therefore, any requirement to repair, or intervene with, the pre-installed subsea equipment is normally a very expensive operation. This can be summarized by stating that the subsea oil and gas production systems are characterized by significant costs, technical challenges and severe consequences of failure.

3.1 Methodology of Risk Assessment and Management

An integrated and holistic risk management system is essential for the successful development, application and installation of subsea systems. For increasingly complex risk-management programs to be fully effective, insurers need consistent, qualitative, and wide-ranging information about risk (Virginia R. Prevosto 2014) . The various subsea operations require a risk assessment and risk management system that are capable of identifying and managing potential hazards, risk of underwater leaks from live wells, economic risks associated with non-productive time, costs of possible down times and unplanned events.

This study gives the decision maker in the field a tool to help him/her to assess and manage risks associated with these operations, by providing accurate risk assessments for each step in the operations. (Maryam Kalantarnia, 2009)

In this study, the main focus will be developing a risk assessment and risk management framework to address specifically the hazards associated with the commissioning, transportation, and the installation operations of a subsea rigid spool.

The framework developed can then be custom-built into a risk assessment and management system that would be handed to the safety supervisor and/or the operation engineer in charge. It is envisioned that the system would consists of a number of modules containing the following:

- Hazard Identification checklist (to identify the different scenarios that can cause each hazard).
- Hazard control checklist (to identify different control measures to prevent or mitigate each identified hazard).
- An engineered risk matrix. A risk matrix is a tool that multiplies the hazard severity by the likelihood of such hazards. It is used to help the decision maker to assess the associated risks in order to determine whether operations should proceed, proceed with caution or come to a complete stop.

- A hazard flow chart. The flow chart is used to show the identified hazards, the different scenarios for a hazard to occur, the severity of the identified hazards and the likelihood of occurrence of the identified hazards. Also it shows whether to proceed or stop operations until the risk is reduced.

3.2 Steps of the Methodology

The method adopted in this study was to apply an integrated approach using various risk perspectives.

The first step in the methodology is to lay out a detailed description of the sequence of operations for a subsea rigged spool starting the initial site integration test. This is carried out on the spool after the manufacturing phase is completed, before its final commissioning in the offshore subsea field.

The second step is to identify the hazards associated with each step of this detailed operational sequence.

The third step is to implement control means to eliminate or reduce the possibility of hazards from happening or mitigate the incident’s consequences should they occur.

In the fourth step, the likelihood of occurrence for each hazard identified is estimated. In the final step, after developing an associated Risk Matrix for the subsea rigid spool of interest, a hazard flow chart is constructed.

3.2.1 Description of Operational Sequence

After the Rigid Spool has been completely built, there are 3 main operational processes. They are carried out before the spool is installed at the final spot in its subsea field. These three processes are as follows:

- Step 1- Site Integration Test (S.I.T.)
- Step 2 - Spool Logistics and Transportation from test sites to the Offshore Field
- Step 3 - Spool Installation and Commissioning Operations

Each step was explained in detail in Chapter 2.

3.2.2 Identifying the Hazards in Each Operational Step

A Hazard is defined as "a condition, event, or circumstance that could lead to or contribute to an unplanned or undesirable event." [Principles of Risk-Based Decision Making]. Seldom does a single hazard cause an accident. More often, an accident occurs as the result of a sequence of causes. A hazard analysis will consider the state of the system; for example, the operating environment, as well as failures or malfunctions.

From the above definition, the possible hazards of each operational step and the associated possible scenarios are identified.

Identified Hazards in Step 1 Site Integration Test:

1. Equipment Unavailability

Such a hazard will have crippling effects on the operation and will cause costly delays. The scenarios for this hazard are:

- Wrong equipment ordered for the job.
- Equipment does not meet location specific technical requirements such as available power rating.
- Equipment held at customs due to improper customs papers.
- Equipment unavailability due to late delivery.

2. Rigid Spool Lifting Incident during Vertical Positioning:

Before the spool body and piping pressure tests start, the spool needs to be filled with the testing medium, water or MEG. In this process it needs to be moved into the vertical position from its horizontal position. During this move, there is a risk of a lifting incident happening, which could be caused by one of the following scenarios:

- Lift failure due to crane machine failure.
- Lift failure due to incorrect, or absence of, a lift plan.
- Lift failure due to human error.
- Lift failure due to unknown weights (underestimation of the weight).
- Lift failure due to failed rigging equipment.

3. Over Pressuring Spool Body during Hydro-test:

During a pressure test, there is always the risk of over pressuring which could lead to devastating consequences.

A number of scenarios could lead to this:

- Equipment pressure control system failure.
- Human error applying the wrong pressure.

Identified Hazards in Step 2 Spool Logistics and Transportation from test sites to the Offshore Field:

The transportation and the logistic activity, associated with moving the rigid spool from its fabrication and test facility to its offshore field location, is accompanied with a number of risks during its journey. These hazards are as follows:-

1. Hazards during preparation for the transportation via road:-
    - A spill during the dewatering operations.
    - A lifting incident during horizontal positioning.
    - Road accident during transportation to port.
2. Hazards during preparing rigid spool in port to be loaded on vessel:-
    - Lifting Incident during vertical positioning.
    - Spill during filling spool with submerging fluid.
    - Lifting Incident during positioning on the vessel.
3. Hazards during the offshore journey to subsea field:-
    - Rigid spool tipping to the side due to improper tie down to deck.
    - Rigid spool tipping down or hit by other object due to bad weather during the trip to the field.

Hazards Identified during Step 3 Spool Installation and Commissioning Operations:

This is the final step, where the subsea rigid spool reaches its offshore location. It is picked up to be submerged at its final location on the sea bed or in the glory hole in the field. It is then installed and commissioned by a series of tests before it enters its operational life. During these operations a number of risks and hazards are identified as follows:

1. Hazards identified in the pre-spool deployment phase.
   - Damage to Subsea assets during removal of CVC cap due to:

     1. Trapped pressure in lines.

     2. Lifting incident due to crane heave compensator failure.
   - Dropped objects on subsea assets during lowering or raising operations.
   - Undetected damage on CVC hub surface.

2. Hazards identified in the spool deployment phase.
   - Damage to spool while lifting from vessel by falling or striking other fixed objects or equipment.
   - Damage to spool while trying to submerge.

3. Hazards identified during the phase of landing, locking and commissioning the subsea spool.
   - Dropping the spool or any of its accessories.

- Damage by striking any of the subsea assets while landing.
- Damage to spool while making connection.
- Dropping the CVC tools or any of the accessories on the subsea assets while retrieving them back to surface.

From the above, a number of potential hazards have been identified at each operational step. The development of hazard identification checklists can be made for each of the identified potential hazards. These hazards checklists state the various factors that would contribute to increasing the likelihood of an incident occurring.

The following (Figure 10) and (Figure 11) are two examples for a hazard checklist. The first is for the factors that enhance the potential of a lifting incident/hazard. The second is for the factors that enhance the potential of an uncontrolled pressure release incident/hazard. These checklists are filled out by the safety engineer or operation engineer before starting the job.

Factors Regarding the Load:	**YES**	**NO**
● Is this lift considered a heavy lift (the load weight >10 tons)?	☐	☐
● Are the physical features of the load uneven (Uneven in shape or in weight distribution)?	☐	☐
● Does this load contain any radioactive substance?	☐	☐
● Does this load contain any stored fluid?	☐	☐
● Does this load contain any stored fluid under pressure?	☐	☐
Factors regarding the lift operation:		
● Is there a lift plan present?	☐	☐
● Are the crane and rigging rated for lift?	☐	☐
● Are all lifting rigging and the crane certified?	☐	☐
● Are there any new/inexperienced personnel involved in the lift?	☐	☐
● Is it confirmed that NO loose items are on the load before starting the lift?	☐	☐
● Has there been a safety meeting regarding the lift task so that all workers involved know their role and are well informed of the process?	☐	☐
● Will the lift pass over or near other assets?	☐	☐
● Is there other conflicting operation near or around the area of the lift?	☐	☐

Figure 10 A Lifting Incident/Hazard Check List

Factors Regarding the Pressure Testing Equipment:	**YES**	**NO**
● Is the pressure test conducted in a test pit or test chamber?	☐	☐
● Is the pressure test medium water? If not, specify…	☐	☐
● Is this test considered a high pressure test? (Pressure exceeds 3000 PSI)	☐	☐
● Are all pressure control valves and equipment in the testing unit redundant?	☐	☐
● Does this pressure test require a big volume of test medium (if liquid), does it exceed 10 litres?	☐	☐
● Is there a fluid containment system built in should fluid be released or a leak occur during the pressure test?	☐	☐
Factors Regarding the Pressure Test Operations:		
● Is this pressure test carried out subsea?	☐	☐
● Is all the equipment involved in this pressure test inspected and certified?	☐	☐
● Is there any other conflicting operation near or around the pressure test area?	☐	☐
● Are there any new/ inexperienced personnel involved in the testing operations?	☐	☐
● Are there clear pressure testing work procedures to follow?	☐	☐
● Are all pressure testing permits filled out and submitted?	☐	☐
● Are there any other conflicting operations near or around the pressure test area?	☐	☐

Figure 11 An Uncontrolled Pressure Release Check List

3.2.3 Identifying the likelihood of occurrences for the risks and hazards associated with all three operational phases in the case study:

In the context of hazard identification, risk assessment and loss prevention, the term "likelihood of occurrence" gains its most importance. This is because it is a decisive factor in the mitigation process. Knowing the probability or likelihood of occurrence of a certain hazard will determine how to address it.

In this study we use an integrated approach in which a number of methods are combined to determine the likelihood of occurrence for each anticipated hazard. These methods are as follows:

- Judgments made by expert groups and people with special competence. Their judgments of the likelihood of a matter are based on former experience of such operations.
- Observational data (facts) from statistical historical records for incidents occurring during similar operations.
- Perceived risk information on certain equipment used; for example, the probability of a crane failure due to hydraulic failure or human error. Also, how that probability would change when the crane's life nears its maximum capacity. The same goes for equipment such as the hydraulic pressure unite. The manufacturer will have information on the reliability of the equipment, the probability of failure, and "factors affecting" such probability.

The following are examples of implementing such tools to determine the likelihood of occurrence of a number of possible hazards, associated with the three spool operational phases of this study.

Likelihood of occurrence for a hazard in step 1 [site integration test]:

For example, the likelihood of occurrence for over pressuring the spool body during the hydro-test can be determined at a particular spool at a particular site by the following:-

- A technical review of the hydraulic pressure unit used to pressure the spool body. The manufacturers recommendations in terms of reliability of the system components and weather tests are needed on the testing unit. As a result, we can estimate the likelihood of equipment failure leading to over pressuring the spool body.
- Groups of experts or people with experience to evaluate the site and the technicians carrying out the job, using their experience to determine the likelihood of a human error leading to over pressuring the spool body.
- Reviewing actual cases of spool body over pressuring that took place in the most recent period spectrum [5 years as an example] compared to the total number of similar operations carried out.

According to the above methods, we can come up with estimated likelihood of occurrence value for over pressuring a rigid spool, during a spool body hydro- test at a certain location.

Likelihood of occurrence for a hazard in step 2 Spool Logistics and Transportation from test sites to the Offshore Field:

The example is the likelihood of occurrence for a road accident during the transportation of the spool from the SIT site to the seaport, and this would be determined as follows:-

- Groups of experts or people with experience to evaluate different routes and conditions from site to port, and the likelihood of accidents due to striking fixed or moving objects.
- A revision to the actual cases of road accidents for a wide load while moving the rigid spool over a certain period of time, as well as the statistical times of these accidents [day , night], and [summer , winter].
- A review of the accident history of the transport company, by tracking both the driver's driving history and the company's fleet accident history.

From the above methods we can come up with estimated likelihood of occurrence value for a road accident involving the transportation of a rigid spool from a certain S.I.T location to the seaport .

Likelihood of occurrence for a hazard in step 3 Spool Installation and Commissioning Operations:

The example is the likelihood of occurrence for an incident of a rigid spool striking any of the other subsea assets while landing the spool in the designated place , which could occur due to a number of scenarios as follows :-

- Technical review of the vessel crane heave compensator and loading cells malfunction probability, and the vessel dynamic positioning DP system and its probability of a malfunction during operations.
- Experts groups or people with experience to evaluate the subsea field layout and the initial work procedures to determine the likelihood of the spool striking another subsea asset.
- A revision of similar incidents where subsea assets collided subsea during the installation phase.

Using the tools stated above, the implementation of probability theory as a common technique and to avoid mathematical complexity in the analytical methods of probability theory ,the Monte Carlo simulation is also a preferable method to use to address uncertainties due to randomness in the estimates of input parameters (events probability) Hammonds et al., 1994.

An assessment is carried out to determine the likelihood of occurrence associated with different events during the different operations carried out on the subsea rigged spool where the following likelihood of occurrences was conceived :-

1:- happens once in every 10 operations. 0.1.

2:- happens once in every 100 operations. 0.01.

3:- happens once in every 1000 operations. 0.001.

4:- happens once in every 10000 operations. 0.0001.

5:- happens once in more than 10000 operations > 0.0001.

To aid the field supervisors and the decision makers in the field in determining the likelihood of occurrence of the different hazard scenarios in different operational conditions an engineered likelihood of occurrence checklist is created for different hazards and for different operational conditions to guide the decision maker in determining the accurate likelihood rank for each case. Such likelihood of occurrence checklists can be created for :-

- Different lifting hazards scenarios.
- Different transportation hazards scenarios.
- Different pressure release hazard scenarios.
- …etc.

Please see (Table 1) as an example of a likelihood of lifting incident hazard occurrence checklist.

The colors in table 1 refer to:

Green: It's safe to proceed with operation.

Light Green: It's safe to proceed with operations with caution.

Yellow: Take caution before you proceed with operations.

Orange: Operation need to be stopped to lower risk levels.

Red: Operations need to come to an immediate stop to address the high risk issue.

Likelihood of Occurrence of a Lifting Incident during Lifting Operations	Scenario	1	3	5	7	10
	Lift is 0 – 60% of crane safe work capacity or rigging capacity.	X				
	Lift is 60 – 90% of crane safe work capacity or rigging capacity.		X			
	Lift is 90 – 110% of crane safe work capacity or rigging capacity.			X		
	Crane and/or rigging are not certified while lifting a load 0 – 60% of crane safe work capacity.		X			
	Crane and/or rigging have no up to date certification while lifting a load 60 – 90% of crane safe work capacity.			X		
	Crane and/or rigging have no-up-to date certification while lifting a load 90 – 110% of safe work capacity.				X	
	If two unsafe conditions such as [No Lift Plan , Uneven lift , No certification for crane or rigging , inexperienced crane operator or personnel ..etc] occurred during the same single lift and if :- The load is 0 – 60% of crane safe work and/or rigging safe capacity.			X		
	The load is 60 – 90% of crane safe work and/or rigging safe capacity.				X	
	The load is 90 – 110% of crane safe work and/or rigging safe capacity.					X
	If crane is on an offshore vessel and current sea waves are above 3m or wind above 40 knots while: The lifts are 0 – 60% of crane safe work or rigging safe work capacity.		X			
	The lifts are 60 – 90% of crane safe work or rigging safe work capacity.			X		
	The lifts are 90 – 110% of crane safe work or rigging safe work capacity.				X	

Table 1 Likelihood Of Lifting Incident & Hazard Occurrence Check List.

3.2.4 Consequence Assessments

Consequence assessments are carried out to identify the effects of an aftermath of a particular incident and therefore they show the result of harm or damage that would come about in case a particular hazard happens. The importance of hazard consequence assessments comes from the fact that by understanding what's at stake should a particular hazard happen one can develop better risk mitigation strategies.

To determine the consequences of the occurrence of a particular hazard, the following information is needed:

- Cost information for all elements involved in each operation such as equipment costs , labor costs , site costs , equipment rental costs, etc.
- Cost information for fines for delays, downtime, etc.
- Cost of possible environmental damage, associated legal costs, cost of lost production, worker compensation costs, etc.
- The history of similar incidents that happened due to similar hazards and the total losses from such incidents.

Using the sum of the above different methods the following are a number of examples of implementing such tools to determine the consequences resulting from a number of possible hazards associated with the three spool operational phases of this study.

The consequences of a hazard occurrence in Step 1 Site Integration Test:

Examples of the potential consequences a lifting incident involving a rigid spool during the SIT phase using the methods stated above are the following:-

- The complete loss of the spool itself (which could cost anywhere from a few hundred thousand USD to a few million USD).
- Damage to the crane (which could result in the cost of thousands of USD).
- Damage to other assets close by that might be struck (which could costs thousands of dollars).
- The cost of down time of operations due to a damaged spool (workers' pay , site fees , rental equipment cost, ..etc).

From the above example it's clear how this hazard results in heavy financial consequences, and that is without taking into account the consequences in terms of workers getting injured or killed.

The consequences of a hazard occurrence in Step 2 Spool Logistics and Transportation from test sites to the Offshore Field:

In this phase the example also studies the consequences of a lifting incident of a rigid spool but during the spool loading on the vessel where the consequences could result in a far greater loss, as follows:-

- The complete loss of the spool itself (which could cost anywhere from a few hundred thousand USD to a few million USD).
- Damage to vessel, its crane or other assets (could be in terms of hundreds of thousands of USD).
- Down time of the vessel which could reach up to a few hundred thousand USD per day.
- Down time for the project as a whole and the delay to reopen the subsea oil field which could be up from hundreds of thousands to a few million USD per day.

Like the previous example, this consequence estimation does not take into account the consequences of workers getting injured or killed.

The consequences of a hazard occurrence in Step 3 Spool Installation and Commissioning Operations:

This is the most critical and dangerous phase of the operation. In this phase a number of operations are done above subsea oil fields and an incident here can be catastrophic, In the case of the rigid spool striking another subsea asset during installation, the following consequences may occur:-

- Damage to the subsea spool and other already installed subsea assets [the costs would in millions of USD].
- The possibility of a subsea oil spill as a result from the spool striking another subsea asset [the costs here would be overwhelming and could run into tens or even hundreds of millions of USD].
- Best case scenario: No spill, but the costs to test and confirm equipment integrity would cause a delay that could stretch to a few days or even weeks, causing losses that could reach millions of USD.

The above consequence assessment studies give us a better understanding of what's at stake , so using the tools listed above to carry out an assessment to determine the severity of the consequences associated with a subsea rigid spool operation, the following severity levels were conceived :-

1:- An event that would result in equipment's extreme damage [while offshore] and would cause complete offshore operational shutdown for a considerably long period of time, with estimated financial losses per day exceeding $1,000,000 USD.

2:- An event that would result in equipment's partial damage [while offshore] and would cause partial or complete offshore operational shutdown for a short period of time ,with an estimated financial loss per day between $ 500,000 and $ 1,000,000 USD .

3:- An event that would result in equipment damage [while onshore] causing facility operational shutdown for a considerably long period of time and would directly have a negative effect on offshore operations work schedules resulting in down time, with estimated financial losses per day between $ 100,000 and $ 500,000 USD .

4:- An event that would result in equipment damage [while onshore] causing facility shutdown but with little to no effect on the offshore operations with an estimated financial loss per day of between $ 10,000 and $ 100,000 USD .

5:- An event that would result in equipment partial damage [while onshore] causing operational delays but with no effect on the offshore operations, with an estimated financial loss per day to be less than $ 10,000 USD.

3.2.5 An Engineered Risk Matrix for the study.

As safety is more than observations alone, it was necessary to see behind the data and incorporate additional aspects related to risk perception. To have the full risk picture established in a comprehensive way. A broad perspective is required, therefor the following are needed:

- Risk analysis descriptions
- Observational data (facts)
- Judgments made by people with special competence
- Perceived risk information
- Expert groups

This can be summarized in three categories of data which provide different types of information that we can use:

- Losses expressed
- Hazardous situations expressed
- Events and conditions on a more detailed level reflecting technical organizational and operational factors leading to hazards

In this study we used all the above to build a Risk Matrix for the risk assessments and risk management associated with commissioning, transportation, and installation operations of the subsea rigid spool.

The risk matrix has two main axes: hazard severity (an assessment based on the consequences), and the likelihood of such hazards to happen (likelihood of occurrence).

By using the above two factors we create a risk matrix which is a tool made to aid the decision maker during the execution of the different phases of the Subsea Spool commissioning and installations operations.

See the Risk Matrix diagram in Table 2.

Risk Matrix			Likelihood of Occurrence				
			Very Unlikely	Unlikely	Low Possibility	Possible	Probable
			1	**3**	**5**	**7**	**10**
Hazard Severity	Equipment's extreme damage [while offshore] causing complete offshore operational shut down for a considerably long period of time.	**10**					
	Equipment's partial damage [while offshore] and causing partial or complete offshore operational shutdown for a short period of time.	**7**					
	Equipment's damage [while onshore] causing facility operational shutdown for a considerably long period of time and directly negatively affecting offshore operations work schedules resulting in down time.	**5**					
	Equipment's damage [while onshore] causing facility shutdown but with little to no effect on the offshore operations.	**3**					
	Equipment's partial damage [while onshore] causing operational delays but with no effect on the offshore operations.	**1**					

Table 2 Risk Matrix

As per above Risk Matrix :-

If our operation is in the Red Zone then an immediate complete stop of the operation is necessary to re-evaluate and reduce the risks because current risks are unacceptable and need immediate resolution to reduce the level of risk.

If our operation is in the Yellow Zone then we can proceed with caution while working on reducing the risks.

If our operation is in the Green Zone then we may proceed with normal operations.

3.3 Control Tools Used to Prevent and/or Mitigate Hazards

Should the field supervisor or field safety engineer, after using the study here, find that the risk matrix ranking for his upcoming operation is in the Red Zone; then an immediate complete stop to the operation is necessary. Risks must be re-evaluated and reduced when current risk levels are unacceptable and need immediate resolution to reduce the level of risk. Such reduction is done in one of two ways. The first is to reduce the likelihood of occurrence of the hazard, and the second way is to attempt to reduce the severity of the consequences should an incident occur. In the study here, an engineered checklist is developed to be used as a control tool to prevent and /or mitigate the hazard. Such lists are developed for the different hazards and are created by using the expertise and judgment calls made by expert groups and people with special competence. These experts judge of the likelihood of a matter based on former experience with such operations, and they also give out means and steps which must be taken to reduce the probability of occurrence of such hazardous incidents.

See (Figure 12) and (Figure 13) as examples of such checklists.

Control Tools:	**USED**
● An approved work procedure present before starting the job	☐
● Effective communications and permit to work in place, clear escape routes, and good housekeeping	☐
● Pre-operation meeting held with senior engineer or experienced technician in charge	☐
● MSDS present for the test medium used in the pressure test (if applicable)	☐
● Emergency response plans in place should an incident occur	☐
● Barricade the test zone with barriers and signs	☐
● Assurance that all testing equipment (hoses, fittings, pumps, etc.) are certified and suitable for the rated pressure testing	☐

Figure 12 Control Means To Reduce Potential Pressure Release Checklist

Control Tools:	**USED**
● An Engineered lift plan in place.	☐
● An MSDS is present for all fluids in items being lifted.	☐
● Full certification for all lifting rigging used in the lift.	☐
● Pre-operation meeting held with experienced lead personnel in charge.	☐
● Final check carried out to ensure there are no missing or unfastened items before lift.	☐
● Weather conditions, time of day and mental and physical conditions of workers involved taken into account.	☐
● Emergency response planes in place should an incident occur	☐
● Is there a need to complete any extra work permits (working at heights, handling hazardous materials, etc	☐

Figure 13 Control Means to Reduce Potential Lifting Hazard Checklist

3.4 Risk Assessment Flow Chart

A risk assessment flow chart is developed to aid the field safety engineer or field supervisor to determine whether risk levels are acceptable or not. The chart is filled out using the data utilized from the lists and tables that have been described above. For each hazard the safety engineer or person in charge would be reviewing:

- Hazard likelihood checklist.
- Risk Matrix Table.
- Hazard prevention and/or mitigation checklist.

If the risk flow chart is initially completed and, if the risk matrix rank is acceptable, then it's safe to proceed to the next step of the operations. If the matrix is not at an acceptable level, then steps will be made to reduce the likelihood that an incident will occur, or the consequences of the incident, should it occur, or reduce both according to the circumstances of each case. An example is shown in Figure 14.

Risk Assessment Flow Chart

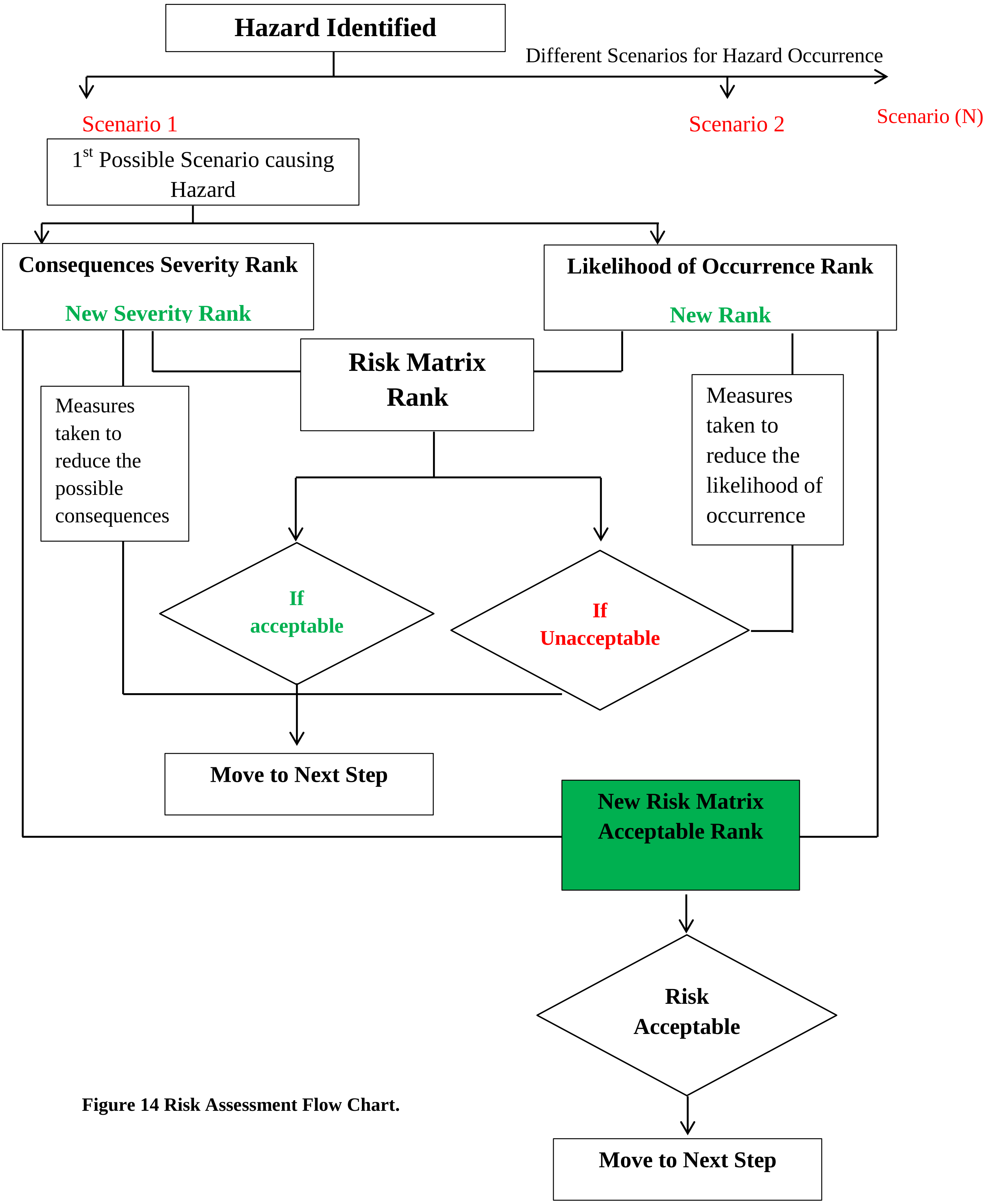


Figure 14 Risk Assessment Flow Chart.

3.5 Summary

The proposed study develops an integrated approach to identify and manage the risks, during the execution of the different operational phases carried out on the subsea rigid spool. The operational phases are from the point the subsea spool is completely fabricated to the final operation steps, when it is installed and commissioned in its subsea slot in its designated subsea field offshore.

The final product of this study will be an uncompleted risk flow chart and a risk matrix table, along with a set of checklists custom built for the operations carried out by the subsea rigid spool. These documents will be handed over to the safety engineer in the field and/or the operational supervisor in charge of the operation. The documents will enable them to have a better understanding of the actual risk level the operation faces and give them the tools to reduce such risks, if they are at an unacceptable level.

CHAPTER 4: IMPLEMENTATION OF THE PROPOSED METHODOLOGY IN A CASE STUDY

The implementation of the proposed study to develop a risk assessment and risk management system will be applied to a case study presented in this chapter. Risk assessment and risk management systems will be used to address the risks associated with the different operational phases of the subsea rigid spool.

The identification and assessment of risks will be followed by a feasible approach to minimize and control the probability and/or impact of any unfortunate events, in addition to the ability to prevent such unfortunate events from occurring and to have a mitigation plan should they happen.

The risks of unfortunate events happening during the subsea spool life cycle are always present, starting from the spool's site integration tests, to the transportation to its offshore field along with all related logistics operations involved , to the final submerging and installation process of the spool subsea in its position in the subsea field offshore. Such risks and unfortunate events can vary with accidents either due to equipment failure, human error, design errors or as a result of disasters created by natural causes, such as extreme weather conditions or legal liabilities, as well as events of uncertain or unpredictable causes.

4.1 Application of Thesis on Subsea Rigid Spool Operations.

The overall objective of the research is to address the hazards facing the different stages of Subsea assets operations from the site integration phase till the final installation in their subsea fields offshore and to develop a risk assessment and risk management approach that can be utilized specifically for subsea assets, where the specific focus is on Subsea Rigid Spool operations.

After the methodology was explored in chapter 3, in this chapter the application of this study will be demonstrated on a particular hazard in one of the operations of the subsea rigid spool and show by implementing such techniques the improvement made to the risk assessment and risk management of our operation to reduce the possibility of an incident from happening and to have mitigation measures in place to address such events should they happen, by knowing the potential consequences regarding their magnitude and affect should they happen.

To give a better idea of how this study would significantly reduce the probability of incidents occurring and its impacts on reducing the negative effects should an undesirable incident occur with more information about the realistic consequences of the existing risks and having a mitigation plan in place, below is a demonstration of an actual accident that occurred with a subsea rigid spool while in the SIT phase in Newfoundland –Canada in the year 2010, the consequences this incident had , and how the application of this study in such operations would improve the overall risk assessment and risk management process .

4.2 Case study of a lifting accident involving a Subsea Rigid Spool at a Fabrication Facility on July 19, 2010

4.2.1 Incident Summary:

On July 19, 2010, a crane commenced lifting a subsea spool (CP3). Please see the attached diagram of the spool. (Figure 15) Husky Investigation Report 2010 .

The lift was from its testing location on fabrication stands at a fabrication facility to another location on transportation stands at the same fabrication facility for additional work when the crane tipped onto its right side dropping the spool. The crane tipped over completely. Please see (Figure 16) By Hassan Elfeki.

The subsea spool contained a Multi-Phase Flow Meter (MPFM) and its 1.11 GBq C-137 radioactive source. Please see (Figure 17) By Hassan Elfeki.

Department of Occupational Health & Safety investigators have conducted an investigation in the incident.

This incident had the potential to result in serious personal injury or fatality to the crane operator and other workers in the immediate vicinity of the crane and its boom. This incident also had potential to have more environmental impact if more hydraulic fluid and/or fuel had been spilled on the ground.

This incident had potential to destroy the rigid spool, running tool and the MPFM. If the MPFM had been damaged this could have led to the C-137 – 1.11GBq radioactive source housing being compromised resulting in radiation exposure.

If the impact of this incident had been greater, there would have been more local and regional media coverage, [Husky Investigation Report 2010]* .

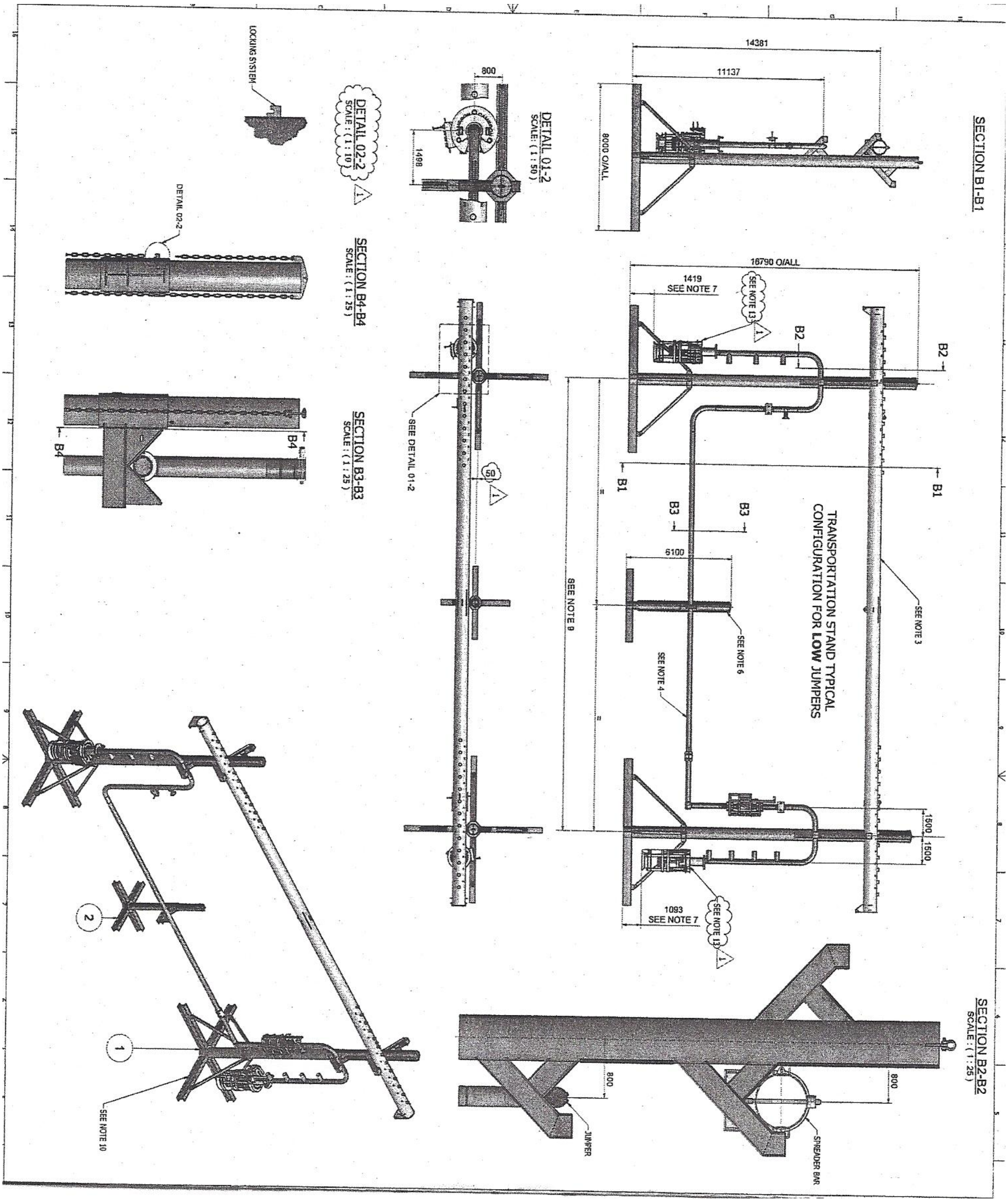


Figure 15 Spool Diagram

Figure 16 Tipped Over Crane

Figure 17 Tipped Over Rigged Spool

An investigation report was launched to determine the root cause of the incident. On July 19, 2010.The scope of this incident investigation stated that: During lifting of the spool, the crane tipped over, resulting in property damage and multiple high potential near misses.

4.2.2 Incident Investigation Overview:

The investigation into the incident was conducted by assembling a team of qualified personnel to confirm the root cause of the incident and provide recommendations to prevent re-occurrence.

4.2.3 Incident Description:

At approximately 1557hrs NST on July 19, 2010, a 170 ton crane commenced lifting a subsea spool (CP3) from its testing location on fabrication stands at a fabrication facility to another location on transportation stands at the fabrication facility for additional work when the crane tipped onto its right side dropping the spool. The crane tipped over completely. The subsea spool contained a Multi-Phase Flow Meter (MPFM) 1687.08 with its 1.11 GBq C-137 radioactive component.

On July 15, 2010, DCH Crane Rentals (DCH) was contacted by the fabrication facility to complete a lift of the subsea spool (CP3) which the fabrication facility was contracted by the oil company to fabricate. The spool was engineered by a 3rd party engineering firm. The lift was originally planned to occur on the afternoon of July 16, 2010, but because of crane unavailability the lift was rescheduled to July 17, 2010.

Prior to the July 17, 2010 lift, the HSE Advisor from the fabrication facility developed a job safety analysis (JSA) and presented it to all those involved with the lift on the morning of July 17, 2010. The lift was unable to be completed on that day as a bolt on one of the Cameron supplied running tools [CVC tool] had sheared off two times before it was determined that the cause of the shearing was due to not having the required funnel guide on the running tool. The oil company representative and the 3rd party engineering firm observer decided to halt operations for the day and continue the lift on Monday, July 19, 2010. The crane remained on site.

Sometime during the morning of July 19, 2010, there was an informal toolbox talk by the lift foreman. All those who would be involved in the lift were present except for one fabrication facility employee who was added to the job scope just prior to the final lift. Just after 1330 hrs NST the crane operator, having discussed the lift with the lift foreman, did a dry run of the final lift with no load. The crane operator was told that the weight of the entire lift would be “just over 40,000lbs”. He cannot remember who told him this. He decided to use 41,000lbs as his value for determining load capacity on his charts. It is now known that the actual weight of the lift was 42,316.45lbs.

The first lift was completed, which consisted of lifting CP3 off the fabrication stands, moving it approximately 10 to 15 feet to the operator’s left and suspending the load about 3 to 4 feet from the ground until an employee from a surveying 3rd party company had completed the survey work. The load was then returned to the fabrication stands to ensure that the rigid spool had not twisted during the lift. After confirming that no twisting had taken place by the base with which CP3 was fitted back on the fabrication stands, the crane operator was then ready to begin the final lift to the transportation stands.

Just prior to the start of the final lift, one of the transportation stands was moved from the roadway where they were originally placed to a location which would make barricading the MPFM more efficient. The crane operator did not check this new distance as he was already supporting the weight of CP3 when the move occurred. No one involved in the lift felt that this change in location would make a difference to the lift. It is now known that the original placement of the transportation stands resulted in the radius of the lift over the side of the crane to be approximately 36 feet, well within the 46 feet limit the crane operator was using. The new placement of the transportation stand placed the radius at approximately 53 feet.

To begin the lift, the lift foreman stood between the load and the crane, with his back to the crane so he could direct the tag line holders on how to respond to the movement of CP3 and also give the signal person direction on which signals to give the crane operator. After moving CP3 past the rear quadrant and into the side quadrant of the crane (approximately 25-30 degrees further than the first lift), CP3 was about three feet above the transportation spools when workers noticed that it was dropping quickly and had passed the intended target. Just prior to the workers noticing this quick lowering of the load, the crane operator felt the crane rock from side to side and was attempting to lower the load as fast as he could in an effort to prevent the crane from tipping. The signal person, who was the only person not focused on the load but rather on the crane, observed the outriggers retracting each time the crane tipped towards the load side.

The crane operator was not able to lower the load fast enough, and with the retracted outriggers, the crane tipped over with the boom landing on the running tools. The crane operator did not leave the cab of the crane until the crane had come to a stop and as a result did not sustain any physical injuries. Due to the boom landing on the running tools, the MPFM was untouched and after a survey of the area was completed by the Authorized Worker, it was determined that the source housing had not been compromised.

4.2.4 Root Cause Analysis:

The oil company has adopted the Tap-Root process for conducting formal root cause analysis. A Tap-Root analysis was performed for this event. The tools used included the Snap-Chart event tree format which recreated the sequence of events that transpired leading up to and following the incident.

The sequence of events was then analyzed to determine the causal factors leading to the identification of the root causes of the incident.

The following Table 3 details the causal factors and associated root causes pertaining to the incident:

Causal Factor #A:	No Lift Plan Used/Developed
Human Performance Difficulty	Quality Control – No Inspection – Inspection Not Required
	Communications – No Communication or Not Timely (near root cause)
	Management System – Standards, Policies or Admin. Controls (SPAC) Need Improvement – No SPAC
	Management System – SPAC Not Used – Accountability Needs Improvement
	Work Direction – Preparation – Work Package/Permit Needs Improvement

Table 3 Causal Factor #A

Causal Factor #B:	**Crane Operator did not check new distance of transportation stands after they were moved as he was already hooked up to load**
Human Performance Difficulty	Management System – SPAC Not Used – Communication of SPAC Needs Improvement
	Management System – SPAC Not Used – Enforcement Needs Improvement
	Procedures - Not Used/Not Followed (near root cause)
	Work Direction – Preparation – Work Package/Permit Needs Improvement

Table 4 Causal Factor #B

Causal Factor #C:	**Crane Computer Incorrectly confirms load at 41,000lbs.**
Equipment Difficulty	Equipment/Parts Defective weight indication – No Inspection (near root cause)

Table 5 Causal Factor #C

4.2.5 Corrective Action Recommendations:

Table 6 outlines the actions that are intended to address the root causes of the incident. It is recommended by the oil operator that consideration for each action be given and rationale be provided where actions are not amended or not completed by the recommended completion date.

Corrective Action Recommendation	Causal Factor	Root Cause
1. A Standard, Policy or Administrative Control (SPAC) to be developed for onshore lifts which includes but is not limited to: criteria for the development of a lift (or a guideline for non-critical lifts such as a checklist); quality control checks to ensure lift plan is being followed; management of change; and responsibilities and authorities for onshore lifts as they pertain to development and execution of the plan.	No lift plan used/ developed	• Quality Control - No Inspection – Inspection Not Required • Communications – No Communication or Not Timely (near root cause) • Management System – SPAC Needs Improvement – No SPAC • Management System – SPAC Not Used – Accountability Needs Improvement • Work Direction – Preparation - Work Package/Permit Needs Improvement
	Crane Operator did not check new distance of transportation stands after they were moved as he was already hooked up to load	• Procedures – Not Used/Not Followed (near root cause) • Work Direction – Preparation – Work Package/Permit Needs Improvement
2. Specific accountabilities, expectations and chain of authority for onshore fabrication and fabrication …(cont.) management are	No lift plan used/developed	• Communications – No Communications or Not Timely • Management System – SPAC Not Used – Accountability Needs Improvement

established prior to awarding contracts.		
3. Contracts to be awarded (or amended) on the condition that the oil company SPAC's (i.e. lift SPAC, SJA, Toolbox Talks, etc.) be followed by contractors; records maintained and made available for review when requested by the oil company.	No lift plan used/developed	• Quality Control – No Inspection - Inspection Not Required • Management System – SPAC Needs Improvement – No SPAC
	Crane Operator did not check new distance of transportation stands after they were moved as he was already hooked up to load	• Procedures – Not Used/Not Followed (near root cause)
Corrective Action Recommendation	**Causal Factor**	**Root Cause**
4. A review of the corrective actions from major stake holders (DCH, manufacturing facility , the 3rd party engineering firm and Cameron) arising from this incident and Oil company's incident investigation be conducted a. Development of required action items and communicated to stake holders.	No lift plan used/developed	• Quality Control – No Inspection – Inspection Not Required • Management System – SPAC Needs Improvement – No SPAC

<table>
<tr>
<td rowspan="2">5. A review of the recommendations as presented in section 4 of the 3rd party report from SLEIPNIR LOGISTICS Inc. found in appendix C of this report is completed and any recommendations which are not currently practiced are to be developed further into actionable items.</td>
<td>No lift plan used/developed</td>
<td>• Quality Control – No Inspection – Inspection Not Required
• Communications – No Communication or Not Timely (near root cause)
• Management System – SPAC Needs Improvement – No SPAC
• Work Direction – Preparation – Work Package/Permit Needs Improvement</td>
</tr>
<tr>
<td>Crane Computer incorrectly confirms load at 41,000lbs</td>
<td>• Equipment/Parts Defective – No Inspection (near root cause)</td>
</tr>
</table>

Table 6 Corrective Action Recommendations.

4.2.6 Lessons Learned due to Incident as per the oil company's Final Report:

- Using 3rd party expert investigators in this investigation became a valuable asset. This practice should be a consideration for all investigations.
- It is of vital importance that all responsibilities for fabrication and fabrication management are clearly defined at the onset of any project and any changes to personnel or scope be addressed immediately.
- Not all 3rd party companies use the same level of change management as the operator's oil company. The oil company specifications for this need to be communicated to all 3rd party companies.
- As the principal operator, all Husky employees must be aware that when at a contractor's site, it will often be perceived that the oil company's rep. is in charge, and as such their actions or inactions may not be questioned. Communications regarding the role that an oil company's rep. will play in the project management process must take place, including key aspects of the project that fall outside of the role of the oil company's rep.
- Any deviation to a lift, formal or informal, must be accompanied by a risk assessment with the new set of parameters causing the lift to be classified as a new lift and treated as such (i.e. if something changes, all values must be re-confirmed and the lift re-assessed).
- If is not safe to assume that a contractor who has been hired based on good reputation and a long work history will always abide by industry best practices and legislative requirements. The only means to evaluate a contractor's suitability is through a well designed and implemented contractor management system.

These are the lessons learned from this incident. Although the report has many positive points, it does not address the main issue which is a failure in the existing risk assessment system. This failure allowed such an incident to happen in the first place, and such lessons will be of less significant value, should we have different subsea equipment or different operating features. Therefore in this research, we address this by creating an optimized risk assessment and risk management system for subsea assets during the different phases of their operations, till they are commissioned in their designated subsea fields.

The core reason why such incidents occur in relatively big numbers despite the massive costly consequences when an incident occurs in most cases is not due to simple factors such as the incompetence of a contractor , or a piece of equipment failing; but rather due to the incompetence of the risk assessment and risk management systems implemented by these companies. The subsea oil and gas industry is a relatively new industry which is rapidly growing; therefore, many places where these assets are being manufactured or tested are places where other activity is usually carried out. For example, the fabrication facility in this case study is a big fabrication facility that builds steel structure elements and items for boats, barges and ports. It is not a specialized fabrication facility for subsea equipment which is custom built with unique features [shape challenges, accessories that contain radioactive substances, ..Etc.].

Therefore putting the blame on such facilities, for not being up to the safety and reliability standards of the oil company, or due to their incompetence, is not the way forward. The aim is to establish a clear guided risk assessment and risk management operations guide to aid in identifying , evaluating and managing these risks and help in the decision making process in every operational step. This would have a significant effect in reducing the likelihood of these incidents of occurring and improve the overall operational performance. In the following, this study will be applied on the same case study shown above. Also, it will be demonstrated how, by utilizing this study, similar incidents can be avoided using practical tools and calculated measures .

4.3 Applying the Research to Case Study Operation

At this point, we shall demonstrate the improvement and added value to subsea operational integrity that this study would add if the risk assessment and risk management system are implemented in such operations. This study will be applied to the case study reviewed above. The first step will be to create an engineered risk matrix by understanding the hazards associated with each step of the operations, the likelihood of occurrence and consequences severity. After the matrix is developed, a number of hazard identification and control checklists will also be developed for each of the identified potential hazards.

These hazards checklists state the various factors that would contribute in increasing the likelihood of a hazard occurrence and will provide suggested means to reduce the likelihood of such hazards from occurring. We shall describe the conditions present before this operation took place and how it would appear to the decision maker, and what mitigation tools could have been implemented to reduce the probability of such incident from occurring.

4.3.1 Developing an Engineered Risk Matrix for the Operations of the Case Study.

The case study concerned a lifting incident that happened when a crane commenced lifting a subsea spool (CP3) from its testing location, on fabrication stands at the fabrication facility, to another location on transportation stands at the fabrication facility for additional work when the crane tipped onto its right side dropping the spool. The crane tipped over completely. The subsea spool contained a Multi-Phase Flow Meter, and the spool was destroyed completely. The possibility of a radioactive leak was high, but due to good luck there was no radioactive leak.

The operations carried out here were on a Subsea rigid spool containing a Multi-Phase which has a 1.11 GBq C-137 radioactive source. Such operation start from the end of fabrication, SIT [Site Integration Test] phase, transportation to the offshore field phase and the deployment and commissioning phase .

To develop the engineered risk matrix, it's required to develop its two main [X, Y] axes. Its first axis is the likelihood of occurrence, and we develop this as following:-

To develop such likelihood of occurrence associated with different hazards that are present during the different operations carried out on the subsea rigged spool, the following likelihood of occurrences were conceived:-

1:- An incident that could occur once in every 10 operations. 0.1

2:- An incident that could occur once in every 100 operations. 0.01

3:- An incident that could occur once in every 1000 operations. 0.001

4:- An incident that could occur once in every 10000 operations. 0.0001

5:- An incident that could occur once in more than 10000 operations. > 0.0001

Each probability of a incident occurring takes a number from 1 to 10 [number 1 is when a incident is least likely to happen with a probability < 1:10,000 and number 10 is when the incident is most likely to happen with a probability equal or > than 1:10].

The 2nd axis is the consequence of such incidents should they occur, the process of determining the consequence assessment of such incident, and the effect of an aftermath of a particular incident. Therefore, they show the result of harm or damage that would come about in case any of the identified incident should occur.

In this case study, we used a number of methods to determine the consequences of the occurrence of the identified incident as follows:-

1st: By analyzing the financial costs of all elements involved in each operation such as asset costs, labor hourly costs, daily site costs, daily or hourly rental equipment costs, etc. Also adding costs such as the project's daily fines for every day of delay after the deadline, the cost of every hour of downtime, and other indirect costs related to operations..Etc.

2nd: The previous history of similar incidents that happened due to similar hazards and the total losses resulting from such incidents.

3rd : Evaluations done by experts determining the cost of certain incidents such as the cost to address an environmental crisis as a result of a radioactive leak or the legal and liability costs should workers gets hurt or worse due while on the job due to a hazard occurring.

The above methods are utilized in this case study to give us a better understanding of what's at stake. By using the tools listed above we carry out an assessment to determine the consequences severity associated with this subsea rigged spool that contains a Roxar Multi-Phase Flow Meter from its phase of site integration phase till final commissioning in its subsea field. The following severity levels were conceived:-

1:- An event that would result in equipment's extreme damage and would cause an uncontrolled radioactive leak from its flow meter during operations on land, or an event that would result in the subsea spool extreme damage while offshore and would cause complete offshore operational shut down for a considerable period of time, or an event that would cause damage to the subsea rigged spool and /or damage to other installed subsea assets that results in a subsea hydrocarbon spill or leak with an estimated financial loss per day exceeding $1,000,000 USD.

2:- An event that would result in the rigged spool's partial damage resulting in a radioactive leak during conducting operations on land, or partial damage to the spool while offshore causing partial or complete offshore shutdown for a short period of time ,with an estimated financial loss per day between $ 500K and $ 1 Million.

3:- An event that would result in equipment's damage while conducting operations onshore , with the possibility of a radioactive leak causing facility operational shut down for a considerably long period of time and would directly have a negative effect on offshore operational work schedules resulting in down time , with an estimated financial loss per day between $ 100,000 and $ 500,000 USD .

4:- An event that would result in equipment damage while conducting onshore operations which would result in facility shutdown but with little to no effect on the offshore operations with an estimated financial loss per day between $ 10,000 and $ 100,000USD.

5:- An event that would result in equipment's partial damage while conducting onshore operations resulting in limited operational delays but with no effect on the offshore operations, with an estimated financial loss per/day to be less than $10,000USD.

By using the two axes to create a risk matrix which is a tool made to aid the decision maker during the execution of the different phases of the Subsea Spool site integration tests , commissioning and installation operations.

In the case study here an evaluation will be carried out after the matrix has been developed, where a review of the conditions present before the lifting accident in the case study took place, how would it appear to the decision maker and what the mitigation tools were that could have been implemented to reduce the probability of such incident from occurring.

Please see the Risk Matrix [Table 7]

Risk Matrix			Likelihood of Occurrence				
			Very Unlikely	**Unlikely**	**Low Possibility**	**Possible**	**Probable**
			1	**3**	**5**	**7**	**10**
Hazard Severity	An event that would result in equipment extreme damage and would cause an uncontrolled radioactive leak while onshore or offshore and would cause complete offshore operational shutdown for a period of time.	**10**					
	An event that would result in equipment partial damage and would result in a radioactive leak during conducting operations on land or while offshore and would cause partial or complete offshore shutdown .	**7**					
	An event that would result in equipment damage [while onshore] causing facility operational shutdown for a considerably long period of time and would directly have a negative affect offshore operations work schedules resulting in down time.	**5**					
	Equipment damage while onshore causing facility shutdown but with little to no effect on the offshore operations.	**3**					
	Equipment partial damage while onshore causing operational delays with no effect on offshore operations.	**1**					

Table 7: Risk Matrix

4.3.2 Developing hazard prevention and mitigation checklists for the case study.

Hazard identification checklists can be developed for each of the identified potential hazards for this specific subsea rigid spool from the start of the 1st SIT phase. These hazards checklists state the various factors that would contribute to increasing the likelihood of a hazard occurring and bring them to the attention of the field supervisor or field safety engineer. These check lists would have been developed by the means described in chapter 3 and presented to the person in charge of executing the job, so they would have been completed before the job was to start, as seen in Figure 18.

	YES	NO
Factors Regarding the Load:		
● Is this lift considered a heavy lift (the load weight >10 tons)?	☐	☐
● Are the physical features of the load uneven (uneven in shape or in weight distribution)?	☐	☐
● Does this load contain any radioactive substance?	☐	☐
● Does this load contain any stored fluid?	☐	☐
● Does this load contain any stored fluid under pressure?	☐	☐
Factors regarding the lift operation:		
● Is there a lift plan present?	☐	☐
● Is the crane and rigging rated for lift?	☐	☐
● Are all lifting rigging and the crane are certified?	☐	☐
● Are there any new/inexperienced personnel involved in the lift?	☐	☐
● Is it confirmed that there are no items missing from the load before starting the lift?	☐	☐
● Has there been a safety meeting regarding the lift task so that all workers involved know their role and are well informed of the process?	☐	☐
● Will the lift pass over or near other assets?	☐	☐

Figure 18 Potential Factors That Could Result in Lifting Incident.

Likelihood of Occurrence of a Lifting Incident during Lifting Operations	Scenario	1	3	5	7	10
	Lift is 0 – 60% of crane safe work capacity or rigging capacity.	X				
	Lift is 60 – 90% of crane safe work capacity or rigging capacity.		X			
	Lift is 90 – 110% of crane safe work capacity or rigging capacity.			X		
	Crane and/or rigging are not certified while lifting a load 0 – 60% of crane safe work capacity.		X			
	Crane and/or rigging have no up to date certification while lifting a load 60 – 90% of crane safe work capacity.			X		
	Crane and/or rigging have no up to date certification while lifting a load 90 – 110% of safe work capacity.				X	
	If two unsafe conditions such as [No Lift Plan , Uneven lift , No certification to crane or rigging , inexperienced crane operator or personnel ..etc] occur during the same single lift and if :- The load is 0 – 60% of crane safe work and/or rigging safe capacity.			X		
	The load is 60 – 90% of crane safe work and/or rigging safe capacity.				X	
	The load is 90 – 110% of crane safe work and/or rigging safe capacity.					X

Table 8 Lifting Incident Likelihood Of Occurrence.

Control Tools: **USED**

- An Engineered lift plan in place. ☐
- An MSDS is present for all fluids in items being lifted. ☐
- Full certification for all lifting rigging used in the lift . ☐
- Pre-operation meeting held with experienced lead personnel in charge. ☐
- Final check carried out to ensure no missing or unfastened items before lift. ☐
- Weather conditions, time of day and mental and physical conditions of workers involved taken into account ☐
- Emergency response plans in place should any lifting incident occur. ☐
- Emergency response plan in place to address uncontrolled incident involving hazardous materials: toxic material, radioactive material ..etc. ☐
- Is there a need to complete any extra work permits (working at heights, handling hazardous materials, etc.) ☐

Figure 19 Factors To Reduce Lifting Hazards.

4.3.3 Implementing the risk assessment and risk management study in this case study.

By applying this risk assessment and risk management study and by using the tools we developed as a risk matrix for the activities carried out during the subsea spool (CP3) site integration test operations, we shall demonstrate how the lifting incident that took place on July 19, 2010, at the fabrication facility could have been prevented. The incident took place when a crane commenced lifting the subsea spool (CP3) from its testing location on fabrication stands at a fabrication facility to another location on transportation stands at the fabrication facility for additional work. The crane tipped onto its right side dropping the spool; the crane tipped over completely. The subsea spool contained a Multi-Phase Flow Meter, which has a 1.11 GBq C-137 radioactive source.

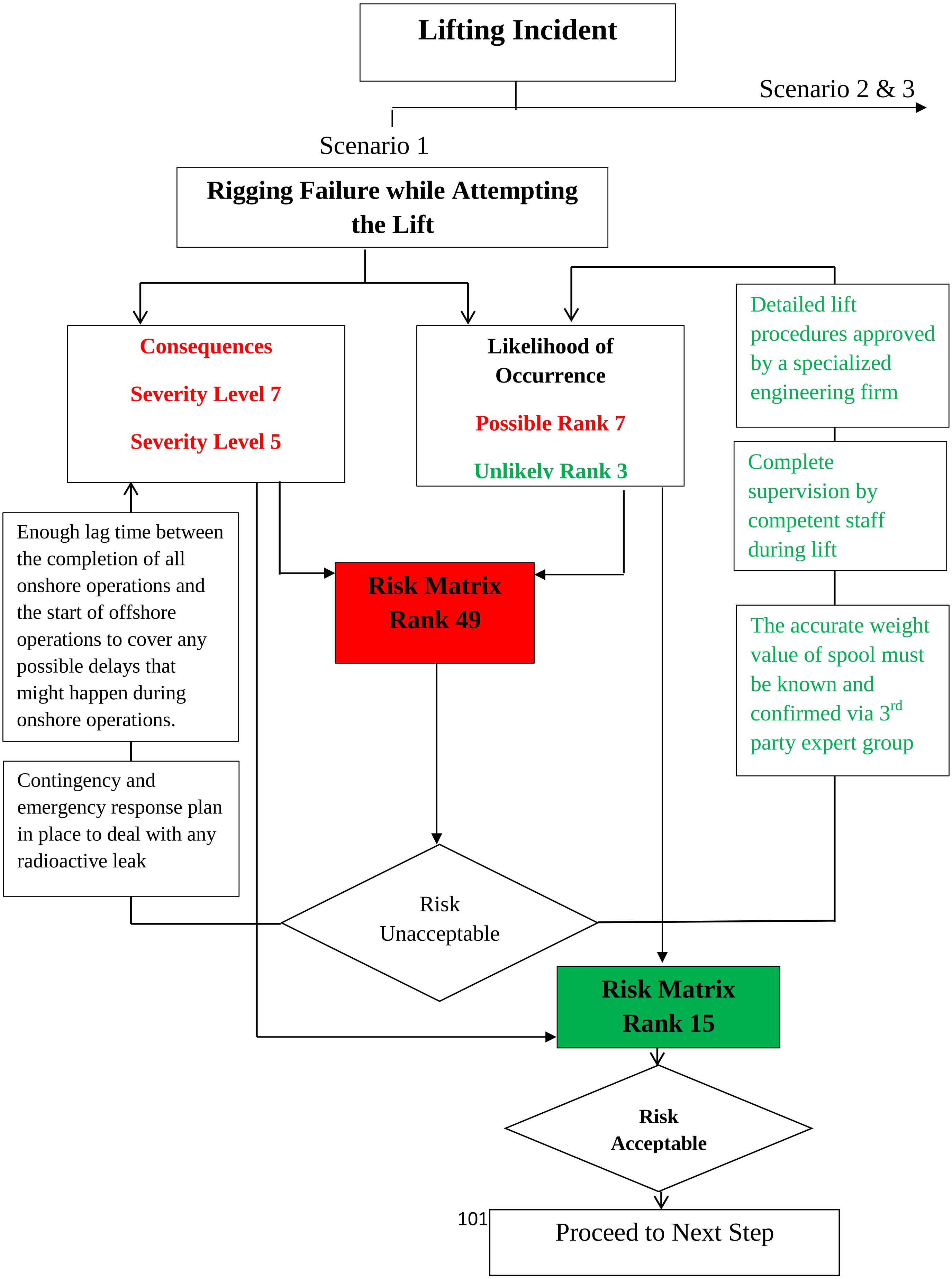
Before commencing the lift, the operation manager in charge or QHSE Engineer would have done the following:-

1st:- Identify possible hazards associated with such an operation, and different possible scenarios if such hazards occur:-

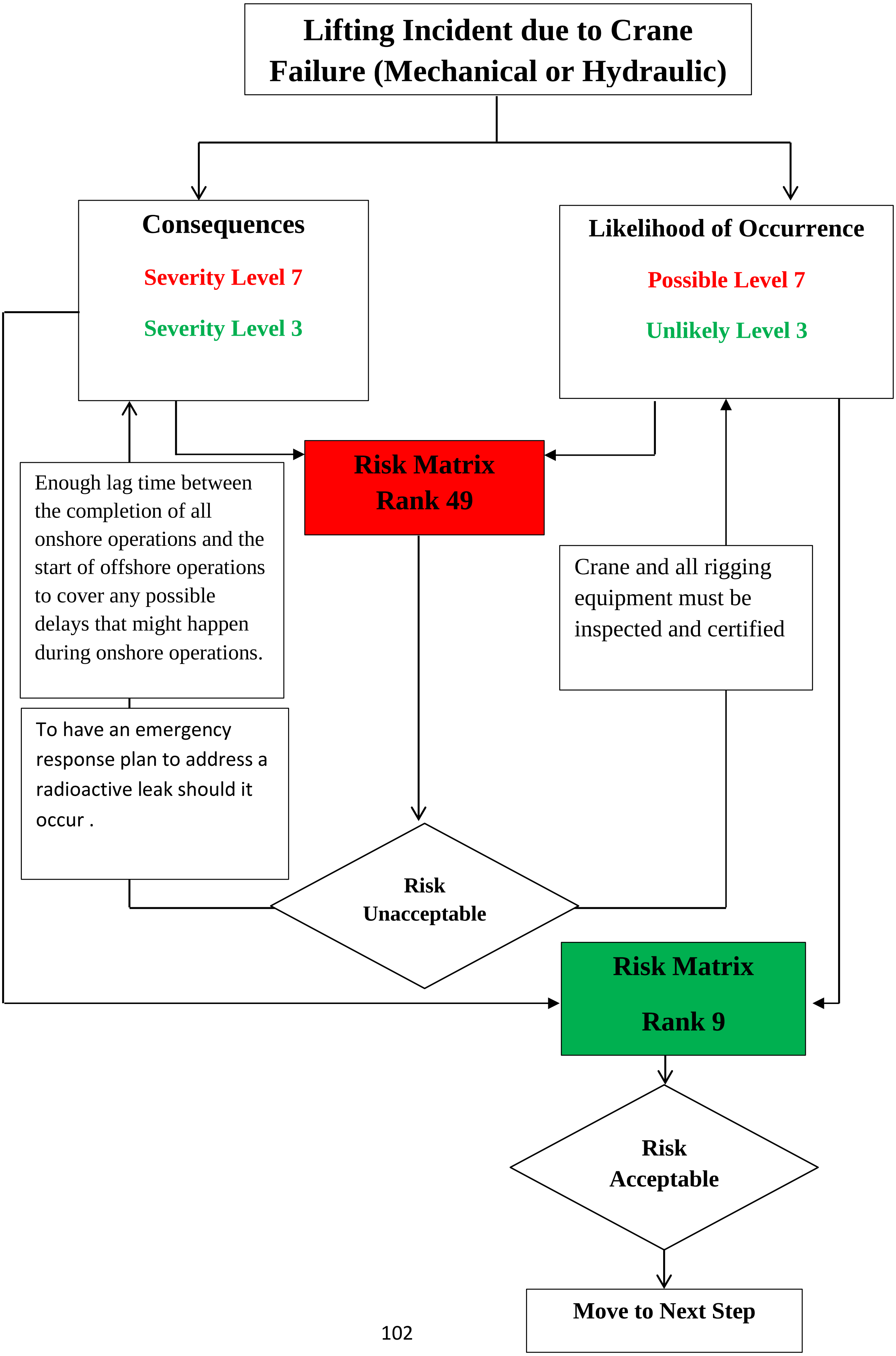
- A lifting incident involving dropping the spool.
- A lifting incident involving striking the spool with other fixed objects.

2nd:- Utilize the engineered risk matrix we developed for this spool S.I.T operation to aid in the decision making.

3rd:- Develop a flow chart we shall use as initial data input with all the facts of the situation on the morning of July 19, 2010. …. Please see the following flow charts.

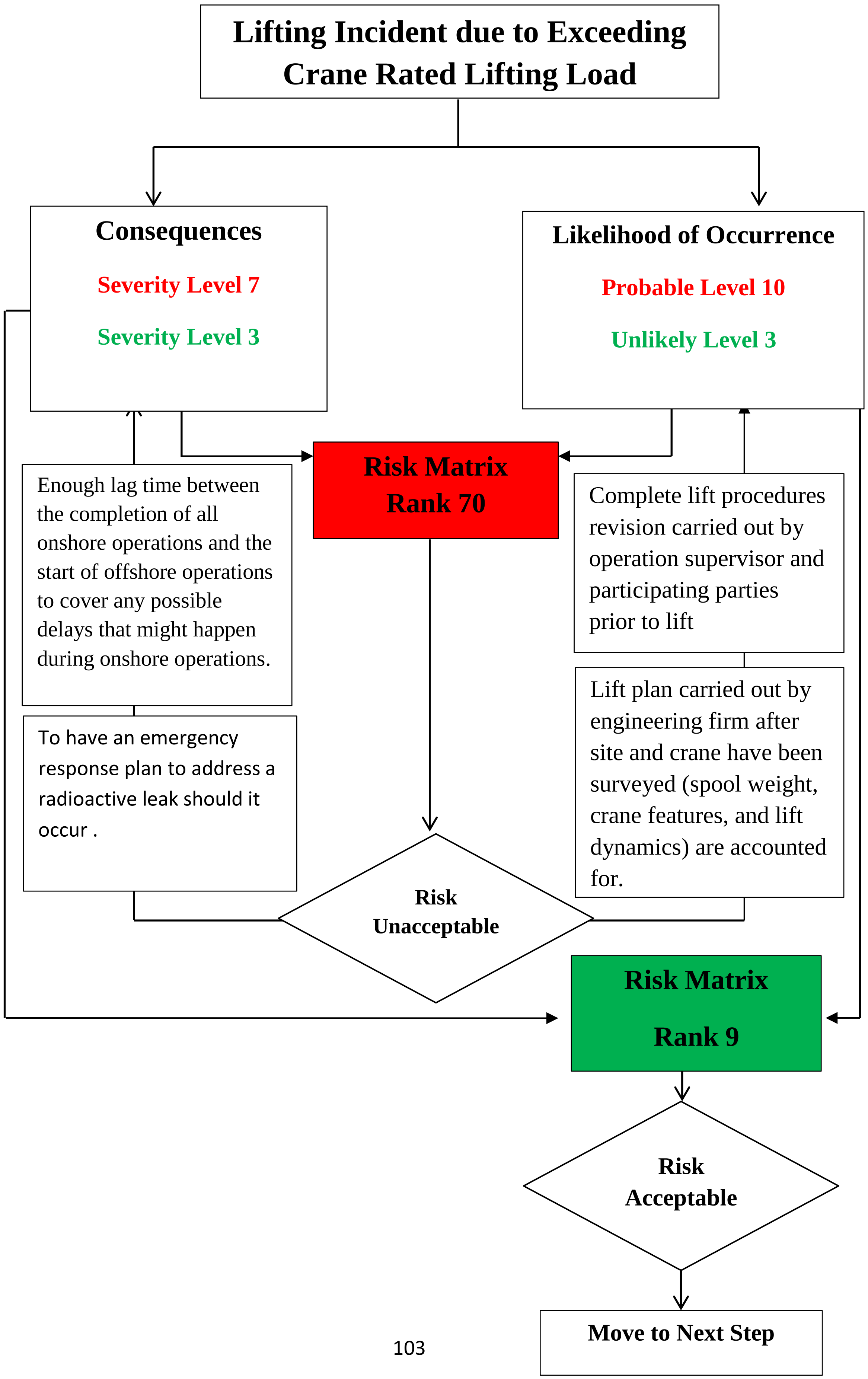

Lifting Incident
Scenario 2 & 3
Scenario 1
Rigging Failure while Attempting the Lift
Consequences
Severity Level 7
Severity Level 5
Likelihood of Occurrence
Possible Rank 7
Unlikely Rank 3
Detailed lift procedures approved by a specialized engineering firm
Complete supervision by competent staff during lift
The accurate weight value of spool must be known and confirmed via 3rd party expert group
Enough lag time between the completion of all onshore operations and the start of offshore operations to cover any possible delays that might happen during onshore operations.
Contingency and emergency response plan in place to deal with any radioactive leak
Risk Matrix Rank 49
Risk Unacceptable
Risk Matrix Rank 15
Risk Acceptable
Proceed to Next Step

Scenario 2



Lifting Incident due to Crane Failure (Mechanical or Hydraulic)
Consequences
Severity Level 7
Severity Level 3
Likelihood of Occurrence
Possible Level 7
Unlikely Level 3
Risk Matrix Rank 49
Enough lag time between the completion of all onshore operations and the start of offshore operations to cover any possible delays that might happen during onshore operations.
Crane and all rigging equipment must be inspected and certified
To have an emergency response plan to address a radioactive leak should it occur .
Risk Unacceptable
Risk Matrix
Rank 9
Risk Acceptable
Move to Next Step

Scenario 3


Lifting Incident due to Exceeding Crane Rated Lifting Load
Consequences
Severity Level 7
Severity Level 3
Likelihood of Occurrence
Probable Level 10
Unlikely Level 3
Risk Matrix Rank 70
Enough lag time between the completion of all onshore operations and the start of offshore operations to cover any possible delays that might happen during onshore operations.
To have an emergency response plan to address a radioactive leak should it occur .
Complete lift procedures revision carried out by operation supervisor and participating parties prior to lift
Lift plan carried out by engineering firm after site and crane have been surveyed (spool weight, crane features, and lift dynamics) are accounted for.
Risk Unacceptable
Risk Matrix
Rank 9
Risk Acceptable
Move to Next Step

As per the above flow charts, it is important to point out that completing the charts for the consequences severity and hazard identification and the likelihood of occurrence charts was predetermined for this operation using the tools we have discussed earlier in the study.

The role that the operation supervisor or the QHSE Engineer on location would have had on the morning of the incident was to take 15 min of his time to fill out the checklist sheets. Then the engineer would have completed the 3 hazard flow charts as per all 3 lifting hazard scenarios stated here, which were the 3 possible for a lifting hazard the morning of the lift in the case study.

The initial likelihood for any of the mentioned 3 scenarios of a lifting incident had rank numbers in the red zone which required an immediate stop to the operation and mitigation measures. These measures should have been taken before work proceeded, as we see in the following:-

In the 1st scenario:-

A lifting incident due to rigging equipment failure due to the following facts:

There was:

- No accurate knowledge of the actual CP3 spool weight.
- No lift plan developed to check suitability of rigging equipment.
- No quality control inspection to identify condition of rigging equipment.
- No proper supervision present before and during the start of the operation.

For these reasons the likelihood of a lifting incident due to rigging failure was a level 7 [possible] which along with the severity of the operation [also a severity level 7] brings the overall risk matrix number to 49 which is in the red zone. At this point, operations should have stopped and mitigation steps should have been taken to reduce this risk hazard probability to an acceptable figure.

In the 2nd scenario:-

One lifting incident due to crane's mechanical or hydraulic failure due to the following facts:

There was:

- No quality control inspection carried out to confirm both the mechanical and hydraulic integrity of the crane [especially when taking into to account the age of that crane].
- No lift plan developed to determine the precise lift job that the crane was required to do, and whether or not it was within the crane's safe work limits.
- No accurate knowledge of the actual CP3 spool weight.

As a result, the likelihood of a lifting incident due to crane mechanical or hydraulic failure was at a level 7 [possible] which along with the severity of the operation [also a severity level 7] brings the overall risk matrix number to 49 which is in the red zone. At this point, operations should have stopped and mitigation steps should have been taken to reduce this risk hazard probability to an acceptable figure.

In the 3rd scenario:-

One lifting incident due to crane exceeding lifting capability due to the following facts:

There was:

- No accurate knowledge of the actual CP3 spool weight.
- No lift plan present to give detailed information on where the crane and spool were positioned and how far the crane would reach out along with other operational details.
- No quality control inspection carried out to confirm both the mechanical and hydraulic integrity of the crane especially when taking into account the age of that crane.
- No proper supervision present before and during the start of the operation.

As a result, the likelihood of a lifting incident due to the crane exceeding lifting capability was at a level 10 [probable] which along with the severity of the operation [also a severity level 7] brings the overall risk matrix number to 70 which is in the red zone. At this point, operations should have stopped and mitigation steps should have been taken to reduce this risk hazard probability to an acceptable figure.

As I have just demonstrated, the lifting incident happened when a crane commenced lifting a subsea spool (CP3) from its testing location on fabrication stands at the fabrication facility to another location on transportation stands at the fabrication facility, where the crane tipped onto its right side dropping the spool.

This lifting accident resulted in the crane tipping over completely. The subsea rigid spool that contained a Multi-Phase Flow Meter and the spool were destroyed completely. The possibility of a radioactive leak was high, but due to good luck there was no radioactive leak. This serious incident could have been worse. The accident could have been completely avoided if the proposed study was implemented, where the need for the operation to come to a complete stop would have been clear to the person in charge. By using the tools in this study, it would have been clear that with the operational conditions and circumstances that were present the morning of July 19, 2010, it was too dangerous to proceed. Measures to reduce the risk of a lifting incident were needed before the operation proceeded, which could have avoided this incident.

CHAPTER 5 CONCLUSION AND FUTURE WORK

5.1 Summary

In the proposed study, a comprehensive risk assessment and risk management tool is custom built for the subsea rigid spool, to manage the operation related risks that the subsea sea spool is subjected to from the completion of its fabrication to the point it has been commissioned in its subsea slot in its designated subsea field.

The study attempts to develop a risk assessment and management tool that is easy to use and effective. Also, it can be used by the field operation supervisors or the QHSE field engineer to identify the hazards present during every operational step, determine whether the job is safe to proceed or not, and give means to reduce the risks to ALARP before resuming operational activity.

The final product of this study if implemented would be a set of custom made checklists and tables. They can provide the operation supervisor with data regarding the consequence of hazards should they occur, the likelihood of a certain hazard to occur, a risk matrix to give an indication of what's an acceptable risk and what's not, control measures to be set in place to reduce the current unacceptable level or a risk to acceptable levels and an uncompleted risk flow chart to be completed with the data provided for every different hazard scenario and the means taken to reduce risks to acceptable levels.

5.2 Future Work

5.2.1 Development of risk assessment and management systems for other subsea assets

All subsea equipment and assets are custom-made products as well as the subsea rigid spool, and there is no production line to produce a subsea Christmas-Tree (XMT), subsea manifold , or any other subsea asset.

These subsea assets and equipment are built as per the customers, (oil companies) field requirements and as per customer policies and field development strategic planning. This results in unique equipment being ordered for each project .

This uniqueness would be different in terms of size, shape, weight, added accessories, materials used to build it, different methodology and nature of testing these assets , different logistical challenges and different ways to transport these assets whether by land, sea or air[in some cases], and the different work procedures and ways of commissioning them subsea.

Therefore the development of custom made risk assessment and risk management systems for every individual subsea asset would be area for future work in order to have an integrated system to accurately identify, manage and if need be mitigate the hazards that are associated with each individual asset in every different operational activity it undertakes before it is functional in its subsea slot in its designated subsea field.

5.2.2 Development of a computerized subsea assets risk management system.

In today’s world almost all middle and large sized work entities in all industries use a form of computerized work management system or CWMS and/or computerized maintenance management system (CMMS).

Generally CWMS & CMMS are software programs or a combination of programs that are displayed to the users as a number of modules. CWMS is designed to computerize the work management process (for example maintenance work) and its associated support processes (e.g., inventory, purchasing and capital projects). These computer software programs are designed to assist in the planning, management, and administrative procedures required for effective work management.

The CWMS is a business tool that allows control over the linked work and material processes, and at the same time provides a means for collection of valuable cost and work history data.

These processes include work initiation (work request), planning and scheduling work orders, work execution and closeout. In addition, the inventory and purchasing processes provide the necessary materials and services that facilitate work. (Terry Wireman, 2011)*.

All these processes are related to each other through workflow that allows the electronic simulation of business procedures.

Therefore, an area for future work would be to develop a computerized subsea risk assessment and risk management systems for different subsea assets, that can be integrated in the computerized work management systems in use by oil companies. The new computerized subsea risk assessment and management program can be made to be integrated with the existing computerized work management systems software program used by the oil company, so that whenever a work order is issued, it automatically incorporates the approved risk assessment and management procedures, along with all the other features of the work order such as work procedures , labur hours , 3rd party involvement , materials used ….etc.

REFERENCES

AIChE (2000). Guidelines for chemical process quantitative risk analysis (2nd Edition ed.). New York, USA: Center for Chemical Process Safety/AIChE.

Albert P. Iskrant : Accident mortality data as epidemiologic indicators., Am J Public Health Nations Health. Feb 1960; 50(2): 161–172, PMC1373133.

Ayyub, B. M. (2003). Risk analysis in engineering and economics. NEW York,USA: Chapman and Hall/CRC.

Badreddine, A., and Amor, N. B. (2010). *A dynamic barriers implementation in Bayesian-based bow tie diagrams for risk analysis.* Computer Systems and Applications,ACS/IEEE International Conference on, 1-8.

Bedford, T., and Cooke, R. (2001). Probabilistic risk analysis: Foundations and Methods (1st ed.) Cambridge University Press.

BURULLUS Gas Company – Subsea Facilities EPIC , WDDM Phase VIII-A Development Project [RIGID JUMPER INSTALLATION PROCEDURE] Contract no. BUR/PRJ/003/2010.

BURULLUS GAS COMPANY- WDDM PHASE VIII-B Development Project [Fabrication Yard Activities-Hydrotest & Meg Filling Procedure for Jumpers and Goosenecks] Contract no. BUR/PRJ/008/2011.

Crowl, D. A., & Louvar, J. F. (2001). Chemical process safety, fundamentals with applications (2nd ed.). Upper Saddle River, New Jersey, USA: Prentice Hall PTR.

Daneshkhah, A. (2004). Uncertainty in probabilistic risk assessment: A review, Unpublished manuscript.

Ferdous, R. (2006), *"Methodology for Computer Aided Fuzzy Fault Tree Analysis"* , A Thesis Submitted to Memorial University of Newfoundland, Canada, in Partial Fulfillment of the requirements for the Degree of Master of Engineering.

FMC Technologies web site , http://www.fmctechnologies.com/SubseaSystems.aspx in Feb2014.

Hammonds S.J., Hoffman O.F. and Bartell M.S. (1994). *An Introduction Guide to Uncertainty Analysis in Environmental and Health Risk Assessment.* Technical report No. ES/ER/TM-35/R1). SENES Oak Ridge, Tennessee.

Harold E. Roland, Brian Moriarty (1990). System Safety Engineering and Management. John Wiley & Sons. ISBN 0471618160.

Hauptmanns, U. (1988). *Fault tree analysis for process industries engineering risk and hazard assessment* . In Engineering risk and hazard assessment (pp. 21-59) Florida, US:CRC Press Inc.

Heinrich HW (1931). Industrial accident prevention: a scientific approach. McGraw-Hill.

Hollnagel, E. (2004). Barriers and Accident Prevention. Ashgate Publishing Limited. UK

HSE UK (2009). Offshore Injury,I11 Health and Incident Statistics. *Health and Safety Executive Report, HSR 2009-1, Merseyside, UK.*

Husky Energy Investigation Review, (2010). DCH Crane Incident at M&M Offshore Ltd. Facility.

Jon Mainwaring , Rigzone Staff, March 28th 2012 , https://mb50.wordpress.com/tag/jack-up-rig/.

Kaplan, S. and Garrick, B. (1981) *On the quantitative definition of risk*. " Risk Analysis, I(1), 11-27. Doi:10.11 11/j.1539-6924.1981.tb01350.x.

Kjellen, U. (2000). *Prevention of Accident through Experiences Feedback*. Taylor and Francis. London, UK

Kumamoto, H., and Henley, J. E. (1996). *Probablistic risk assessment and management for engineers and scientists* (2nd ed.) Wiley-IEEE Press.

Lee, F. (1996). Loss prevention in the process industries (2nd ed.). Butterworth-Heinemann,Oxford.

Lee, F.P. (2005). In Mannan S., O'Connor M.K. (Kds.), Loss prevention in the process industries (3rd ed.) Elservier.

Maryam Kalantaria , Faisal Khan , Kelly Hawbodt *(Dynamic risk assessment using failure assessment and Bayesian theory)* , Journal of Loss Prevention in the Process Industries. 22(2009) 600-606.

Modarres, M. (2006*). Risk analysis in engineering techniques, tools and trends*. Bocca Raton, Florida, USA.: Taylor and Francis.

Panagiota Katsakiori , George Sakellaropoulos , Emmanuel Manatakis , Article (*Towards an evaluation of accident investigation methods in terms of their alignment with accident causation models)* Safety Science 47(2009) 1007-1015 .

Principles of Risk-Based Decision Making . ABS Consulting, ISBN 0-86587-908-7

Smith, D. R., Frazier, D., Reithmaier, L. W. and Miller, J. C. (2001). Controlling Pilot Error. McGraw-Hill Professional. p. 10. ISBN 0-07-137318.

Stephens, M., Nessim, M., Chen, Q. (1995). A Methodology for the Risk Based Optimization of the Pipeline Integrity Maintenance Activities. *PIRAMID Technical Reference Manuel No. 1.2,* Center for Engineering Research Inc., Edmonton, Canada.

Stranks, J. (2007). Human Factors and Behavioural Safety. Butterworth-Heinemann. pp. 130–131. ISBN 9780750681551.

Spillius, Andrew (18 June 2010). The Telegraph (London). Retrieved 2010-06-18. http://www.telegraph.co.uk/finance/newsbysector/energy/oilandgas/7836982/BP-oil-spill-could-cost-100bn.html (On Oct. 2013)

Terry Wireman (2011), Successfully Utilizing CMMS/EAM Systems, ISBN 978-0-9832258-7-4.

Virginia R. Prevosto , web site reviewed on April 2014 , http://www.iso.com/Research-and-Analyses/ISO-Review/Holistic-Risk-Management-and-Quantification.html.

Wang, Y. (2004*). Development of a computer-aided fault tree synthesis methodology for quantitative risk analysis in the chemical process industry*. (Doctor of Philosophy Texas A and M University). , 1-164