Faculty of Engineering and Safety

NEW PERSPECTIVES FOR AN INTELLIGENT RISK-BASED DECISION SUPPORT FRAMEWORK FOR ASSET INTEGRITY MANAGEMENT

Means for Sustainable Asset Integrity Management in the Norwegian High-North

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PREFACE

This thesis completes my master's degree in Technology and Safety in the High North at UiT – The Arctic University of Norway.

I desired to write this thesis following knowledge and interests developed during and after taking courses in Operations and Management -TEK-3001, Cold Climate Engineering and Risk Based Inspection and Condition Monitoring – TEK 3009 project in Autumn, 2013, Spring 2014 and Autumn 2014 respectively.

I would like to express my sincere appreciation to my principal supervisor Associate Professor, Dr. Maneesh Singh, for his unwavering support and encouragement, in the face of challenges I had to face writing this thesis from abroad - far distance in Nigeria. I am also grateful to Professor Javad Barabady and Yonas Zewdu Ayele PhD., for their support. I will not forget to express my sincere thanks to Mike Wikkleson of Aker Solution, AS Norway, for all the support provided during the short time in collaboration with Aker Solution, AS, Norway.

To all the, who took time to provide answers to the research questionnaire, I am grateful. To my family, my parents, my lovely wife, I say thank you for all the prayers and support.

ABSTRACT

Constrained within the substantial uncertainties and risks existing in the Arctic, operators have defied all odds and have succeeded to establish oil and gas operations in the Barents Sea, with Snøhvit and Goliath, on stream in 2007 and 2016 respectively (Norwegian Petroleum Directorate, 2018). In addition, other fields are springing up, like the Skrugard and Havis oil and gas fields, estimated to contain 400–600 million barrels of recoverable oil equivalents. All these are projected to attract sustained investment and create more economic opportunities for oil service firms to operate and establish their oil and gas assets facilities in the Barents Sea (Lloyd's and Chatham House 2012).

These assets and many more in future will face heightened integrity issues considering the prevalent climatic and challenging operating conditions in the Arctic. The Arctic area is a unique, complex and risky frontier, thereby amplifies the need for a robust integrity management strategy to curb the challenges and assure safe, profitable and sustainable oil and gas development.

Previous study have shown that oil and gas operation in the Barents Sea attracts significant risks, hence adequate caution, robust assets integrity management strategies need to be taken into consideration by existing operators and future interested investors (Lloyd's and Chatham House 2012). It is noteworthy to say that, except for the scarce infrastructure, unstable political regimes, weather uncertainties and weak emergency preparedness, the oil and gas operations in Norwegian Barents Sea is marginally not different from other parts of the Norwegian Continental shelf (Henningsgård, 2013).

Hence, one can argue that the thriving Assets Integrity Management strategies applicable in other region of the Norwegian Continental Shelf can be used in the Barents Sea, with some improvement to address the gaps, some of which are namely these:

- Eliminate run-to-failure maintenance approach for maintenance. Replace with predictive/proactive and reliability centered approach
- As much as possible apply Quantitative Risk methods to quantify risk and integrity issues, to support risk-informed decision, due to high uncertainties in the Barents Sea,
- Apply Smart Data/Information Management approach, that supports Assets Performance Management.

Integrating Risk-based methods in asset integrity management will continue to thrive and they are adaptable to the use of intelligent decisions support system. This thesis focuses on gap analysis of Assets Integrity Management with the aim of identifying critical success factors which are often neglected but are the bed rock of asset integrity management. Then the knowledge of these critical success factors will be used to upgrade existing decision support system framework for asset integrity management that can be implemented in the Arctic, particularly in the Barents Sea to achieve the desired goal.

To sustain health, safety and environment (HSE) values, the framework targets to increase the degree of preparedness to detection and prevention of integrity related issues, such that assets can fulfil their purpose throughout their lifecycle.

Two key drivers for the development of the upgrade framework were considered and they are:

1. ***To assure higher degree of early detection and intervention against integrity issues:*** This is intended to proactively identify integrity management issues by robust data processing approach that will collate valuable information towards positive preventive actions.

2. ***To assure higher degree of risk predictability of mechanical integrity issues:*** This is intended for early risk identification and management.

In this thesis and from the authors perspective, **Data and Risk Decision Management** were proposed as the two CSFs which impact other well-established Critical Success Factors in a positive and profitable result orientated direction.

The ultimate question in the thesis was, to show how improved Data and Risk Decision Management will achieve the two driving objectives, which culminates to increasing the degree of preparedness for preventive intervention on solving integrity issues?

In response to this challenge, the thesis aimed at providing answers to the following:

1. What is required and/or needed to improve Data & Risk Decision Management strategy, to increase the degree of proactiveness?

2. How will Data and Risk Decision Management influence the asset integrity focus areas namely high, reliability, availability and maintainability?

Background research materials regarding Data and Decision Management, Risk Management, Degradation Monitoring and Control, Inspection Strategy and Management, and Operation and Maintenance Management, Asset Integrity Management, were investigated and thoroughly studied before some suggestive conclusion were drawn. The study is based on literature review of previous work and was analyzed empirically in-line with the regulatory framework for AIM in Norway and empirical case study of semi-quantitative RBI analysis to demonstrate some aspects of Data & Risk Decision Management.

The suggestions made in this thesis are only a microcosm of all the aspects of the framework, and further research is necessary to:

- Improve methods for proactive risk identification and mitigation
- Aid development of performance indicators for proactive risk thresholds
- Improve the understanding of data quality and possible use as a performance indicator

Having said that, there is need for more sophisticated approach to data collection, processing and visualization in a way to aid smart risk communication and reduce risk exposure. Lessons and application of management strategies in other industrial applications e.g. financial industry require to be thoroughly researched for possible application in the Oil and Gas Industry. Holistic knowledge (technical and other aspects) about varied factors that influence risk need to be supported by quality data for managing risk.

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LIST OF ABBREVIATIONS

AIM:	Asset Integrity Management
CoF:	Consequence of Failure
CM:	Condition Monitoring
DI:	Design Integrity
DM:	Damage Mechanism
HSE:	Health Safety and Environment
IO:	Integrated Operations
KPI:	key performance Indicator
MTTF:	Mean-Time -To -Failure
NCS:	Norwegian Continental Shelf
NII:	Non-intrusive Inspection
OGP:	Oil and Gas Producers
OI:	Operational Integrity
OpEX:	Operating Expenditure
PoD:	Probability of Detection
PoF:	Probability of Failure
PM:	Preventive Maintenance
PSA:	Petroleum Safety Authority
RBI:	Risk Based Inspection
TI:	Technical Integrity
TIM:	Technical Integrity Management

CHAPTER 1
INTRODUCTION

1.0.Background

"Those who cannot remember the past are condemned to repeat it" – George Santayana (Dr. Peter McClean Millar, 2015)

The Oil and Gas Industry is full of challenges, with very high cost, resources and time exposure. That notwithstanding, there are growing interests for oil and gas development in the vulnerable and sensitive environment of the Arctic (Arctic Monitoring and Assessment Programme (AMAP), 2007, Lloyd's and Chatham House 2012). Classical example is in the Barents Sea Area Norway, which has presented more profitable frontiers for oil and gas development opportunities, considering the successful establishment of Snøhvit and Goliat, facilities in 2007 and 2016 respectively. Two-thirds of the Norwegian's undiscovered oil lies off its northern coast in the Arctic's Barents Sea, and for the petroleum industry and particularly Norwegian, asset integrity management for facilities in these new fields is crucial.

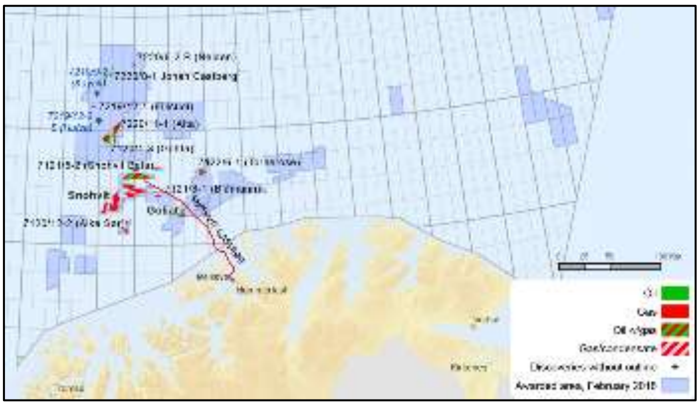


Figure 1: Fields and discoveries in the Barents Sea (Norwegian Petroleum Directorate, 2018)

More so, the fact that operators are continuously required to ensure safer environment and financially sustainable investments, underpins the primary basis for the emergence of asset integrity management in the industry. Research has shown that many operators have been influenced to implement robust asset integrity solutions following catastrophic incidents like the Piper Alpha, Texas City Refinery, Mocando blowout etc.(Ramasamy et al., 2015).

Figure 2: Texas City Refinery – Texas - 2005 (Dr. Peter McClean Millar, 2015)

Also, regardless of the price of oil, operators are required to stay within the regulatory boundaries, as no justification is acceptable to the compromise of health, safety, environment and quality (HSEQ). Therefore, operators in the Barents Sea, need to consistently strive to improve on their asset integrity management strategy, because a well-managed asset integrity program, will aid operators to identify and reduce operational risks before they escalate, as well as facilitate higher operational excellence and attain profitable assets life cycle.

It is noteworthy to say that, except for the scarce infrastructure, unstable socio-political situation, weather uncertainties and weak emergency preparedness, the Oil and Gas operations in Norwegian Barents Sea is marginally not different from other parts of the Norwegian Continental shelf (Henningsgård, 2013). Hence one can argue that the thriving Assets Integrity Management strategies applicable in other region of the Norwegian Continental Shelf can be used in the Barents Sea, with some minor improvement. Some of these existing or future/ required improvement have been seen to influence many researchers to continue to collaborate in finding innovative ways to strengthen the Norwegian Arctic offshore and petroleum related technology and competence (Thor Christian Andvik et al, 2017).

Research has continued to identify key enablers for performance of an Asset Integrity Management (AIM) Program, but it is important to identify which Critical Success Factors (CSF) largely influence the AIM program performance by either increasing or decreasing the "degree of preparedness to detection and prevention of an asset integrity related issue".

1.1. Purpose of the Thesis (Industry Challenge)

As we all know, the Asset Integrity Management (AIM) practice is as old as the industry itself and it keeps evolving by the day. Many operators have been able to identify critical success factors (CSFs) that drive their AIM program, yet there is no end to discovering more optimization opportunities amongst the already established AIM CSFs, particularly in this age of operational excellence (OE) (Ernst and Young (EY), 2015), and very importantly to support and sustain oil and gas asset development and management in high uncertainty areas like the Norwegian Barents Sea. This thesis focuses on identification and demonstrating the optimization opportunities within Risk and Data Management areas, amongst other known AIM Critical Success Factors (CSFs). The author proposes that these optimization opportunities, have very valuable influence potential to bring about the desired operational excellence envisaged by operators in the industry. Based on this, existing decision-making framework was upgraded and presented as an intelligent risk-based decision support framework for asset integrity management that can be implemented particularly for oil and gas asset integrity management within the Barents Sea. The possible optimization opportunities cover the AIM three (3) core elements, spanning through the asset life cycle namely:

- Design Integrity (DI)
- Technical Integrity (TI)
- Operational Integrity (OI)

Two key drivers for the development of the upgrade framework were considered and they are:

1. ***To assure higher degree of early detection and intervention against integrity issues:*** This is intended to proactively identify integrity management issues by robust data processing approach that will collate valuable information towards positive preventive actions.
2. ***To assure higher degree of risk predictability of mechanical integrity issues:*** This is intended for early risk identification and management.

The ultimate question in the thesis was, to show how the proposed framework will achieve the two driving objectives, which culminates to increasing the degree of preparedness for preventive intervention on solving integrity issues?

In response to this challenge, the thesis aimed at providing answers to the following:

1. What is required and/or needed to improve Data & Risk Decision Management strategy, to increase the degree of proactiveness?

2. How will Data and Risk Decision Management influence the 3 (three) key AIM aspects (DI, TI and OI) to achieve high asset, reliability, availability and maintainability?

1.2. Structure of the Thesis

The structure of the Thesis is divided into Four Core Chapters:

Chapter 1: Introduction – Background, Purpose of the Thesis, Structure of the Thesis, Research Methodology and Thesis Limitations
Chapter 2: Oil and Gas Development in the Barents Sea and Asset Integrity Management: An Overview. This is the literature review or theory, covering Assets Integrity, Data and Risk Management.
Chapter 3: Research Methodology
Chapter 4: Survey results and analysis
Chapter 5: Case study on Data & Risk Visualization and its impact on decision making
Chapter 6: Discussions, Observation and Recommendation
Chapter 7: Conclusion

1.3. Methodology

1.3.1. Research Approach

There are two research approaches considered namely: deductive and inductive.
In the deductive method, the identified theories are used to produce a hypothesis and aim at data collection. Then the hypothesis will be tested either be confirmed or rejected, to justify the theory ((Bell, 2003). The inductive method is the opposite of the deductive method. The author therefore infers the outcome of his or her findings. Theory is the outcome of this method. ((Bell, 2003).

The chosen suitable approach for this work is the deductive approach and according to (Bell, 2003), which is shown in Figure 3 below:

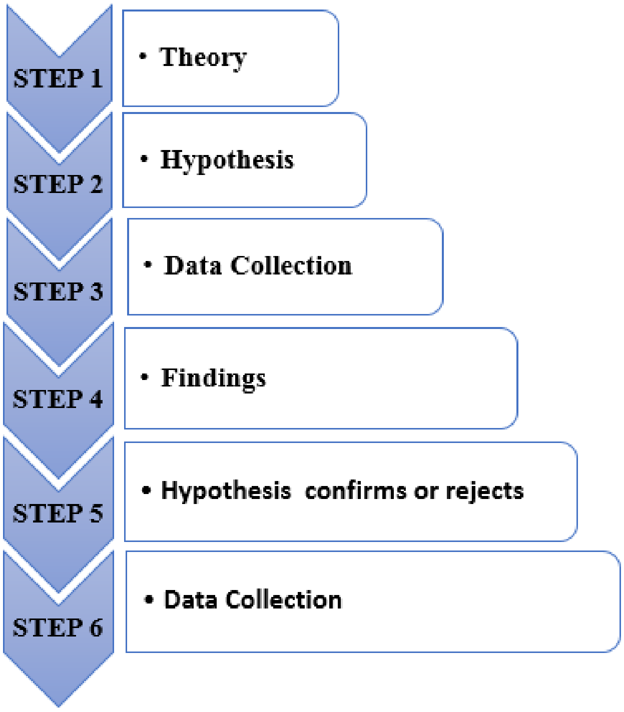


Figure 3: The process of deduction (Adopted from (Bell, 2003).

1.4. Limitations of the Thesis

The first limitation was focusing on Barents Sea of Norwegian High North. Literature reviews were based on previous work by other researcher and journals. I was not able to reach my desired target audience, which is asset integrity management practitioners in Norwegian oil and gas industry, hence I resorted to utilizing reachable audience within the oil and gas industry in Nigeria. I have also used what I termed "indirect extrapolated judgement" whereby I drew some general inference from other researchers work, current developments in the industry and the academia, with a list of the specific journals and research work used.

The proposed upgraded decision support system framework was not tested using any real case study, hence the suggestion and recommendation are just an extrapolation and generalized. The author's lack of industry experience needs to be considered.

CHAPTER 2
OIL AND GAS DEVELOPMENT IN THE NORWEGIAN BARENTS SEA AND ASSET INTEGRITY MANAGEMENT: AN OVERVIEW

2.0.Introduction

With increasing oil and gas asset establishment in the Barents Sea area, it is important to consistently strive towards improving the existing or emerging asset integrity management strategies that will assure sustainable oil and gas development without compromising health, safety and environment (HSE) and regulatory requirement.

For better understanding of AIM performance in the Barents Sea, it is important to make known some characteristics of the Norwegian Barents Sea – features and challenges, that influence the performance of AIM within the oil and gas industry. This chapter is in two parts: Part 1- Norwegian Barents Sea operational conditions. Part 2 – An overview of AIM, AIM usage status in NCS- Barents Sea and AIM sustenance. Most importantly, we will review of some AIM critical success factors and share the authors opinion as regards Risk and Data Management from a renewed perspective as the critical success factors on which the authors hypothesis was built upon.

2.1. Norwegian Barents Sea Operational Conditions

Unknown to many, the Norwegian Barents Sea share a lot in common when compared with the rest area of the Norwegian Continental Shelf (NCS). The operational conditions in Barents sea are not significantly different from those in other areas of the NCS, except for factors like scarce infrastructure, unstable socio-political situation, weather uncertainties and weak emergency preparedness (Henningsgård, 2013). Hence one can argue that the Assets Integrity Management strategies used in other region of the Norwegian Continental Shelf can equally be applied in the Barents Sea. This can be achieved by closing all necessary risk exposures due to the Arctic nature of the area, by careful operational planning, application of suitable emerging technologies to drive proactive detection of integrity and risk issues. For instance, existing technologies such as corrosion control in wet gas pipelines by means of pH stabilization, used successfully in the areas in the Norwerian Sea – Åsgard and Huldra, was being optimized for implementation in Snøhvit – Barents Sea (Norwegian Academy of Technological Sciences (NTVA), 2005).

Nevertheless, let us examine Barents Sea, vis a vis, geographical setting, the oil and gas development opportunities, operational challenges and review of Asset Integrity Management in the NCS.

2.1.1. The Barents Sea Geographical Setting

The Barents Sea is located approximately 15°E to 31°E and 70° N to 74.5°N, which is the area between the coast of northern Norway (Tromso / Hammerfest) and Bjørnøya (Bear Island) south of Svalbard as shown in the map in figure 1.

Figure 4: Barents Sea Map (www.ft.com, 2017)

2.1.2. Oil and Gas Development Opportunities in the Barents Sea

The Barents Seas has experienced a great number of oil and gas discoveries in the past decade. In 2013, the Barents Sea south-east was opened for petroleum activities, with estimated 85% of the remaining undiscovered resources located in the Barents Sea (Jon Fredrik Muller et al., 2016). The Barents Sea also has the highest volume estimate and production prospects when compared with the North Sea and Norwegian Sea, see Figure 5. below.

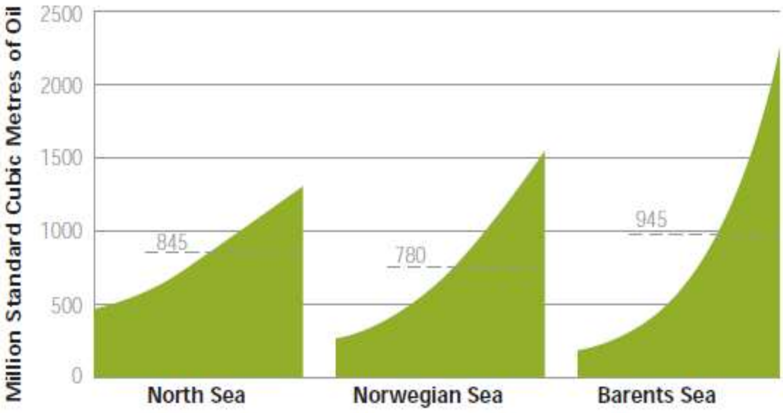
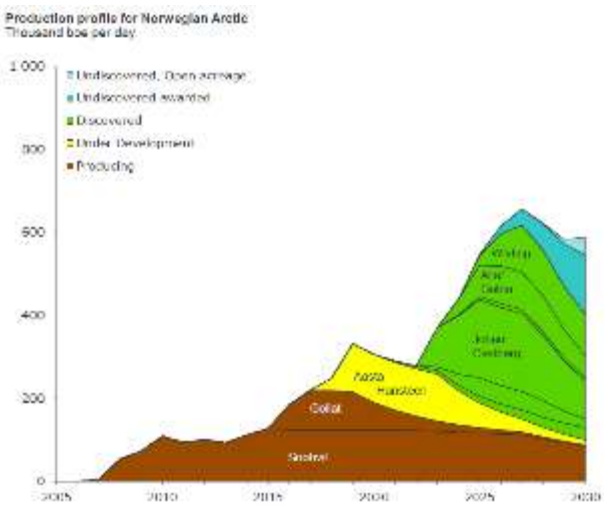


Figure 5: Estimated undiscovered hydrocarbon resources in the North, Norwegian and Barents Seas (Lloyd's and Chatham House 2012)

Many operators have already established, commenced manning their assets/facilities such as Goliat (by Eni), Snovit and Johan Castberg (by Statoil), and others - Lundin Petroleum and OMV. The production within the Norwegian Arctic is projected to grow from 2016 – 2019, with Goliath and Aasta Hansteen being completed, while production may hit 600kboe/d by the beginning of 2020 considering the forecasted startup of Johan Castberg, Alta/Gohta and Wisting (Jon Fredrik Muller et al., 2016).



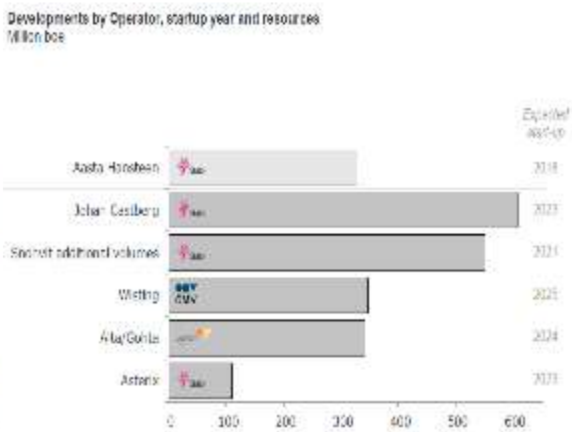


Figure 6: Production profile for Norwegian Arctic Source: (Jon Fredrik Muller et al., 2016)

Figure 7: Development by Operator, startup year and resources Source: (Jon Fredrik Muller et al., 2016)

2.1.3. Climatic Condition and Operational Challenges in the Barents Sea

As earlier said, the climate in the Norwegian Arctic is considered milder compared to several other typical Arctic offshore areas globally and this has created some semblance with other climatic conditions with other areas of the NCS.

2.1.4. The main Arctic challenges and Characteristics can be summarized as follows (Jon Fredrik Muller et al., 2016):

1. Currents, wind and waves in Barents are similar as the North Sea
2. In general, there is low risk of icebergs and sea ice in Barents Sea, but it increases Northwards
3. Polar lows, snow, fog, darkness and Icing are the main Arctic challenges in the part of the Barents Sea where their main possibilities for operations are. These issues need attention from the industry. In addition, some areas of the Barents Sea are challenging due to long distance, sand, shallow reservoirs

It is a known fact that one of the most critical elements in asset integrity programs is inspection, maintenance and repair (IMR) (Mahmoud Aboelatta, 2018). Due to the climatic condition and challenging operational condition in Barents Sea, traditional IMR techniques will continuously require to be optimized for safe and efficient application.

For offshore static and subsea oil and gas fields, equipment IMR activities are executed either:

- Externally (assessing the external condition of the equipment)
- On-stream (assessing the internal condition from the exterior of the equipment)
- Internally (assessing the internal condition of the equipment)

Due to high uncertainty, this will invariably give room for more conservative design, installation and operation. Some of these uncertainties are:

- Human behavior in an offshore arctic environment
- Environmental and logistics changes
- Equipment condition monitoring difficulties
- Tools and devices inaccuracies

Table 1: Current Developmental Challenges and Characteristics of the Barents Sea (Jon Fredrik Muller et al., 2016)

Design and construction of offshore platforms	Johan Castberg is planned with features including water-borne heating for the helideck and covered walkways with open gaps on the sides where the wind can blow away snow
Onshore plants and terminals	Statoil has formed a partnership called "Barents Sea Oil Infrastructure" together with the partners on Goliat, Wisting and Alta/Gohtato to see if a reloading terminal to serve these and future discoveries would be feasible.
Asset integrity management	The Barents Sea is in general a very corrosive area and prone to severe weather conditions. The best available technology for surface equipment protection and condition monitoring is required.
Drilling operations and well control	Wisting is an extreme case with the reservoir located only 250 meters below the seabed requiring long-reach horizontal wells are needed in order to develop the field
Environmental protection, monitoring and oil spill systems	A big challenge for operations in darkness will be to survey and position potential oil spill equipment properly
Subsea facilities and pipelines	Technology for increased tiebacks will be a key to develop potential resources due to lack of current infrastructure and large distances
Property and personnel protection and training	The Nordkapp Maritime Training Centre and the Norwegian Fire Protection Training Institute to provide training in oil spill response operations. The two centers will work together to develop a new training programme for oil spill contingency activities.
Weather forecasting, surveillance and communications	CIRFA has several ongoing projects for forecasting and surveillance in the arctic regions; (1) Ocean remote sensing, (2) Sea ice, icebergs and growler remote sensing, & (3) Oil spill remote sensing
Vessel design and shipbuilding	Two new winterized contingency vessels were designed and built, dedicated to Goliat operations. In addition, two PSVs are also in operations. The Johan Castberg project will require similar vessels.
Ice Management	The southern part of the Barents Sea is not ice-prone, and as such, ice management systems are not necessary.
Maritime operations	Specialized marine equipment vessels for

Also, according to (Abdelmounam Sherik et al., 2017), a recent study of 3,700 failure cases over a 35-year period showed that corrosion damage accounted for 60% of all failures, with environmental cracking constituting approximately 35% of all reported corrosion-related failures. Figure 8 shows the distribution of the reported damage mechanisms.

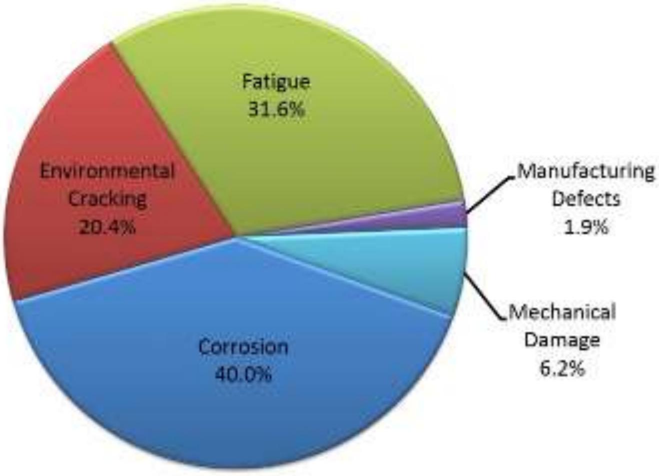


Figure 8. Distribution of the reported damage mechanisms study of 3,700 failure cases from 1975- 2009(Abdelmounam Sherik et al., 2017).

The author by inference, collaborates with (Jon Fredrik Muller et al., 2016) and (Abdelmounam Sherik et al., 2017) on the fact that one of the major issues that will face the development of oil and gas in the Barents Sea will be asset integrity management. Hence, we progress to understand Asset Integrity Management, to understudy the opportunities for improvement.

2.2. Understanding Asset Integrity Management

2.2.2. Terminology Overview

The concept of Asset Integrity Management is better understood when we explain the two independent words namely "Asset Integrity" (AI) and "Asset Management" (AM), fused together to form the term "Asset Integrity Management".

The first term, "Asset Integrity" AI, is also composed of two words: "Asset" and "Integrity", which mean different things depending on the context. To start with, lets explain the word "Asset", defined as "an item, thing or entity (pipeline, production facility, drilling barge, etc.) that has potential or actual value to an organization (British Standards Institution (BSI), 2014). In a similar context, "industrial asset" can be defined as any physical core, acquired (i.e., the organization has either the possession or the custody of the assets) elements of significant value to the organization, which provides and requests services for this organization (R.M. Chandima Ratnayake, 2012).The second word "Integrity" has been considered as the prevention of the loss of containment of a fluid or energy from the asset/facilities (Dr. Peter McClean Millar, 2015). Other authors have also explained integrity thus, as maintaining the pressure containing envelope or keeping hydrocarbon inside pipes and vessels (R.M. Chandima Ratnayake, 2012). Hence, “Asset Integrity” AI, can be defined as the ability of an asset to perform its required function effectively and efficiently whilst protecting health, safety and the environment (Dr. Peter McClean Millar, 2015).

Asset Management (AM) on its own is referred to, as the integrated, whole life, risk-based management of industrial physical assets (R.M. Chandima Ratnayake, 2012) and was said to date back to the late 1980s in the North Sea oil and gas industry due to increased regulatory compliance after the Piper alpha incident. According to PAS- 55-1, Asset Management is defined as systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for achieving its organizational strategic plan (British Standards Institution (BSI), 2014).

Therefore, with all the definition provided above, Asset Integrity Management is the means of ensuring that the people, systems, processes and resources that deliver integrity are in place, in use and will perform when required over the whole lifecycle of the asset (Dr. Peter McClean Millar, 2015). In other words, Asset Integrity Management can be referred to as the complete and wholly integrated organizational strategy for optimising efficiency and maximizing profit and revenue from operating assets.

It is important to note that the definition and need of AIM is primarily determined by the time to failure and the likelihood of a loss of integrity. These factors change across the oil and gas industry sectors with regards to design, material selections, damage mechanism and degradation, the prevalent environmental condition in which the materials/facilities are exposed to and other operational risks.

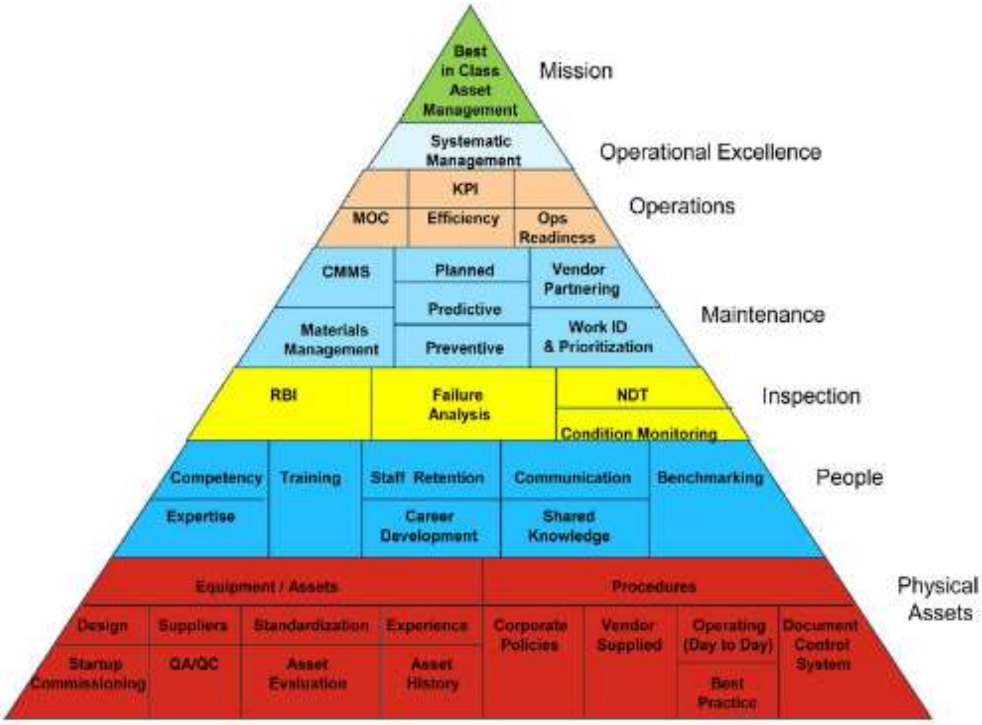


Figure 9: Asset Management Triangle (Dr. Peter McClean Millar, 2015)

In simple term, we can infer that asset integrity and asset integrity management is the fundamental of any asset management program (See Figure 10). Therefore, asset integrity plays key role and demands to be continually improved upon to assure business profitability.

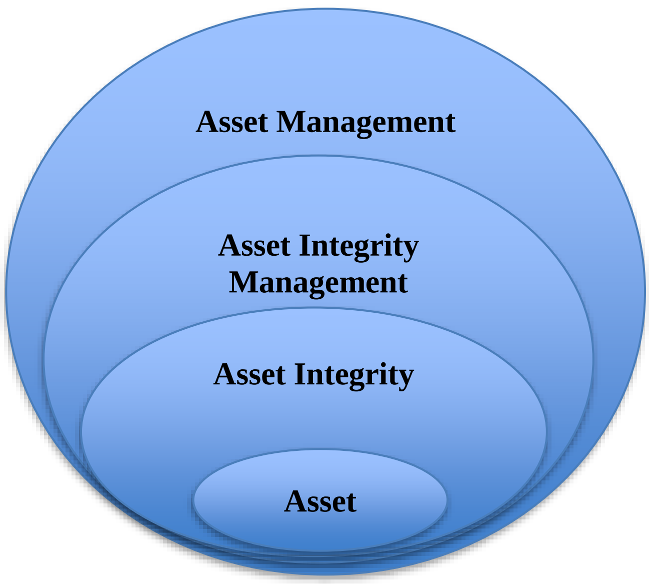


Figure 10: Asset Management Program (Adopted from (*Oluwaseun O. Kadiri et al., 2013)

According to (Dr. Peter McClean Millar, 2015). The aim of the asset integrity management process is to provide a framework for the following:

- Compliance with company standards, regulatory and legislative requirements
- Assurance of technical integrity by the application of risk based or risk informed engineering principles and techniques
- Delivery of the required safety, environmental and operational performance
- Retention of the License to Operate
- Optimization of the activities and the resources required to operate the facilities whilst maintaining system integrity
- Assurance of the facilities' fitness for purpose Some of the contributing factors to the assurance of current and continued asset integrity are represented in the following figure.

2.2.3. Benefits of Asset Integrity Management

1. Promote asset reliability, availability and maintainability
2. Improve asset condition monitoring, maintenance planning and save inspection cost
3. Improve safety and performance of personnel
4. Improves efficient use and performance tracking of equipment
5. Enhances facilities operational performance and overall profitability
6. Assists operators and managers to optimise spare parts management for repair, replace and mitigate solutions.
7. Ensure full compliance with organization corporate goals and standard industry legislations and regulations

2.3. Assets Integrity Management Core Elements

2.3.2. Asset Integrity Definition:

An asset is said to have integrity when it is operated and maintained in a manner such that the product of likelihood of failure and the consequence of failure results in risk as low as practically reasonable (ALARP) to people, environment and organization.

Mathematically we can say that:

Integrity (Risk ALARP) = (Probability of failure) x (Consequence of Failure)

To ensure overall asset integrity, holistic management of all element of asset integrity is need ed and according to (R.M. Chandima Ratnayake, 2012), Asset Integrity is comprised of three core elements namely:

- Design Integrity, (DI),
- Technical Integrity (TI)
- Operational Integrity (OI)

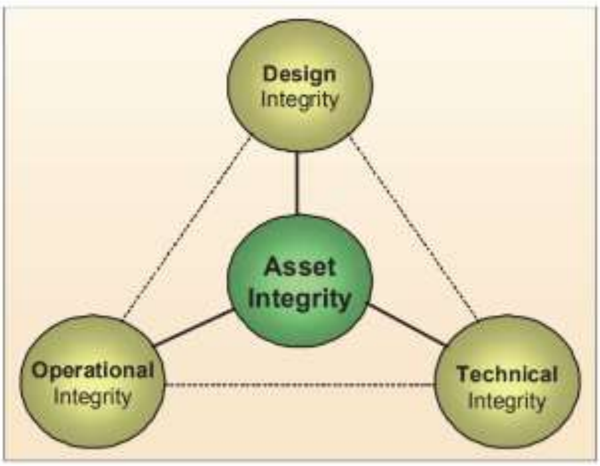


Figure 11: Core Elements of Asset Integrity (Adopted from Jan de Jong, 2009)

Hence provision of asset and integrity management support to facilities span through conception, design, construction, commissioning, operations, revamp, life extension and de-commissioning phases.

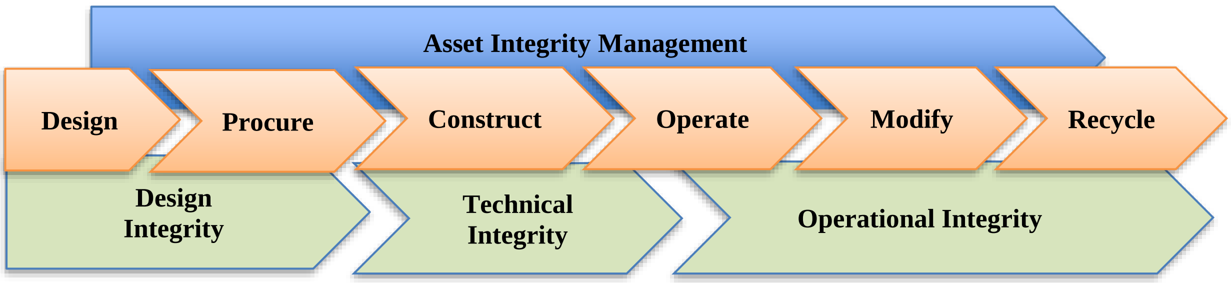


Figure 12: Asset Life Cycle AIM Integration

Throughout asset life cycle phases, AIM assists to integrate its core elements to ensure that the assets are optimally useful. These three (3) core elements are explained further.

2.4. Design Integrity (DI)

Design Integrity refers to the "assurance that facilities are designed in accordance with governing standards and meet specified operating requirements" (R.M. Chandima Ratnayake, 2012). In other words, the ability of an asset designed to carry-out its intended purpose effectively and efficiently without compromising its HSE impact (Rao R.A. Rao et al., 2012). From the Figure 13, we can see that an equipment may attain design and technical integrity, but once in use, will need more maintenance and modifications to sustain the integrity while in service. The challenge is how to continuously improve and sustain the asset's integrity, through the lifecycle without compromising. In the authors view, this is a challenge for operators in the Barents Sea with unique and challenging environment. This brings the principles and strategies of condition monitoring, risk-based inspection (RBI) and maintenance into play to ensure that the original design parameters are sustained without compromising integrity.

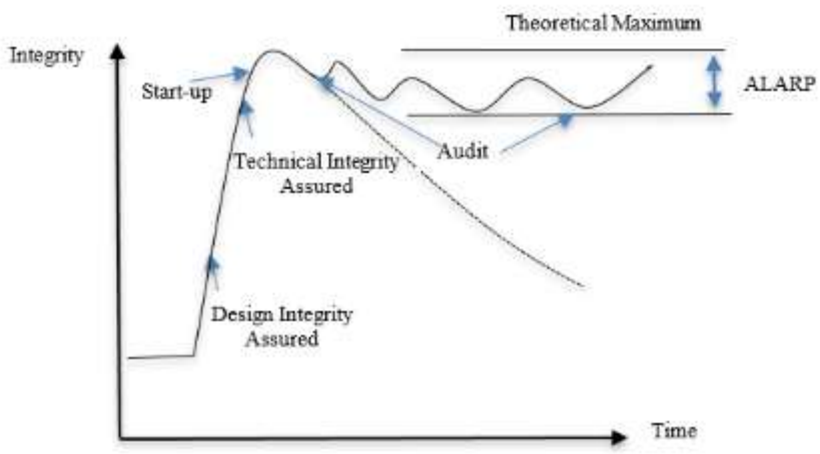


Figure 13: Progressive confidence of integrity starting from the design phase (Hossam Aboegla, 2017)

2.5. Technical Integrity (TI)

Technical integrity is considered the "appropriate work processes for inspection and maintenance systems and data management to keep the operations available" (Jan de Jong, 2009). In other words, Technical Integrity, involves effective execution of inspection, maintenance and repair programs (IMR). It is ensured during the operation and maintenance state of the asset life phases, with the aim to identify integrity issues, maintain and sustain already established technical integrity of the plant or facility. Let us review some factors that impact asset integrity and key aspects of Technical Integrity Management (TIM) Program.

2.6. Effect of Ageing Asset Technical Integrity

"An ageing equipment/asset, is an equipment for which there is evidence or likelihood of significant deterioration and damage taking place or for which there is insufficient information and knowledge available to know the extent to which this possibility exists"(HSE, 2006).

To quantify an equipment technical integrity, the subject "ageing" must be put in perspective. Ageing primarily is not about how old, but what is known about the equipment condition at any point in time and how it changes over time. It does not matter if the equipment is new, old, in service or out of service (HSE, 2006). This implies that ageing is multifaceted that touches various areas as shown in Figure 14.

During oil and gas production, process fluid (gas or liquid) which is normally pressurized are stored or transported from one point to another using equipment. These equipment face various deterioration mechanisms, ageing, failure and could result into explosion particularly if a combustible gas or evaporating liquid is accidently released into the atmosphere (Jan Roar et al, 2006). One critical line of defense from dangerous release is the integrity of an equipment.

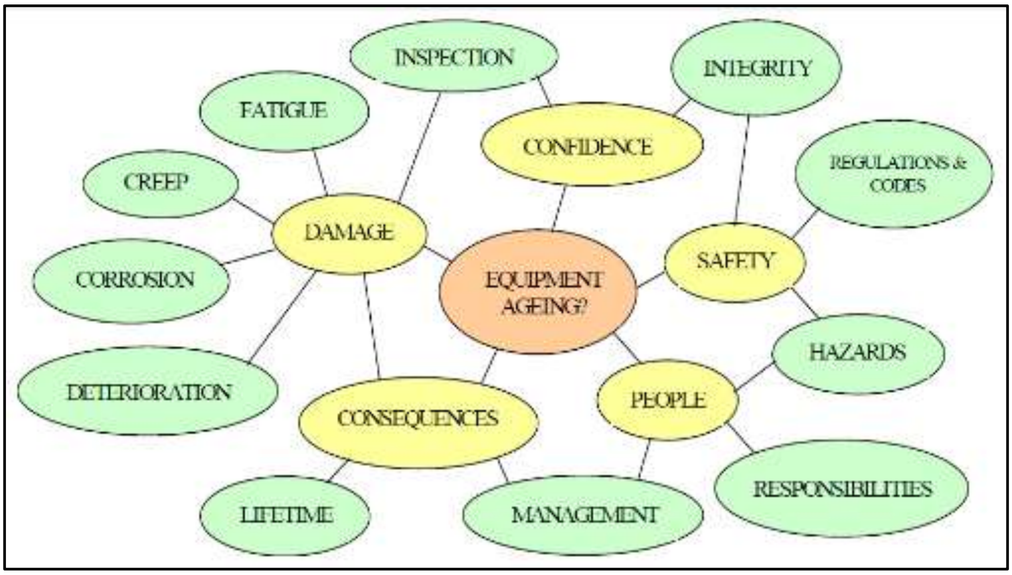


Figure 14: Issues discussed for the management of an ageing equipment (HSE, 2006)

2.6.2. Effect of Failure on Asset Technical Integrity

"Failure is the termination of the ability of an equipment to perform a required function (function or combination of functions which are considered necessary for the equipment to provide a given service"(Marquez, 2007). Many at time, people misunderstand fault and failure; but "Fault" is a state after "Failure" whereas "Failure" is an event.

Fundamentally, equipment fails due to **wear, corrosion or fatigue/stress**, which follows different failure mechanisms which are addressed in subsequent section in this project. Failure is caused due to one or the combination of the following:

- design failure,
- manufacturing failure
- installation failure
- mishandling failure
- maintenance failure

2.6.3. Ageing and Failure Development & Propagation

How do the failure and ageing processes bring about an equipment loss of function to a significant degree that an equipment is called failed? In Figures 7 and 8, speed of failure and its development/propagations is illustrated which are influenced by the following factors:

- Time since birth: This result to ageing damage whereby material's physical, metallurgical and or chemical properties undergoes modification, whether the material is in service.
- How much time the equipment is in operation and exposure to wear, corrosion or stress:

The impact of these factors mentioned above, in addition to other factors such as environmental factors (which could result to fluctuation and sudden events) all culminate to an irreversible process commonly referred to as degradation

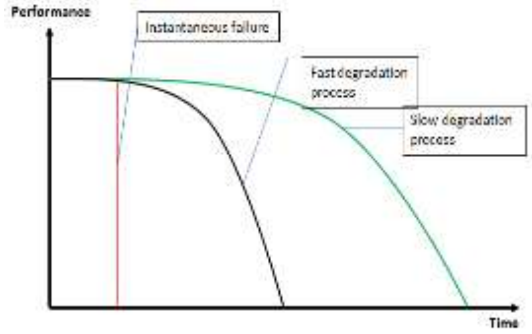


Figure 15: Speed of Failure– adopted from (Tore Markeset, 2014)

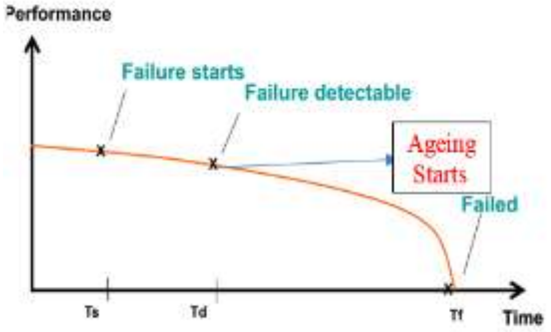


Figure 16: Failure Development Process

From the Figures 15 and 16 above, we can see that depending on the speed of the degradation, users could monitor the degradation or not, depending on when the failure initiation process is detectable. Advancement in technology is required to enable early detection of failure or degradation or any sign that integrity might be comprised from the very onset. This may come in form of data gathering and mapping – using data mining approach.

2.6.4. Managing Ageing throughout Asset Life Stages

The stages of equipment life influence the required surveillance required within the integrity management framework. It depicts the quantity of cumulative damage, the rate of deterioration and the limits within FFS* is satisfied. It provides guidance on what an equipment may be experiencing when the user knows the equipment stage in life.

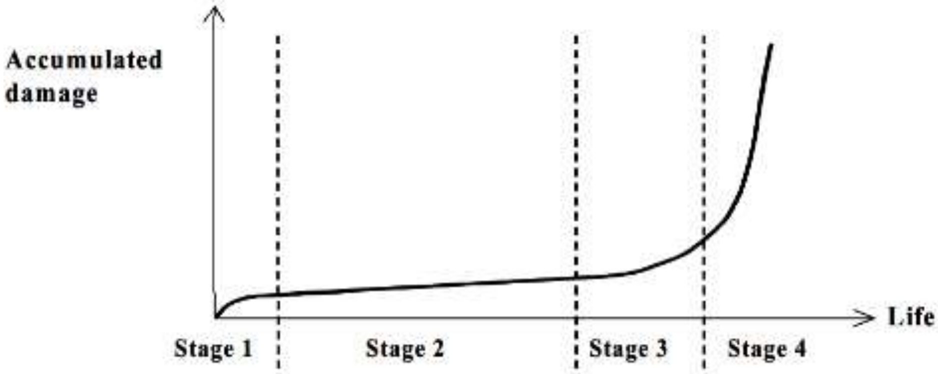


Figure 17: Variation of accumulated damage during equipment service (HSE, 2006)

These four stages as illustrated in Figure 17, are further explained below for better understanding:

Stage 1 - Post commissioning (Initial): This is when the equipment is just put in service. Here failure rate is normally high caused by inherent design, material and fabrication weakness. Also, adjustments in the equipment due to installation stresses, mal-handling or due to "shake-down" as the equipment tries to redistribute its load. At this stage, it will be proper to carry-out a thorough assessment to achieve early life integrity.

Stage 2 - Risk-Based (Maturity): here the equipment is predictable and reliable with a more stable rate of damage accumulation. Critical issues requiring attention is minimal. Condition monitoring, inspections by NDT and routine maintenance activities are done on a confirmatory basis of initial assumptions.

Stage 3 - Deterministic (Ageing): At this stage, increasing rate of degradation is observed justified by high accumulated damage. Quantitative approach is most appropriate for risk, integrity and remnant life evaluations.

Stage 4 - Monitored (Terminal): Highest damage accumulation is envisaged, with greater certainty for mitigation to be applied. Here it becomes most crucial to ensure equipment is safe while still in service. This is a time when Fitness for Service (FFS) are most important with condition based predictive maintenance strategy applied.

2.6.5. Ageing Indicators

For obvious reasons, ageing indicators are symptoms that indicate ageing damage in an equipment. But when ageing indicator exist alongside a risk factor, then risk level of the equipment is escalated. While ageing indicators are known symptoms, risk factors are condition that has the potential to accelerate degradation. Some examples are illustrated in Table 2.

Table 2: Ageing Indicators and Risk Factors

Ageing Indicator	**Risk Factor**
Blistering or damage to surfaces	Equipment age, Poor condition of paint and surface coating
Leakage	Repair
Lack of process stability	Change of service
Inspection result	Design fatigue life/corrosion allowance utilized
Product quality	Recurring service problems

2.6.6. Measuring or monitoring Ageing & Failure

Integrity is a measure of ageing damage sustained over time in an equipment. In this respect, inspections play a major role, irrespective of the stage of the equipment. Figure 18. shows how inspection is integrated in the general integrity management through an equipment life.

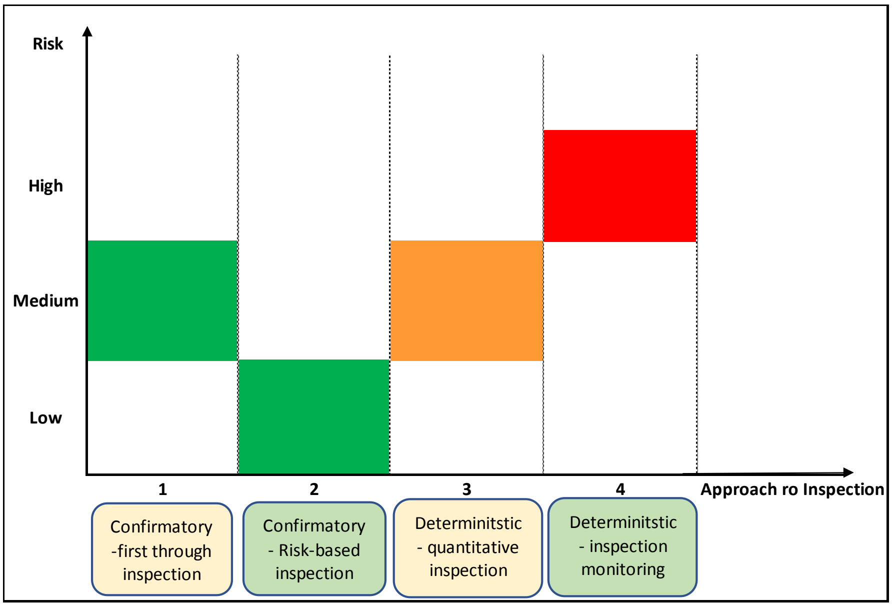


Figure 18: Approach to Inspection at the different stages of equipment life (HSE, 2006)

1. Confirmatory-first thorough (finger-print/benchmark) inspection

This is the first post-commissioning inspection required. It is usually thorough enough to establish a baseline integrity for the equipment from the onset. Some of the things to be confirmed include wall thickness, surface cracks in the weld or physical or obvious flaws.

2. Confirmatory – risk-based inspection

At this stage, initial integrity issues must have been resolved having concluded the benchmark inspection. Equipment should be in its best stable operation phase. Using the baseline integrity status, further inspection interval may be required considering expected and unexpected damage mechanisms that may set in. Condition monitoring is also initiated as part of the inspection program to help monitor parameter that has the potential to accelerate degradation rate. Figure 11: show some other parameter to be monitor for some damage mechanisms.

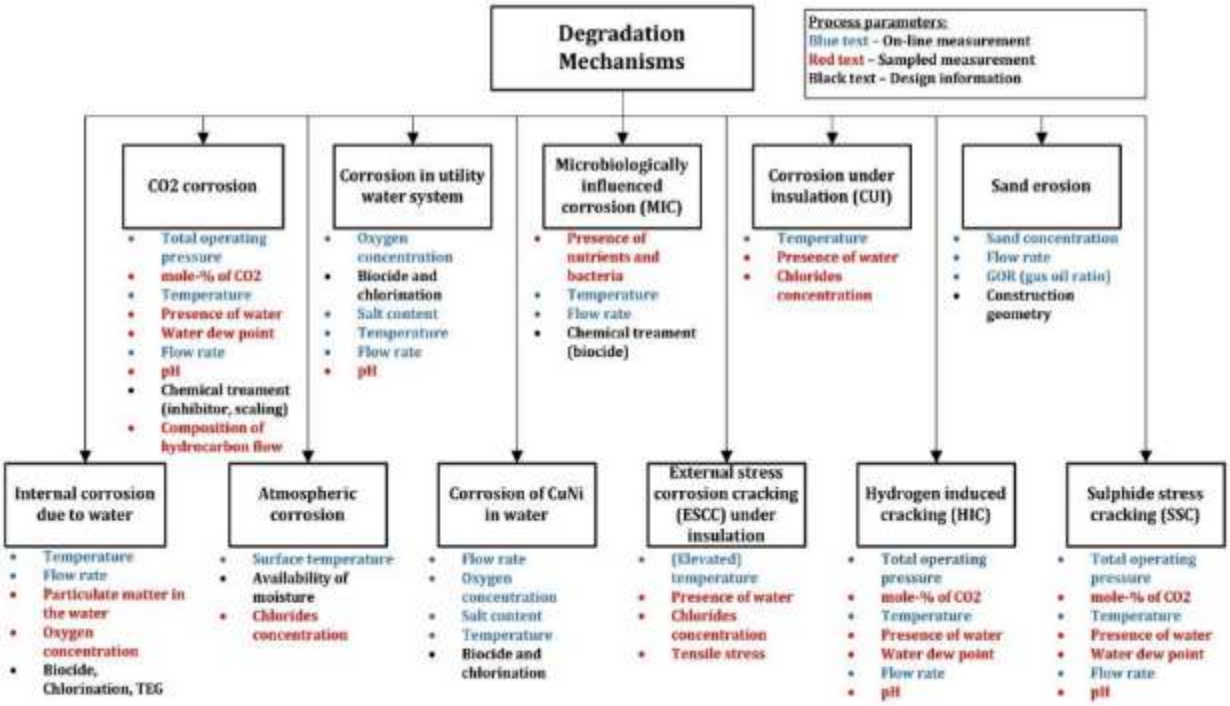


Figure 19: Damage Mechanisms and corresponding parameters (Singh et al, 2011)

3. Deterministic – quantitative inspection

At this stage, ageing is expected to have set it. Failure detection is very high and probability of failure increases; hence a determine inspection approach is most suitable. Confidence in the inspection data becomes a very important, an input data for FFS* assessments and successive inspection plan.

4. Deterministic – monitoring inspection

As the equipment design life elapses, actual failure is envisaged based on the remaining life evaluation. Inspection/monitoring data become most important as a basis for deciding equipment continued use in service. The user has the only task of using inspection and continuous /on-line monitoring to ensure that safety limits is not exceed prior to equipment life termination.

2.7.Technical Integrity Management Program

To achieve high technical integrity, involves risk assessment as well as Inspection, Maintenance, Repair (IMR) and Monitoring activities and these approaches have been summarily explained in the following paragraphs.

2.7.2. Risk Definition

Risk has been given several definitions. According to (NORSOK Standard Z-013, 2010), risk is defined as the "combination of the probability of occurrence of harm and the severity of that harm". It "expresses the danger that undesirable event represents to human beings, the environment and economic values"(Javad Barabady, 2014). In other words, risk associated with an activity means the combination of possible future incidents and their consequences, and associated uncertainty (PSA, 2014). Therefore, risk relates to confidence of how safe or reliable is an item. This loss of confidence is a measure of the integrity hence high risk mean low integrity.

Risk is an expectation not the event. For risk to exist there must be hazard; whereby hazard is any physical activity, situation or condition with the potential to cause harm, like (Marvin Rausand, 2010);

- Human injury or death
- Damage to the environment
- Damage to physical assets
- Loss of production

Once risk can be quantified or described, then we can relate that to integrity. In order to quantify risk, risk assessment must be carried out.

2.7.3. Risk Assessment Overview

Risk assessment entails a lot of processes namely establishing of the context, performance of the risk analysis, risk evaluation, and assuring that the communication and consultations, monitoring and review activities, performed prior to, during and after the analysis has been executed, are suitable and appropriate with respect to achieving the goals for the assessment (NORSOK Standard Z-013, 2010). In simple term, risk assessment is an exercise to quantify the danger inherent in a hazardous situation in a way that will help the user apply necessary steps not to endanger human, environment and physical assets.

In measuring risk, two elements must be established. First is the Risk indicator while the second is the Safety Performance Indicator Risk indicator the output of a risk analysis - which is the structured use of available information to identify hazards and to describe risk (NORSOK Standard Z-013, 2010). A risk indicator is a proof of what is known about a specific activity or operation. According to (NORSOK Standard Z-013, 2010), a general approach to risk assessment is illustrated in Figure 19.

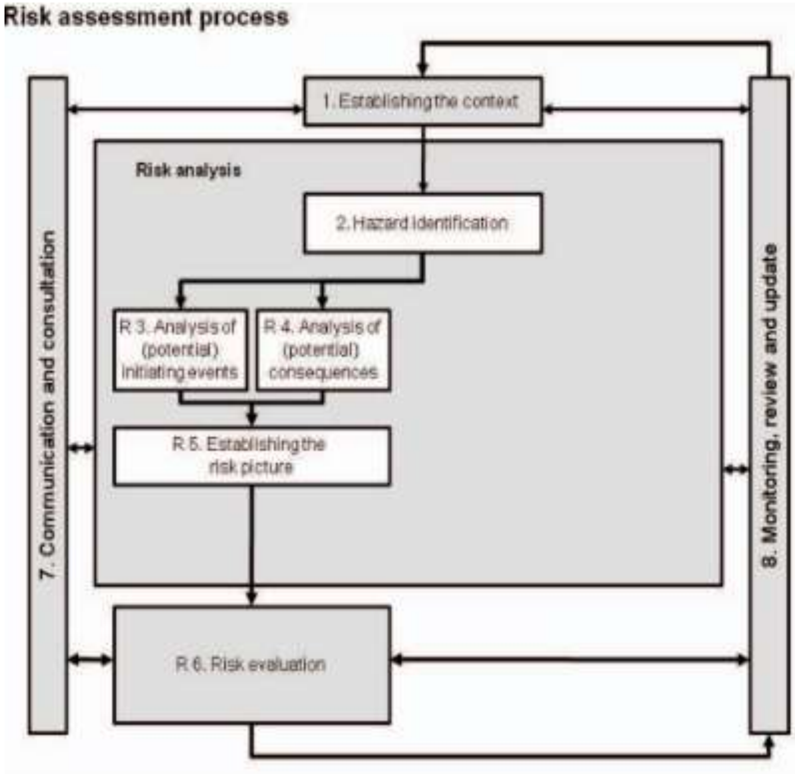


Figure 19: The Process of Performing a risk assessment (NORSOK Standard Z-013, 2010)

2.7.4. Risk-based approaches for Technical Integrity Management

Technical integrity of an equipment is about what is known about the risk inherent or facing it. Decisions taken on how to improve an equipment integrity is based on the risk status of the equipment. When risk is reduced to its minimum, an equipment technical integrity is obviously increased thereby ensuring greater availability and efficiency.

2.7.5. Risk Based Inspection (RBI) Application in Technical Integrity Management

RBI is a formal approach aimed at prioritizing inspection based on assessment of the risk to items of an equipment, in terms of consequence of failure (CoF) and probability of failure (PoF). "It provides focus for inspection activity, to address explicitly the threats to the integrity of the asset and its capability to generate revenue through production" (DNV, 2010). The risk-based approach - RBI, plays a vital role as it encompasses the pivotal processes that informs an optimum (evidence-based and cost effective) decision basis for integrity management. Standard industry recommended practices applicable for to topsides static process equipment, include DNV-RP-G101, API RP 580 and 581. RBI is also a recognized tool for meeting legislative requirement (HSE-Health Safety Executive, 2001).

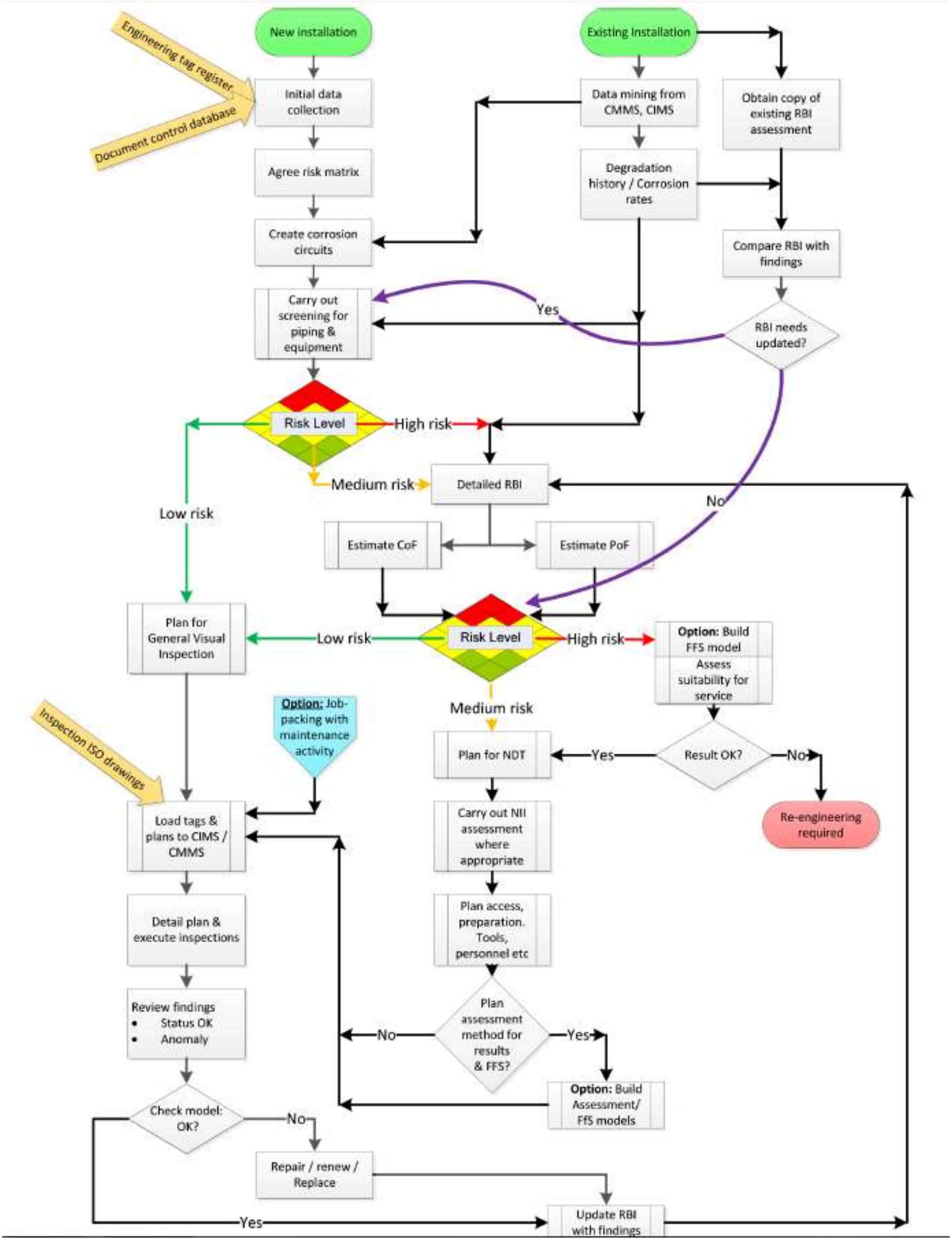


Figure 21: Risk Inspection Workflow (Dr. Peter McClean Millar, 2015)

2.7.6. Maintenance Approaches in Technical Integrity Management

Effective maintenance of equipment is critical in any Asset Integrity Management strategy. Maintenance Engineers are aware that equipment integrity demands strong organizational discipline to adhere to set bench marks and key performance indicators. They ensure maintenance operations effectiveness are measured and can predict future performance and use the gathered data obtained to make sound risk-informed decision where to make improvements. Often time operators lose money and face high risk exposure due to wrong maintenance decisions as shown in Figure 22 and 23 while not attaining the right balance between maintenance need and required integrity thresholds as shown in Figure 24.

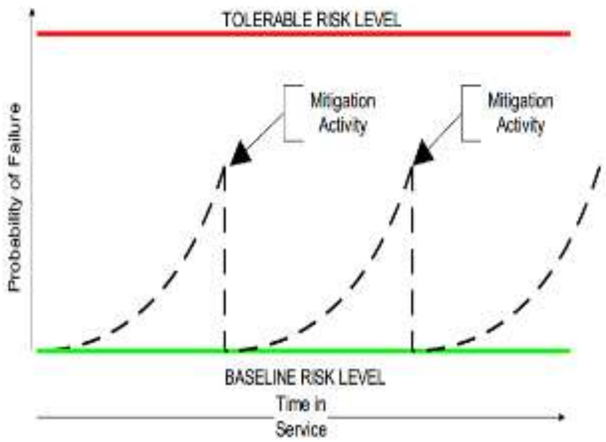


Figure 21: Maintain too early - Excessive cost ((Reza Shahrivar-OCEANEERING, 2012).

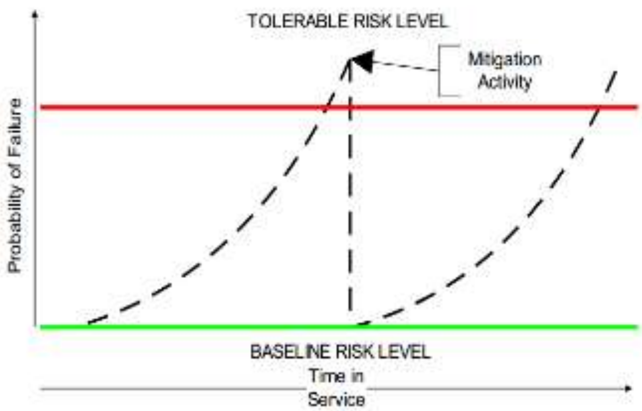


Figure 22: Maintain too late – Excessive risk

Similarly, recent research by SINTEF-MARINTEK, shows typical maintenance issues for offshore static equipment on NCS as illustrated in Figure 3 (Herald Sleire, 2009).

Figure 24: Maintenance Issues and Impact on Safety, Integrity and Availability (Herald Sleire, 2009)

2.8. Important Maintenance Aspects that Impact Technical Integrity

Irrespective of the maintenance strategy being deployed in any Assets Integrity Program, one focus for operators is to understand the equipment performance. Maintenance metrics help operators to achieve this and they are very important, as they drive the actualization of overall business goal by minimizing or eliminating unexpected breakdowns as well as assist operators in making precise decisions (Bryan Christiansen, 2018).

2.9. Categories of Maintenance Metrics

Maintenance metrics are categorized as key performance indicators (KPI) which are either:

- Leading Indicators: KPIs that signal future events, e.g. Estimated vs actual performance and PM Compliance
- Lagging Indicators: KPIs that follow the past events e.g. Mean Time To Repair (MTTR), Overall Equipment Effectiveness OEE and Mean time between failure (MTBF).

The application of these maintenance metrics and the utilization of the data into actionable information, knowledge, can provide both qualitative and quantitative insights, which are great ways to spot opportunities for asset integrity improvement (Bryan Christiansen, 2018).

According to (Bryan Christiansen, 2018), the following are some critical maintenance metrics which operators should closely monitor to improve and optimize asset integrity.

1. Planned maintenance percentage (PPC)

Simply put, this metric identifies how much maintenance work carried-out on an asset which was a part of a preventive maintenance plan versus how much time put in while repairing it due unplanned brake down.

The calculation is as follows:

PPC= (scheduled maintenance time/total maintenance hours) x 100

2. Overall Equipment Effectiveness (OEE)

This is the measure of an equipment productivity. It provided informed data on the effectiveness of an organization’s maintenance processes considering factors like equipment quality, performance, and availability.

A 100% OEE means that your system by no means defective, as fast as possible, and with no stops in the production. It is believed that understanding OEE and the underlying losses, organizations can gain significant insights into how to improve their asset integrity operational processes.

To calculate the OEE, you multiply the availability by the performance and quality:
OEE = availability x performance x quality

3. Mean time to repair (MTTR)

MTTR is the measure of the repairable items' maintainability. This is the time spent between when repairs started and when completed on an equipment. It covers repair time, testing period, and time to return to the normal operating condition. Operators target to reduce MTTR as much as possible.

To calculate MTTR, you divide the downtime period by the total number of downtimes:
MTTR= (SUM of downtime periods/ total number of repairs)

4. Mean time between failure (MTBF)

MTBF informs about the expected lifetime for a piece of equipment. Higher MTBF, the longer before it experiences failure. It helps to predict and prepare for a failure or fix some preventive work.

To calculate the MTBF, you divide the total operational time by the number of failures:
MTBF= (SUM of operational time/total number of failures)

5. Preventive maintenance compliance (PMC)

PM compliance is defined as the percentage of the preventive work scheduled and completed in a set time. E.g. 60 Work Orders (WO) (that are a part of the PM plan) scheduled but 51 completed at month end.

In this case: *PMC= (51/60) x 100 = 85%*
This tells you that 85% of all preventive WO's have been covered for selected month. This metric doesn't tell you if the WO's have been completed on time.

2.9.2. Condition Monitoring and Inspection for Enhanced Technical Integrity

2.9.2.1. Application of Condition Monitoring

"Condition is a generalized method for establishing a machines' health using measured parameters which reflect changes in the machine's mechanical state"(Tore Markeset, 2014).

Condition monitoring is instrumental to maintenance of offshore topsides systems as illustrated in Figure 20, due to the following reasons (Singh et al, 2011) and (Herald Sleire, 2009):

- Provides evidence–based criteria for plant optimization decisions, by providing system's real-time status.
- It reduces maintenance cost and increases regularity
- Provides required data/information for remaining life estimation. It affords traceability of changes in the operating condition because of slow or sudden changes in the services (process and utility systems).
- Makes early fault detection possible, by monitoring key process parameters that indicates onset of failure particularly in fast deterioration when degradation mechanisms are "non-inspectable".

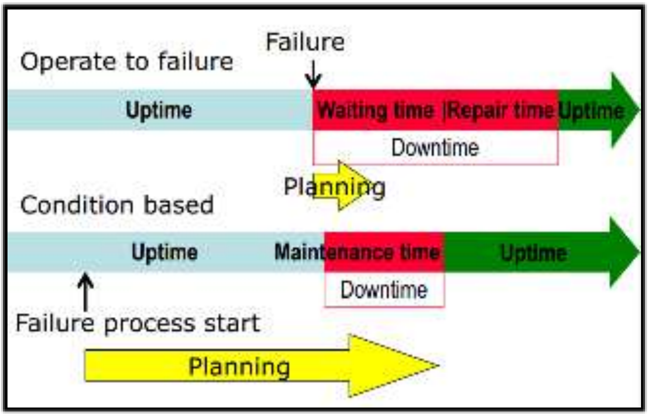


Figure 25: Effect of Condition Monitoring (Tore Markeset, 2014)

2.9.3. Condition Monitoring Methodology

In general an effective CM will consists of the following steps (Rao, 1998):

- Identify critical systems, select CM techniques
- Setting baseline/alerts
- Data collection
- Data assessment
- Fault diagnosis and repair
- System review

These steps can be implemented in a systematic way as illustrated in Figure 26 (Tore Markeset, 2014)

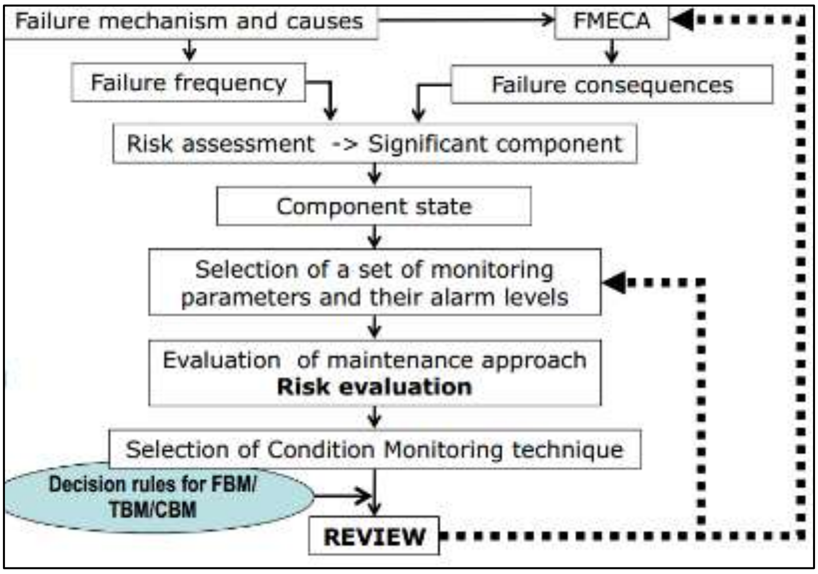


Figure 26: Example of a Condition Monitoring Methodology (Tore Markeset, 2014)

Condition Monitoring (CM) is comprised of three major components(KUMAR U., 2009) a). **Measuring,** b). **Diagnosing** and c). **Informing.**

- Measuring: This is the use of sensors to receive energy from a measured medium which then gives an output signal depending on the measured quantity
- Diagnosing: This involves using microprocessor and control electronics to monitor the process, and record, store and manipulate the data from the sensors
- Informing: This is achieved in two stages – "how to inform" and "what to inform". How to inform, refers to use of a display to present processed data in a way understandable by users. "What to inform", considers "who to inform" to inform the categorization of processed data such that data required by the production personnel is presented differently from data required by maintenance personnel who is interested in machines health.

2.9.4. Use of data in Condition Monitoring

CM can only be possible if and only if useable data is available. Data types can be categorized into (Singh et al, 2011):

- Design data
- Operation data
- Historical data (inspections records, maintenance, corrective actions or modifications)

The processes of collection, storage, interpretation, and conversion of data into useful format is vital for our decision making, for which (Singh et al, 2010) has provided a systematic approach. Furthermore, a summary of current issues facing condition monitoring in the NCS and their causes are also presented in Table 3, which justifies the research need in this area.

Table 3: Issues facing Condition Monitoring for Offshore Static Equipment on NCS (Herald Sleire, 2009)

Scope	**Status and Issues**
Equipment technical condition	Poor and less prioritized
Monitoring information	Information is not fully utilized
Signal reliability	Questionable signals due to unreliable instrumentation
Fault detection methods	Distorted and varied detection method, whereby %contribution to failure detection is given as: • casual observation/unknown: 60-65%, • Periodic preventive maintenance: 10-15% • Continuous condition monitoring: 10-15% • Inspection: 5% • Other (production interference, on demand etc.)

2.10. Operational Integrity (OI)

Operational integrity can be explained as the application of appropriate knowledge, experience, manning, competence and decision-making data to operate the plant as intended throughout its life cycle (Ratnayake R.M.C, 2012). Here we consider human factors and its interfaces with systems and equipment. Incidents have been traced to originate from issues due to crew incompetence and system/ process failures. Many a time we have seen that information and data mishandling have deceived or made human to err. Hence the role of data and information in sound decision making is a critical factor in operational integrity and sustainability of Assets Integrity management as seen in picture below Figure 27, a case study of an Oil and Gas Company- ExxonMobil Operations Integrity Management System showing the interconnectivity of all the factors including human factor in driving operational excellence for assets integrity management.

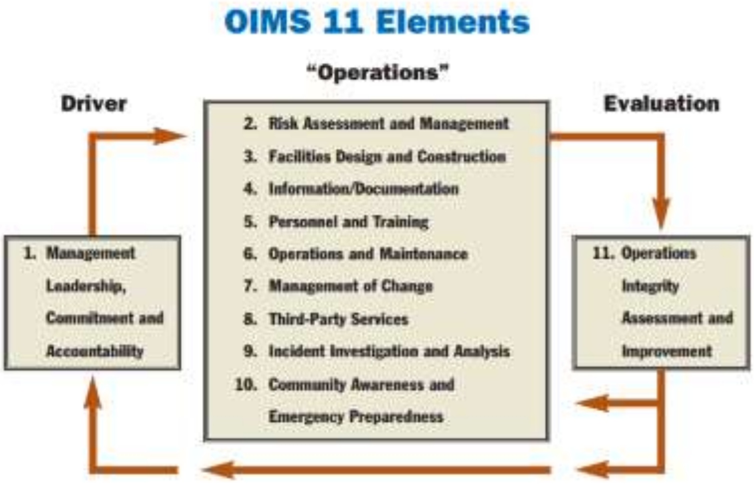


Figure 27: ExxonMobil Operations Integrity Management System Framework (Lee R. Raymond, 2004)

Studies as shown in Figure 28 below, have also showed that organizational challenges and its influence on asset integrity management point to knowledge management as key to sustainable asset integrity management.

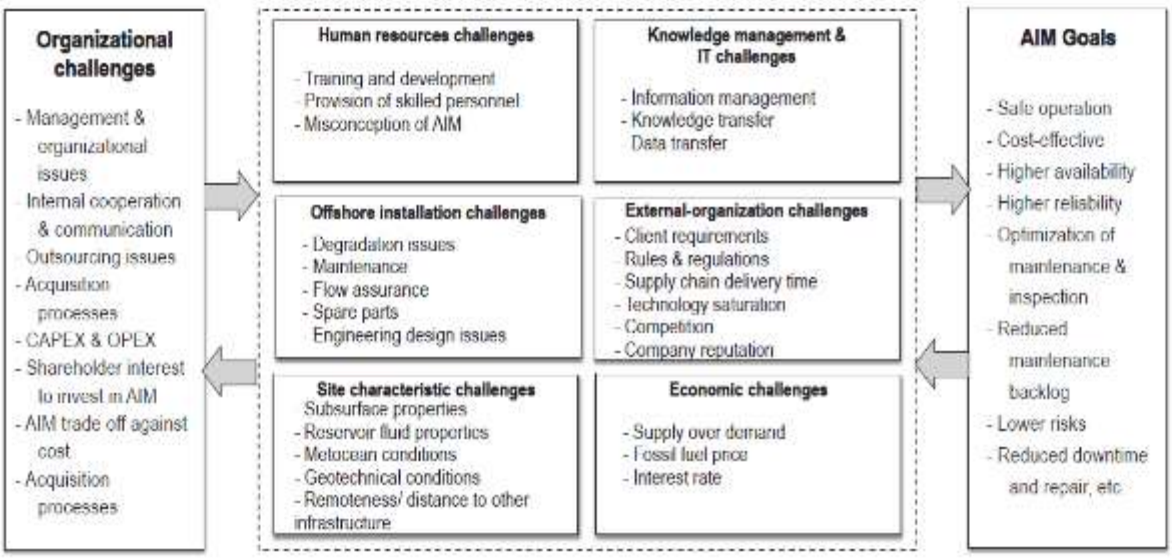


Figure 28: Influence of AIM Challenges in organizations with offshore petroleum production asset to reach AIM goals (Mayang Kusumawardhani et al., 2016)

Overtime, due to pursuit for operational excellence (OE), it has become pertinent to re-evaluate existing approach to asset integrity management and give opportunities to test other perspective as relates to asset integrity performance improvement suitable for use in high uncertainty areas.

2.11. Critical Success Factors CSFs for Assets Integrity Management: An Overview

For this study, we have homed-in on the CSFs that widely influences Assets Integrity Performance across its element namely; Design Integrity (DI), Technical Integrity (TI), Operational Integrity (OI).

2.12. Critical Success Factors Definition

Firstly, Critical Success Factors (CSFs) have been defined as those limited number of areas in which results, if they are satisfactory, will ensure successful competitive performance for the organization (Prapawadee Na R Ranong et al., 2009). In other words they are crucial element that supplies the means, knowledge, or opportunity that allows for the success of an assigned task or mission (CI Glossary, 2011).They imply core areas where things must be done correctly for the set goal to be accomplished, for instance to ensure optimal performance of assets. Also, other authors have interpreted this to mean variety of principles, systems and tools that can be applied towards the sustainable improvement of key performance metrics, invariably those that ensure maximum effectiveness and efficiency (Ernst and Young (EY), 2015). Deficiency in the right application of CSFs, is tantamount to an organization scoring below its desired goal. From review of many oil and gas companies, critical success factors attract the best of attention to ensure high performance. These factors have been summarised by so many oil and gas company and has formed part of the policy and goals/ mantra for the day-to-day running of the company.

A great number of factors have been researched and in use in many Assets Integrity Management models across the industry. For instance, there are 20 core elements contained in the Energy Institute (EI) Process Safety Management (PSM) Standards which addresses focus areas of operations that organizations that need to be stewarded correctly to assure the integrity of their operations (Mohamed Attia, 2018). Each element is broken down to other expectations which meet the desired goal of the element.

Those 20 elements are:

1. leadership commitment and responsibility,
2. identification and compliance with legislation and industry standards,
3. employee selection,
4. placement and competency,
5. health assurance,
6. workforce involvement,

7. communication with stakeholder,
8. hazard identification and risk assessment,
9. documentation, records and knowledge management,
10. operation manuals and procedures,
11. process and operational status monitoring, and handover,
12. management of operational interface,
13. standards and practices,
14. management of change and project management,
15. operational readiness and process start-up,
16. emergency preparedness,
17. inspection and maintenance,
18. management of safety critical devices,
19. work control permit to work and task risk management, and
20. contractor and supplier selection and management.

As we know, AIM is not new, and the application of data and risk management principles is not new either, but changing conditions create opportunities for operators and industry to fully maximize available potentials. It is in the interest of this study to holistically access the emerging perspectives of data and risk management as one the driving Critical Success factors that will bring about the required edge for AIM profitability and efficiency in times like this.

2.13. New perspective to data and risk management for an intelligent risk-based decision support framework asset integrity management

Figure 29: Moving Beyond Data Lakes to Real-Time Analytics for Operational Intelligence (Stephen Collins, 2018)

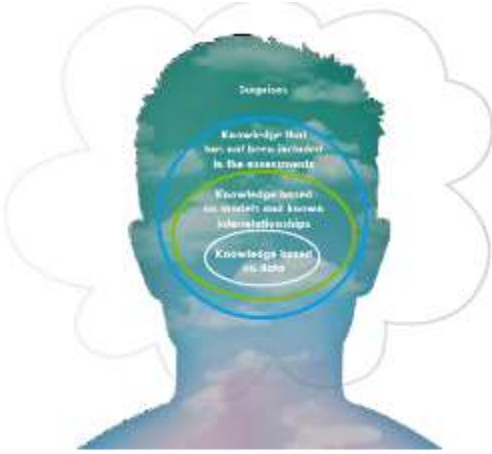


Figure 30: Knowlegde Sources for Decision Makers Adopted from (Petroleum Safety Authority, June 2018)

Irrespective of seemingly well-established asset integrity management CSFs in practise in the industry today, there are yet optimization opportunities that can bring about the required expectation in Assets Integrity.

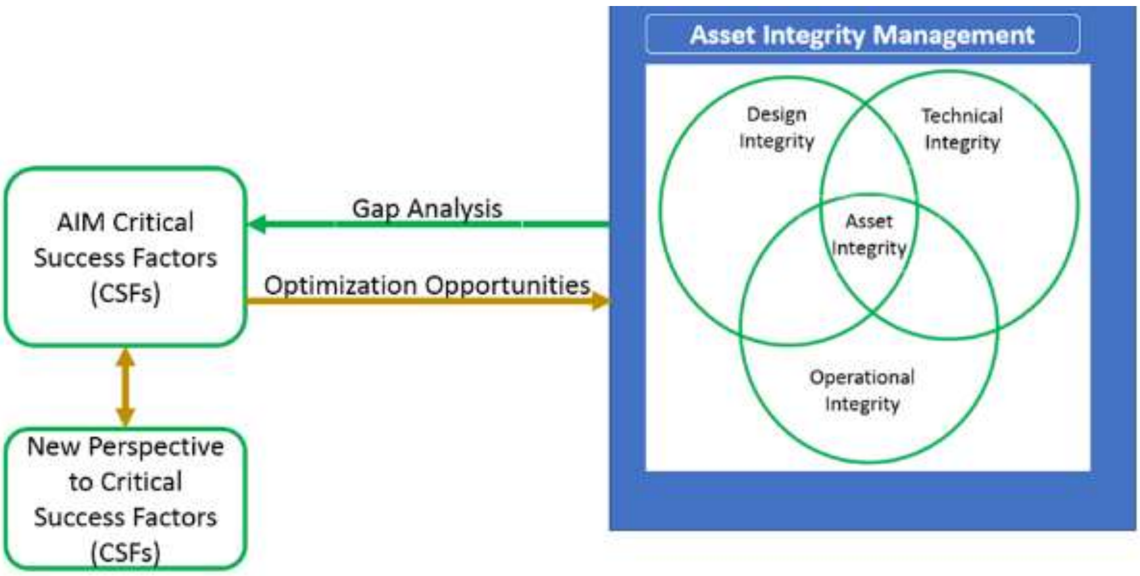


Figure 31: Gap Analysis for Asset Integrity Management Optimization Opportunities

These emerging and new perspectives are grouped under two aspects – Data Management and Risk Management aspects, with the hypothesis provided below:

Hypothesis	Meaning
H1	*Robust Risk Management Approach is critical for "Intelligent Asset Integrity Management" (iAIM):* *A concept of all practices that avails the precise proactive asset integrity assessment by holistic performance monitoring through the asset life cycle.*
H2	*iAIM requires a Data Management System with capabilities to capture, integrate, visualize and analyze data and able to be fed with real-time assessment data, as well as be able to produce decision data in a fast and simplistic manner, to sustain overall organizational goal throughout the asset life cycle.*

2.3.Data Management Optimization Aspects

In many cases across the industry, data management is very uninteresting due to high level of integration and coordination required from many independent data sources, hence it rarely gets the required attention; until there is a major incident during which low-quality, incomplete and inaccurate data are identified as root causes or a major contributing factor. The good news is that operators now see the need to seek many ways to ensure appropriate utilization of data for proactive integrity monitoring to forestall unplanned equipment failures and reliability problems. In line with this, the author as well as other authors believe that data management is a critical success factor which influences AI as summarised in Table 32 below.

Figure 32. Data Management as a Critical Success Factor in AIM, adopted from (John Reynolds, 2012)

Considering emerging oil and gas development locations in Barents Sea, we can see that current approaches to managing data will no longer sufficiently provide the high-quality fundamentals required to obtain new insights for improving asset management operations. The ability to obtain insight and value from asset centralized data is very crucial to effectively manage and optimize Asset Integrity Management work processes. This demands for tools which supports collaborative work process integration, optimization and risk/data visualization. There is need for full access to asset data, so that current condition and performance will be monitored while providing a comprehensive framework to effectively plan, report and support Asset Integrity Management operations.

2.4.Risk Management Optimization Aspects

There is no way a zero-risk can be achieved in any process facility. Nevertheless, research has shown that there is improvement in risk management across the oil and gas industry and a corresponding reduced tolerance for hazards and risks (Petroleum Safety Authority, June 2018). The application of inherently safer best-practice design principles has contributed to minimized residual risk. That notwithstanding, there is a level of risk remaining that need to be managed.

In the light of this, many operators continue to seek optimization opportunities that will further reduce risk exposures as low as reasonably possibly. Other perspectives to risk management is all about how decision is made based on the knowledge of it. It is risky to made risk decision without adequate data, or data which you do not have enough understanding about. Many have argued that visualization and analytics has become more important in risk communication to close the gap. Similarly, the author as well as other authors believe that risk management is a critical success factor which influences AI as summarised in Table 4 below.

Table 4: Comparisons between the authors' proposed Critical Success Factors (CSFs) and other authors

Comparisons between the authors' proposed Critical Success Factors (CSFs) and other authors							
#	Proposed CFSs/ KEs / Authors	Risk Management Aspects			Data Management Aspects		
		Risk- Based Methods	Risk-informed Descision Support	Risk Visualization	Data Digitization	Data Analytics	Data Visualization
1	PSA (2018) Integrated & Unified risk mgt in petroleum industry	■	■	■			■
2	Jonathan Martinez (2018) Using Digital Data Mgt. Systems to Streamline Work Processes				■		
3	TIBCO - Analytics for Risk Management					■	
4	Michael Brenner - How Data Visualization Improves the Oil and Gas Industry			■			■
5	Alejandro C. Torres-Echeverria (2016) - The House of Integrity: Modern Asset Integrity Management	■	■	■	■	■	■
6	Hossam Aboegla - Asset Integrity Management Enablers for Engineering Assets (2017)	■					
7	Bouchra Delille - key element for successful integrity management (2009)	■	■				
8	Stephen Collins-Moving Beyond Data Lakes to Real-Time Analytics for Operational Intelligence (2018)			■	■	■	■
9	Mahmoud Aboelatta- Managing Risk associated with the Integrity and reliability of subsea fields using Bayesian networks (2018)	■		■			■
10	Mehna Raissi et al - Data Visualization in Credit Risk Management, 2015			■		■	■
11	Devon Brendecke- Real-rime Operating Decision Made Easier		■		■	■	
12	Mohamed Attia - How to develop a Proactive Risk-based Integrity Management Framework for Plant Assets	■					
13	Vipin Nair -Cognitive Inspection Analytics in Asset Performance Management, 2018			■	■	■	■
14	David Aldrich- Harnessing the Power of Big Data to Drive Improvements in Reliability and Maintenance (2017)			■	■	■	■
15	Jeffrey Foushee - How well-maintained data can add value to your reliability program(2016)	■		■	■	■	■
16	Stephen Flory - Achieving the Full Potential of Asset Performance Management Platforms (2017)		■	■	■	■	■
17	Victor Borges et al., - The Rise of Asset Performance Management (2017)	■	■	■	■	■	■

1(Petroleum Safety Authority, June 2018), 2(Jonathan Martinez, 2018) 3(TIBCO, 2012),4(Brenner, 2016), 5(Alejandro C. Torres-Echeverria et al., 2016), 6(Hossam Aboegla, 2017), 7(Delille, 2009), 8(Stephen Collins, 2018), 9(Mahmoud Aboelatta, 2018), 10(Raissi, 2015), 11(Devon Brendecke, 2013), 12(Mohamed Attia, 2018), 13(Vipin Nair, 2018), 14(David Aldrich, 2017),15(Jeffrey Foushee et al., 2016),16(Stephen Flory, 2017), 17(Victor Borges et al., 2017)

CHAPTER 3

RESEARCH METHODOLOGY

3.0 Introduction

This chapter will describe the methodology used in this study. Firstly, the choice of study, research philosophy, research purpose, research approach and research strategy are presented. Subsequently, the data collection method that provides information on how to collect sources is explained. Finally, the validity and reliability of our research is explained.

3.1. Choice of Study

Many assets integrity model is out there and currently in use in the industry today. These models utilize standard guideline and have a lot in common about the critical success factor. The choice to focus on data and risk management, became important, due the fact that risk decisions are taken based on output of data processing system. The moment data management is bad, risk management will be wrongly applied thereby jeopardizing the entire assets management program. The author believes the study will result in meaning outcome for leaders to implement for the benefit of their asset.

3.2.Research Philosophy

This study is based constructionism as its ontological major, instead of objectivism. According to Wikipedia "Constructionism (in the context of learning) is the idea that people learn effectively through making things.". We also applied an epistemological major, - positivism, which affirms that all knowledge regarding matters of fact is based on the "positive" data of experience and (2) that beyond the realm of fact is that of pure logic and pure mathematics(britannica, 2018). Therefore, we applied the deductive approach which entails generating hypotheses that aim at data collection.

3.3.Research Approach

Research approaches can be deductive or inductive. In this study, the deductive approach (a top – down) approach was applied, which entails generating hypothesis that aim at collection of data. After the hypothesis is generated, it is then tested - confirmed or rejected before the hypothesis is either confirmed or revised (Bell, 2003)

Figure 33: The process of deduction

The first part of this study is the theory, the literature review. The literature review covered assest integrity management and the review a set of critical success factors based on existing literatures, books and publications. This stage produced the hypothesis. Followed by our data collection strategy which is through questionnaires and interviews. Then we analyzed our results of our data collection, during which each question was evaluated for the hypothesis category to confirm or reject.

3.4.Research Strategy

There are two major approach to this; the quantitative method which entail collection of numeric data, and the qualitative method e.g. interviews, which emphasizes words rather than numbers. Tin this study, we combined the quantitative approach with the deductive research approach.

3.5.Data Collection Method

In this study we used the self-completion questionnaire which was designed based on certain questions primarily for obtaining data.

3.6.Sample selection

Our sample was focused on persons with 8 years' experience and above and working within the asset integrity management sector of the oil and gas industry. A total of potential samples of seventy (70) were considered, out of which sixty-four (64) respondents provided feedback.

3.7.Design of questionnaire

The questionnaire contains twenty (20) questions and is divided into the following segments:
The first part consists of respondent's details and discipline background.

The second part investigates each of the critical success factors according to the hypothesis. A sample questionnaire is showed in Appendix.1.

3.8.Survey procedure

Based on the options available and closeness to target respondents, most of the survey were printed hard copy and sent to the respondents to fill and return. Some were sent electronically via email to some few distant respondents, to be printed and hand-filled and scanned back to me . The questionnaire was distributed to respondents September 12, 2018 and collected on October 7 for analysis. The analysis is described in chapter 4.

3.9.Data analysis

This study used quantitative method to collect data and the univariate analysis method was used for the data analysis. There are three basic technique for analyzing quantitative data namely (1) Univariate analysis (2) Bivariate analysis and (3) Multivariate analysis (Bell, 2003). The univariate approach analyses one factor at time. The univariate analysis is the simplest form of analyzing data. “Uni” means “one”, so in other words your data has only one variable. It doesn’t deal with causes or relationships (unlike regression) and it’s major purpose is to describe; it takes data, summarizes that data and finds patterns in the data (Wikipedia, 2014).

CHAPTER 4
SURVEY RESULTS AND ANALYSIS

4.0. Introduction

In this chapter, we presented the result of all the empirical data collated from our self-completion questionnaire.

4.1. General Survey Analysis Information

We targeted personnel positions working within the Assets Integrity Management sector of the Oil and Gas industry in Nigeria, with minimum of 8years working experience, to ensure valuable response. The results of this survey were analyzed using Microsoft Excel program.

Firstly, the demographic results are presented to demonstrate the general information of our survey.

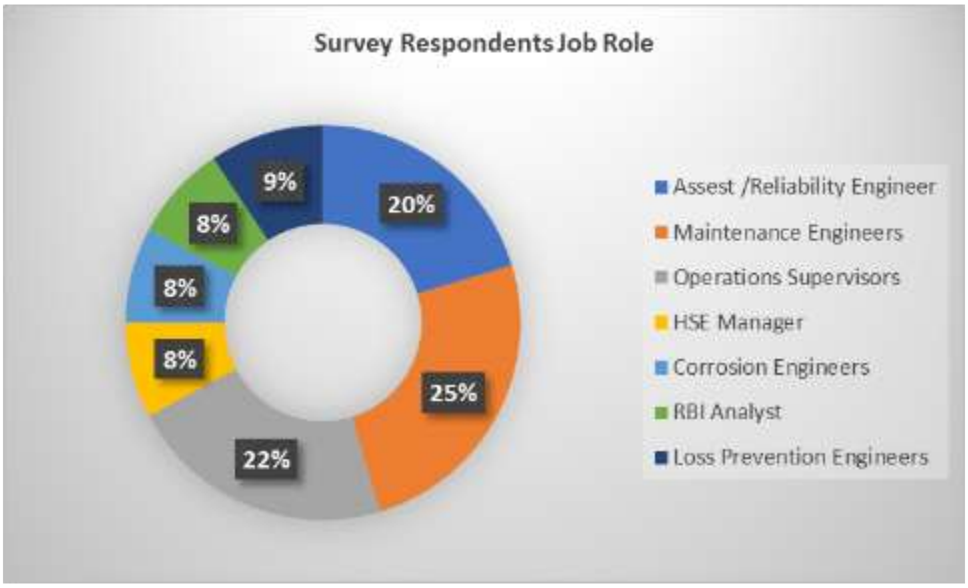


Figure 34: Survey Respondent Job Role with the Oil and Gas Assets Integrity Management Sector

The figure above shows the respondent job role spread and the percentage breakdown. Out of seventy (70) number questionnaires distributed, there was sixty-four (64) valid responses. The respondent's percentage spread per job role are as follows: 20%, as An Asset/ Reliability Engineer, 25% as Maintenance Engineer, 22% as Operations Supervisor, 8% as HSE Manager, 8% as Corrosion Engineers, 8% as RBI Analyst, and 9% as Loss Prevention Engineer. The spread of the respondent was practicable and adequate for the survey analysis.

4.1.General Survey Analysis Information

To start with, Table 5 Overall Survey Percent Aggregated Score, shows the percentage of each answer from the respondents which will be used for the overall survey performance, as well as the performance by hypothesis question.

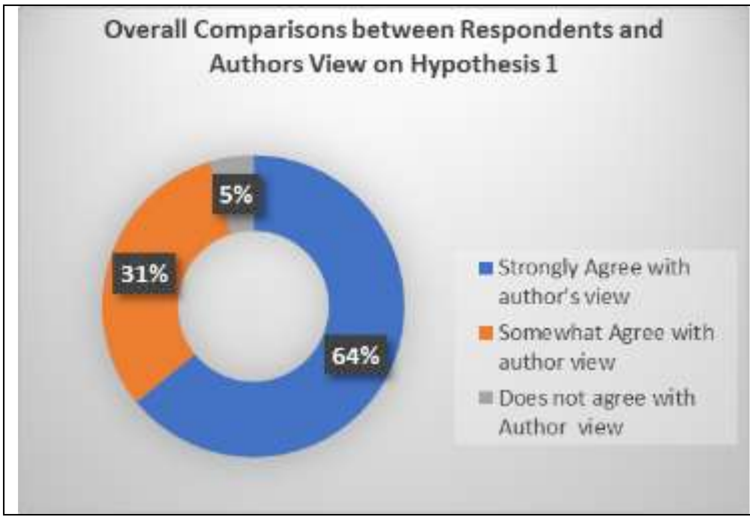
4.2.Criteria for Respondents Average Score per Hypothesis

To establish to what degree, the respondents agree with the authors view on each hypothesis, the following criteria was set before the questionnaire was distributed.

- Strongly Agree: Avg. Score >80%,
- Somewhat Agree: Avg. Score >50%< 80%,
- Disagree: Avg. Score <50%

Table 5: Overall Survey Percent Aggregated Score

Hypothesis			Aggregated Score				
			Strongly Agree (4)	Agree (3)	Somewhat Agree (2)	I dont Know (1)	Disagree (0)
H1	A	Do you agree that Robust Risk Management Approach is critical for an effective Asset Integrity Management?	41%	33%	11%	9%	6%
	B	Risk-based Assessment methods are critical and need to have the ability to proactively identify potential integrity risks	59%	22%	8%	6%	5%
	C	Risk-informed decision support should an integral within the Asset Management Framework	61%	20%	8%	6%	5%
	D	There is great value derivable from application of Risk Visualization Tool in your Asset Integrity Management Work Processes	48%	36%	11%	3%	2%
H2							
	A	Do you think the Oil and Gas Industry not utilizing the power of big data maximally in its Asset Integrity Solutions	61%	39%	0%	0%	0%
	B	Do you agree in maintenance performance monitoring, that good data is required to generate maintenance metrics as follows PPC, OEE, MTTR,MTBF, PMC.	69%	22%	3%	3%	3%
	C	Do you agree that digitization of inspection, operations and maintenance work processes will reduce and/or reduces maintenance error	70%	30%	0%	0%	0%
	D	Good data are readily available for use by Operations personnel to carry-out required Risk Assessment, Reliability Studies, Inspection and Maintenance Planning	67%	33%	0%	0%	0%
	E	Do you agree that maintenance errors and unscheduled shutdown are traceble to dirty data	61%	28%	11%	0%	0%
	F	Do you agree that incidents, accident and fatalities are traceble to dirty data	66%	30%	3%	2%	0%
	G	Do you agree that O&G organization can save significant cost if the use of dirty data can be minimized or eliminated	70%	28%	2%	0%	0%
	H	Do you agree that Digital data helps to streamline work process, thereby reducing error associated with human interaction	66%	27%	6%	2%	0%
	I	Data Visualization is widely utilized in Risk / Integrity communication	64%	27%	2%	5%	3%
	J	Do you agree that Data Visualization aid in smart decision making	45%	34%	5%	14%	2%
	K	There is great value derivable from the application of Data Visualization in in your Asset Integrity Management Work Processes	59%	38%	0%	3%	0%

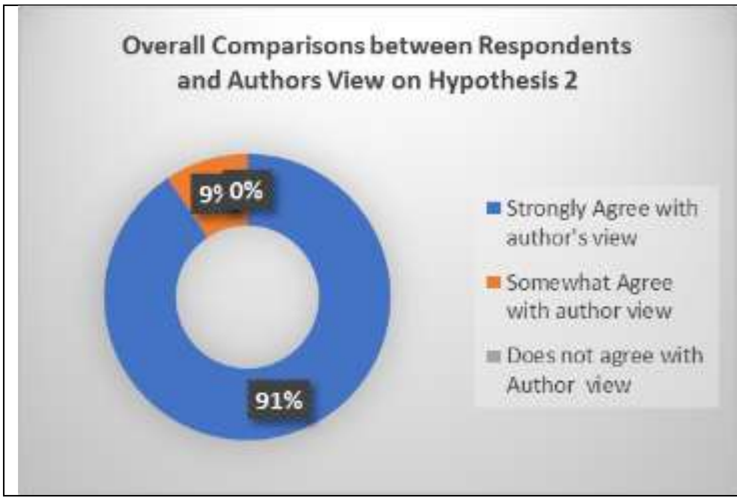


Data below represents the respondents view about author's hypothesis 1:

- Strongly Agree: 64%
- Somewhat Agree: 31%
- Disagree: 5%

Figure 35. Overall Comparisons between Respondents and Authors View

The results of the Figure 35 show that majority of the experts agree to a high degree with the author's hypothesis 1.



Data below represents the respondents view about author's hypothesis 2:

- Strongly Agree: 91%
- Somewhat Agree: 9%
- Disagree: 0%

Figure 36. Overall Comparisons between Respondents and Authors View

The results of the Figure 36 show that majority of the experts agree to a higher degree with the author's hypothesis 2.

4.3.Analysis of Respondents View on Each Hypothesis Question

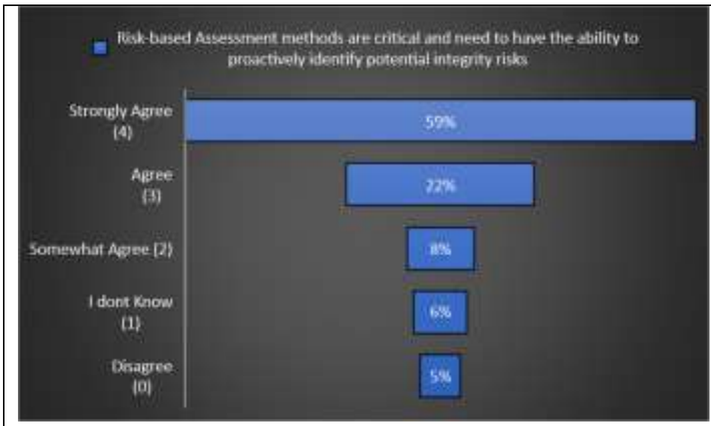
Here, we will present the results of each of the contributing factors. Based on the questionnaire structure, in which we divided the questions into two factors, namely Risk Management and Data Management.

Data below represents the respondents view about the hypothesis question H1-A.

- Strongly Agree: 41%
- Agree: 33%
- Somewhat agree:11%
- I don't know: 9%
- Disagree: 6%

From the data above most respondents agree to the authors view

Figure 37: Hypothesis question H1-A

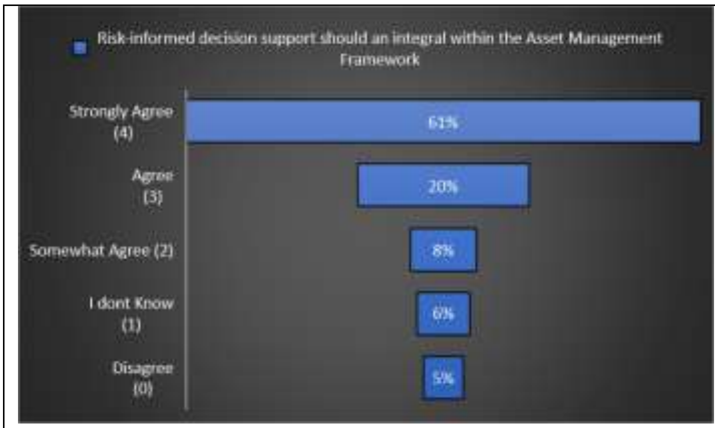


Data below represents the respondents view about the hypothesis question H1-B.

- Strongly Agree:59%
- Agree: 22%
- Somewhat agree: 8%
- I don't know: 6%
- Disagree: 5%

From the data above most respondent agree to the authors view

Figure 38: Hypothesis question H1-B

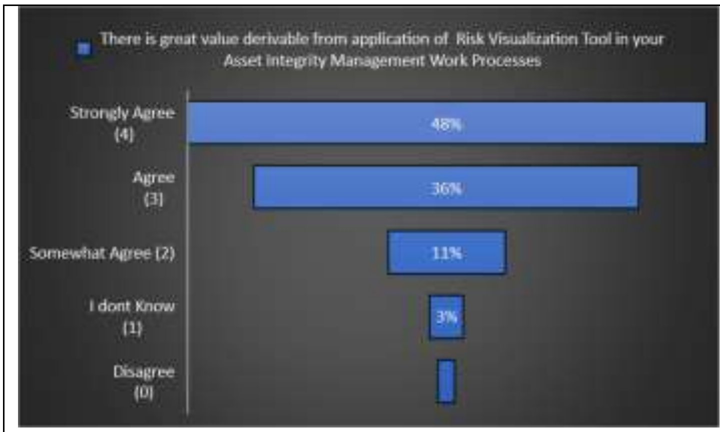


Data below represents the respondents view about the hypothesis question HI-C.

- Strongly Agree: 61%
- Agree:20%
- Somewhat agree: 8%
- I don't know: 6%
- Disagree: 5%

From the data above most respondents agree to the authors view

Figure 39: Hypothesis question H1-C

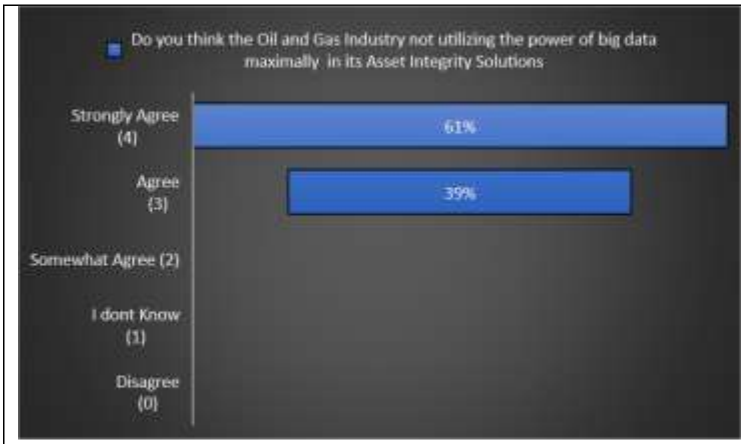


Data below represents the respondents view about the hypothesis question.

- Strongly Agree: 48%
- Agree: 36%
- Somewhat agree: 11%
- I don't Know: 3%
- Disagree: 0%

From the data above most respondents agree to the authors view

Figure 40: Hypothesis question H1-D

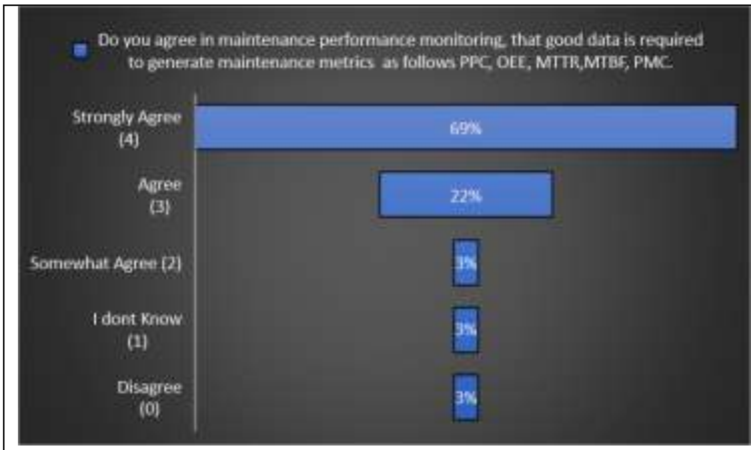


Data below represents the respondents view about the hypothesis question.

- Strongly Agree: 61%
- Agree: 39%
- Somewhat agree: 0%
- I don't Know: 0%
- Disagree: 0%

From the data above most respondents agree to the authors view

Figure 41: Hypothesis question H2-A



Data below represents the respondents view about the hypothesis question.

- Strongly Agree: 69%
- Agree: 22%
- Somewhat agree: 3%
- I don't Know: 3%
- Disagree: 3%

From the data above most respondents agree to the authors view

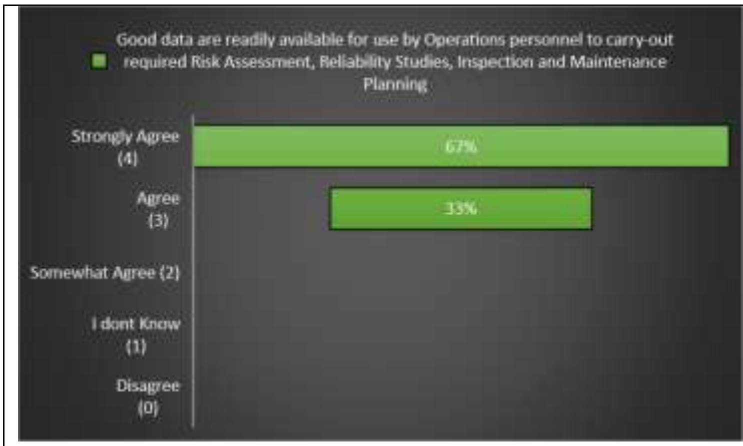
Figure 42: Hypothesis question H2-B

Data below represents the respondents view about the hypothesis question.

- Strongly Agree: 70%
- Agree: 30%
- Somewhat agree: 0%
- I don't Know: 0%
- Disagree: 0%

From the data above most respondents agree to the authors view

Figure 43: Hypothesis question H2-C

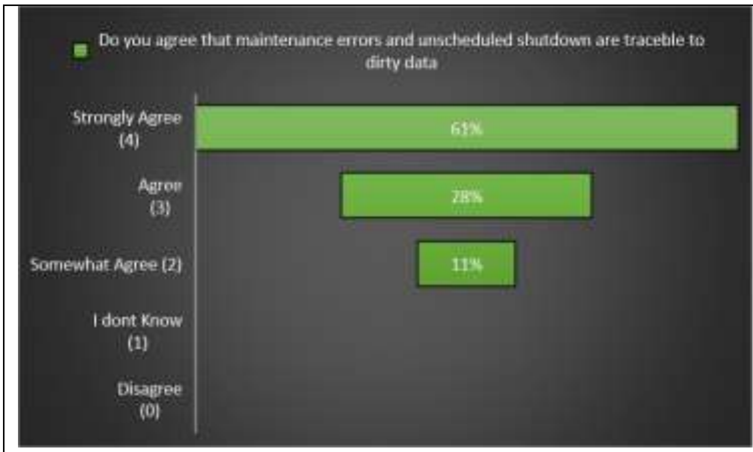


Data below represents the respondents view about the hypothesis question.

- Strongly Agree: 67%
- Agree: 33%
- Somewhat agree: 0%
- I don't Know: 0%
- Disagree: 0%

From the data above most respondents agree to the authors view

Figure 44: Hypothesis question H2-D

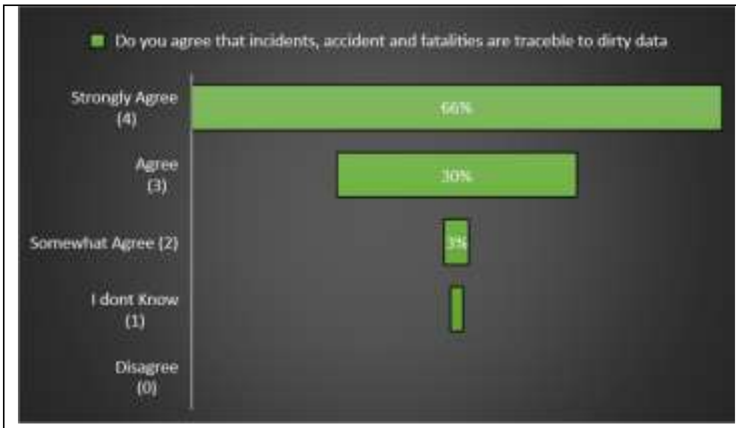


Data below represents the respondents view about the hypothesis question.

- Strongly Agree: 61%
- Agree: 28%
- Somewhat agree: 11%
- I don't Know: 0%
- Disagree: 0%

From the data above most respondents agree to the authors view

Figure 45: Hypothesis question H2-E

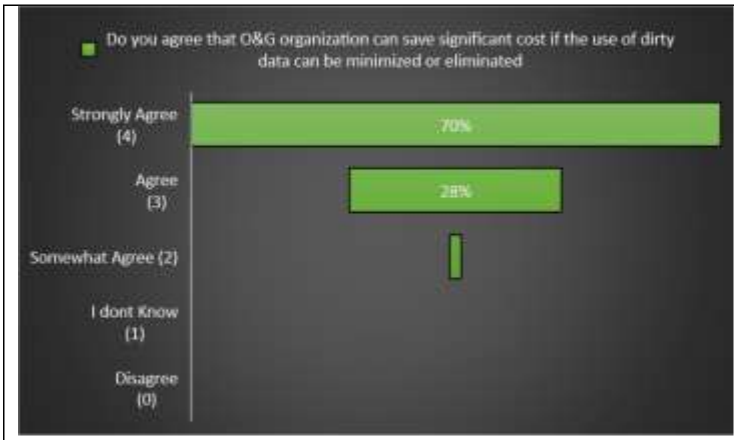


Data below represents the respondents view about the hypothesis question.

- Strongly Agree: 66%
- Agree: 30%
- Somewhat agree: 3%
- I don’t Know: 1%
- Disagree: 0%

From the data above most respondents agree to the authors view

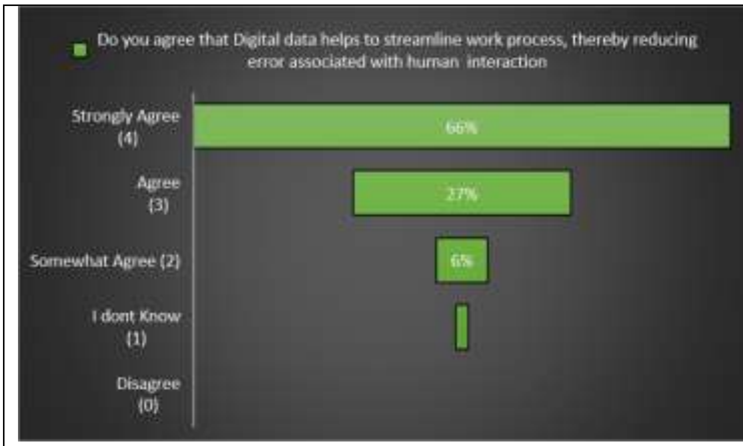
Figure 46: Hypothesis question H2-F



Data below represents the respondents view about the hypothesis question.

- Strongly Agree: 70%
- Agree: 28%
- Somewhat agree: 1%
- I don’t Know:0%
- Disagree: 0%

From the data above most respondents agree to the authors view

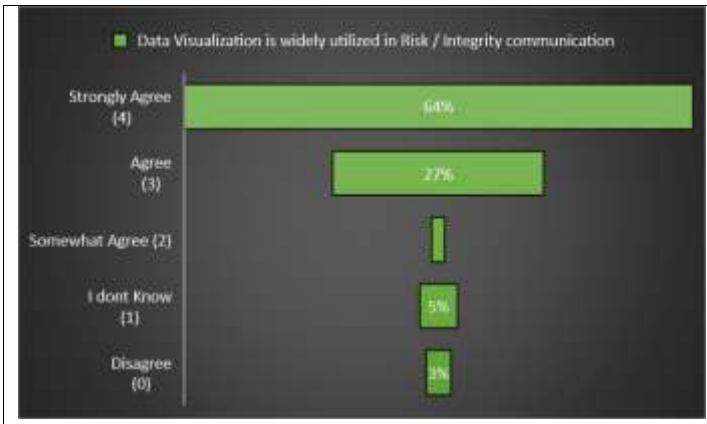


Data below represents the respondents view about the hypothesis question.

- Strongly Agree: 66%
- Agree: 27%
- Somewhat agree: 6%
- I don’t Know:1%
- Disagree: 0%

From the data above most respondents agree to the authors view

Figure 48: Hypothesis question H2-H

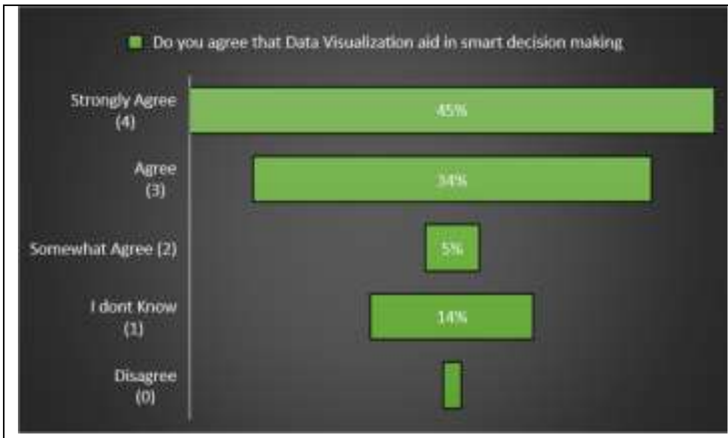


Data below represents the respondents view about the hypothesis question.

- Strongly Agree: 64%
- Agree: 27%
- Somewhat agree: 1%
- I don't Know:5%
- Disagree: 3%

From the data above most respondents agree to the authors view

Figure 49: Hypothesis question H2-I

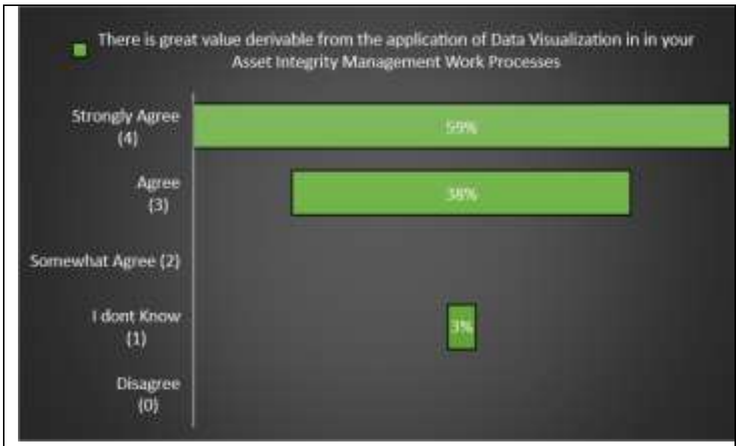


Data below represents the respondents view about the hypothesis question.

- Strongly Agree: 45%
- Agree: 34%
- Somewhat agree: 5%
- I don't Know: 14%
- Disagree: 1%

From the data above most respondents agree to the authors view

Figure 50: Hypothesis question H2-J



Data below represents the respondents view about the hypothesis question.

- Strongly Agree: 59%
- Agree: 38%
- Somewhat agree: 0%
- I don't Know: 3%
- Disagree: 0%

From the data above most respondents agree to the authors view

Figure 51: Hypothesis question H2-K

Summarily, one of the major finding from this survey is that while many respondents seem to understand the value of improved data and risk management due to emerging technological advancement, many of them have not had a personal experience in utilizing any of these emerging tools to process data or visualize risk. It is obvious from the answers provided, as many do not have strong agreement to the authors view where it was expected. For this purpose, we used a free visualization tool called “Tableau Public” to process typical RBI data and was able to represent data differently from the traditional ways of presenting risk. This was done to ascertain the respondents view on the data and risk visualization and how it can influence asset integrity management by helping to make smarter risk-informed decisions.

CHAPTER 5

CASE STUDY ON DATA VISUALIZATION AND ITS IMPACT ON DECISION MAKING

5.0. Introduction

Integrity and Risk communication needs to be presented in a simple way for easy interpretation and fast decision making. The simpler the better they say. We have tried to demonstrate the power of Data Visualization using a simplistic approach and we carried out another pilot test survey amongst some select respondents to ascertain if their comprehension / decision-making time for a set of data presented in two separate formats – traditional (Excel Spreadsheets) versus Data Visualization Software.

The visualization software used for this study is available to the public and it is called Tableau Public. It has the capability of helping the user apply data for visualization in different customizable patterns.

Due to lack of real-time RBI data, I used data from a trial RBI study carried out on a process facility located within the NCS. The RBI study was part of my course work on Risk Based Inspection and Condition Monitoring Course in The Arctic University of Norway, University of Tromso. One of the challenges I had then, was the volume of data I had to manage and the use of traditional Microsoft Excel Program to record and analyse my data. Even after aggregating the data and used it to form a Risk Matrix, I found it very cumbersome to manage the data and interpret it and make smart decision out of it. I could imagine the vast data the oil and Gas Industry is generating and the value of Data and Risk Visualization

4.4.RBI Data Visualization (Pilot Survey)

The data from the RBI study as shown in Tables 6,7 & 8 were inputted into the visualization software which produced the visualizations we see below in Figures 52,53, and 54. And these visualization and tables were used to carry-out the second-round of data gathering of using self-completion questionnaire to test both Hypothesis 1 and 2. In the second part of the questionnaire, the respondent were asked to compare their comprehension of PoF Evaluation in Tables 6,7 & 8, Risk Estimation of Time Dependent Degradation Mechanisms and External Inspection Plan for Non-time Dependent Degradation Mechanism using the traditional approach versus the Visualization presentations in Figure 52,53 and 54.

Table 6: PoF Evaluation of Time-Dependent Degradation Mechanisms

Corrosion Group Color Code	Corrosion Circuit ID	Line Tag	Pipe Diameter	Wall Thickness	Product Sevice Code	Material	Degradation Model	Degradation Group	Expected Damage: Internal	Expected Damage: External	Temp. (50°C)	Pres. (Bar)	Release rate	Internal Corrosion: Time (Yr)		Internal Corrosion (Mean Rate=0.25, SD=0.2): Mean depth of Corrosion (mm)	Internal Corrosion: PoF/ Rank	External Corrosion: Time (Yr)		External Corrosion (Mean rate =0.454, SD=0.529): Mean depth of Corrosion (mm)	External Corrosion: PoF/ Rank
	04-PL-CB	8"-PL-10019-C3B	8	6.35	PL	CS	RM	HC	**CO_2 corrosion** - Internal thinning of areas /local wall internal wall thinning NB: Hot spots	Atmospheric corrosion - Uniform and local corrosion of external surfaces - Thinning in pathces NB: Hot Spots	50	M	M	1991	3	0.75	0.000E+00	1989	1	0.45	0.000E+00
														1993	5	1.25	0.000E+00	1990	2	0.91	1.000E-04
														1995	7	1.75	0.000E+00	1991	3	1.36	7.000E-04
														1997	9	2.25	0.000E+00	1992	4	1.82	1.280E-02
														1998	10	2.5	0.000E+00	1993	5	2.27	8.210E-02
														1999	11	2.75	1.000E-02	1995	7	3.18	6.270E-01
														2000	12	3	4.900E-01	1997	9	4.09	9.790E-01
														2001	13	3.25	9.900E-01	1998	10	4.54	9.980E-01
														2002	14	3.5	1.000E+00	1999	11	4.99	1.000E+00
		10"-PL-10020-C1B	10	6.35	PL	CS	RM	HC	**CO_2 corrosion** - Internal thinning of areas /local wall internal wall thinning NB: Hot spots	Atmospheric corrosion - Uniform and local corrosion of external surfaces - Thinning in pathces NB: Hot Spots	51	M	M	1991	3	0.75	0.000E+00	1989	1	0.45	0.000E+00
														1993	5	1.25	0.000E+00	1990	2	0.91	1.000E-04
														1995	7	1.75	0.000E+00	1991	3	1.36	7.000E-04
														1997	9	2.25	0.000E+00	1992	4	1.82	1.280E-02
														1998	10	2.5	0.000E+00	1993	5	2.27	8.210E-02
														1999	11	2.75	1.000E-02	1995	7	3.18	6.270E-01
														2000	12	3	4.900E-01	1997	9	4.09	9.790E-01
														2001	13	3.25	9.900E-01	1998	10	4.54	9.980E-01
														2002	14	3.5	1.000E+00	1999	11	4.99	1.000E+00
	05-DC-CB	3"-DC-47039-C3B	3	5.49	PL	CS	RM	HC	1. **CO_2 corrosion** **2. Galvanic corrosion** - Internal thinning of areas /local wall internal wall thinning - Local corrosion due to contact between SS and CS NB: Hot spots	Atmospheric corrosion - Uniform and local corrosion of external surfaces - Thinning in pathces NB: Hot Spots	52	M	M	1991	3	0.75	0.000E+00	1989	1	0.45	0.000E+00
														1993	5	1.25	0.000E+00	1990	2	0.91	1.000E-04
														1995	7	1.75	0.000E+00	1991	3	1.36	7.000E-04
														1997	9	2.25	0.000E+00	1992	4	1.82	1.280E-02
														1998	10	2.5	0.000E+00	1993	5	2.27	8.210E-02
														1999	11	2.75	1.000E-02	1995	7	3.18	6.270E-01
														2000	12	3	4.900E-01	1997	9	4.09	9.790E-01
														2001	13	3.25	9.900E-01	1998	10	4.54	9.980E-01
														2002	14	3.5	1.000E+00	1999	11	4.99	1.000E+00

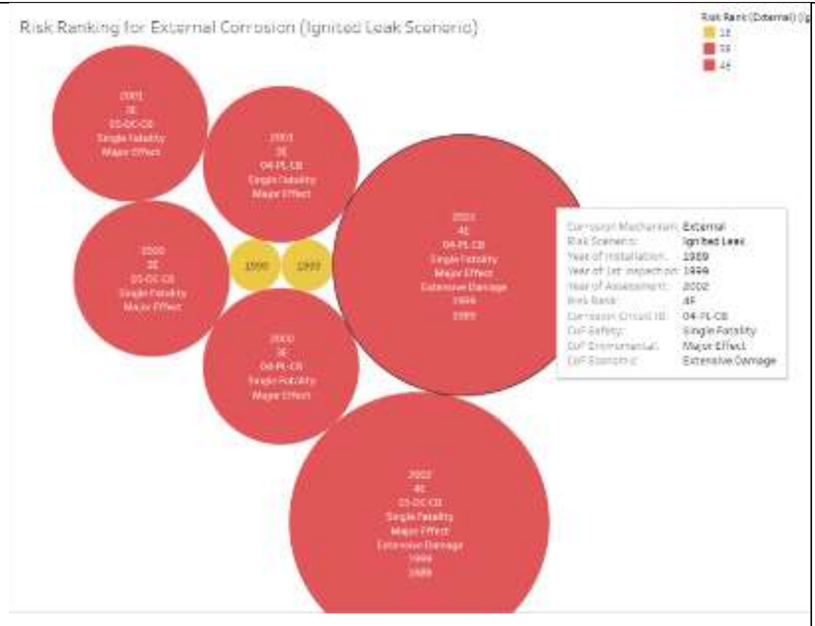
Table 7: Risk Estimation of Time Dependent Degradation Mechanisms

Corrosion Circuit	Service Decription	Tags	Time (Year)	PoF Rank External Corrosion	External Corrosion – Ignited Leak: CoF Safety	CoF Env.	CoF Eco.	Final CoF	Risk Rank	External Corrosion – Unignited Leak: CoF Safety	CoF Env.	CoF Eco.	Final CoF	Risk Rank
04-PL-CB	Separated oil to 2nd stage separator	8"-PL-10019-C3B	11	1	D	D	E	E	1E	E	E	C	E	1E
			12	3					3E					3E
			13	3					3E					3E
			14	4					4E					4E
		10"-PL-10020-C1B	11	1	D	D	E		1E	E	E	C		1E
			12	3					3E					3E
			13	3					3E					3E
			14	4					4E					4E
05-DC-CB	Unseparated process liquid to closed drain	3"-DC-47039-C3B	11	1	D	D	E	E	1E	E	E	C	E	1E
			12	3					3E					3E
			13	3					3E					3E
			14	4					4E					4E

Table 8: External Inspection Plan for Non-time Dependent Degradation Mechanism

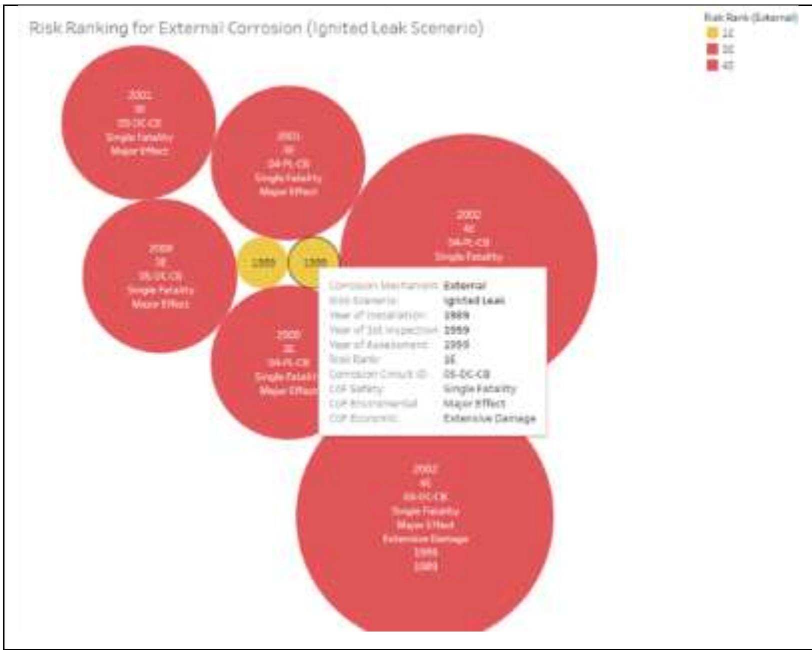
External Inspection Plan for Non-time Dependent Degradation Mechnanisms												
Corrosion Circuit	Service Decription	Tags	PoF Rank	CoF Category	Time to Inspect (Years)	Installation Year	1st Inspection	Failure to Monitor	Inspection Technique	Inspection Effectiveness	Comment
01-PM-DA	Well Stream	16"-PM-10001-D25A	2	E	4	1989	1992	- Local corrosion and pitting of external surfaces Hot Spots - Discolouration around welds and jonts - water/dirts collection ponts - Flanges - Underclamps	- CVI, PT - GVI for screening hot spots	Highly effective 100% of hot spots	Considering a 1st stage separation and risk,a highly effective inspection is recommended. The 1st inspection result will provide basis for the next inspection time.
		16"-PM-10002-D3A	2		4						
02-PG-DA	Separated gas to Compressor	12"-PG-10025-D3A	2	E	4						
		12"-PG-10026-D3A	2		4						
		3"-PG-10027-D3A	2		4						
		12"-PG-10028-D3A	2		4						
		12"-PG-20002-D3A	2		4						
03-BH-SA	Gas to flare	4"-PG-10084-D3A	2	E	4						
		3"-PG-101D6-S3A	2		4						
		14"-BH-50028-S1A	2		4						
		14"-BH-50030-S1A	2		4						
		14"-BH-50033-S1A	2		4						
		8"-BH-50031-S1A	2		4						
		16"-BH-50032-S1A	2		4						
05-DC-DA	Unseparated process liquid to closed drain	3"-PL-10107-D3A	2	E	4						
07-WP-DA	Produced water to Hydrocyclone	12"-WP-10024-D3A 12"-WP-10024-D3A-PP	2	E	4						

4.5.Risk/Data Presentation Using Data Visualization Software – Tableau Public



In this risk visualization for the Corrosion Circuit - 04-PL CB, we can view multiple information by simply placing the mouse over the circle. We can see the corrosion circuit, the year of installation as 1989 and the year of first inspection as 1999. We can also view the CoFs for Safety, environmental and Economic cases.

Figure 52: Visualization for Risk Rank for Corrosion Circuit 04-PL-CB (Obiora Ilora, 2018)



In this risk visualization for the Corrosion Circuit - 05-DC-CB, we can view multiple information by simply placing the mouse over the circle. We can see the corrosion circuit, the year of installation as 1989 and the year of first inspection as 1999. We can also view the CoFs for Safety, environmental and Economic cases.

Figure 53: Visualization for Risk Rank for Corrosion Circuit 05-DC-CB (Obiora Ilora, 2018)

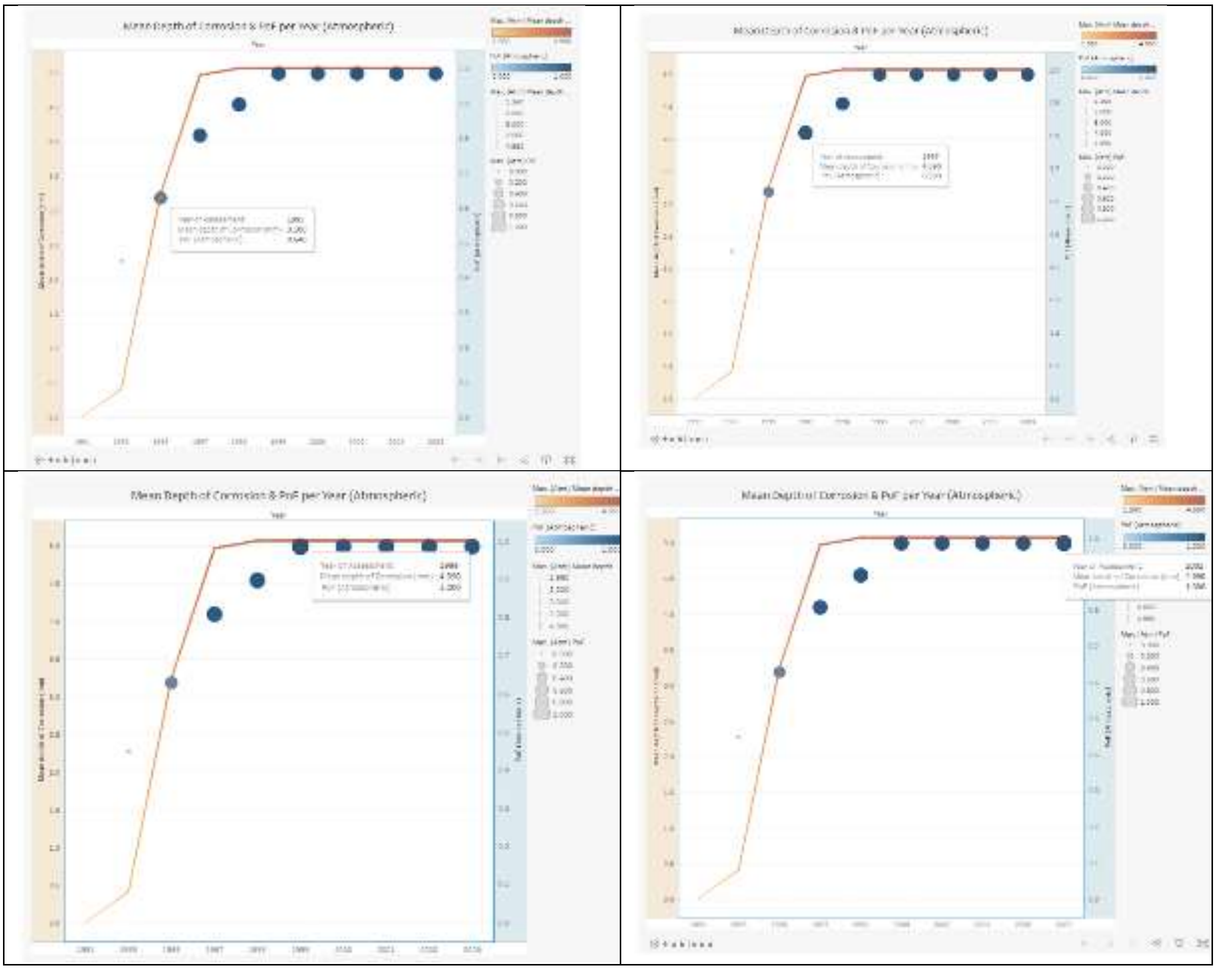
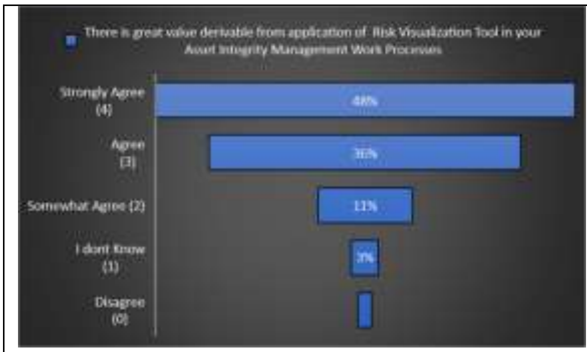


Figure 54: Visualization for Mean Depth of Corrosion & PoF per Year (Atmospheric-External Corrosion) (Obiora Ilora, 2018)



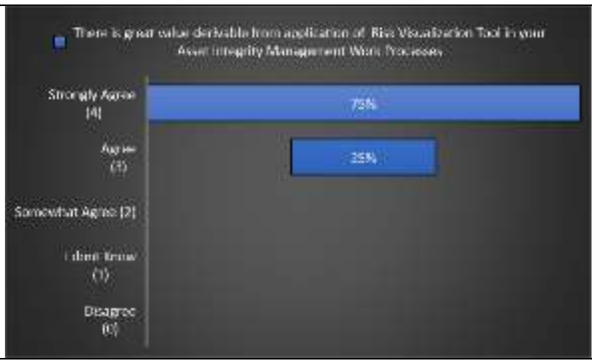
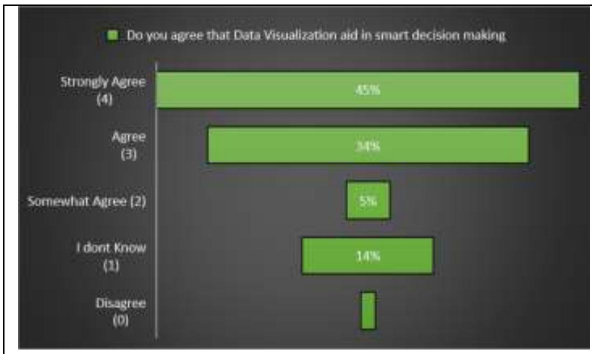


Figure 55: First Respondents Survey Result

Figure 56: Second Respondent Survey Result

From the respondent's first and second survey results, it can be deduced that the repondents were able to make better judgement with the visualization approach to data representation, hence were able to provide firm answers in the second survey.



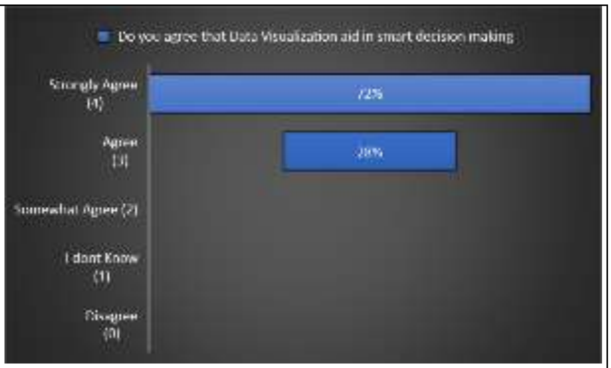
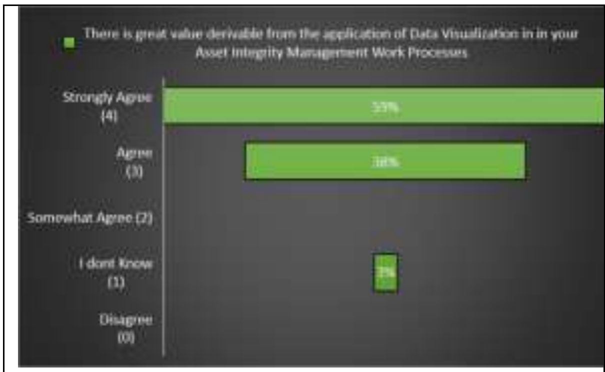


Figure 57: First Respondents Survey Result

Figure 58: Second Respondent Survey Result

From the respondent's first and second survey results, it can be deduced that the repondents were able to make better judgement with the visualization approach to data representation, hence were able to provide firm answers in the second survey.



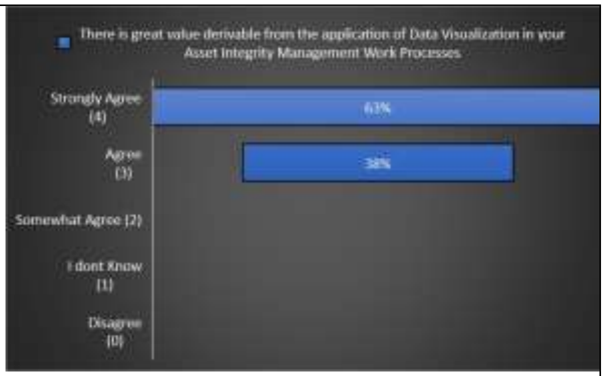


Figure 59: First Respondents Survey Result

Figure 60: Second Respondent Survey Result

From the respondent's first and second survey results, it can be deduced that the repondents were able to make better judgement with the visualization approach to data representation, hence were able to provide firm answers in the second survey.

4.6.Integrated Data Transformation and Risk Decision-Making Framework

The modified Integrated Data Transformation and Risk Decision-Making Framework is an improved framework, after the earlier proposed version proposed by Mannesh Singh. It integrates Data Visualization and Analytics at the Reasoning and Decision Support Stages respectively. The framework also show how a Risk-informed decision is incorporated in the cycle.

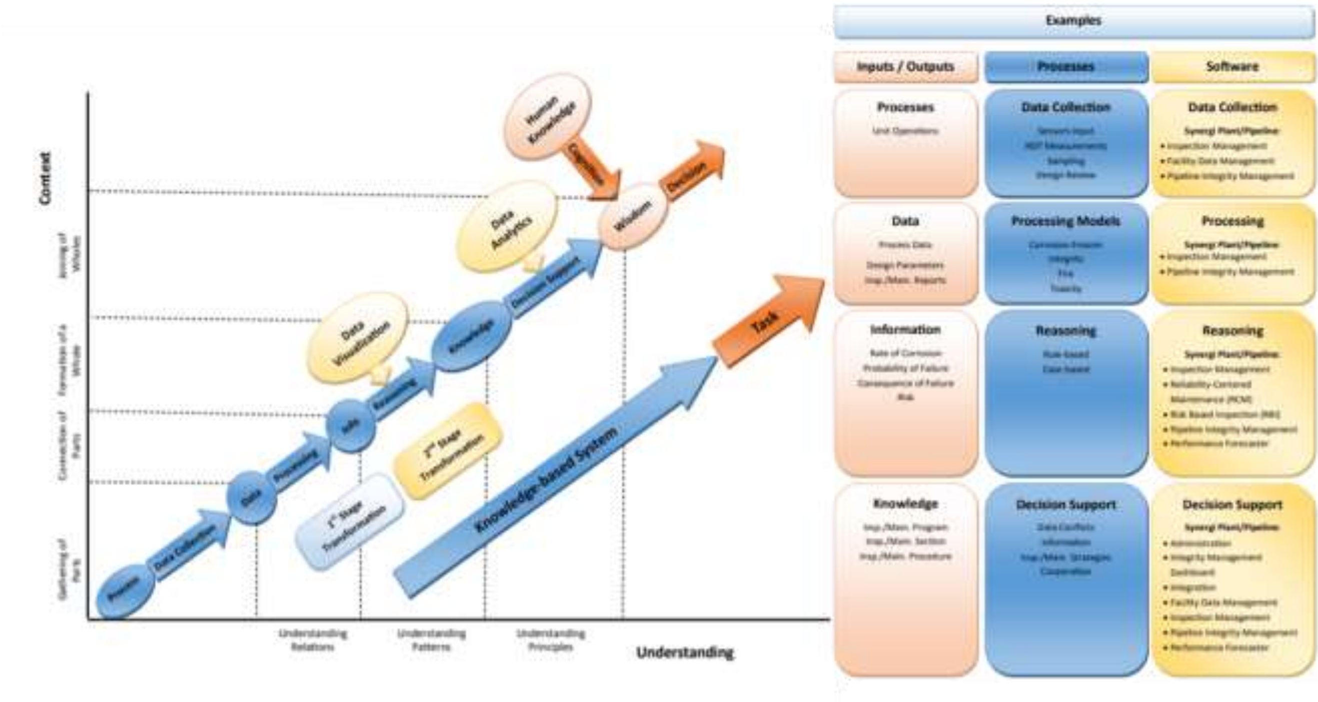
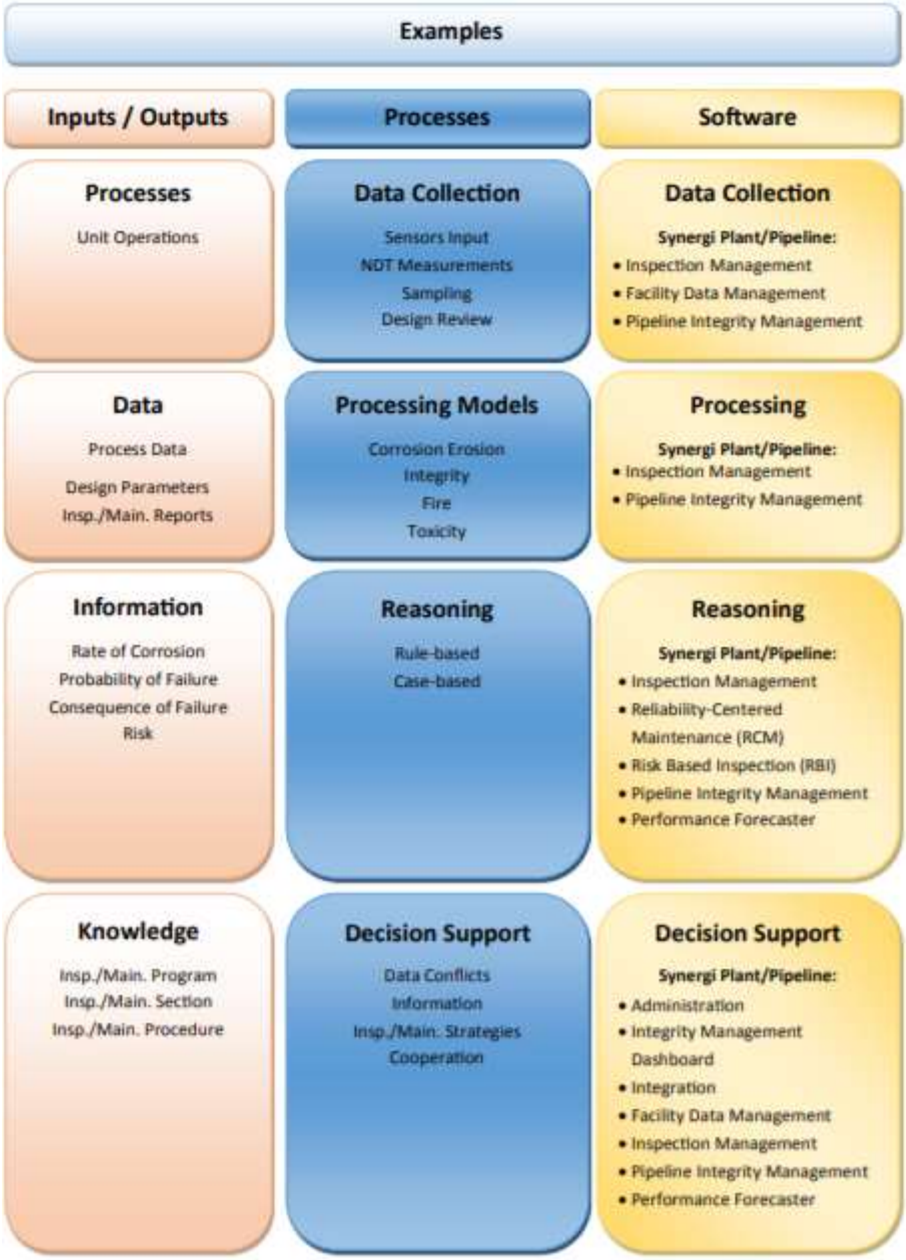


Figure 61: Improved steps in data transformation into decision adopted from (Mannesh Singh et al., 2011)


Examples
Inputs / Outputs
Processes
Software
Processes
Unit Operations
Data Collection
Sensors Input
NDT Measurements
Sampling
Design Review
Data Collection
Synergi Plant/Pipeline:
• Inspection Management
• Facility Data Management
• Pipeline Integrity Management
Data
Process Data
Design Parameters
Insp./Main. Reports
Processing Models
Corrosion Erosion
Integrity
Fire
Toxicity
Processing
Synergi Plant/Pipeline:
• Inspection Management
• Pipeline Integrity Management
Information
Rate of Corrosion
Probability of Failure
Consequence of Failure
Risk
Reasoning
Rule-based
Case-based
Reasoning
Synergi Plant/Pipeline:
• Inspection Management
• Reliability-Centered Maintenance (RCM)
• Risk Based Inspection (RBI)
• Pipeline Integrity Management
• Performance Forecaster
Knowledge
Insp./Main. Program
Insp./Main. Section
Insp./Main. Procedure
Decision Support
Data Conflicts
Information
Insp./Main. Strategies
Cooperation
Decision Support
Synergi Plant/Pipeline:
• Administration
• Integrity Management Dashboard
• Integration
• Facility Data Management
• Inspection Management
• Pipeline Integrity Management
• Performance Forecaster

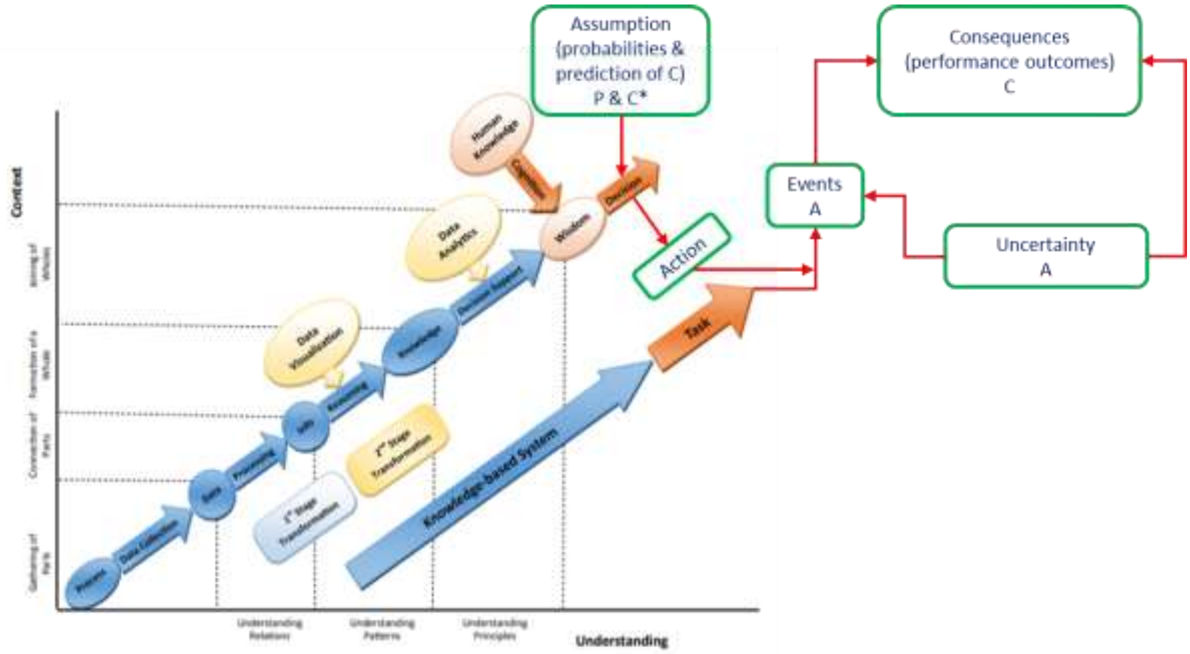


Figure 62 : Integrated Data Transformation and Risk Decision-Making Framework (Adopted from (Mayang Kusumawardhani et al., 2016) and (Mannesh Singh et al., 2011)

CHAPTER 6

DISCUSSIONS, OBSERVATIONS AND RECOMMENDATIONS

6.0.Objectives / Purpose of Analysis

The analysis was carried-out to test (confirm or reject) the hypothesis proposed as follows:

- *Hypothesis 1 - that Robust Risk Management Approach is critical for "Intelligent Asset Integrity Management" (AIM): A concept of all practices that avails the precise proactive asset integrity assessment by holistic performance monitoring through the asset life cycle.*
- *Hypothesis 2 - that iAIM requires a Data Management System with capabilities to capture, integrate, visualize and analyze data and able to be fed with real-time assessment data, as well as be able to produce decision data in a fast and simplistic manner, to sustain overall organizational goal throughout the asset life cycle.*

The hypothesis focuses on the fact that Risk and Data Management are amongst the Critical Success factors CSFs, which greatly influence the overall Asset Integrity Management. The analysis substantiated the proposed optimization opportunities which has the potential of improving an Asset Integrity Management program.

6.1. Findings and Observations:

But based on the research data analysis, we observed that even though the available group of oil and gas asset integrity professionals used for the analysis were all resident in Nigeria, they displayed good knowledge and understanding of risk management and the role of data management on asset integrity management performance. Their view is not far from the view of reputable authors (table 4) as contained in chapter 3 - the literature review. Hence the finding from the analysis can be said to represent world standard expert opinion on the subject matter, and in this case can be applicable to Assets Integrity Management in the Barents Sea, NCS.

This can be attributed to the fact that many asset integrity management professionals uphold their individual company asset integrity management policies and principles and are very conversant with the gaps and optimization opportunities within their system.

6.2.Gaps and Optimization Opportunities in Asset Life Cycle

DI – an integral part of Asset Integrity becomes more important as the asset lifecycle matures, hence the application of optimized intelligent risk and data management during the asset design stage of an asset will orchestrate great cost saving opportunities as the asset development evolves. The optimization opportunities will incorporate integrity assurance methodologies such as reliability, availability and maintainability analysis (RAM analysis) and associated decision forecasting during the asset design stage of the oil and gas industry. In a similar manner Technical and Operational Integrity aspects, incorporates the application of the risk and data management approach to asset integrity management during operations. The value is manifest in areas such as reduced cost, staff motivation, operation and maintenance resources management, efficiency and general operational excellence.

When we consider the three main types of asset data necessary to improve operational excellence and performance, then it becomes important that we can proactively obtain structured and well-documented attribute data, as well as conditional data, in order to provide insights into an asset's physical state. More so, the dynamic operational excellence of the 21st century imply that effective risk- informed decision-making will increasingly rely on asset intelligence, greatly influenced by data quality.

6.3.Recommendations

1. Data integration is a cumbersome work for many operators; hence it becomes a necessity for collaboration between oil and gas operators to maintain or co-host data hubs where various data network interconnect and interact. This proposed data hub will enable the full development and application of risk and integrity proactive analytics vital for a robust asset integrity management.
2. Asset Integrity Management framework need to be consistently improved with new emerging perspective to risk and data management in order to achieve an all-encompassing risk-based approach to design, operations and maintenance.
3. Need for a technological advancement for an asset risk and integrity management dashboards, that aid or facilitate intelligent decisions which will be centred upon performance and visible actual condition of an asset.
4. Need for a technological advancement that employs data integration capabilities from devices – drones, sensors, and specialized robots using mobile applications.

5. Need for operators to make data risk and integrity data accessibility a cross industry culture not limited to the asset integrity group alone through data presentation in concise dashboards, and in a predictive approach and capability to capture improvement opportunities for improved designs.
6. For places like Barents Sea, it will serve operators better by applying simulation of accidental events and analysing their impact, such that users can understand and visualize the risk source as well as impact on people, asset and surrounding environment.
7. Incorporate in standard regulatory requirement for industry corporate policies, the use of risk quantification approach in contrast to traditional risk analysis approach, to drive the risk-based aspects through design, maintenance and operations.

6.4.Research Challenges

I was seriously and negatively impacted by inadequate infrastructure and facilities in my domicile location, where I carried-out the research. Poor internet connectivity made it extremely difficult to reach to my original target audience in Norway and hence I would say that my research findings was reasonable but founded on some generalizations. Given another opportunity I would expand the scale and audience for data collection and analysis.

Due to stringent company policies, some respondents were not able to provide feedback at all, while those that provided feedback did so anonymously.

CHAPTER 7
CONCLUSION

7.0.Final remarks

In-line with the set objectives, this research project has proposed a framework termed Intelligent Risk Based Integrity Management Framework. The benefits derivable from this framework when implemented will be of great benefit to all stakeholders in the NCS, particularly those that are interested in Norwegian Barents Sea.

More so, as oil and gas operations in the Norwegian Arctic, attracts more optimism, amidst prevalent challenges, continuous improvement in this area of technical integrity management becomes more of a need than a want.

7.1. Areas of Further Research

The suggestions made in this thesis are only a microcosm of all the aspects of the framework, and further research is necessary to:

- Improve methods for proactive risk identification and mitigation
- Aid development of performance indicators for proactive risk thresholds
- Improve the understanding of data quality and possible use as a performance indicator

Having said that, there is need for more sophisticated approach to data collection, processing and visualization in a way to aid smart risk communication and reduce risk exposure. Lessons and application of management strategies in other industrial applications e.g. financial industry require to be thoroughly researched for possible application in the Oil and Gas Industry. Holistic knowledge (technical and other aspects) about varied factors that influence risk need to be supported by quality data for managing risk.

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APPENDIX 1: Questionnaire

APPENDIX 1

INTRODUCTION:

This questionnaire is to support provide expert judgement view to confirm or reject the authors Hypothesis as contained below:

SCOPE:

The scope of this questionaire is to identify the Critical Success Factors (CSVs) that largely influence the performance of an asset integrity management program in the oil and gas industry.

CONFIDENTIALITY: Information provided will be kept confidential, for research purposes only**.**

PART 1: RESPONDENT DETAILS

Company, Name & Address (Optional): ____

Name of Personnel: ____ Job Role: ________________________

Telephone Number: ____________________________Email: _______________________________

The author had formluated the following hypothesis following several literature review of so many others authors' opinion on critical success factors that inflluence Asset Integrity Managment. Please kindly indicate to what extent you agree or disagree with this with the aim to "Confirm" or "Reject" the Hypothesis.

Hypothesis 1	Robust Risk Management Approach is critical for "Intelligent Asset Integrity Management" (iAIM): A concept of all practices that avails the precise proactive asset integrity assessment by holistic performance monitoring through the asset life cycle.
Hypothesis 2	iAIM requires a Data Management System with capabilities to capture, integrate, visualize and analyze data and able to be fed with real-time assessment data, as well as be able to produce decision data in a fast and simplistic manner, to sustain overall organizational goal throughout the asset life cycle.

		Question	**Strongly Agree**	**Agree**	**Somewhat Agree**	**I dont Know**	**Disagree**
			4	**3**	**2**	**1**	**0**
H1	**A**	Do you agree that Robust Risk Management Approach is critical for an effective Asset Integrity Management?					
	B	Risk-based Assessment methods are critical and need to have the ability to proactively identify potential integrity risks					
	C	Risk-informed decision support should an integral within the Asset Management Framework					
	D	There is great value derivable from application of Risk Visualization Tool in your Asset Integrity Management Work Processes					
H2							
	A	Do you think the Oil and Gas Industry not utilizing the power of big data maximally in its Asset Integrity Solutions					
	B	Do you agree in maintenance performance monitoring, that good data is required to generate maintenance metrics as follows PPC, OEE, MTTR,MTBF, PMC.					
	C	Do you agree that digitization of inspection, operations and maintenance work processes will reduce and/or reduces maintenance error					
	D	Good data are readily available for use by Operations personnel to carry-out required Risk Assessment, Reliability Studies, Inspection and Maintenance Planning					
		Do you agree that maintenance errors and unscheduled shutdown are traceble to dirty data					
	F	Do you agree that incidents, accident and fatalities are traceble to dirty data					
		Do you agree that O&G organization can save significant cost if the use of dirty data can be minimized or eliminated					
	H	Do you agree that Digital data helps to streamline work process, thereby reducing error associated with human interaction					
		Data Visualization is widely utilized in Risk / Integrity communication					
	J	Do you agree that Data Visualization aid in smart decision making					
		There is great value derivable from the application of Data Visualization in in your Asset Integrity Management Work Processes					

Appendix 2: Source File for Data Visualization on Tableau Public Software:

- https://public.tableau.com/profile/obiora.ilora#!/