Risk-Based Integrity Management (RBIM) of Oil & Gas Offshore Fixed Steel Structure Platform

By

Ahmed Elmasry

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ABSTRACT

Oil and gas offshore facilities structures operating in harsh environments are associated with high risk and the likelihood of failures. Hence, frequent inspections are needed to enhance the integrity and reliability of these 'platforms' structures using a rigorous strategy.

The purpose of this research is to develop an integrity management strategy for an above and underwater offshore platform steel structure using risk-based integrity management assessment. This strategy is developed in four steps: step one identifies the elements of the platform structures suitable for risk-based integrity management; in step two, identifies anomalies and degradation mechanisms. The third step is hazard identification using qualitative risk analysis, by hazard and operability model, and quantitative risk analysis, by the fault tree model, to calculate the probability of failure then qualitative assessment assigns the consequences. Step four ranks the risk to prioritize inspection and maintenance schedule and build an integrity management strategy.

As an outcome of this thesis, we are able to identify and categorize the degradation and deterioration mechanisms for the fixed steel structure platforms and gain an understanding of platform structural risks and rank these according to severity. Consequently, increase and enhance the reliability and integrity of the platform using an appropriate integrity management strategy. The proposed risk-based integrity management analysis proved that the risk-based inspection and risk-based maintenance methods used in this work are effective in terms of time, efficiency and cost, through reducing the frequency of inspection from 12 months to 24 or 36 months in some cases.

COVID-19 IMPACT STATEMENT

Covid-19 has impacted our lives and capabilities to go around our everyday lives. Our academic life has also been affected by the pandemic through several means. Some of these factors include our ability to communicate with colleagues, travel, collecting data, access to labs, funds, and software. In this statement, I am clarifying the original plan of this research and the changes it had to incur to cope with the limitations imposed by the pandemic.

In this research, I studied the risk-based integrity management of oil and gas offshore fixed steel structure platform. The original work plan was to develop and implement a risk-based integrity management strategy for the jacket platform using a risk-based approach. The work was divided into several steps and stages. The first step was to identify system and elements susceptible to degradation mechanisms and failure. Second step was to identify the possible hazards for the structure and develop a Hazard identification (HAZID) using a qualitative risk analysis by Hazard and Operability (HAZOP) study. This part of the study was to be used to provide a holistic view on the risk assessment of the system. The holistic view is needed to build a detailed quantitative risk assessment and to present the possible consequences as to provide details for the quantitative risk assessment. Afterward, the risk analysis was to be made followed by risk determination and risk-based inspection. Based on the above, an efficient integrity management strategy was to be developed.

In the first step, the needed information was accessible, and I was able to select the system suitable for my study (fixed steel structure platform), and the details of the system. Consequently, I was able to successfully identify the elements of the platform susceptible to degradation and failure. Also, the data needed to identify the anomalies and the degradation mechanisms causing failure and the safety critical elements of the topside and underwater structure, was gathered successfully. In addition, the data for the HAZOP study was accessible and the HAZOP study was performed as planned.

However, the third step is what incurred the most impact due to Covid-19. In order to cope with Covid-19 pandemic, multiple restriction was imposed. These restrictions obstructed the continuity of this research step as planned. In order to hurdle those obstacles, some changes were adopted to the methodologies of data collection and analysis. These changes were done to the research to accommodate safety and public health emergency measures.

In the original plan the quantitative risk analysis (QRA) technique, fault tree analysis (FTA), used to calculate the probability of failures then qualitative risk assessment of consequence of failure. Through FTA modeling we can determine the probabilities of failures using the platform elements reliability data which originally could be collected offshore but due to COVID 19 limitation a reasonable assumption was made for these data instead as well uncertainty and sensitivity study implemented to use it in the QRA model. Based on that model, risk determination and risk-based inspection was made and an efficient integrity management strategy.

Due to the pandemic offshore field data collection is challenging and not applicable the data collection from the field was exchanged with case study and assumed data for jacket platform, the platform type considered in this study is a four-legged fixed type oil platform.

Instead of applying quantitative sensitivity and uncertainty analysis, qualitative measures were adopted in order to present and explain the uncertainties on the quantitative risk assessment model, some of the mathematical models had to be simplified as well. Some data for failure probabilities on platform topside and underwater elements were assumed.

In addition, the consequences assessment was planned to be quantitative as well, however, due to the difficulty of accessing offshore fields and real data, I had to resort to the qualitative approach instead.

Mathematical and engineering analysis as well are unable to be done due to limited access to licensed software. With COVID-19 Pandemic there are difficulties accessing library and archival resources and research allowances. In addition, COVID-19 has impacted the social and the scientific interactions with colleagues that usually helps in brainstorming and ideas that could have improved the research.

Covid-19 has obstructed my ability to collect the needed data from the field to build a quantitative Risk assessment model, probability of failure, consequence of failure assessment and the uncertainty and sensitivity analysis. In order to overcome this challenge, I have changed some of my strategies and data inputs. I had resorted to qualitative studies whenever possible instead of quantitative analysis. In addition, I had to assume some of the data based on available information, field experience and reasonable ranges. This research was completed to the best possible capabilities during the extraordinary times we are going through. As discussed, in spite of the constraints imposed due to Covid-19 health and safety measure, I was able to continue 70% of the work through assuming data, changing some models and changing some parts of the plan.

ACKNOWLEDGEMENT

All praises are for Almighty Allah, who by his will, I had the opportunity to enroll and pursue a Master of Engineering thesis-based program at Memorial University.

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TABLE OF CONTENTS

LISTS OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

RBIM	Risk Based Integrity Management
RBI	Risk Based Inspection
RBM	Risk Based Maintenance
HAZOP	Hazard and Operability Model
HAZID	Hazard Identification
FTA	Fault Tree Analysis
ETA	Event Tree Analysis
FMECA	Failure Mode, Effects, And Criticality Analysis
RCA	Root Cause Analysis
ALARP	As Low as Reasonably Practicable
SHE	Safety, Health and Environment
SCE	Safety Critical Elements
GBS	Gravity-Based Structure
FPSO	Floating Production, Storage and Offloading
AIM	Asset Integrity Management
CA	Certifying Authorities
KPI	Key Performance Indicator
PoF	Probability of Failure
CoF	Consequence of Failure

PFP	Passive Fire Protection
NDE	Non-Destructive Examination
NDT	Non-Destructive Test
GVI	General Visual Inspection
CVI	Close Visual Inspection
UT	Ultrasonic Thickness Inspection
PT	Dye Penetrant Inspection
MT	Magnetic Particle Inspection
ET	Eddy Current Inspection
RTR	Real Time Radiography
CR	Computerized Radiographic
PEC	Pulsed Eddy Current
ROV	Remotely Operative Vehicle
API	American Petroleum Institute
DNV	Det Norske Veritas
BOP	Blow Out Prevention
DES	Derrick Equipment Set
LQ	Living Quarter
SIM	Structural Integrity Management
QRA	Quantitative Risk Assessment

CHAPTER 1: Introduction

Introduction to Oil & Gas Offshore Structure

Oil and Gas Offshore structures have unique commercial and technical characteristics. Economically, offshore structures are reliant on oil and gas production, which is directly associated with worldwide investment and affected by oil prices. Oil prices increased in 2008 worldwide, and consequently, a lot of offshore structure projects started during that time period. Only a few specialized faculties of engineering focus on offshore structural engineering, including the design, operation, and maintenance of fixed offshore platforms or other types. This may be due to the limited amount of offshore structural projects compared with the number of onshore steel structure projects, such as residential facilities, factories, and infrastructure projects. All multinational oil and gas producer companies are interested in offshore structures (1). These companies provide support and funding for research and development that will improve the capability of their engineering firms and services contractors to support their business needs (1).

Safety and Asset integrity in the oil and gas sector is essential due to the hazardous nature of offshore operations and environmental hazards (2). The offshore environment is the most extreme condition of operation in the oil and gas industry (2). The purpose of the risk assessment and asset integrity management is to provide the operator with a detailed understanding of all aspects of the risks and degradation mechanisms that may impact people, assets, and business.

Asset integrity management is essential for protecting assets, lives, properties, and the environment. There are several uncertainties related to working offshore that necessitates having a proper integrity management strategy in place.

Offshore Platforms Types

Offshore oil and gas platforms are massive structures equipped with facilities for drilling and production of oil and gas inside the ocean. An offshore oil platform may be fixed or floating based on design and fie-specific requirements.

The various types of offshore platforms Shawn in figure 1:

1. Fixed steel structure platforms (Jacket Platform)
2. Compliant Towers
3. Concrete gravity-based structure (GBS)
4. Tension leg platforms
5. Semi-submersible
6. Floating Production, Storage and Offloading (FPSO)

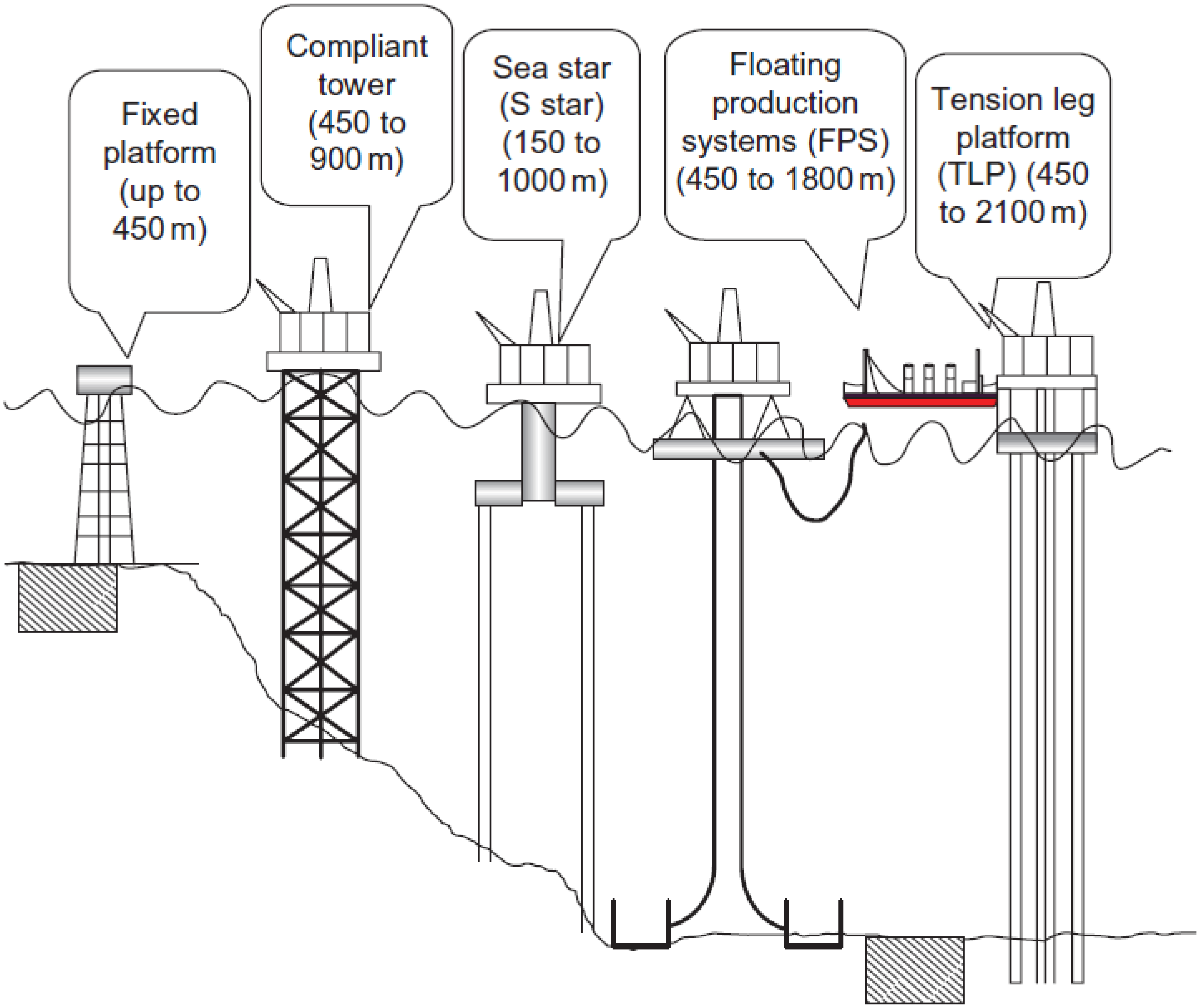


Figure 1: Typical types of offshore platforms (1)

Introduction to Asset Integrity Management

What is Asset Integrity?

Asset integrity is the term for an asset's capacity to run safely, effectively, and accurately. This applies to the entirely of an asset’s operation, from its design phase to its decommissioning and replacement. The challenge of implementing asset integrity is how to balance the inspection, maintenance, and replacement of assets throughout their life cycle with the costs to business – in terms of finance, time, and resources.

At its heart, it is the managing of the degradation of assets.

Asset Integrity Management (AIM)

Asset Integrity Management is the way of ensuring that the resources, processes, systems, and procedures that deliver integrity are utilized, in place and will perform when needed over the entire lifecycle of the asset (2). Even If the risk of an incident is not reducible to zero, a significant reduction in the probability of occurrence and consequence is achieved by applying an efficient AIM strategy. The AIM strategy enhances the asset’s overall integrity, reliability, and performance. AIM is also described as the continuous assessment process implemented during design, construction, installation, and operations to ensure that the facilities persist in being fit for service.

The integrity management covers the equipment, their supporting structures, and other systems to prevent, detect, control, or mitigate against major accident hazards. A loss of integrity could have an impact on the safety of personnel, impact on the environment, on asset and\or on production and business.

Asset Integrity Management strategy aims to:

- Ensure you have the business processes, systems, tools, competence, and resources to guarantee integrity throughout the asset lifecycle.
- Comply with the company's procedures, industry standards, regulatory and certifying authorities (CA) requirements.
- Assure technical integrity by the application of risk-based inspection, maintenance, engineering principles, and techniques.
- Ensure the facility comply with the required safety, environmental and operational KPIs.
- Optimize the plans, activities and the resources needed to operate the facilities safely and maintaining integrity.
- Minimize the degradation of assets and assurance of the facility fitness for purpose.

There is a set of procedures, requirements, and activities, which are carried out by different parties to ensure the maintenance of t the overall integrity of the asset. Included in these activities are HAZID and risk assessment process, maintenance and inspection activities, anomalies management, condition monitoring process, topsides integrity management process, subsea integrity management process, certifying authority requirements and regulatory compliance. These various inputs to the overall integrity management are summarized in the following figure 2

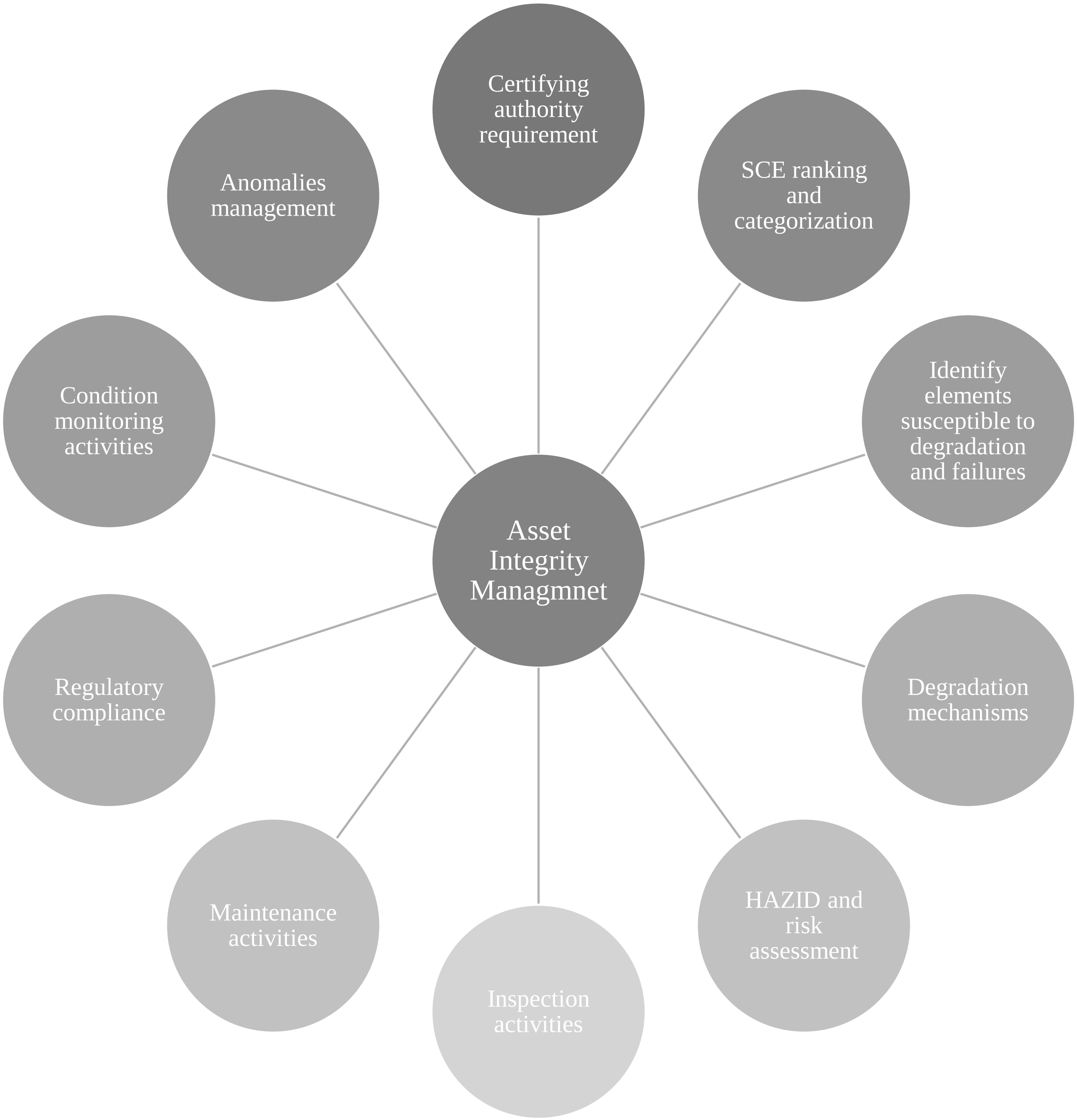


Figure 2: Various inputs to the integrity management for offshore structure platforms

Risk-Based Integrity Management (RBIM)

Risk-based integrity management is considered the most appropriate approach for determining inspection and maintenance strategies for assets. RBIM allows you to find an optimal balance between asset integrity and business risk, consequently maximizing efficiency and safety. A risk-based integrity management approach focuses on assessing asset exposure to degradation and failure risks. RBIM provide asset owner the ability to apply appropriate inspection and maintenance resources to those assets which providing the optimal integrity for assets and cost-effectively return (3).

The objective of a risk-based integrity management approach is to ensure and provide the required confidence in the system integrity and consequently maximize its operating availability while optimizing the resources used to maintain the system integrity. The basic steps of an RBIM are:

- Establish and define the required levels of confidence in system integrity.
- Develop detailed knowledge as possible of the system past, present, and future operating conditions and environment.
- Analytically assess and rank the risks of each potential failure mode specific to the system and highlighting the uncertainties.

A risk-based inspection (RBI) and risk-based maintenance (RBM) approaches are then considered to eliminate the risks considered to be unacceptable and the uncertainties in the integrity management, and to maintain and increase system efficiency and integrity.

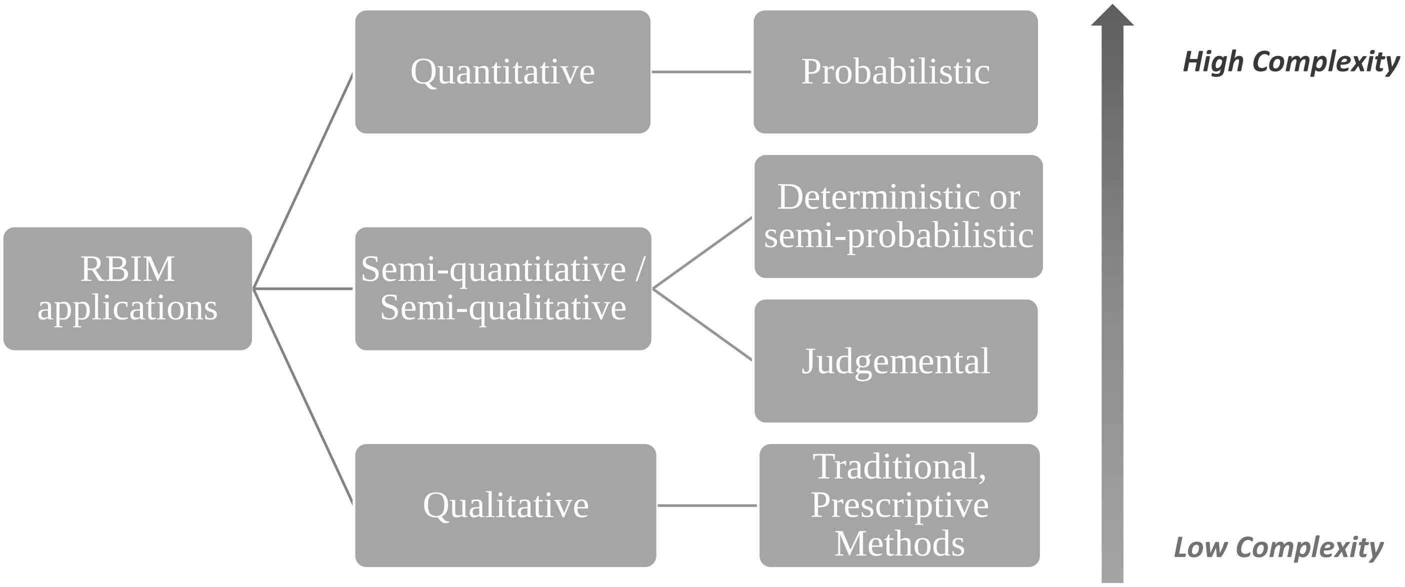


Figure 3: Different Approaches to RBIM

RBIM Approaches

The different approaches to risk-based integrity management are summarised in figure 3. The traditional, prescriptive approach is shown to indicate where it fits in the level of RBIM thinking.

- RBIM approach aims to develop, optimize, and implement an effective and efficient asset integrity management system for all asset types.

- RBIM implementation can be used by the operating companies that own offshore assets to enhance their asset integrity, operate safely, reduce inspection costs, and eliminate the frequency inspection and downtime.

Research Objective and Scope

The objective of this research is to develop an integrity management strategy for the oil and gas offshore jacket platform using RBIM approach.

RBIM approach is carried out to prove that the risk assessment, RBI and RBM methods used in this work are effective in terms of time efficiency and cost as well. This work can be used by the operating companies that own offshore steel structure platforms to enhance their asset integrity, reduce inspection costs and eliminate the frequency inspection.

In this study, the risk-based integrity management strategy is developed using risk assessment methods (hazard and operability study, probabilities of failures assessment and consequences assessment) to provide the needed details and results for risk ranking for both probabilities and consequences. Risk categorization is used in inspection and maintenance prioritization and intervals assigning, which means risk-based approaches (RBI and RBM) are better and more efficient from safety, time, resources and cost perspectives. This can help to decrease the operation downtime, resources time and intrusive inspection and maintenance work on the system that might not be essential to be done on a preventive routine schedule.

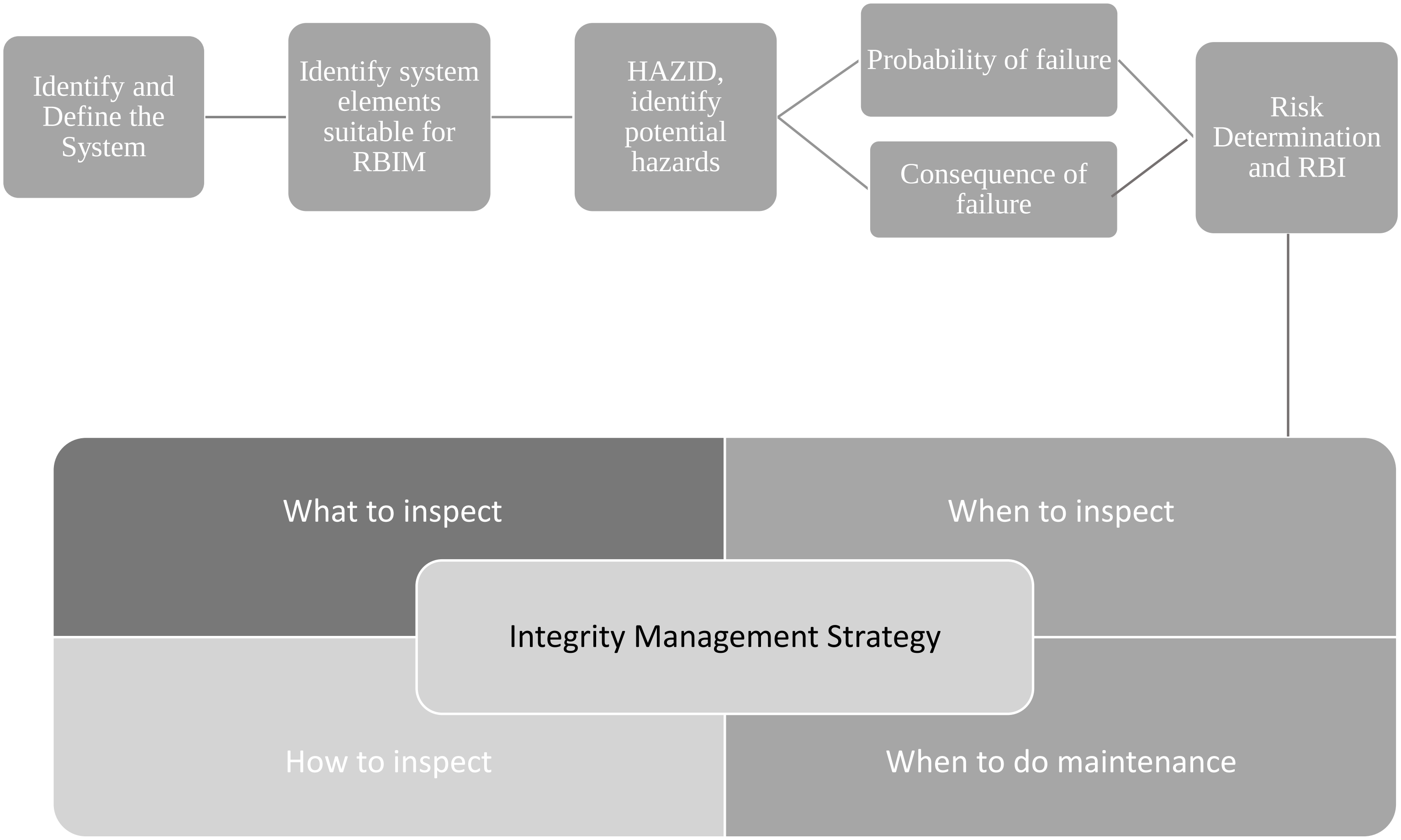


Figure 4: RBIM flow chart

The process of the implementation described in the flow chart in figure (4) is as follow:

1. Identify and define the system, which is oil and gas offshore manned fixed steel structure platform, then identify the elements of the platform structures suitable for the RBIM.
2. Understanding and identifying degradation mechanisms and anomalies affecting the system.
3. Platform safety-critical elements (SCEs) identification to be able to categorize and rank priorities based on criticality to be considered during RBI and RBM process.
4. Hazard identification (HAZID) using a qualitative method Hazard and operability study (HAZOP) to provide a holistic view of hazards, anomalies, possible causes, possible consequences, and what action is required.
5. Risk analysis by applying quantitative risk analysis technique fault tree analysis (FTA) used to calculate and assess the probability of failures, then a qualitative assignment of consequences using engineering judgment and experience in the field.
6. Risk determination and RBI
7. Risk ranking in order to prioritize inspection and maintenance schedule and build an integrity management strategy.

As an outcome of this thesis, we:

1. Identify and categorize the degradation and deterioration mechanisms for the fixed steel structure platforms.
2. Increase and enhance the reliability and integrity of the platform using an appropriate integrity management strategy.

3. Enhance the safety, mitigate and eliminate hazards by decrease nonessential inspection and maintenance works and by decreasing the frequency of these scopes by applying risk-based approaches, consequently, decrease inspection and maintenance cost.
4. Gain an understanding of platform structural risks and rank these according to severity.
5. Identify critical locations or components that should be included in the inspection plan. Further, this study also allows the inspection and integrity team involved in the asset integrity management to provide input concerning the operational criticality of components, which may identify different inspection locations than those driven by routine planned preventive inspection and maintenance.
6. Identify and evaluate variables that may impact structural integrity.
7. Identify potential consequences of damage (i.e., asset/production, people, environment, business)
8. Develop an RBI method and inspection strategies from an evaluation of the risk associated with a platform.
9. Develop an RBM plan based on prioritization of structural anomalies performed using a risk-based approach and Risk Matrix, based on risk evaluation then we proceed with the maintenance plans to optimize maintenance efficiency, cost, and system reliability

CHAPTER 2: Literature Review

The offshore oil and gas platforms are a high-risk operation facility, which is mainly dependant on the capability and integrity of these facilities. In this industry, even a small failure of facilities could cause serious consequences, such as environmental pollution, immediate personnel injuries and long-term health problems, loss of income and reputation, etc. So, asset integrity management and efficient operation are more attractive to the oil producers' companies. Almost every offshore oil and gas asset owner and operator wants to develop an asset integrity management strategy to operate safely, economically, and maintain the reliability of their assets.

In the oil and gas industry, the maintenance costs are 40% of the total costs that are mostly spent on non-essential planned maintenance activities (4). The objective of integrity management is to eliminate the operational risks by implementing an efficient inspection and maintenance plans to reduce the business risk. The high demands of conduct integrity management activities in cost-efficient ways make the management level of assets management continuously search the ways to optimize and improve the maintenance and inspection management. That led to the development of integrity management strategies, which has shifted from time-based preventive approaches to the risk-based approaches, to improve the inspection and maintenance activities planning (5). The risk-based approach could have better decision making to optimize allocate resources to the most important maintenance and inspection activities based on the priorities of risk and resources limitation. That could control the cost of inspection and maintenance activities.

The purpose of this research is to develop a risk-based integrity management tool, built specifically for the offshore steel structure platforms. This tool covers the risk-based inspection and risk-based maintenance approaches for such platform structures to manage asset integrity sufficiently from safety and cost perspectives. In order to develop such an improved integrity management tool, an overview of the different existing risk-based approaches studies was done in industry today was reviewed, the work in (6) development of RBI procedures and proof the efficiency of implementing the RBI which led to the development of new Inspection, Maintenance and Repair (IMR) procedures to be applied to FPSOs. This has encouraged major companies and class societies to adopt Risk-Based Inspection (RBI) as one of the most appropriate procedures for IMR planning of FPSOs. Consequently, the challenge for both parties is to develop and implement RBI methodologies, which guarantee profitability and competitiveness of FPSOs whilst ensuring the required structural integrity throughout the service life. This study only focuses on RBI as the major driver of the facility integrity, but actually, to have a sufficient integrity management strategy, it is better to apply RBM approach as well to eliminate the maintenance activities of such FPSOs. Classification societies and oil producers are aware of these new requirements and are now engaged in the development of RBI, to consolidate the best practices in the form of standard methodologies to be applied by the industry. A method used by Bureau Veritas for risk-based SIM of offshore jacket platforms has been presented in (7). The method presented in (7) method provides risk-based inspection strategies and programs in compliance with the first standard for SIM . The risk assessment method comprises semi-quantitative and quantitative assessment levels (7). Thus, in addition to providing the risk level, it also provides an understanding of that risk. Concerning the quantitative methods, they implement existing approaches for computing the probability of failure (7).

Hazard Identification:

There are now available many methods of hazard identification (HAZID) and techniques preliminary to hazard analysis (8). Such as" Checklists, What if? Analysis, FMEA, HAZOP, Event tree analysis (ETA), and Fault tree analysis (FTA). The Center for Chemical Process Safety has given overviews of these and other methods of hazard identification. A hazard is not always known until an accident occurs (9). It is important to identify the hazards and diminish the risk well in advance of an accident (9).

Hazard and Operability (HAZOP) model

The hazard and operability "HAZOP" study is a prime method for the identification of hazards. HAZOP study is now well established as a prime method for the identification of hazards on process plants. It does, however, make considerable demands in time and effort on the engineering teams involved (8). It has therefore appeared attractive to try to develop computer codes for HAZOP. It is recognized that HAZOP activity is a creative task and developers of such codes have usually been wary of suggesting that their systems could replace HAZOP, preferring instead to indicate that they should be used as aids to, or in advance of, HAZOP (8). The basic idea is to let the mind go free in a controlled fashion in order to consider all the possible ways that operational failures can occur. Before the HAZOP study is started, detailed information on the operation must be available (9). The HAZOP technique is a structured and systematic examination of a product, process, or procedure or an existing or planned system (10). This is a qualitative technique based on the use of guide words that question how design intent or operating conditions may fail to be achieved at each step of the design process or technique. The guide words must always be appropriately selected to the process, which is analysed, and additional guide words can be used. This technique is applied by a multidisciplinary team during a series of meetings where work areas and operations are defined and each of the variables that influence the process are applied to the guide to verify the operating conditions and detect design errors or potentially abnormal operating condition (10).

Risk Analysis

Risk analysis uses information and data to identify initiating events, causes, and consequences of these events, and then expresses risk. The information and data includes expert experience, engineering team experience, design data, historical data, and operation procedure. All together help in identifying and estimating the probabilities of failures and possible consequences of undesirable events (11).

Risk analysis intends to provide likely information to support decision making. By implementing risk analysis, the decision-maker can know different concerns and can choose the most effective and efficient solutions from cost and safety perspectives to reduce the risk to as low as reasonably practicable (ALARP) level (11).

The results of risk analysis are screened based on the combination of the probability of failures and the potential consequences of failures using a risk matrix. The analysis could be qualitative, quantitative, or semi-quantitative (semi-qualitative) based on the requirement of results and the available information:

- The qualitative analysis mainly based on experts' judgment and experience.
- The quantitative analysis has a deeper analysis using logic models to simulate the probability and consequences.
- The semi-quantitative way is to both use the descriptive information and simulation models to present the risk.

The commonly used methodologies of risk analysis are event tree analysis (ETA), fault tree analysis (FTA), bow-tie, hazard and operability analysis (HAZOP), root cause analysis (RCA) and failure mode, effects, and criticality analysis (FMECA),

Risk Concept

Risk is used to identify the danger that undesirable events occurs to human, environment, or business (12). Another definitions of risk are: Risk is "the considered expected loss or damage associated with the occurrence of a possible undesired event"(13), risk is a combination of the probability of events happening within a time period and the consequences related to that event (14). Risk can be identified in qualitative and quantitative ways. When the risk is identified quantitatively, we use the probability and consequence equation:

$$\textbf{Risk} = \textbf{Probability} \times \textbf{Consequence}$$

The risk is unknown as the probabilities and consequences of an undesirable event are unknown. Both must be identified through systematic risk analysis. The risk analysis is is done by first identifying hazards. Hazard is anything that is a potential source of harm related to human injury, damage to the environment, damage to property or loss in production (15).

Uncertainty and Sensitivity Analysis

Uncertainty Analysis

In order to assess uncertainties in risk analyses, an uncertainty analysis is much used and recommended. To perform uncertainty analysis, there are a quantitative method and qualitative or semi-quantitative method (16).

The semi-quantitative approach to uncertainty analysis is often considered as a simplified method compared to the quantitative approach. The results are expressed qualitatively, and therefore provide a more thorough explanation of what the uncertainty means in relation to the safety and other relevant aspects of the risk analysis.

The qualitative approach, on the other hand, often reveals a certain probability distribution as a description of the uncertainty.

The added information from the uncertainty analysis helps create a descriptive picture of the risks involved, which includes knowledge of both, more and less, certain information. Being aware of the level of uncertainty entails the information that lies in the awareness and knowing the weaknesses and facts one does not have the basis of finding. If this is accepted and acknowledged, specific boundaries of future events are not set, i.e. one does not exclude uncommon or unique events. This further involves being better equipped to handle prospective surprises as well as basing all decisions on a more realistic basis (16).

The uncertainty analysis is an assessment of the uncertainty factors connected to the Quantitative Risk assessment (QRA) model, and it covers the following main tasks:

A) Identification of uncertainty factors
B) Assessment and categorization of the uncertainty factors with respect to the degree of uncertainty
C) Summarisation of the uncertainty factors' importance

Sensitivity Analysis

Sensitivity analysis is performed to prevent the likelihood that minor changes to assumptions and/or data will change the conclusions of the risk assessment. Outcomes from the sensitivity analysis present how the results depend on different conditions and assumptions. The sensitivity analysis highlights the importance of significant quantities and can provide a basis for determining uncertainty (17).

In quantitative risk assessment, sensitivity analysis is required in accordance with regulations to demonstrate the robustness of the risk model and are as such an illustration of the uncertainties (18).

The sensitivity analysis is a bit like the uncertainty analysis in the way that assumptions and probable variations concerning calculations are assessed. The sensitivity analysis shows the effect of different input parameters/values, which allows one to see how sensitive the calculations are to changes in assumed input parameters and consequently realize the level of importance of assumptions.

This thesis presents a method for risk assessment, RBI, and RBM and inspection plan development as part of the risk-based integrity management of offshore fixed steel structure platforms. The RBIM approach provides a risk assessment for the platform's topside and underwater structure, identifying the platform elements susceptible to various degradation mechanisms, in the meantime classifying the platform safety-critical elements. This is very important in the phase of risk ranking; also, a HAZID study is applied for the platform's structural components (e.g. Helideck structure). The risk assessment uses semi-quantitative/semi-qualitative approach to assign the probabilities of failures and consequences and this will be respectively quantitative for the probabilities of failures using fault tree analysis model and qualitative assessment to assign and rank the consequences. The RBIM method then used at a high level to perform relative risk ranking of platform elements in order to identify the most at risk and which require more inspection focus or at the unit level to define inspection interval and general inspection requirements, which allows, if required, local inspections' scope to be defined. The quantitative method involves a probabilistic assessment method to support RBI study. The inspection and maintenance strategy and program, developed by the method presented in this thesis, are focused on the routine topside and underwater inspections, and are based on the comprehensive risk analysis implemented for the integrity management of fixed offshore platforms.

CHAPTER 3: Identify System and Elements Susceptible to Degradation Mechanism and Failure

System: Fixed steel structure platform (Jacket platform – 4 legs)

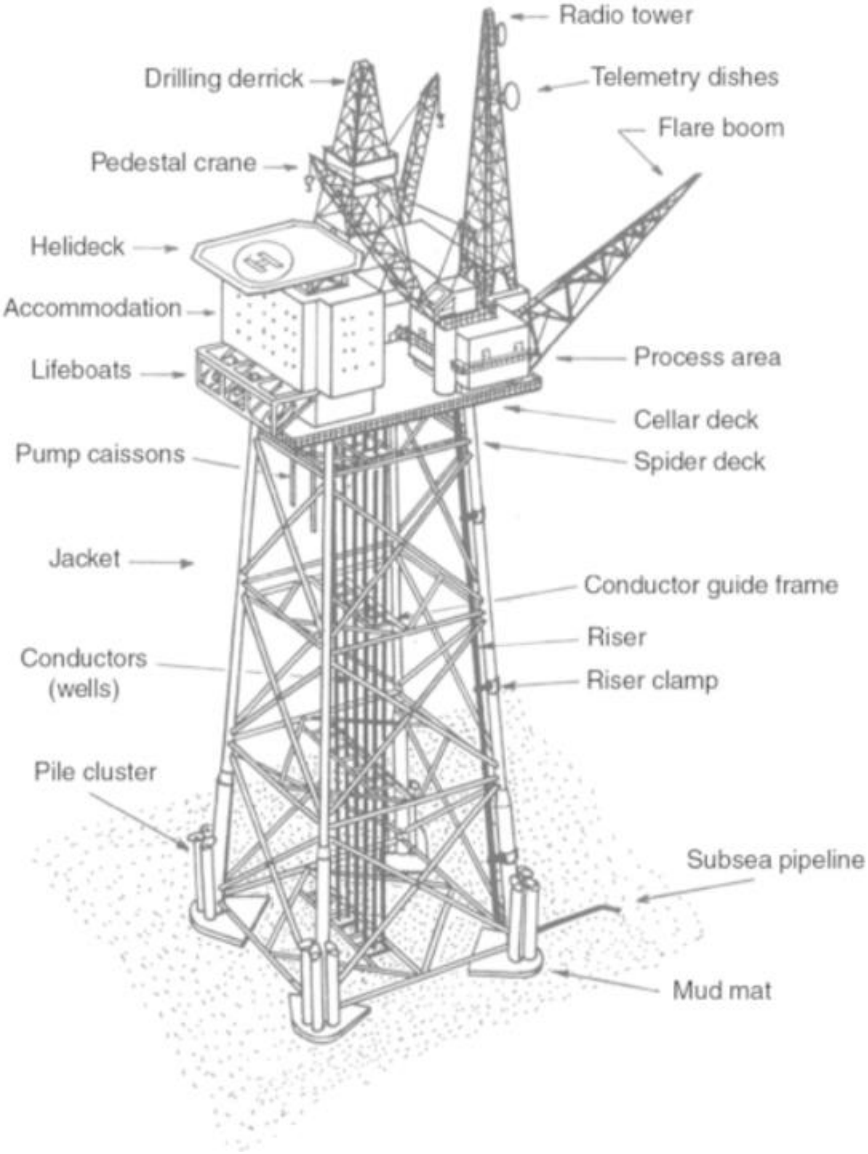


Figure 5: Typical offshore fixed steel structure platform (19)

Platform elements susceptible to degradation and failure:

Topside Structures:

(platform decks, pedestal cranes, helideck, flare boom, derrick structures, lifeboats station, living quarter structure, walkways, stairs, handrails, gratings) are shown in figure 5.

Underwater Structures:

(Jacket legs, Risers, Anodes, Piles, spools, pipelines) are shown in figure 5.

Degradation mechanisms and anomalies, causing failure of structures as in (20):

- Overstressed primary steel member leading to significant damage and repair
- Coating failure and corrosion leading to damage in primary/secondary member
- Deterioration of personnel access structure (e.g., walkways, stairs, handrails, etc.) resulting in injury to personnel
- Cracking in primary steel member leading to significant damage and repair
- Cracking in secondary steel member leading to significant damage and repair
- Overstress damage indicated by dents, buckles or distortion to plates or brackets
- Coating degradation, corrosion on structural members or plating
- Rust staining from welds in coated areas may indicate weld failure
- Debris lodged on structural members, which could damage coatings or influence corrosion
- Loose or otherwise damaged pipe clamps or other appurtenances

- Loose structural cladding
- Corrosion – can be due to loss of corrosion prevention barriers such as coatings or anodes
- Fatigue – crack propagation and eventually fracture of fatigue sensitive locations.
- Leaks or flooding and Pitting
- Coating breakdown or damage
- Dropped objects (laydown area)
- Poor drainage (pooled water)
- Structural overload, Construction defects
- Local corrosion at welds (pitting, grooving, etc.)
- Loading from rotating equipment (pumps)

Safety-Critical Elements identification

In order to safely manage the structural integrity of the offshore platforms, the operator must identify all structural elements that may represent sources of risk as the platform ages. Those risks can then be managed and/or reduced through proper integrity management strategy

Safety critical elements (SCE) are components and systems of an installation that directly

impede or restrain the effect of an incident, including a pollution event. SCE identification have a key role in risk categorization and ranking, knowing the SCEs of the system ensures adequate inspecting, testing and maintenance programs are in place, and appropriately prioritized. Table 1 identifies the components of each of these SCEs in detail.

Jacket platform structure Safety Critical Elements		
No.	**Safety Critical Element Title**	**Components of Safety Critical Element**
1	Critical Topside structure	- Cranes and lifting equipment structure and support - Flare boom structure - Hydrocarbon retaining equipment supports - Blast and fire wall support structure - Relief system supports - Telecoms tower supports - Open drain system structures (drain boxes) - Critical seawater system supports - Evacuation equipment supports (lifeboats, life rafts) - Helideck structure and supports - Escape and evacuation route support - Dropped object protection structures - DES structure (BOP support, including skid rails and supports) - Topsides/underwater jacket connection points
2	Critical underwater structure	- Subsea Structures - Supports for Risers - Spools - Piles

Table 1: Identification of SCEs

CHAPTER 4: Hazard Identification (HAZID)

HAZOP analysis for oil and gas offshore jacket platform

The system, subsystem and nodes for an offshore jacket platform structure HAZOP analysis is shown in Table 2

System	Sub-system	Nodes
Offshore Jacket Platform above and under water structures	Offshore Jacket Platform structures susceptible critical elements	Decks Primary & Secondary steel members Personnel access structures Pipes racks and clamps Pedestal cranes Drilling Derrick structures Helideck structures Lifeboat stations Living quarter structures Jacket legs Risers Anodes Piles Spools Subsea pipelines

Table 2 : Identification of system, subsystem, and nodes for HAZOP analysis

Hazard and Operability (HAZOP) study

The HAZOP study presented in Table 3 identifies the potential hazards and operability issues in the steel structure platform and identifies anomalies, possible causes, possible consequences, and actions required.

System:	Offshore Jacket Platform above and under water structures			
Subsystem:	Offshore Jacket Platform structures degradation mechanism			
Study Node	**Anomaly**	**Possible causes**	**Possible consequence**	**Action required**
Decks Primary & Secondary steel members	Cracks	-Fatigue, loads -Collided object	-Crack propagation -Steel member failure -Structure damage	-GVI of structure for signs of overstress -GVI of welded connections for signs of cracked connections -CVI/NDT required at any anomalous location based on predicted damage
	Coating degradation	- Surface corrosion - Paint failure	-Excessive corrosion lead to steel structure failure	-GVI of structure for signs of overstress, coating breakdown and excessive corrosion -CVI/NDT required at any anomalous location based on predicted damage
	Dents	- Collided objects - High stresses	-Structure damage	-GVI of structure for signs of dents, damage

				-CVI/NDT required at any anomalous location based on predicted damage
Living quarter & Personnel access structures	Cracks	-Fatigue, loads -Collided object	-Same as above -Deterioration of personnel access structure (e.g., walkways, stairs, handrails, etc.) resulting in injury to personnel	-GVI of personnel access structures (e.g., walkways, stairs, handrails, etc.) -CVI of exterior stairwell cantilevered support connections -CVI welded/bolted bottom supports and elevated supports for each external stair tower -CVI LQ support structure connection -GVI cladding beneath living quarters
	Corrosion of dissimilar metal connections	-Coating Failure	-Excessive corrosion -Steel surface failure -Galvanic corrosion of dissimilar metal	-GVI of structure for signs of overstress, coating breakdown and excessive corrosion -CVI interface connections between dissimilar metals for deformation, corrosion, and rust from below

			connections of personnel access structure resulting in injury to personnel -Coating failure and corrosion requiring repair	-GVI to ensure no leaks onto structural members -CVI/NDT required at any anomalous location based on predicted damage
	Deformation & dents	- Collided objects - High stresses	-Structure damage	-GVI of structure for signs of dents, damage -GVI of drains to ensure they are clear and providing proper drainage and prevent standing water -CVI/NDT required at any anomalous location based on predicted damage
	separated members	-Collision -Structure damage	-Deterioration of personnel access structure (walkways, stairs, handrails, etc.)	-GVI of personnel access structures (e.g., walkways, stairs, handrails, etc.) -CVI of exterior stairwell cantilevered support connections

			resulting in injury to personnel	-CVI welded/bolted bottom supports and elevated supports for each external stair tower -GVI to ensure no leaks onto structural members -CVI/NDT required at any anomalous location based on predicted damage
	loose cladding fasteners	-Structure vibration -Lack of maintenance	-Detachment leading to significant damage and repair and resulting in injury to personnel	-CVI accessible areas of flanged connection between dissimilar metals along the LQ perimeter
	Damaged handrails	- Collided objects	-Deterioration of personnel access structure resulting in injury to personnel	-GVI of personnel access structures (e.g., walkways, stairs, handrails, etc.)
	Damaged walkways grating	- Dropped objects - Fabrication deficiencies	-Deterioration of personnel access structure resulting	-GVI of personnel access structures (e.g., walkways, stairs, handrails, etc.)

			in injury to personnel	
Pipes racks and clamps	Cracks	-Fatigue, loads, Collided object	-Detachment of pipes leading to damage and repair	-GVI of pipe racks for mechanical damage and welds -CVI/NDT required at any anomalous location based on predicted damage
	Corrosion	-Coating failure -Exposed metal	-Excessive corrosion lead to steel structure failure	-GVI of structure for signs of overstress, coating breakdown and excessive corrosion -CVI/NDT required at any anomalous location based on predicted damage
Pedestal cranes	cracks	-Fatigue, loads, Collided object, stresses	-Cracking in crane pedestal support bracing leading to significant damage and repair	-GVI of welded connections for signs of cracked connections -CVI/NDT required at any anomalous location based on predicted damage
	Coating degradation	-Corrosive environment -Paint failure	-Coating failure and corrosion of boom rest or brace	-GVI of general coating condition assessment

			connections leading to loss of boom rest use and repair of brace	-GVI to identify signs of corrosion and steel wastage and gross structural damage -CVI of Crane pedestal framing connections for signs of overstress, coating breakdown and excessive corrosion -CVI crane boom rest framing connections for signs of overstress, coating breakdown and excessive corrosion -CVI/NDT required at any anomalous location based on predicted damage
	Wire ropes deterioration	- Harsh operations - Service lifetime	-Wire ropes cutting leading to loss of crane availability	-Annually wire rope inspection as per API 9A and applicable codes and standards.
Drilling Derrick structures	cracks	-Fatigue, loads -Collided object	-Cracking in primary/secondary steel member leading to	-GVI of structure for signs of overstress, coating breakdown and excessive corrosion

			significant damage and repair	-GVI of drains to ensure they are clear and providing proper drainage -GVI of personnel access structures (e.g., walkways, stairs, handrails, etc.) -CVI of support structure and connections for rotary table, deadline anchor, mouse hole catwalk machine, and BOP handling system
	Loose bolts	-Structure vibration -Lack of tightness	-Detachment leading to significant damage and repair and resulting in injury to personnel	-CVI/NDT required for drilling rig deck structure (aside from derrick feet) based on low predicted damage -GVI of welded connections for signs of cracked connections -CVI HP pipe support structure connections -CVI of Derrick pedestal welds (NDE as applicable)

				-CVI of BOP handling system welds -CVI drawworks support structure welds -CVI of crane pedestal framing connections
Helideck structures	cracks	-Fatigue, loads, Collided object	-Cracking in helideck steel support structure leading to damage and repair	-GVI of welded connections for signs of cracked connections -GVI of structure for signs of overstress -GVI of personnel access system -CVI/NDT required for helideck based on low predicted damage
	Painting failures	-Corrosive environment	-Corrosion of helideck support structure member leading to significant damage and repair	-GVI of structure for signs of overstress, coating breakdown and excessive corrosion including planking landing area Survey position, orientation, coloring, and dimensions of all helideck markings for damage due to repeated use

	SafetyNet failure	-Harsh weather -High winds	-Detachment leading to significant damage and repair and resulting in injury to personnel	-CVI safety netting and connections (bolts and reinforcement clamps)
Lifeboat stations	Cracks	-Fatigue, loads, Collided object	-Cracking in survival craft support frame leading to significant damage	-GVI survival craft support frame -CVI survival craft support frame connections to Lower Deck -CVI life raft service rail framing and connections -CVI foundation, davit arm and keel supports, sheave houses, and escape chute connections -CVI winch foundation framing members and connections -CVI survival craft support frame connections
	Coating degradation	-Corrosive environment -Paint failure	-Excessive corrosion lead to steel structure failure	-GVI of welded connections for signs of cracked connections

Jacket legs	Marine growth	-Marine fouling organism	-Under water structure surface corrosion - Paint and coating failure	-ROV survey for underwater structure anodes inspection
	Exposed structure	-Surface corrosion	-Coating failure and Thickness losses	-ROV UT measurements for wall thickness nominal measurements
	Accidental load boat impact	-Boat or barges collision	-Damage of boat landing and barge pumpers	-ROV GVI on under water boat landing fenders and structure
Risers	Coating degradation	-Corrosive environment -Paint failure	-Wall thickness losses	-ROV UT measurements for wall thickness nominal measurements
	leaks	-cracks	-Oil Pollution -Loss of production	-ROV survey for any cracks, leaks or pollution
Spools	leaks	-cracks	-Oil Pollution -Loss of production	-ROV survey for any leaks may lead to loss of production
	Coating degradation	-Corrosive environment -Paint failure	-Wall thickness losses	-ROV UT measurements for wall thickness nominal measurements

Piles	Soil erosion	-Soil erosion at seabed near platform	-Platform structure vibration and fatigues	-Structure vibration monitoring -Piles GVI using ROV or divers

Table 3 : Hazard and Operability (HAZOP) analysis

The objective of the above HAZOP study presented in Table 3 is to identify potential hazards operability issues in the platform and to identify anomalies, possible causes, possible consequences, and actions required, which can estimate the risks in accordance with the risk assessment. The qualitative HAZOP analysis technique uses a systematic approach. Hence, by this analysis, we already can use it in probabilities of failure and consequences assessment. Consequently, RBI analysis and RBIM strategy, and it allows selecting the most important preventive recommendations for implementation.

CHAPTER 5: Risk Analysis (PoF and CoF Assessment)

Quantitative Probability of Failure (PoF) Assessment

There are several approaches to a quantitative Probability of Failure (PoF) analysis. An example is taking a probabilistic approach, where failure data or expert judgment are used to calculate a PoF. A different approach is used when there is a lack of historical failure data on the specific system of interest. In this situation, the general industry, operating company, or manufacturer failure data are used. The applicability of these general data is evaluated and judged. Such adjustments to general values may be made by knowledgeable personnel for that system to account for the potential deterioration that may happen in the system and the effectiveness of inspection performed. (14)

Case Study: Probability risk assessment for jacket platform structure failure using (FTA)

The platform type considered in this study is a four-legged fixed type oil platform. It is a four-legged jacket platform and consists of a steel tubular space frame. The topside structure consists of a lower deck, cellar deck, main deck, upper deck, helideck, living quarter, drilling derrick and pedestal crane. The jacket legs are horizontally braced with tubular members at all levels. In the vertical direction, the jacket is X-braced with tubular members. The platform is permanently fixed on four piles.

The model data and assumptions in Table 4 are based on a knowledge base, available information, and experience judgment in the field

Event	Assumption
PoF due to an earthquake (21)	0.0001554
PoF due to fire/explosion based on the worst-case scenario in (22)	0.25
PoF in drilling derrick Module structure	0.08
PoF due to boat/Barge collision (23)	0.01
Structures drain system PoF due to blockage /leaks of outboard drains	0.11
Helideck structure and supports PoF due to Fatigue, loads cracks	0.017
PoF due to soil erosion at seabed near platform	0.019
PoF due to platform structure vibration and fatigues	0.007
PoF due to cracks and damages caused by dropped objects	0.13
PoF because of legs steel degradation due to Marine growth corrosion effect	0.11
PoF of Cathodic protection system	0.09
PoF of bracing steel degradation due to Marine growth corrosion effect	0.13
PoF due to Surface corrosion on exposed areas	0.085
PoF of Structure cracks due to Fatigue, loads	0.017
PoF of Structure damage due to excessive corrosion	0.07
PoF of pipe racks and clamps due to Fatigue, loads, cracks	0.13
PoF because of detachment of pipes leading to damage due to Excessive vibration	0.16
PoF damage due to Fatigue, loads, Collided object	0.068
PoF of cracking in survival craft support frame leading to significant damage	0.078
PoF because of degradation due to environmental conditions	0.06
PoF because of degradation due to exceeding Service lifetime hours	0.08
PoF of wire ropes cutting due to lack of inspections and maintenance	0.27
PoF because of cracks due to Fatigue, loads, stresses	0.089
PoF because of cracks due to Coating failure and corrosion of boom rest or brace connections	0.019

Table 4 : FTA model PoF data and assumptions

	Name	Description	Gate/Event	Probability	Reliability
1	BE1	Failure due to earthquake	Basic event	0.000155	0.99984
2	BE2	Failure due to fire/explosion	Basic event	0.25	0.75
3	BE3	Failure in drilling derrick Module structure	Basic event	0.08	0.92
4	BE4	Failure due to boat/Barge collision	Basic event	0.01	0.99
5	BE5	Structures drain system failure due to blockage /leaks of outboard drains	Basic event	0.11	0.89
6	BE6	Helideck structure and supports failure due to Fatigue, loads cracks	Basic event	0.017	0.983
7	BE7	Soil erosion at seabed near platform	Basic event	0.019	0.981
8	BE8	Platform structure vibration and fatigues	Basic event	0.007	0.993
9	BE9	Soil erosion at seabed near platform	Basic event	0.019	0.981
10	BE10	Cracks, damages due to dropped objects	Basic event	0.13	0.87
11	BE11	Legs steel degradation due to Marine growth corrosion effect	Basic event	0.26	0.74
12	BE12	Failure due to Surface corrosion on exposed areas	Basic event	0.18	0.82
13	BE13	Cathodic protection system failures	Basic event	0.09	0.91
14	BE14	Bracing steel degradation due to Marine growth corrosion effect	Basic event	0.26	0.79
15	BE15	Failure due to Surface corrosion on exposed areas	Basic event	0.18	0.82
16	BE16	Cathodic protection system failures	Basic event	0.09	0.91
17	BE17	Structure cracks due to Fatigue, loads	Basic event	0.017	0.983
18	BE18	Structure damage due to excessive corrosion	Basic event	0.13	0.87
19	BE19	Failure of pipe racks and clamps due to Fatigue, loads, cracks	Basic event	0.24	0.73
20	BE20	Detachment of pipes leading to damage due to Excessive vibration	Basic event	0.31	0.69

21	BE21	Damage due to Fatigue, loads, Collided object	Basic event	0.068	0.932
22	BE22	Cracking in survival craft support frame leading to significant damage	Basic event	0.17	0.83
23	BE23	Degradation due to environmental conditions	Basic event	0.06	0.94
24	BE24	Degradation due to exceeding Service lifetime hours	Basic event	0.08	0.92
25	BE25	Wire ropes cutting due to lack of inspections and maintenance	Basic event	0.6	0.4
26	BE26	Cracks due to Fatigue, loads, stresses	Basic event	0.15	0.85
27	BE27	Cracks due to Coating failure and corrosion of boom rest or brace connections	Basic event	0.22	0.78
28	Gate 1	Failure in foundation	OR-Gate	0.0026	0.997
29	Gate 2	Failure in jacket structure	OR-Gate	0.4631	0.536
30	Gate 3	Failure in topside structure	OR-Gate	0.4977	0.502
31	Gate 4	Failure due to pedestal cranes collapse	OR-Gate	0.4358	0.564
32	Gate 5	Failure in Piles	AND-Gate	0.0001	0.999
33	Gate 6	Failure in Mud mat	AND-Gate	0.0024	0.997
34	Gate 7	Jacket Legs failures	OR-Gate	0.2589	0.741
35	Gate 8	Jacket Bracing failures	OR-Gate	0.2755	0.724
36	Gate 9	Failure on primary / secondary deck structure	OR-Gate	0.0858	0.914
37	Gate 10	Piping system failure	OR-Gate	0.2692	0.730
38	Gate 11	Evacuation equipment supports failure (lifeboats, life rafts)	OR-Gate	0.1406	0.859
39	Gate 12	Failure due to Wire ropes deterioration	OR-Gate	0.3686	0.631
40	Gate 13	Failure due to Cracking in crane pedestal support bracing	OR-Gate	0.1063	0.893

Table 5 : FTA probability data for Fixed Steel Structure Platform failure.

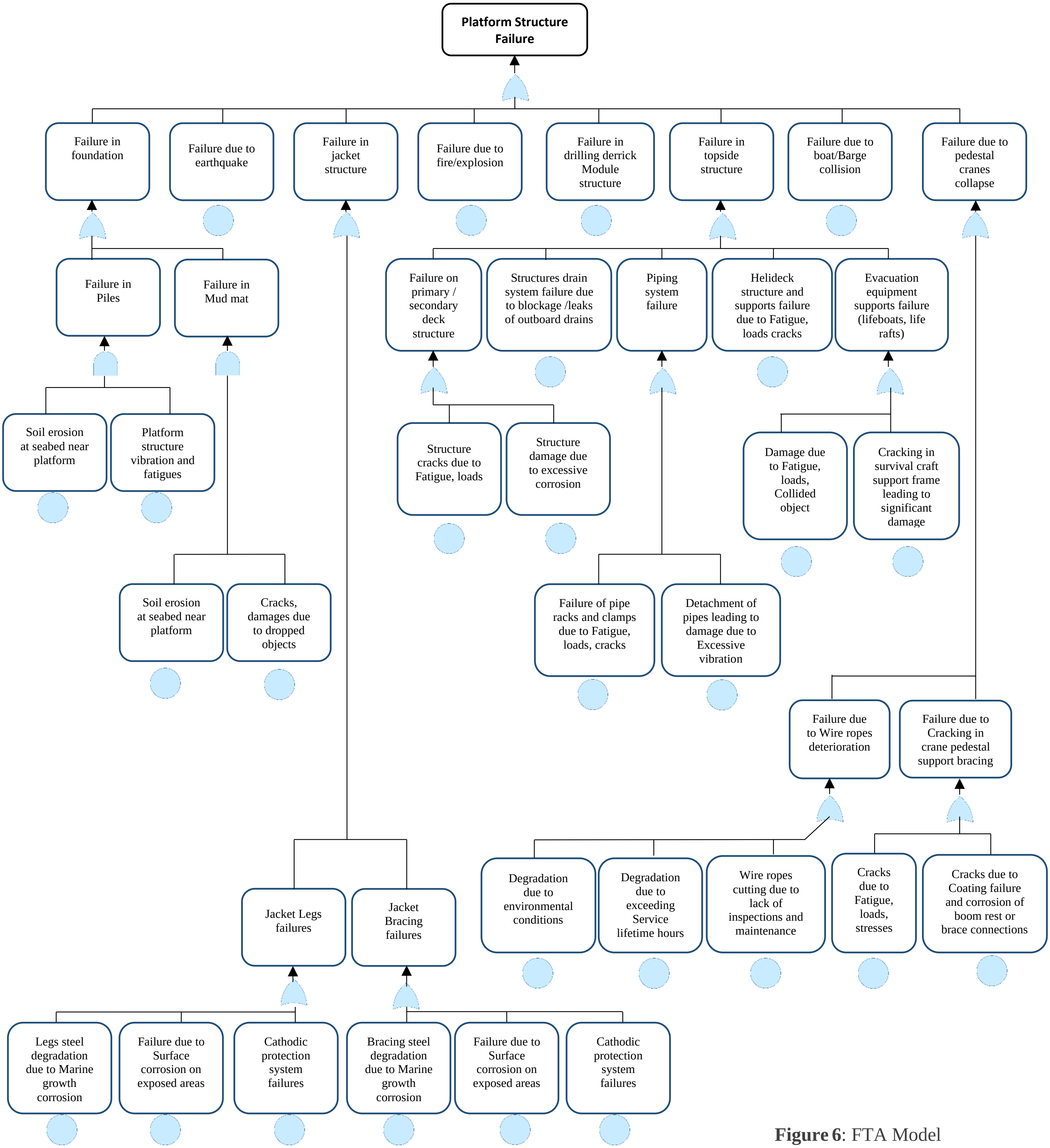
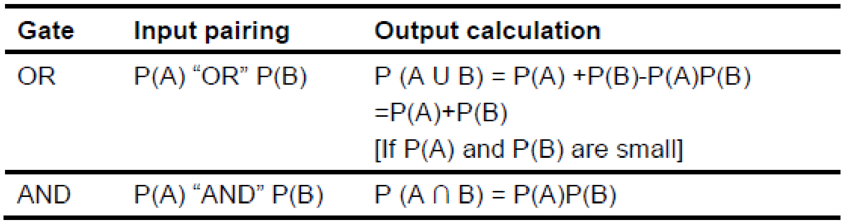
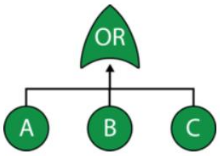


Figure 6: FTA Model

Failure Probabilities calculation APPENDEX - A



Gate	Input pairing	Output calculation
OR	P(A) “OR” P(B)	P (A U B) = P(A) +P(B)-P(A)P(B) =P(A)+P(B) [If P(A) and P(B) are small]
AND	P(A) “AND” P(B)	P (A ∩ B) = P(A)P(B)



$$R_{System} = R_A \cdot R_B \cdot R_C$$

The outcome of analysis:

Based on the quantitative analysis completed using FTA diagram depicted in figure 6 and the results of the probabilities of failure calculation in Table 5, We can divide the platform structure element to high risk, moderate risk, and low risk. This means the most critical SHE and business equipment on the facility are assigned the highest failure probabilities. In this analysis we identify the elements having high risk rank such as (passive fire protection system PFP, lifting equipment, pedestal cranes, Helideck, lifeboat station and living quarter) then moderate risk such as (jacket legs and bracing degradation, pipe racks and clamps cracks and fatigues, personnel access structure, Pipes racks and clamps, Drilling module structures, evacuation equipment) then low risk elements (platform primary and secondary steel structure, anodes, underwater structures and subsea pipelines, earthquakes).The outputs we have from this analysis ise used along with CoF results to help assign RBI matrix and integrity management plan.

Model uncertainty and sensitivity analysis

The probabilities in PoF assessment are knowledge-based (subjective) and used as a measure of uncertainty and sensitivity. The knowledge-based understanding of a probability, P, is necessary to simplify the analysis and calculations of PoF, as well as directly assessing the uncertainties.

Uncertainty and sensitivity analysis seek to produce more desirable outcomes, by providing insights about the uncertainties relating to possible consequences of a decision and reducing these uncertainties. In QRA, most approaches to figure out uncertainty look to be based on the belief that uncertainty relates to the calculated probabilities and expected values.

The next step is to rate all uncertainties. Degree of uncertainty is categorised in the Table 6 by one or more of the following descriptions as suited to the situation.

Uncertainty	Description
High	- The data not available, or unreliable - The assumptions represent strong simplifications - There is lack of agreement/consensus among experts - The events involved are not well understood; degradation models are non-existent or known/believed to give poor predictions
Medium	- Some reliable data are available - The assumptions are somewhat reasonable

	- There are variations in the consensus of experts - The events involved are well understood, but the degradation models used are simple/crude
Low	- Much reliable data available - The assumptions are very reasonable - There is broad agreement/consensus among experts - The events involved are well understood; the degradation models used are known to give predictions with the required accuracy

Table 6 : Degree of uncertainty (16)

For the sensitivity analysis similar categorization to be performed as shown in following Table 7.

Sensitivity	**Description**
High	- Relatively small changes in base case values needed to alter the outcome (e.g. exceeded risk acceptance criterion) - High degree of uncertainty
Medium	- Relatively large changes in base case values needed to alter the outcome - Medium degree of uncertainty
Low	- Unrealistically large changes in base case values needed to alter the outcome - Low degree of uncertainty

Table 7: Degree of sensitivity (16)

The uncertainty- and sensitivity factors' grading (low, medium or high) are scores of how significant the particular components and events are in relation to the entire system PoF assessment.

The uncertainty factors found in the assumption that the jacket platform failure data could be varied depending on operation, service and environmental conditions and asset condition.

Determination of uncertainty and sensitivity degrees:

A) As shown in Table 8 Probabilities data assumptions have a Low degree of uncertainty as data obtained form (21), (22), (23). Degree of sensitivity is also Low.

Uncertainty factor	Degree of Uncertainty	Degree of Sensitivity
PoF due to earthquake	L	L
PoF due to fire/explosion	L	L
PoF due to boat/Barge collision	L	L

Table 8: Summarized degree on uncertainty and sensitivity (L)

B) Probabilities data assumptions have a Medium degree of uncertainty and sensitivity as a data assumption are somewhat reasonable, the degree of uncertainty in this case judged to be Medium due to limited amounts of data as presented in Table 9.

Uncertainty factor	Degree of Uncertainty	Degree of Sensitivity
PoF in drilling derrick Module structure	M	M
Structures drain system failure due to blockage /leaks of outboard drains	M	M

Helideck structure and supports failure due to Fatigue, loads & cracks	M	M
PoF due to platform structure vibration and fatigues	M	M
PoF because of legs steel degradation due to Marine growth corrosion effect	M	M
PoF due to Surface corrosion on exposed areas	M	M
probability of Cathodic protection system failures	M	M
PoF of bracing steel degradation due to Marine growth corrosion effect	M	M
PoF of Structure cracks due to Fatigue and loads	M	M
PoF of Structure damage due to excessive corrosion	M	M
PoF of pipe racks and clamps due to Fatigue, loads, cracks	M	M
PoF because of detachment of pipes leading to damage due to Excessive vibration	M	M
PoF of cracking in survival craft support frame leading to significant damage	M	M
PoF because of degradation due to environmental conditions	M	M
PoF because of degradation due to exceeding Service lifetime hours	M	M
PoF of wire ropes cutting due to lack of inspections and maintenance	M	M
PoF because of cracks due to Fatigue, loads, stresses	M	M
PoF because of cracks due to Coating failure and corrosion of boom rest or brace connections	M	M

Table 9: Summarized degree on uncertainty and sensitivity (M)

C) Probabilities data assumptions have a High degree of uncertainty due to lack of documentation for sea bottom conditions and soil erosion at seabed. The degree of sensitivity is judged to be High because a probable sea bottom condition can potentially lead to cracks in the piles and foundation. And similar exposure to dropped objects have a High degree of uncertainty, the degree of sensitivity is also High because the unknown circumstances may lead to dropped or collided objects as shown in Table 10.

Uncertainty factor	**Degree of Uncertainty**	**Degree of Sensitivity**
PoF due to soil erosion at seabed near platform	H	H
PoF damage due to Fatigue, loads caused by Collided object	H	H
PoF due to cracks and damages caused by dropped objects	H	H

Table 10: Summarized degree on uncertainty and sensitivity (H)

The analysis is established as an addition to the risk assessment model in order to implement all uncertainties in relation to assumptions and simplifications in the risk prioritization and categorization and accordingly the final RBIM strategy consideration.

All assumptions, simplifications, etc. made in the previous sections should by this phase have been noted, and hence be of significant attribution when identifying the uncertainty factors.

Consequence of Failure (CoF) Assessment

The consequences assessment of platform structure can include: impact on public safety, employee safety, the environment, business, and direct and indirect financial costs. The focus of any RBI program applied to Oil and Gas platforms structures must be safety driven and cost efficient. Although the other consequences are undoubtedly significant, they must not be given higher importance than safety. As well, the importance of safety must not be diluted due to the inclusion of other consequences in an RBI program.

As a minimum, the following factors must be considered for each failure scenario identified during the consequence assessment:

- Expected failure modes – coating degradation, surface corrosion, crack, missing components, loose bolts, etc.
- Frequency and density of employee population,
- Process fluid properties (with respect to flammability, toxicity, exposure limits and reactivity),
- Potential for fatality or knockdown
- Potential of collapse.
- Potential for explosion and fire
- Environmental impact.

The outcome of this consequence assessment should be considered when determining risk (see Risk Determination below).

It is useful to assess the consequences of failure in both mitigated and unmitigated states. This will allow for a determination of the effectiveness and reliability of the mitigation used and may highlight other forms of mitigation that would be more beneficial.

For each failure mode identified, it is necessary to develop a credible consequence scenario arising from the anomalies could lead to failure. This limiting scenario should include the events that lead to inspect or repairing the equipment to meet its performance requirements. Examples of failure modes resulting in consequence scenarios are as follows:

- Cracking in primary steel member leading to significant damage and repair
- Deterioration of personnel access structure (e.g., walkways, stairs, handrails, etc.) resulting in injury to personnel
- Coating failure and corrosion leading to damage in primary/secondary member

There are four categories of consequences that need to be assessed for each credible risk scenario: SHE (Safety, Health and Environmental) consequences, and business/ financial consequences, crucial consequences, Non-Crucial consequences.

<u>Category I:</u> “SHE consequence” The evaluation of SHE consequences involves identification of the hazards present due to anomalies and findings within inspections. These are anomalies captured during inspections that need to be addressed immediately if the anomaly has a high probability of causing a failure; they pose a large risk to safety.

<u>Category II:</u> “Business/Financial consequence” Business consequences are estimated based on anomalies/findings captured during inspections that need to be addressed as soon as possible as a failure could lead to lost margin (or production) costs, shutdown, slowdown,

off-spec product, repair costs and loss of customer goodwill. The consequences should be estimated separately for each of the following:

- Maintenance/repair costs to restore the required level of structure integrity
- Loss of profit margin (or production) during a platform shutdown or turnaround

Category III: "Crucial consequence" Crucial consequences are estimated based on anomalies/findings captured during inspections that need to be addressed but do not require immediate attention. Anomalies/findings can be monitored in frequency basis on upcoming inspections to determine the degradation class and when action needed for these anomalies.

Category IV: "Non-Crucial consequence" Non-Crucial consequences are estimated based on anomalies/findings captured during inspections that do not cause a risk to business, structural integrity or safety.

Qualitative Consequences Analysis

A qualitative approach involves identification of the system elements, and the risks present as a result of operating conditions. Based on expert knowledge and experience, the consequences of failure (safety, health, environmental and financial impacts) can be estimated for each system element (14).

For this approach, a consequences category (very high, high, moderate, or low) is typically assigned for each element in the system.

The following Table 11 shows the consequence of failure for the anomalies found on steel structure platform

Undesired Event (Anomaly)	Consequence	Consequence category	Risk ranking
Platform Deck pooling	No consequence	IV	Low
Disconnected/missing grounding/bonding cables	No consequence	IV	Low
Minor coating degradation on primary / secondary steel structure	Coating / painting deterioration	III	Moderate
Excessive coating degradation on primary / secondary steel structure	Steel structure damage and failures needs repair	II	High
Minor surface corrosion on primary / secondary steel structure	Steel structure thickness deterioration and losses	II	High
Excessive surface corrosion on primary / secondary steel structure	Steel structure damage and failures needs repair	II	High
Cracks on Primary and secondary steel members	Cracking in primary/secondary steel member leading to significant damage and repair	I	Very High
Cracks on LQ and personnel access structures	Deterioration of personnel access structure (e.g., walkways, stairs, handrails, etc.) resulting in injury to personnel	I	Very High
Cracks on Pipe racks and clamps	Piping system failure	II	High

Damage on boat landing /Barge bumper	Difficulties for support vessels and barges to approach the platform	II	High
Blockage /leaks of outboard drains	Structures drain system failure	II	High
cracks on Helideck structure and supports	Cracking in Helideck substructure leading to significant damage and repair	II	High
Loose bolts	Dropped objects resulting personnel injury	I	Very High
Platform structure vibration and fatigues	Overstress may lead to fatigues and cracks on platform beams	II	High
Damaged Grating or missing connections	Deterioration of grating affect platform structure integrity	III	Moderate
Marine growth on Jacket Legs steel degradation	surface corrosion and steel structure degradation lead to failure in jacket structure	III	Moderate
Anodes damages	Cathodic protection system failure causes excessive corrosion that leads to structure deterioration	III	Moderate
Cracking in survival craft support frame	Cracking in survival craft support frame leading to significant damage and repair	II	High
Cracks on Pedestal Crane critical areas and welds	Cracking in crane pedestal leading to significant damage and crane collapse resulting in injury to personnel	I	Very High
Damaged Lifeboats/supporting structure	Evacuation equipment supports failure (lifeboats, life rafts)	I	Very High

Table 11 : Consequence categories and risk ranking

CHAPTER 6: Risk Determination & Risk matrix

Risk Determination

Based on the described consequence and probability of failure, the risk level for each item can be assigned (24). The RBI program should explain how risk is derived. Usually, consequence and probability are plotted versus each other in a matrix with the location of the point falling into a range with a pre-defined risk index. A risk matrix example is shown as per the below Figure 7.

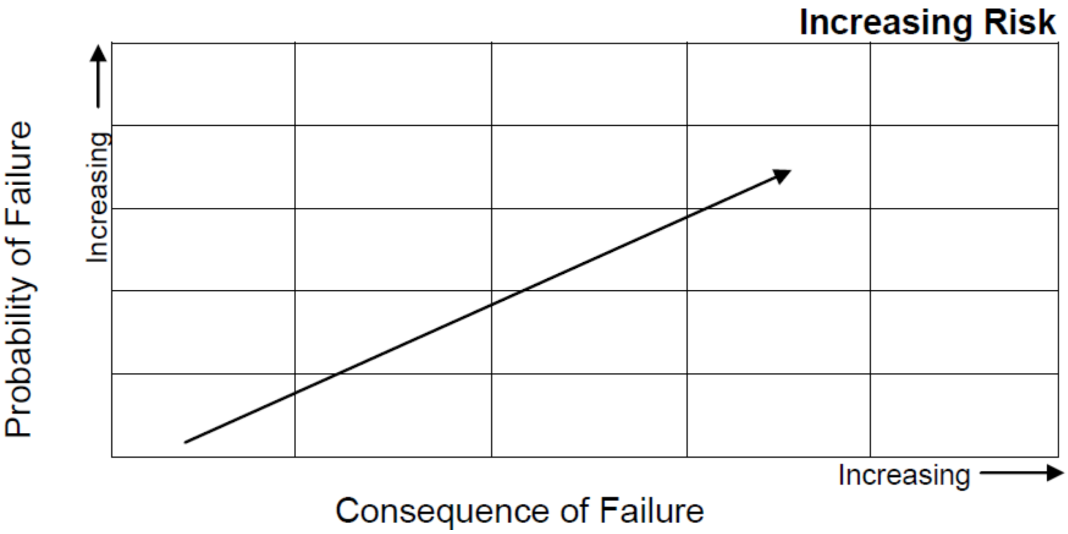


Figure 7 : Risk Matrix (13)

Basically, the resulting risk for each item (High, Moderate, Low) based on the assessment should be used to determine the inspection frequency and strategy. The most important and critical step during this stage is the assignment of the level of risk to the matrix. The RBI program should identify how each risk will be addressed in terms of inspection frequency, scope and other mitigation techniques.

After PoF and CoF are created, the risk ranking process consists in rating the platform structural elements risk levels from lower to higher risk levels with regard to PoF and CoF ranking Table 12 and Table 13.

The results of the risk ranking developed will be used for the RBI process to prioritize the criticality and inspection efforts. (7)

(PoF) Probability of failure

(PoF) Ranking	(PoF) Description
Very Low	Once in 100 or more facility lives Practically Impossible "Failure not foreseeable under normal operating conditions within the remaining life of the asset"
Low	Once in 10 facility lives Not Likely to Occur "Failure possible within life of asset"
Medium	Once in the facility life Possibility of Occurring Sometime "Failure probable within life of asset"
High	5 times in the facility life Possibility of Isolated Incidents "High probability of failure within life of asset"
Very High	20 or more times in the facility life Possibility of Repeated Incidents "Very high probability of failure within life of asset"

Table 12 : (PoF) Probability of Failure ranking (25)

(CoF) Consequence of Failure

Consequence Category	**General Considerations**			
	Health or Safety	*Public Disruption*	*Environmental Impact*	*Financial Impact*
I (Very High)	One or more fatalities, or serious long-term health impact on public.	Large community; evacuation of 1000 people or more; continuing national attention.	Major, or extended duration or full-scale response.	Corporate (~$50M)
II (High)	Serious injury to personnel, but limited impact on public.	Small community; evacuation of 25 to 1000 people; provincial attention.	Serious, or significant resource commitment.	Region or affiliate (~$5M)
III (Moderate)	Medical treatment for personnel, but no impact on public.	Minor (families); evacuation of less than 25 people; local attention.	Moderate, or limited response of short duration.	Division or Production Unit (~$500K)
IV (Low)	Minor impact on personnel (first aid).	Minimal to none; no evacuations; minor inconveniences to a few people.	Minor, or no response needed.	Other (~$50K)

Table 13 : (CoF) Consequence of Failure ranking (25)

Risk Matrix

Risk matrices are the most commonly used tools for risk categorization in qualitative and semi-quantitative risk assessment. As per the risk concept, the consequences of failure and the probability of failure are placed in a matrix to present the risk level. Typically, the risk levels are categorized into three regions shown in the matrix in Table 14.

- The high-risk level is shown in the red color.
- The medium risk level is shown in medium region of matrix with yellow color.
- The low risk level is shown in the green color.

	Probability of failure				
Consequence of failure	**Very High**	**High**	**Medium**	**Low**	**Very Low**
I	High	High	High	Moderate	Moderate
II	High	High	Moderate	Moderate	Low
III	Moderate	Moderate	Moderate	Low	Low
IV	Moderate	Low	Low	Low	Low

Table 14 : RBI Risk matrix (25)

CHAPTER 7: Risk-Based Integrity Management Strategy

Risk-based integrity management strategy attempts to answer four important questions related to integrity of the system: (i)what to inspect? (ii)When to inspect? (iii) How to inspect? (iv)When to do maintenance? Having known the answers to these four questions, it is safe to say that integrity planning based on risk approach is expected to provide efficient and optimized inspection (RBI) and maintenance (RBM), which minimizes the consequences of system downtime or failure.

Risk-Based Inspection (RBI)

The Risk-based inspection (RBI) is a recognized decision-making technique to optimize inspection plans and intervals for offshore steel structure platform topside and subsea elements based on risk involving the probability of failure (PoF) and consequence of failure (CoF). RBI has been one of the many dedicated activities within offshore asset management that contribute to controlling and minimizing offshore risk (26).

The objective of RBI is to determine what incident could occur in the event of an equipment failure, and how likely is that incident could happen (14). RBI analysis prioritizes risk level based on the probability and consequences with regards to different degradation mechanisms. Then the inspection plan is redesigned according to the risk levels may impact the asset.

RBI analysis is a robust method that can provides a linkage between the mechanisms that lead to platform structural elements degradation and the inspection approaches. If the failure mechanisms or degradation is predictable or detectable, then RBI could provide the information needed to determine where, what, how and when to inspect, to reduce the uncertainty in the predicted deterioration and/or as a means of identifying deterioration before it becomes critical (26). The non-destructive examination (NDE) techniques are typically used for the inspection.

RBI Process

To implement RBI analysis for each susceptible element, the consequences of failure (CoF) and probability of failure (PoF) are assessed firstly. Both then combined to obtain risk of failure. (25)

Deliverables of an RBI assessment to the inspection program:

- Prioritization of high-risk components “**WHAT** to inspect?”
- Determination of inspection intervals “**WHEN** to inspect?”
- Selection of best inspection method “**HOW** to inspect?”

Benefits of using RBI approach

- RBI approach help to optimize the inspection interval, which eliminates the cost and hazards from other high frequent inspections.; more risks will be reduced compared with the typical inspection.
- Inspection prioritized based on elements where the safety, economic or environmental risks are identified as being high, accordingly reducing the frequency to low-risk elements.
- RBI analysis helps to determine the following:

  - Elements of the platform that should be inspected.
  - Degradation mechanism that should be considered.
  - Intervals of inspections.
  - Methods and types of inspection that should implemented.
- Probability of failure can be modelled by investigating the probabilities of the various outcomes using a fault tree approach.
- RBI approach ensuring that the overall risk does not exceed the risk acceptance limit set by the certifying authorities, regulatory and/or operator.
- Identifying the optimal inspection or monitoring methods according to the identified degradation mechanisms and the agreed inspection strategy.

However, the optimized inspection program by RBI will not be affected. So, the RBI not only provides the right approach for the inspection, but also the most effectively and efficiently with regards to safety, cost and time.

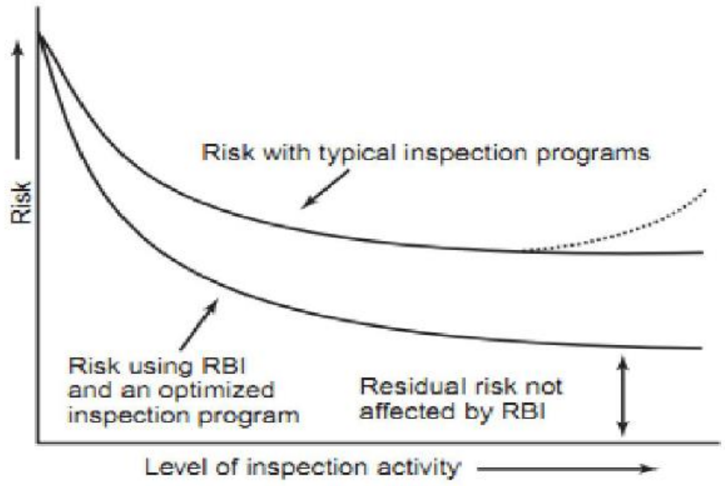


Figure 8 : Management of risk using RBI (14)

RBI Method implementation for offshore steel structure platform

Risk-based inspection able to be conducted using techniques that are qualitative, quantitative, or semi qualitative/semi quantitative. practically, most risk-based inspection efforts are conducted applying a semi qualitative/semi quantitative method.

Quantitative approach

Quantitative approach can be construed as model-based approach, where suitable models are implemented, a numerical value is calculated. Quantitative values can be expressed and presented in qualitative terms make it simple by assigning bands for PoF and CoF and assigning risk values to risk categories (14). By this approach the results can be used to calculate with more accuracy, when the risk acceptance threshold will be breached. The method is logical, detailed, consistent and documented. (25)

Qualitative approach

Qualitative approach can be construed as expert judgement-based approach, there is no numerical values assigned, but instead a descriptive ranking is provided (low, medium or high). Qualitative ranking is generally the outcome of applying an engineering judgement-based approach to the assessment. (25)

The privilege of using a qualitative approach is that the assessment can be achieved promptly and at low initial cost, there is not much requirement for detailed information, and the results are simply presented and understood. But taking into consideration that the results are subjective, based on the opinions, experience and judgment of the RBI team. It is not straightforward to obtain results other than a ranking of items in terms of risk; the estimation of inspection interval based on the risk acceptance limit is not possible. (25)

Semi-quantitative/Semi-qualitative approach

Approaches are semi-quantitative or semi-qualitative in the following cases:

Parts of the RBI assessment are carried out using qualitative or quantitative methods:

- PoF assessment is quantitative and the CoF assessment is qualitative or vice versa.
- PoF and CoF assessments are quantitative, whereas the risk ranking and time to inspection assessment are qualitative (14).

In this thesis work I used semi-quantitative/semi qualitative approach, using the quantitative probability of failure analysis method FTA, and implementing qualitative consequence of failure analysis based on criticality and using engineering judgment, logic assessment and experience in the field

What to inspect “inspection plan”

In-service inspection is primarily concerned with the detection and monitoring of deterioration. In order to establish appropriate inspection plan, we should prioritize the plan based on the criticality of each element on the system using RBI approach, using results for the probabilities and consequences analysis from the previous chapters we are able to rank the platform elements based on the criticality using RBI matrix and make it on groups (group A high “red”, group B moderate “yellow “ and group C low “green”) to assign the inspection frequency for each group, in the following Table 15 inspection categories grouping

Group A	Group B	Group C
Pedestal cranes	Personnel access structures	Decks Primary & Secondary steel members
Helideck structures	Pipes racks and clamps	Jacket legs
Lifeboat stations	Drilling Derrick structures	Risers
Living quarter structures		Anodes
		Piles
		Spools

Table 15 : Inspection categories grouping

When to inspect “inspection frequency”

Once the risk associated with individual equipment items has been determined and the relative effectiveness of different inspection techniques in reducing failure probability has been considered, an optimum combination of inspection methods and frequencies can be decided. The RBI assessment will focus attention on the equipment and associated deterioration mechanisms representing the most risk to the facility, thereby providing a better linkage between the mechanisms that lead to equipment failure and the inspection approaches that will effectively reduce the associated risks.

The primary product of the RBI assessment effort will be an inspection plan for each equipment item evaluated. The inspection plan will detail the unmitigated risk related to the current operation. For risks considered unacceptable, the plan will contain the mitigation actions that are recommended to reduce the unmitigated risk to acceptable levels. The level of unmitigated risk will be used to evaluate the urgency for performing the inspection and assign priorities to the various inspection/examination tasks. For those equipment items where inspection is a cost-effective means of risk mitigation, the plans shall describe the type, scope and frequency of inspection/examination recommended and the level of mitigation achieved.

Through group ranking, inspection frequency can be assigned on 6m, 12m, 24m and 36 months basis focusing and increasing frequency on high risk elements and eliminate frequency accordingly on moderate and low risk elements would be sufficient from financially perspective, eliminating inspection and maintenance down time and optimum with regards to resources use, availability and as well more safely.

Assigning 6 and 12 monthly inspection plans for high risk elements and 2 yearly for the moderate elements and 3 yearly for low risk elements which have lesser failure probabilities and degradation mechanism.

The initial RBIM plan could be changed during the asset lifetime based on findings and anomalies which mean frequencies be able to be changed and amended by the integrity team.

How to inspect “inspection strategy”

Various inspection techniques are usually available to detect any given deterioration mechanism, and each method will have a different cost and effectiveness. Inspection methodology should be placed using popular Non-destructive tests (NDT) inspection techniques described in Table (16) with compliance with industry standards and codes. It should be aligned with certifying authorities and regulatory requirements as well.

NDT inspection techniques to be used:

To execute the regulatory inspections a combination of qualitative and quantitative inspection techniques will be needed. The intent is to execute GVI or CVI to support baseline inspections for RBI.

General visual inspection (GVI)	A survey of an area of interest to identify anomalies, areas of damage to coatings, insulation or dimensional changes and prioritize close visual inspections within that area of interest.
Close visual inspection (CVI)	Visual inspection for surface defects within 1m of the selected area.
Real Time Radiography (RTR)	A screening tool that uses an electronically produced image, rather than on film, so that very little lag time occurs between the item being exposed to radiation and the resulting image.
Pulsed Eddy Current (PEC)	A screening tool that uses an electromagnetic inspection technology to detect flaws and corrosion in ferrous materials typically hidden under layers of coating, fireproofing, or insulation.
Surface Inspection	Inspection method that only examines the surface of a material for near surface discontinuities. Surface inspection methods include PT, MT and ET.
Ultrasonic (UT)	An inspection technique based on the propagation of ultrasonic waves in the object or material tested.
Computerized Radiography (CR)	An inspection technique based on the propagation of radiation in an object that uses imaging plates instead of film.

Table 16: Various NDT inspection methods

The following NDT techniques and recommended frequencies to be implemented for Jacket platform structure elements presented in Table 17

System	***Sub system***	***Inspection recommended Frequency***				***Inspection Type***			
		6 Month	*Annual*	*2-Yearly*	*3-Yearly*	*GVI*	*CVI*	*NDT*	*ROV*
Topside	Cellar Deck				✓	✓		*	
	Lower Deck				✓	✓		*	
	Main Deck				✓	✓		*	
	Upper Deck				✓	✓		*	
	Living Quarters structures		✓			✓		*	
	Drilling Derrick Structures			✓		✓		*	
	Personnel access structures (Walkways, handrails, stairwells)			✓		✓	✓	*	
	Crane Pedestals structure	✓	✓			✓	✓	*	
	Flareboom structure			✓		✓		*	
	Drain system structures (drain boxes)			✓		✓		*	
	Evacuation equipment supports structure (lifeboats station)	✓	✓				✓	*	
	Helideck structure		✓				✓	*	

	Blast and fire wall support structure		✓				✓	*	
	Blast and fire doors		✓				✓	*	
	PFP on structural steel		✓				✓	*	
	Pipes racks&clamps			✓			✓	*	
	Topsides/Jacket connection points				✓			✓	
Jacket	Jacket legs				✓			*	✓
	Jacket bracing				✓			*	✓
	Risers				✓			*	✓
	Risers clamps				✓			*	✓
	Anodes				✓			*	✓
	Mud mat				✓			*	✓
	Pile cluster				✓			*	✓
	Spools				✓			*	✓

✓	Inspection Activity Required
	No Inspection Activity Required
*	NDT work required if any anomaly needs more investigation

Table 17 : Overview of inspection plan

Risk-Based Maintenance (RBM)

Risk-based maintenance (RBM) methodology provides a tool for maintenance planning and decision making to mitigate the PoF & CoF of equipment. The objective of the RBM is to diminish the overall risk of facilities, by the focus on the most critical areas and to prioritize the factors that are critical, and then allocates the resources and scheduling maintenance activities in line with the priority of failure, safety and cost constrain (13).

Development of RBM is similar to the procedure of RBI, the process of RBM is based on two aspects: risk assessment and maintenance planning based on results of risk assessment. The RBM intends to address alternative maintenance plans and solutions to manage risks on systems. These systems plan to highlight risks from a safety/health/environment and/or business perspective. In these plans, cost-effective actions for risk mitigation are recommended, along with the resulting level of risk mitigation (26). However, RBM implementation work is complicated.

Requirements of the application of RBM

The implementation of RBM requires well-developed procedures and strict standards to ensure the work is well conducted, and the risks are reduced to a reasonable level in cost-effective and cost-efficient ways. The RBM is based on risk and reliability analysis.

According to the process of RBM, the general requirements are:

- Before the risk and reliability assessment, cost-effective and cost-efficient evaluations, the acceptable risk level and criteria must be clearly defined by the expert's analysis and judgment

- The application of RBM is based on team efforts of the multi-disciplinary employee. The senior management should allow the team leader to select the multi-disciplinary employee with the required competence from the different departments.
- Throughout the analysis, the necessary level of data and information should be available. The company should have a good information system and documentation management to guarantee the needed support and information are accessible. And the employee related to the assessment should cooperate with the team members freely.
- The methodologies and techniques selected should be able to conduct in the company, and they should be able to provide results the analyst team desired.
- For better utilization of resources, the detailed level of assessment and evaluation should be conducted in line with the criticality of the facility or system (26).

When to do maintenance “mitigation strategy”

Maintenance strategy

The purpose of maintenance is to mitigate or eliminate the consequences of a failure of equipment. This may be by preventing the failure before it occurs, which is what Planned Maintenance and Risk-Based Maintenance is concerning about. It is designed to preserve and restore equipment reliability by replacing or repairing damaged components before they fail. The ideal maintenance program would prevent all equipment failure before it occurs.

RBM application

For the various types of systems, the RBI could be conducted firstly. It takes use of the detailed data and information to analyze the failure modes, causes, and effects using a quantitative, qualitative, or semi-quantitative/semi-qualitative approach to assign the PoF and CoF for corresponding failures. When the PoF and CoF have been assigned, the detailed risk levels of failures can be ranked using risk matrix, and relevant scenarios can be evaluated to reduce the potential risks.

All the alternatives will be evaluated by RBM analysis; the high-risk area will be highly prioritized with the consideration of budget constrain, available techniques, and time limitations. The cost should be controlled without compromising the risk.

By implementing of Risk-Based Maintenance concept through the risk analysis (PoF and CoF modeling) results and risk matrix criticality assignment, will enable us to proceed accordingly with developing an efficient maintenance plan to minimize the cost of maintenance, increase the availability of equipment, improve safety and optimize the resources and finally have a reliable system.

CHAPTER 8: Conclusions and Recommendations

Conclusion

Integrity Management aims at increasing the availability, reliability, and maintainability of any system, taking into consideration safety, environmental issues, and the optimization of total life cycle costs. The risk analysis approach integrates PoF and CoF analysis. Risk-based integrity management strategy attempts to answer four essential questions related to the integrity of the system: (i)What to inspect? (ii)When to inspect? (iii) How to inspect? (iv)When to do maintenance? Answering these four questions guarantees that the integrity planning based on risk approach is expected to provide cost-effective risk-based inspection and maintenance. which minimizes the consequences (related to safety, environment, and business) of system downtime or failure. Resulting in better asset utilization and safer operations. Risk-based integrity management strategies are used to improve the existing inspection and maintenance procedures and intervals through optimal decision procedures in different phases of the life cycle of the asset.

Optimal integrity management planning for offshore platforms structures is a topic of considerable interest in the oil and gas industry. An efficient framework for integrity management is risk-based decision analysis. It is possible to establish risk-based integrity management methodologies, that is, to say inspection and maintenance plans, which are based on the criticality of structural components.

This thesis presents a detailed RBIM analysis, which may be applied to the most critical components of the structure. An example of the application of the procedure is given for an offshore fixed steel structure platform. This research develops an integrity management strategy for an above and underwater offshore platform steel structure using RBIM assessment. This thesis presents a new methodology for integrity management (risk-based integrity management). The proposed method is more comprehensive and quantitative. It comprises five main modules: (i) Identification of degradation mechanisms, anomalies and SCEs (ii) Hazard Identification module (HAZOP study), (iii) risk analysis module, (iv) Risk determination and risk ranking (v) RBI and RBM strategy module. : The first module identifies the elements of the platform structures suitable for the RBIM and the platform safety-critical elements to categorize and rank priorities based on criticality to be considered during RBI and RBM process. The second module identifies the anomalies and the degradation mechanisms affecting the platform structure, through doing hazard identification using a qualitative risk analysis by HAZOP. In the third module that risk analysis is carried out using quantitative risk analysis technique (FTA) to calculate the probabilities then an assignment of the consequence of failure using qualitative analysis based on available information and resources. The fourth module ranks the risk to prioritize inspection and maintenance schedules and build an integrity management strategy. The final module develops the RBI model to support the RBM and integrity management strategy implementation.

This thesis demonstrates the applicability of the proposed methodology by applying it to an offshore steel structure platform. An RBIM analysis is carried out to prove that the RBI, RBM methods used in this work are effective in terms of time, efficiency, and cost.

The oil producer companies own offshore steel structure platforms can use this method to enhance their asset integrity, reduce inspection costs and reduce the frequency inspection.

Also, it can be applied in different oil and gas offshore systems typically by following the RBIM process and steps applied in this thesis Identifying system SCE, implementing HAZID, risk analysis (consequences and probabilities assignment) then developing integrity management plan based on RBI and RBM outputs.

Recommendation for future work

A) Development of risk-based integrity management strategy for other oil and gas assets

RBIM planning approach can be implemented for several offshore assets and systems, e.g. (different platforms types, subsea systems assets, offshore loading & offloading terminals and oil and gas process systems). Therefore the development of risk-based integrity management principles for every individual oil and gas offshore and the subsea asset would be an area for future work in order to have an integrated system able to optimize the availability and reliability of the asset during its lifetime as well as able to mitigate the hazards and guide oil producers companies operate their assets efficiently with perspective to safety, resources, time and cost.

B) Applying quantitative risk assessment to identify the consequence of failures

A methodology for risk-based integrity management planning could be enhanced by using QRA for PoF and CoF as well, quantitative models will provide much better analysis results, in this work PoF was completed using a QRA and CoF was done using qualitative risk assessment which means this study considered a semi qualitative/semi quantitative risk based approach , using QRA methods such ETA on assessing the CoF will give more detailed analysis which is more reliable and make the decision maker taking confident decision with regards to their asset integrity management planning.

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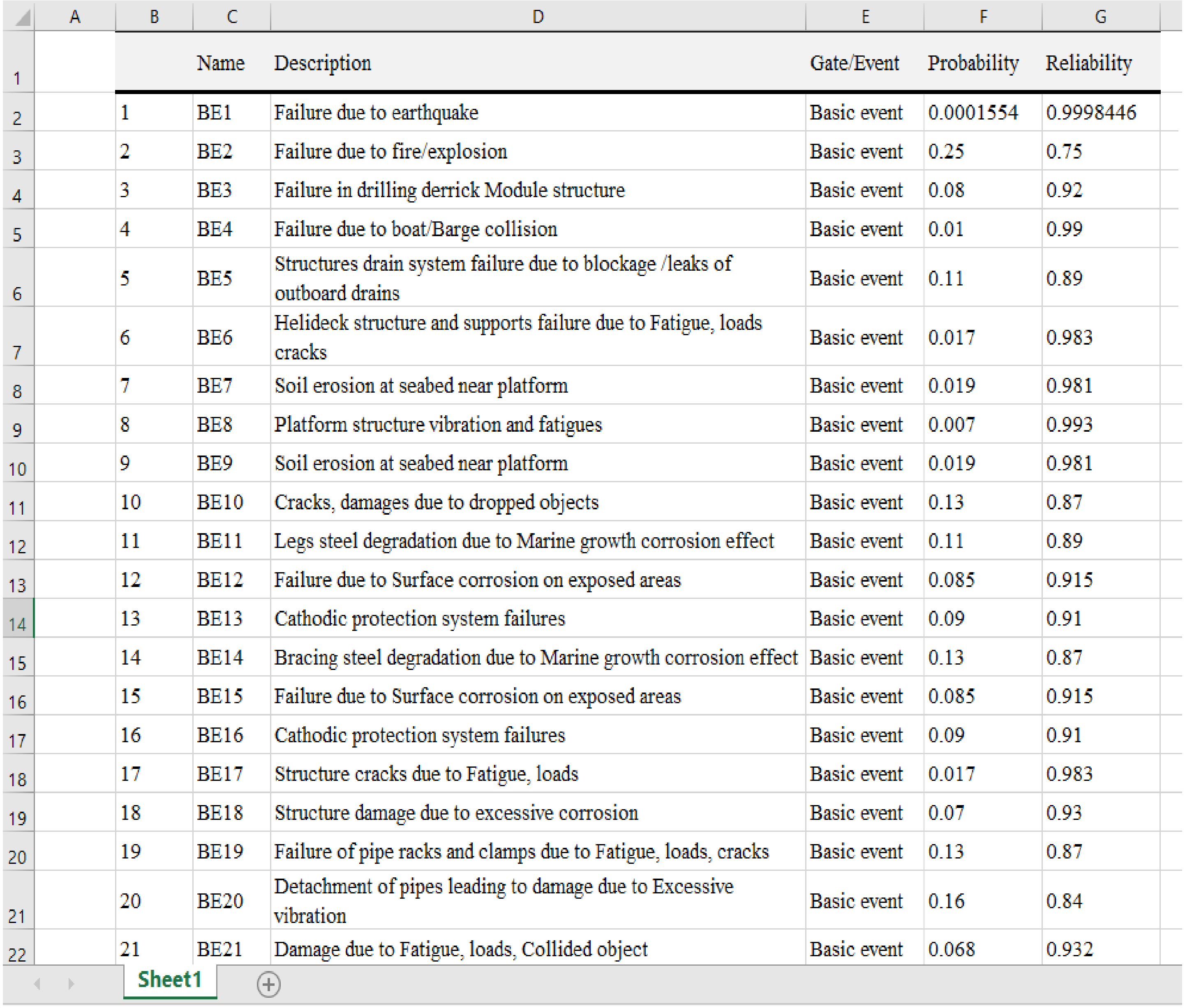
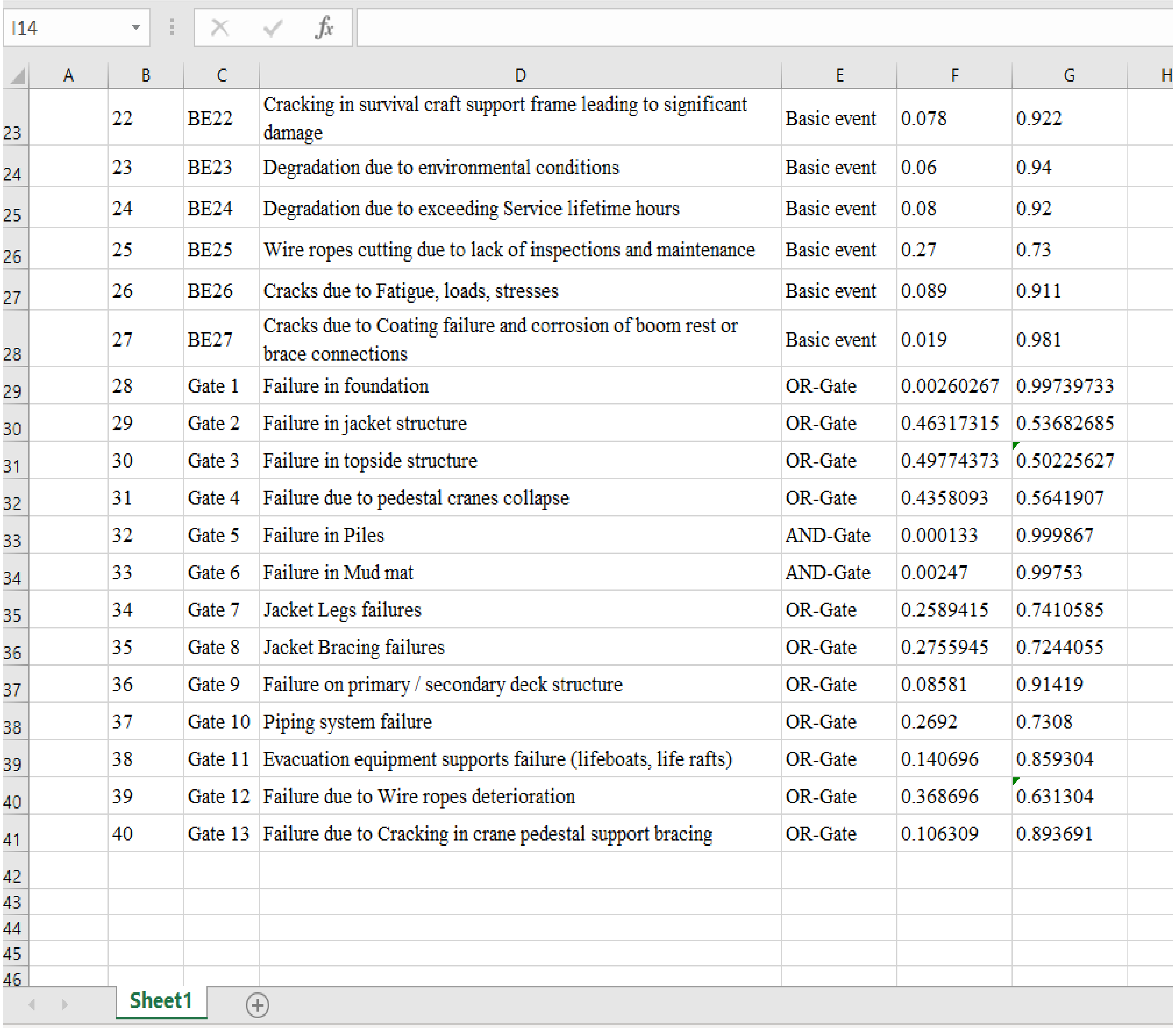
APPENDEX – A: FTA - Failure Probabilities calculation



	Name	Description	Gate/Event	Probability	Reliability
1	BE1	Failure due to earthquake	Basic event	0.0001554	0.9998446
2	BE2	Failure due to fire/explosion	Basic event	0.25	0.75
3	BE3	Failure in drilling derrick Module structure	Basic event	0.08	0.92
4	BE4	Failure due to boat/Barge collision	Basic event	0.01	0.99
5	BE5	Structures drain system failure due to blockage /leaks of outboard drains	Basic event	0.11	0.89
6	BE6	Helideck structure and supports failure due to Fatigue, loads cracks	Basic event	0.017	0.983
7	BE7	Soil erosion at seabed near platform	Basic event	0.019	0.981
8	BE8	Platform structure vibration and fatigues	Basic event	0.007	0.993
9	BE9	Soil erosion at seabed near platform	Basic event	0.019	0.981
10	BE10	Cracks, damages due to dropped objects	Basic event	0.13	0.87
11	BE11	Legs steel degradation due to Marine growth corrosion effect	Basic event	0.11	0.89
12	BE12	Failure due to Surface corrosion on exposed areas	Basic event	0.085	0.915
13	BE13	Cathodic protection system failures	Basic event	0.09	0.91
14	BE14	Bracing steel degradation due to Marine growth corrosion effect	Basic event	0.13	0.87
15	BE15	Failure due to Surface corrosion on exposed areas	Basic event	0.085	0.915
16	BE16	Cathodic protection system failures	Basic event	0.09	0.91
17	BE17	Structure cracks due to Fatigue, loads	Basic event	0.017	0.983
18	BE18	Structure damage due to excessive corrosion	Basic event	0.07	0.93
19	BE19	Failure of pipe racks and clamps due to Fatigue, loads, cracks	Basic event	0.13	0.87
20	BE20	Detachment of pipes leading to damage due to Excessive vibration	Basic event	0.16	0.84
21	BE21	Damage due to Fatigue, loads, Collided object	Basic event	0.068	0.932



	A	B	C	D	E	F	G	H
23		22	BE22	Cracking in survival craft support frame leading to significant damage	Basic event	0.078	0.922	
24		23	BE23	Degradation due to environmental conditions	Basic event	0.06	0.94	
25		24	BE24	Degradation due to exceeding Service lifetime hours	Basic event	0.08	0.92	
26		25	BE25	Wire ropes cutting due to lack of inspections and maintenance	Basic event	0.27	0.73	
27		26	BE26	Cracks due to Fatigue, loads, stresses	Basic event	0.089	0.911	
28		27	BE27	Cracks due to Coating failure and corrosion of boom rest or brace connections	Basic event	0.019	0.981	
29		28	Gate 1	Failure in foundation	OR-Gate	0.00260267	0.99739733	
30		29	Gate 2	Failure in jacket structure	OR-Gate	0.46317315	0.53682685	
31		30	Gate 3	Failure in topside structure	OR-Gate	0.49774373	0.50225627	
32		31	Gate 4	Failure due to pedestal cranes collapse	OR-Gate	0.4358093	0.5641907	
33		32	Gate 5	Failure in Piles	AND-Gate	0.000133	0.999867	
34		33	Gate 6	Failure in Mud mat	AND-Gate	0.00247	0.99753	
35		34	Gate 7	Jacket Legs failures	OR-Gate	0.2589415	0.7410585	
36		35	Gate 8	Jacket Bracing failures	OR-Gate	0.2755945	0.7244055	
37		36	Gate 9	Failure on primary / secondary deck structure	OR-Gate	0.08581	0.91419	
38		37	Gate 10	Piping system failure	OR-Gate	0.2692	0.7308	
39		38	Gate 11	Evacuation equipment supports failure (lifeboats, life rafts)	OR-Gate	0.140696	0.859304	
40		39	Gate 12	Failure due to Wire ropes deterioration	OR-Gate	0.368696	0.631304	
41		40	Gate 13	Failure due to Cracking in crane pedestal support bracing	OR-Gate	0.106309	0.893691	
42								
43								
44								
45								
46								