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Creating Integrated Digital Platform for Apply Sørco's Asset Integrity Tools

by

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ABSTRACT

There is always a strong motivation in oil and gas industry same as the other complex industrial systems to keep the assets well maintained during the life span. The main reason behind that motivation is the desire to keep them working at desired functional state with regard to the health, safety and environmental risk. Regarding to challenges to achieve the desired conditions in complex industrial systems, Asset integrity Management is offered as a platform which evaluates and integrates maintenance concepts as a solution for such challenges.

However, achieving such integrity is always a challenging task for the companies operating in oil and gas industry due to the complexity of industry and the possibility of human errors regarding to that complexity. With aid of the technological improvements in computer sciences during the last a few decades, highly efficient IT tools were started to be utilized in order to have a solid technical and financial integrity for the challenges regarding to the complexity and human-errors. Hence, Apply Sorcø, as a case study company, has developed its own asset integrity assurance tools called "Structured Information & Management System (SIMS)" to provide a complete and reliable asset integrity solutions in compliance with the regulation.

In this study, we will evaluate and map these asset integrity assurance tools, their functions, requirements and benefits with regulations and underlying reasons to have such asset integrity assurance tools. Finally we will offer an integrated digital platform for the asset integrity assurance tools provided by the case study company with regards to the risk involved in O&G industry.

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TABLE OF CONTENTS

Abstract iii

Acknowledgement iv

Table of Contents v

Table of Figures vii

List of Tables ix

List of Abbreviations x

1) Introduction 1

1.1) Background 1

1.2) Objective and Sub-objectives 2

1.3) Methodology 2

1.4) Limitations 3

1.5) Structure of Report 3

1.6) The Industrial Case: Apply Sørco 4

2) Complex Industrial systems 5

2.1) Oil and Gas Industry (Offshore) as a Complex Industrial System 6

2.2) Interrelationships for Complex Industrial Systems 7

3) Asset Integrity Management 9

3.1) Terminology Overview 9

3.2) Standards and Guidelines for Asset Integrity Management 10

3.3) Asset Integrity Management Services and Products 11

3.4) Basics and Benefits of Asset Integrity Management 12

3.4.1) Key Elements of Asset Integrity 14

3.5) Challenges with respect to the asset integrity 18

4) Maintenance Strategies and Management 19

4.1) Standards and Legislations for Maintenance 19

4.2) Basics of maintenance strategies 20

4.2.1) Corrective Maintenance 21

4.2.2) Preventive Maintenance 21

4.2.3) Condition Based Maintenance ... 23
4.2.4) Reliability-Centered Maintenance (RCM) ... 23
4.2.5) Failure Modes, Effect and Criticality Analysis (FMECA) ... 25
4.3) Maintenance Management ... 25
4.3.1) Maintenance Management Challenges ... 26
5) Establishing Maintenance Management Practice ... 27
5.1) Technical and Functional Hierarchy ... 28
5.2) Consequence Classification ... 30
5.3) Work Flow for Establishing Preventive Maintenance Program ... 31
5.4) Risk Evaluation for Maintenance Decisions ... 31
5.5) Spare Part Evaluation ... 32
6) IT Tools for Asset Integrity Assurance ... 34
6.1) Background ... 34
6.2) Case Study: Asset Integrity Assurance Tools by Apply Sorcø ... 34
6.2.1) Tag Management Module (TMM) ... 35
6.2.2) Consequence Classification Module (CCM) ... 37
6.2.3) Spare Part Evaluation (SPM) ... 40
6.2.4) Planned Maintenance Module (PMM) ... 41
6.2.5) Barrier Monitoring Module (BMM) ... 43
6.2.6) Mapping and Integration of SIMS ... 44
6.3) Prospective Modules and Integration Developments ... 46
6.3.1) Optimization Module (OM) ... 46
7) Integrated Application Structure and Development of Digital Platform (TEST GUI) ... 50
7.1) Design and Development Progress ... 51
7.2) Monitoring (Control) Interface ... 53
8) Discussion ... 56
9) Conclusion ... 59
Bibliography ... 61
Appendix A: Survey ... I
Appendix B: Complementary Figures for Maintenance Programme ... II

TABLE OF FIGURES

Figure 1-1 Challenges in NCS 1
Figure 1-2 Apply Sørco Business Areas 4
Figure 2-1 Generic Illustration for System and Sub-System Approach 5
Figure 2-2 Complex Industrial System Approach: Offshore Platform 6
Figure 2-3 Interrelationships for Complex Industrial Systems 7
Figure 3-1 Asset Management Frame 10
Figure 3-2 Fundamental of Asset Integrity 12
Figure 3-3 Asset Integrity Management Goals 13
Figure 3-4 Key Elements of Asset Integrity 14
Figure 3-5 Asset Integrity Risk Management Process 15
Figure 3-6 Maintenance Management Process 16
Figure 3-7 Asset Integrity during Life Cycle 16
Figure 3-8 Pathway from Complex Industrial Systems to Maintenance Strategy 17
Figure 4-1 Maintenance Strategy Overview 20
Figure 4-2 Bath-tube approach for probable failures during life-time 22
Figure 5-1 Maintenance Management Practice 27
Figure 5-2 Technical Hierarchy Work Process 28
Figure 5-3 Technical (up) and Functional (down) Hierarchy Structures 29
Figure 5-4 Consequence Classification Work Flow 30
Figure 5-5 Spare Part Work Process 33
Figure 6-1 Asset Integrity Tools and Maintenance Management Cycle 35
Figure 6-2 SIMS Tag Management Module 37
Figure 6-3 SIMS Technical Hierarchy 38
Figure 6-4 SIMS Functional Hierarchy 39
Figure 6-5 SIMS Consequence Classification 40
Figure 6-6 SIMS Spare Part evaluation Module 41
Figure 6-7 SIMS Planned Maintenance Module 42
Figure 6-8 Barrier Monitoring System 44
Figure 6-9 SIMS Modules on Project Execution Model (current) 44
Figure 6-10 Integration of SIMS modules (current) 45
Figure 6-11 SIMS Modules on Project Execution Model (prospective concept) 48

Figure 6-12 Integration of SIMS modules (prospective concept) 49
Figure 7-1 SIMS Modular Structure........ 50
Figure 7-2 Design and Development Progress........ 51
Figure 7-3 Architectural Design of Digital Platform (Test GUI) for SIMS 52
Figure 7-4Monitoring Interface Tool Screenshot 54
Figure 7-5 Test GUI: Home (up-left), TMM (upright), CCM (down-left) and SPM (downright) pages........ 55
Figure 7-6 Test GUI (cont): PMM (up-left), OM (upright), BMM (down-left) and Monitoring Tool pages........ 55

LIST OF TABLES

Table 4-1 Maintenance Strategies 24
Table 6-1 Basic Information Registered on Tags 36
Table 6-2 Standard Sub-functions 38
Table 6-3 Maintenance Data to be Reported 47
Table 7-1 Tag Features to Monitor in Control Interface 53

LIST OF ABBREVIATIONS

AI	Asset Integrity
AIM	Asset Integrity Management
ALARP	As Low As Reasonably Practicable
BMM	Barrier Monitoring Module
BoM	Bill of material
BS	British Standard
CBM	Condition Based Maintenance
CCM	Consequence Classification Module
CMM	Condition Monitoring Module
CMMS	Computerized Maintenance Management System
DNV	Det Norske Veritas
EN	European Standard
ENS	Engineering Numbering System
EPCIC	Engineering, Procurement, Construction and Installation and Commissioning
FEED	Front End Engineering Design
FMECA	Failure Mode, Effects and Criticality Analysis
GMC	Generic maintenance concept
GUI	Graphical User Interface
HSE	Health, safety and environment
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
KPI	Key Performance Indicator
MF	Main Function
NCS	Norwegian Continental Shelf
O&G	Oil and Gas
OLF	The Norwegian Oil Industry Association
OREDA®	Offshore and onshore reliability data
P&ID	Process and instrumentation diagram
PEM	Project Execution Model
PM	Preventive Maintenance
PMM	Planned Maintenance Module
PSA	Petroleum Safety Authority (Petroleumstilsynet)
RBI	Risk based inspection
RCM	Reliability centered maintenance
RCMM	Reliability Centered Maintenance Module
SIL	Safety integrity level
SIMS	Structured Information and Management System
SPM	Spare Part evaluation Module
TMM	Tag Management Module

1) INTRODUCTION

1.1) Background

Companies in oil and gas industry like the companies in other complex industries have strong desire to keep their assets well maintained in order to keep them working at anticipated functional state with an effective cost. In addition to that to slow down aging and extending the life time of an asset is a common goal for all operator and owner companies. According to a survey conducted among the companies working in Norwegian Continental Shelf (NCS), 50% of assets which currently is being used in NCS are older than 25 years old. And according to another result of the survey, aging of assets and asset management issues are becoming the most important challenges in oil and gas industry. (Oil and Gas IQ, 2014).

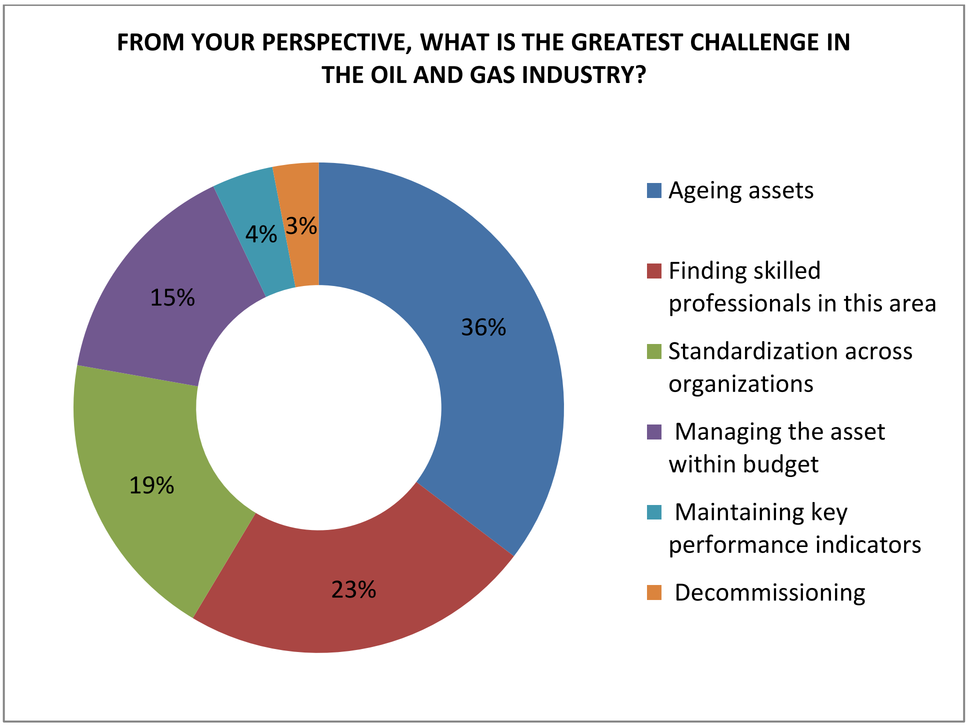


Figure 1-1 Challenges in NCS (Oil and Gas IQ, 2014)

On the other hand, as a fact, accidents like Piper Alpha (1976) and Deep-water Horizon (2010) that had serious consequences on health, safety and environment (HSE) have an inevitable influence on that desire of keeping the assets well maintained and so work safe. And also no matter how old the facility is, having control over the entire tangible and intangible assets helps the companies to achieve this goal. It is essential to have a well-structured organization to have such control and that can be possible only if it is implemented a successful maintenance strategy. In order to implement a successful maintenance strategy, it is essential to have extensive knowledge about the assets in use.

Hence, knowledge on condition of assets and effects of assets on facilities are growing concerns in industry. At this point asset management takes very important role to gather the required information in order to make right decision for achieving sufficient maintenance strategy.

1.2) Objective and Sub-objectives

The main objective of the thesis is creating an integrated digital platform for the asset integrity assurance tools provided by the case study company with regards to the risk involved in O&G industry. In order to achieve main objective clearly and successfully, there is a set of sub-objectives listed below that must be accomplished:

Define the general properties and requirements of industrial systems in which O&G industry is involved.

Evaluate and map these asset integrity assurance tools, their functions, requirements and benefits with regulations and underlying reasons to have such asset integrity assurance tools.

Develop an integrated digital platform (application) for these tools to achieve integrated, compact and reliable industry standards.

1.3) Methodology

The first part of the thesis focuses on the comprehensive academic and industrial literature research about the complex industrial systems (Chapter 2) and asset integrity management (Chapter 3). Maintenance strategies and Management (Chapter 4) depends on the NCS maintenance management practices, and hence, PSA regulations and NORSOK standards has been used as main sources to implement a successful maintenance strategy All required information has been retrieved from international standards, books and articles collected from UiS library and online databases.

The second part of the thesis starts with establishing maintenance management practice as a case study (Chapter 5), continues with identifying and mapping (Chapter 6) all the asset integrity assurance tools provided by the company. Required information are gathered from the internal documentation belongs to the company. To be able to make decision about the GUI design and development (Chapter 7), a survey is conducted amongst the users of the asset integrity assurance tools in the case study company. Online information databases and forums are usually used for the required IT information to be able to develop a digital platform (application).

1.4) Limitations

Since one of the main objectives of the thesis is assessment of asset integrity assurance tools that are provided by the case study company that provides asset integrity services in O&G industry, the thesis will mainly focus on the asset integrity assurance tools in O&G industry provided by the case study company and therefore will not look for the industry practices for other asset integrity assurance tools. Since the final aim of the thesis is creating an integrated digital platform for the asset integrity assurance tools, the thesis will not go in depth with technical details of neither asset integrity management nor maintenance management. However it will present brief information from both approaches to be able to give sufficient background information.

Due to time constrain of the thesis, extended testing and validation phases, releasing beta version and final product of the integrated digital platform application to the end user will be abandoned.

1.5) Structure of Report

Part 1

Chapter 2 gives brief information about the complex industrial systems with regards to risk and their impacts in global scale. Chapter 3 focuses on the asset integrity management, key elements and challenges in connection with the challenges of complex industrial system. Chapter 4 focuses on maintenance strategies and maintenance management as an offered solution by the asset integrity concept. Within this chapter Thesis briefly gives basic information about the maintenance strategies

Part 2

In Chapter 5, a maintenance management practice is established in compliance with the requirement and regulations for NCS and studies the best practice for the oil and gas industry as a case study. In Chapter 6, thesis focuses on the asset integrity assurance tools used to enhance integrity by the case study company which gives the asset integrity services in Oil and Gas industry. Within this chapter, thesis aims to review and assess these tools separately and try to map integration of all asset integrity tools as a one-part complete application according to the regulations and search for prospective improvements. In Chapter 7, basics and processes to develop an integrated digital platform for asset integrity assurance tools in Python programming language is discussed and final results of developing process is presented.

Chapter 8 then discusses the lessons that is learned, challenges and recommendations for future study

Chapter 9, conclusion gives the final remarks for the objectives and results that are achieved.

1.6) The Industrial Case: Apply Sørco

Apply Sørco, here by "Company", is one of the Norway's leading engineering, procurement, construction, installation and commissioning (EPCIC) project supplier. The company headquartered in Stavanger has more than 30 years of experience giving service in oil and gas industry. It is part of the Apply Group Company. Company mainly operates in the oil & gas industry providing MMO and EPCIC services that optimize asset performance onshore and offshore effectively. (Apply Sørco AS, 2014a) Services that are offered by the company as a wide range of excellent solutions are illustrated in Figure 1-2.

Operational Solutions

• Maintenance analysis, planning and support, documentation for operation, systems and operations procedures, training of operators, technical information management

Technical Solutions

• FEED, process analysis and design, detail engineering, procurement & construction and project management support (EPCM), long term maintenance and modification(M&M) contracts, execution of EPCIC projects, safety and automation systems (SAS) and subsea tie-backs to existing facilities, safety and technical integrity upgrades. They all are illustrated in Figure 1-2.

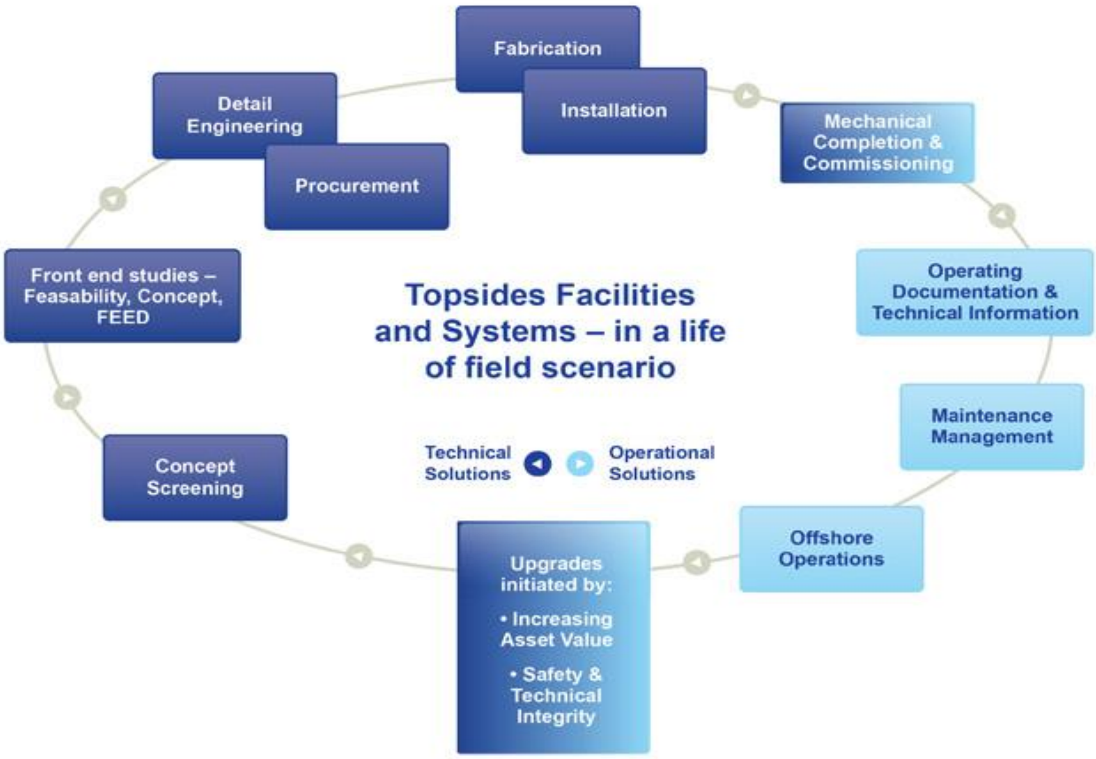


Figure 1-2 Apply Sørco Business Areas (Apply Sørco AS, 2014a)

2) COMPLEX INDUSTRIAL SYSTEMS

In this Chapter, I am going to give brief information about complex industrial systems starting from the definition of basic terms such as system and complex systems.

System can be defined as a group of equipment or components that interacts with each other and are used for common purposes. But more comprehensively definition must involve the people and economic conditions. **Complex Systems** is defined as a system that consists of too many components and relations between each other or with its environment. (Lightsey, 2001) No matter systems can be defined in many different ways depending on their relations with external world, objectives or status etc. they can also be defined as either simple or complex systems at the end.

- Open or closed systems
- Physical or conceptual systems
- Natural or man-made systems
- Static or Dynamic systems
- Tangible or intangible systems
- Simple or Complex systems

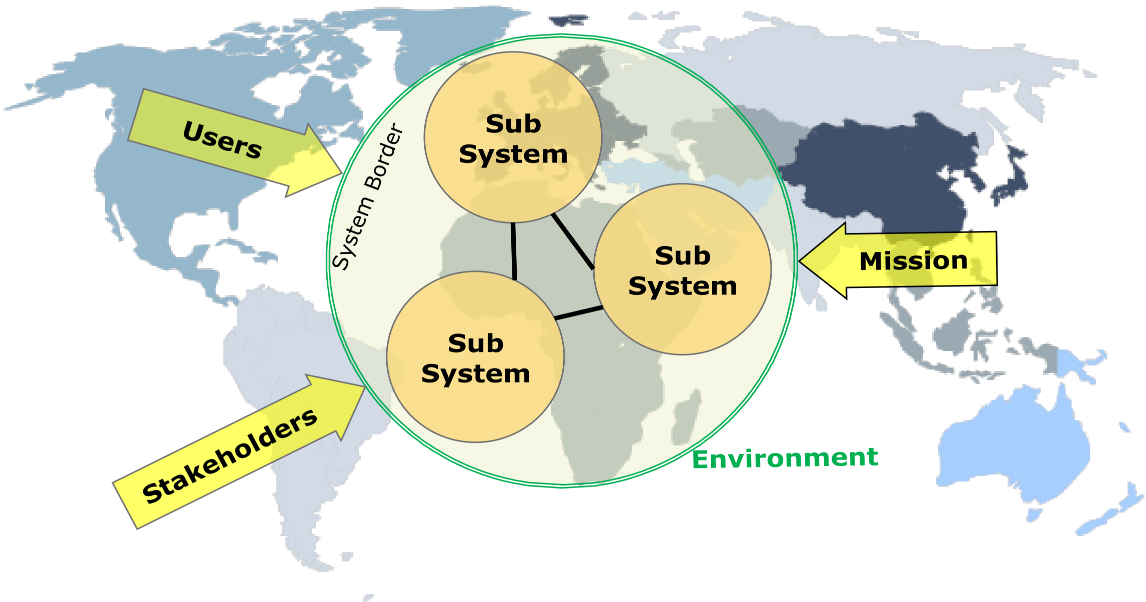


Figure 2-1 Generic Illustration for System and Sub-System Approach

It is obvious that everything we see around us is somehow a part of simple or complex systems. This is an undeniable fact for industrial perspective as well. The only difference is strong industrial content and emphasize on industrial relations. With the background described, it can be said that the functionality of the modern society depends on complex systems that provide either products or services. Some of complex industrial systems that are big part of our modern world today can be listed as follows;

- Communication systems,
- Transportation systems such as airplanes, railways, shipbuilding, maritime etc.
- Information systems such as commercial, production, logistic etc.
- Power systems such as petroleum, offshore industry, energy facilities etc.
- Utility systems such as sewage, clean water, rain water infrastructure
- Medical systems such as hospitals, medical manufacturing plants etc.

Complexity of systems listed above comes from their engineering, operational and managerial difficulties. Each of the complex systems requires many different engineering disciplines for all of the phases during their life time. Beside the thousands of engineers and skilled workers are needed for such systems, tons of raw materials, billions of money, time and energy are also invested in these huge projects. Thus it is obvious that impacts of these complex systems on societies, politics, economics, environment etc. are amazingly big and important.

2.1) Oil and Gas Industry (Offshore) as a Complex Industrial System

Since the beginning of modern age, energy need has become the main concern of modern societies. Hence searching for new energy sources certainly was always top priority and it seems that it will continue. This desire will lead many yet undiscovered energy sources as it did for offshore industry almost 40 years ago.

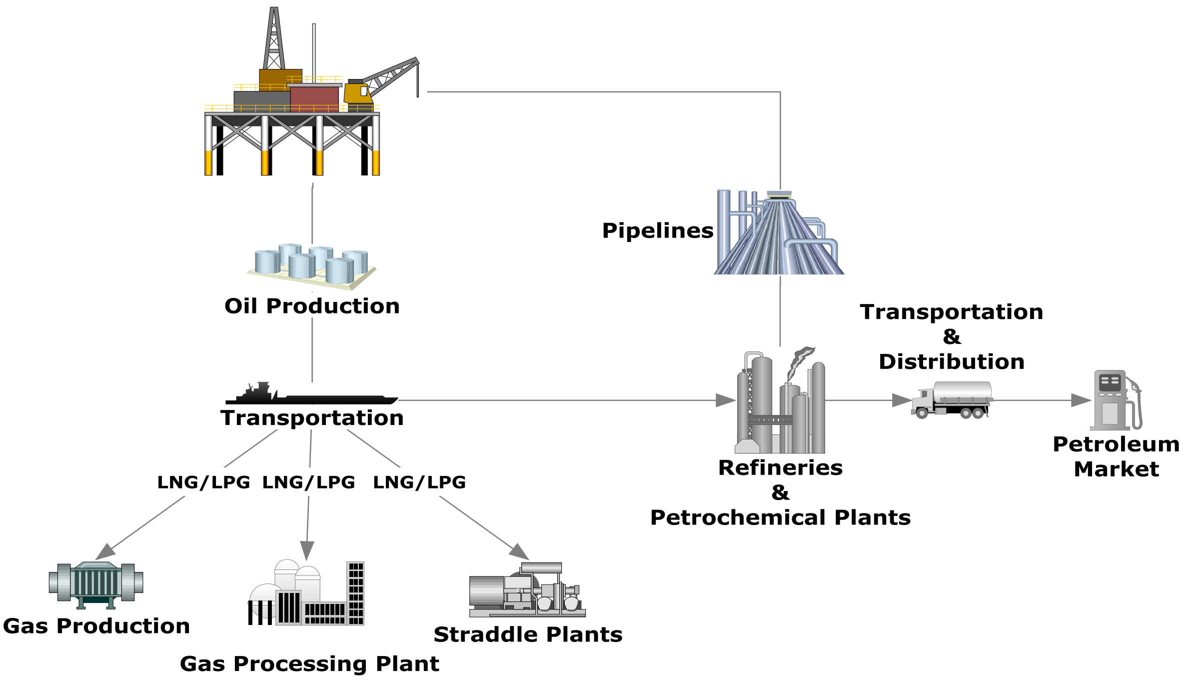


Figure 2-2 Complex Industrial System Approach: Offshore Platform

With the aid of technological improvements, offshore industry is developed quickly during the last four decades and started to respond the energy necessities and demand of people for a sustainable life.

It is simply understandable that we categorized offshore oil platform as a complex industrial system due to its multi-disciplinary engineering, operation and managerial structure. Similar to the definition we made earlier, we can say that emerge of complex systems is related to the dynamic environments and systems' characteristics. Relying on this definition, it can be said that even only the operation difficulties of structures in open seas can make us categorize them as complex systems.

2.2) Interrelationships for Complex Industrial Systems

Complex Industrial systems have great influences in global scales; no matter they are run locally or globally. Of course, this could be possible with globalization and the law of global economics we have in our modern world today. Linked politics, economics and socio-economic environments make everything related to each other and therefore very vulnerable. Just like consequences of banking or financial crisis within USA affecting the rest of the world in 2008 -most recently- from the very first day, a probable catastrophic accident in a North Sea oil platform can easily affect many other complex industrial systems even located in very distance part of the world terribly. Incidents can have catastrophic consequences varying from different economic or politic or social scales. In Figure 2-3 these interrelations are depicted.

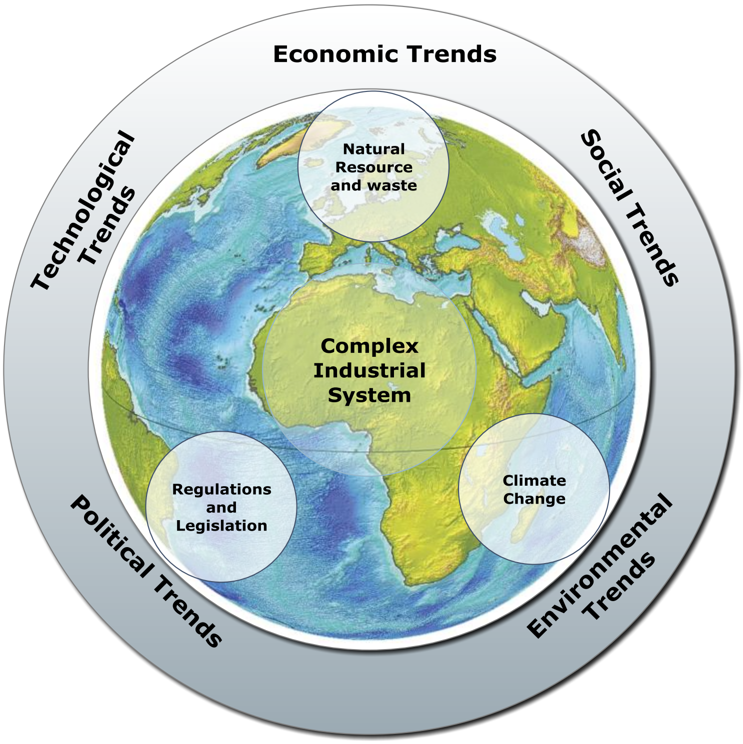


Figure 2-3 Interrelationships for Complex Industrial Systems (EEA, 2012)

In such complex industrial systems, there are many vital parameters to be achieved during the life time of systems due to big influences of complex industrial systems on globe.

Stable: The system has not relation with the external world, working with the pre-defined parameters and has no variations.

Predictable: The system works under predictable conditions. No surprise approach.

Transparent: The entire engineering phases starting from the design to decommissioning are documented explicitly and always accessible for the authorized body.

Controllable: A direct control mechanism involves design, process and rest of the system functions must be implemented.

Reliable: The system simply must operate under desired conditions during the life time.

According to the paradigm mentioned above,(Mina, Braha and Bar-Yam, 2006) we can say that an ideal complex industrial system is the system whose all loops are closed; all possible incidents can be foreseen and mitigated; every single parameters are specified, especially working condition parameters are precisely determined within the limits of its tolerances.

We have tried to describe the ideal complex systems so far. And there are some important questions to ask right here must be:

- How long will the complex system continue to be operated under the conditions it has as it was new build? (Mina, Braha and Bar-Yam, 2006)
- How long does it take to give the first system failure?
- How to mitigate the serious consequences?
- How to have a comprehensive control all over the assets in the industry?

To be able to stay in safe zone, reduce risk and find reliable solutions to the questions asked above, it should be better to have a comprehensive control all over the complex industrial systems. To be able to improve the equipments reliability and so the reliability of the entire plant during their life time, it is highly recommended to have comprehensive understanding about Asset Integrity Management and to take necessary asset integrity implementation.

Asset Integrity can be used as a reliable platform to implement powerful strategies for life extending, reliability, control, stability, transparency etc. shortly everything that a complex industrial system needs to reduce risk during the life time of the facility.

3) ASSET INTEGRITY MANAGEMENT

3.1) Terminology Overview

'*Asset*' according to the British Standards (2014) is defined like "*an item, thing or entity that has potential or actual value to an organization. The value will vary between different organizations and their stakeholders, and can be tangible or intangible, financial or non-financial*".

Asset integrity can basically be defined as the ability of an asset to perform its function properly and efficiently within the limits of its working environment conditions and ability to preserve the health, safety and environment during its lifetime (ABS Consulting, 2010). Asset integrity can be also defined as the strategy and activities which is needed to maintain the required safe and reliable operation conditions for facilities (Hassan and Khan, 2012). It is highly demanded to keep the adverse effect to HSE at the minimum level and keep risk as low as reasonably practicable (ALARP).

Asset Integrity Management is defined by HSE as "*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*" (HSE, 2004) And also reducing risk by providing good design, operating and construction practices in order to prevent major incidents is seen as asset integrity management by OGP (2008).

Within the perspective that is drawn above, we can define Asset Management as a framework creates an organization to valuate process from its assets to organizational objectives while keeping environmental, social and financial cost at a reasonable level and keeping risk, quality of service and performance related to the assets at the desired level at the same time. (British Standards Institution, 2014a)

On the other hand PAS-55 describes asset management 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 the purpose of achieving its organizational strategic plan".* (PAS-55, 2008) Simply what is meant here with the term strategic plan is overall life time for the organization.

As we simply can say that asset integrity and asset integrity management is the backbone of a successful long term asset management policy as well as a reliable maintenance strategy. Hence asset integrity plays vital role and needs to be improved to have enhanced performance and profit.

The relationship between asset, asset integrity, asset integrity management and asset management can be illustrated as it is shown in Figure 3-1.

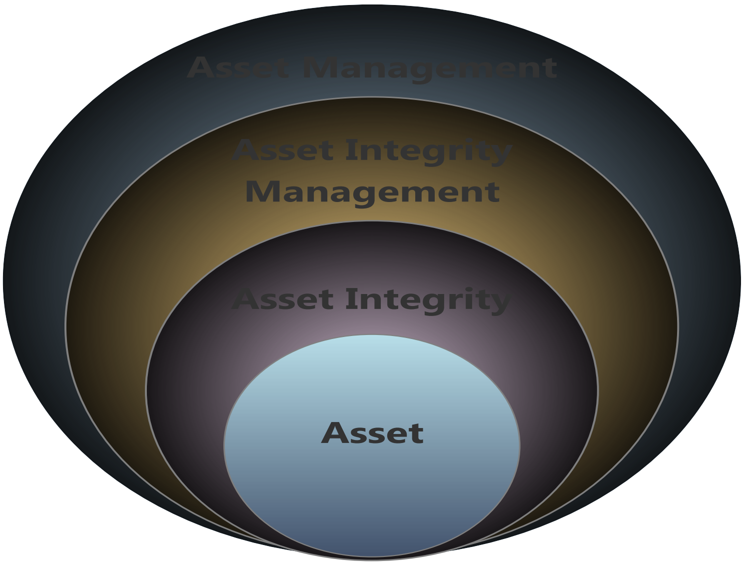


Figure 3-1 Asset Management Frame (British Standards Institution, 2014a)

3.2) Standards and Guidelines for Asset Integrity Management

Asset integrity management and asset management means much more than just paying attention to the financial advantages or durability of the physical assets for business world. (British Standards Institution, 2014b) Hence the attention paid to this field is first considered by a number of organizations under the leadership of Institute of Asset Management and "PAS 55 Asset Management Specifications" is published in 2004. In 2008 The British Standards Institution updated and published the new version of PAS-55. The need for guidance on global scale is also considered by International Organization of Standardization (ISO). "ISO 55000 Asset Management – Overview, principles and terminology", "ISO 55001 Asset Management – Requirements" and "ISO 55002 Asset Management – Guidelines on the application of ISO 55001" are published most recently in January,2014. Due to the importance of subject and lack of standardization, some prominent global organizations, certification and classification societies such as ABS and DNV or International Association of Oil and Gas Producers (OGP), has published their own guidelines. Beside these organizations, as an independent governmental organization, UK Health and Safety Executives (HSE) have also published their own regulatory guidelines.

3.3) Asset Integrity Management Services and Products

Product can be defined briefly as the tangible or intangible output that, according to our point of view, is usually made through an industrial process in order to be sold for income. On the other hand we can define **services** as a set of tangible or intangible actions within a process that produce or maintain a product for a basic public need. (Cambridge University Press, 2014)

In this subchapter, there will be a compilation for products and services provided in the O&G industry regarding to the asset integrity management. This work is compiled from Kadiri (2013). Only intangible services are concerned due to our limitations.

Products

- *Software and Applications* such as CAD/CAM software, database management, administration, analysis, network, CMMS software etc.
- *Simulators* that are able to create a virtual environment for a real training experience for safety, operation, maintenance, inspection etc. purposes.
- Sensors and instrumentation devices that used for determining the condition of asset (NDT tools) or gathering information about the process, or environment.
- Tools and Equipment
- Robots, ROVs

Services

Engineering services within a wide range that covers design, analysis, maintenance and inspection policies. These services throughout a set of analysis supports entire life cycle of plant and provides vital information to make decision about the maintenance programs. Establishing maintenance program is an essential part of the engineering services we consider within this study mainly.

- Inspection and Monitoring
- Spare part management
- Improvement services mostly refer to the repair and maintenance improvements that mainly aim high reliability and availability during the life time of the plant.
- Operation documentation is the process that transforms technical and operational data into understandable format for the end users. P&IDs, block diagrams, data sheets, operation and maintenance manuals are some of the documents that is needed to handled and transformed.
- Training services implies training for personnel from operational perspective.
- Safety and Emergency response stands for safety and emergency response analysis for unexpected events that might cause catastrophic failures. Service includes safety assessment, inspections, test, demonstration of evacuation etc. (Kadiri, 2013)

3.4) Basics and Benefits of Asset Integrity Management

Firstly, it is better to understand the importance of asset integrity in oil and gas industry and reason of the fact that we need. Asset integrity is a multi-disciplinary approach that consider and tries to combine tangible and intangible assets, human resources, project design, planning, IT technologies and tools, operation, commissioning and decommissioning that take place during the lifetime of a project. (Erstad, 2011)

The main reason why we need Asset Integrity is actually its capacity to prevent catastrophic failures and to ensure high availability during the life time. Asset integrity keeps facilities at high level of availability by a taking wide range of important activities. Improving equipment design, inspection, testing, preventive maintenance, predictive maintenance and repair activities by asset integrity tools are the essential part of the asset integrity activities. A sample illustration is shown in Figure 3-2.

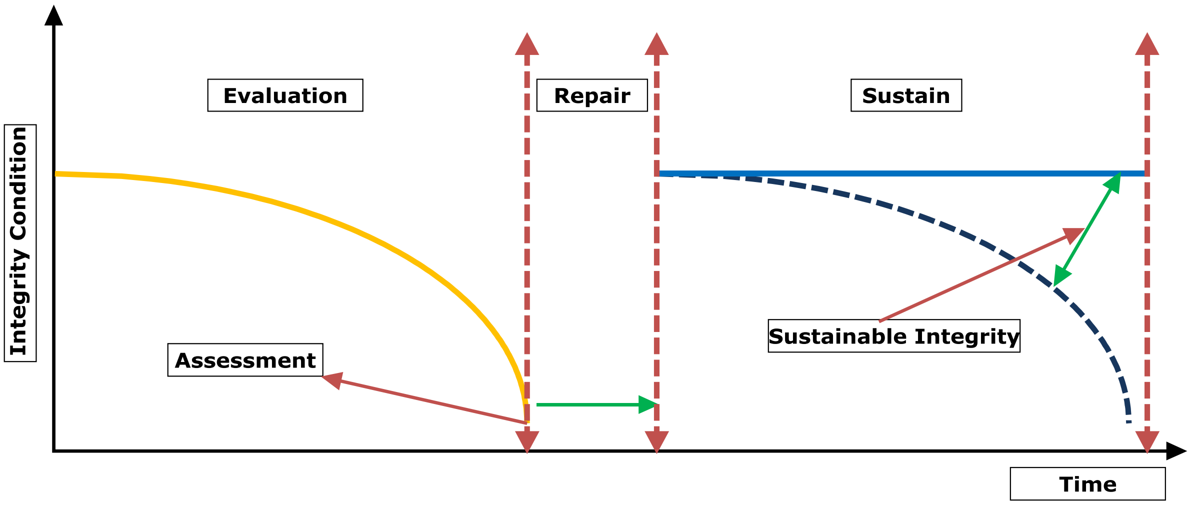


Figure 3-2 Fundamental of Asset Integrity (Adapted from Bax, 2010)

To be able to implement a successful asset integrity management system, it is essential to consider following key parameters as we pointed some of them in complex industrial systems chapter;

- Technological trends
- Economic trends
- Environmental Trends

It is also vital to keep stakeholders well integrated and well informed during the entire asset integrity process.

Asset Integrity, in general, aims very important utilizations for,

- Improving safety and reducing risk, ensuring HSE requirements
- Developing know-how knowledge

- Increasing productivity and efficiency in production, operations and maintenance.
- Improving reliability, availability and maintainability parameters.
- Better understanding of assets and therefore plant condition
- Increasing the life time of assets
- Increase profitability
- Asset Integrity goals and objectives mentioned in this sub-chapter are illustrated in Figure 3-3.

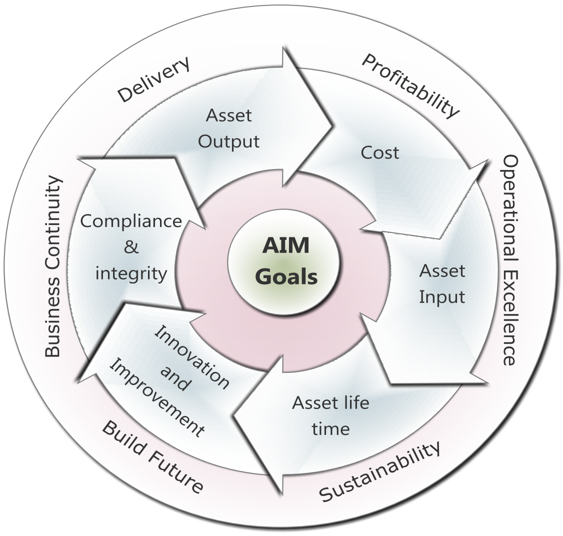


Figure 3-3 Asset Integrity Management Goals (Stork Technical Services, 2014)

In addition to the overall expected benefits of asset integrity management that are mentioned above, asset integrity service companies operating in very competitive markets like oil and gas industry points some other important responsibilities to implement strong asset integrity structure and taking the concept one-step ahead of current trends. The target objectives that are considered to improve continuously can be summarized as follows:

- Improving specialized technical documentation and information related services
- Delivering anticipated financial results according to budgets
- Providing quality services to the market.

As we discuss in Complex Industrial Systems, we need to have stability, control, transparency, reliability etc. starting from the first day of planning, hence it is essential to implement asset integrity from very first day of the project design to the end of its economic life in order to achieve the asset integrity goals and utilize the concept. This can be possible only if a strong and comprehensive strategy that includes all elements of asset integrity is developed.

3.4.1) Key Elements of Asset Integrity

Asset integrity can be divided into three sub-categories as it is shown in the Figure 3-4. This categorization simply depends on life cycle stages of assets and art of management.

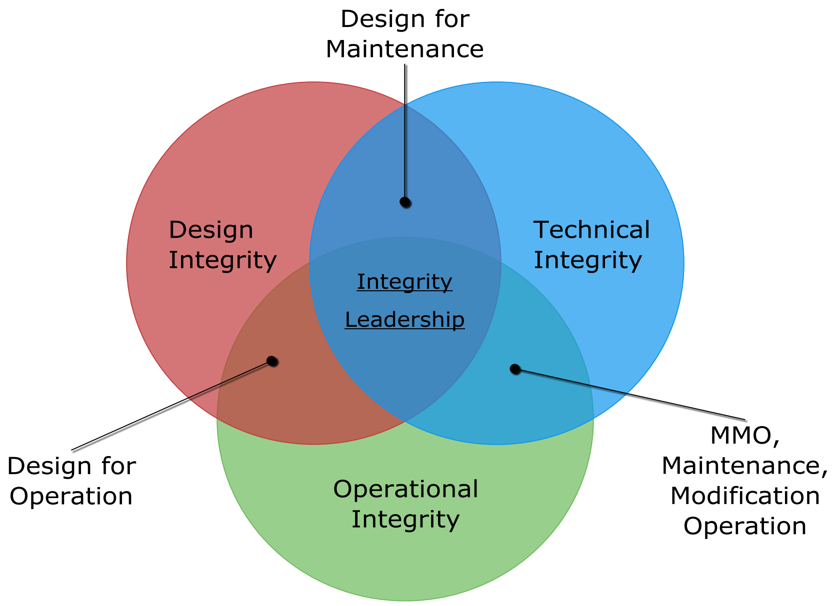


Figure 3-4 Key Elements of Asset Integrity (Pirie and Østby, 2007)

Operational Integrity can be defined as the ability to operate plant safe. (Adair, Filmalter and Mahlangu, 2008) and covers all the events, assessments and activities related to the operations. Hence, human resources are an important part of operational integrity and must be integrated to the rest of the integrity system. Monitoring and analyzing operational conditions continuously are vital for safe and reliable operational integrity.

Operation integrity requires appropriate knowledge, competency, experience, labor force etc. to be able to operate facility safe during the life time. It requires adequate integration with the maintenance and safety processes. (Pirie and Østby, 2007)

Design Integrity covers a wide range engineering scope from initial engineering analysis of assets that is supposed to be used to fulfill the safety and functional requirements during the life span of the project. Design integrity basically includes risk management process, simulations, calculations, blue-print preparations and financial assessments to making decisions for materials and technology. Design integrity can be accomplished by conducting comprehensive researches and audits during initial construction phase of the plant.

From industrial point of view, design integrity is considered as defining and building up safety barriers according to the recognized regulations and international standards. Furthermore design integrity aims to improve these barriers and reduce risk in order to prevent major accidents. (Pirie and Østby, 2007) As we see the risk and probable benefits of risk reduction actions to be taken, we can say that it is very important to implement a successful risk analysis method to achieve successful design integrity through the life time of facility. Methodology for a successful risk management policy is given in In Figure 3-5.

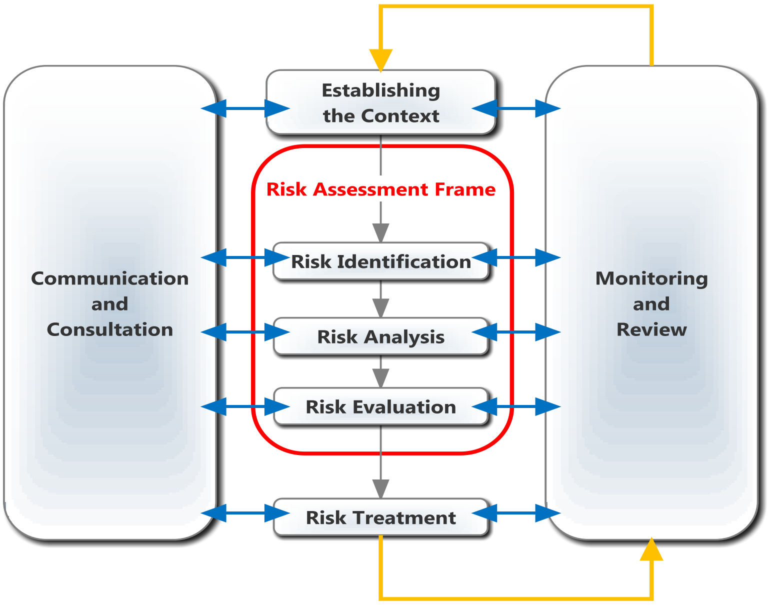


Figure 3-5 Asset Integrity Risk Management Process (British Standards Institution, 2011)

Technical Integrity can be simply defined as fundamental maintenance and data management activities required to keep the operation of the plant available. (Pirie and Østby, 2007) Technical integrity work processes covers inspection, maintenance, modification and reliability of physical assets. It considers technical condition of assets and related information.

Technical integrity should be obtained within all the three major stages of an asset through its commercial life with a maintenance perspective. These three major stages simply covers the entire work processes during the life time of project and is defined by (Liyanage, Badurdeen and Ratnayake, 2009) as:

- EPCIC (Engineering, Procurement, Construction, Installation and commissioning)
- Operation stage
- Decommissioning or termination stage

Providing the best HSE conditions within the stages defined above is the main objective of technical integrity during the life time of the plant. (Erstad, 2011) However this is a challenging task if we consider that all of the equipments used in production facilities are exposed to degrading and, by nature, having declining performance parameters during the life time. As we know, degrading can cause either partial failures and relatively simple consequences or bigger failures and catastrophic consequences by time. Hence, to be able to have safe and reliable operational conditions, required maintenance actions must be taken in compliance with the maintenance management loop illustrated in Figure 3-6 and probable failures due to degrading must be eliminated with the aid of maintenance actions. This is the way to enhance and strengthen technical integrity of an asset throughout its life time.

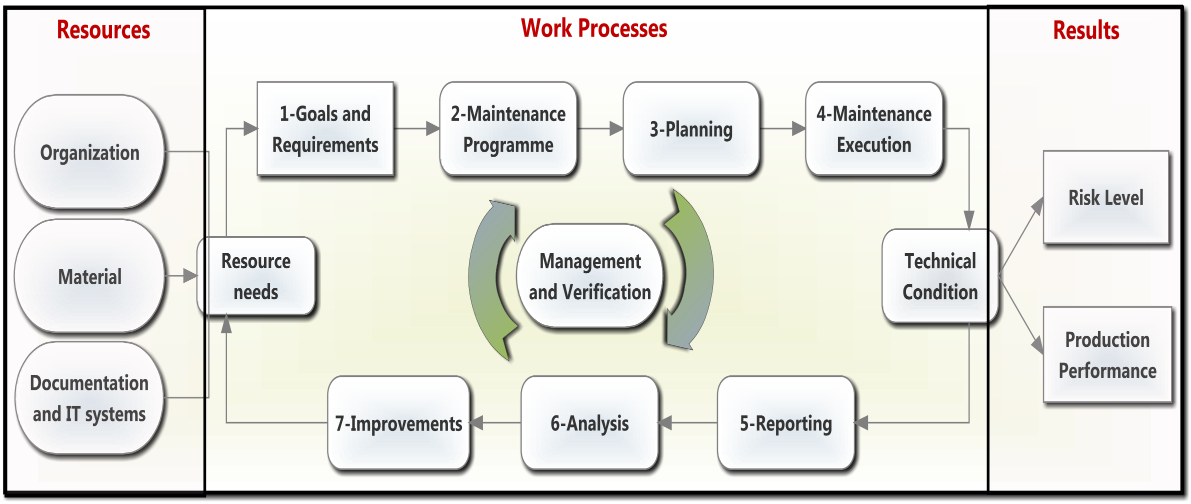


Figure 3-6 Maintenance Management Process (PSA, 1998)

In reality, in order to maintain the facilities, prevent degradation and extend the life time of assets, it is very important to keep maintenance management process working and updated during the life time of project. This is the only way to have a high level of technical integrity and so a successfully implemented asset integrity management system. A robust and integrated maintenance strategy can keep the plant working efficiently and reduce the risk to the ALARP levels.

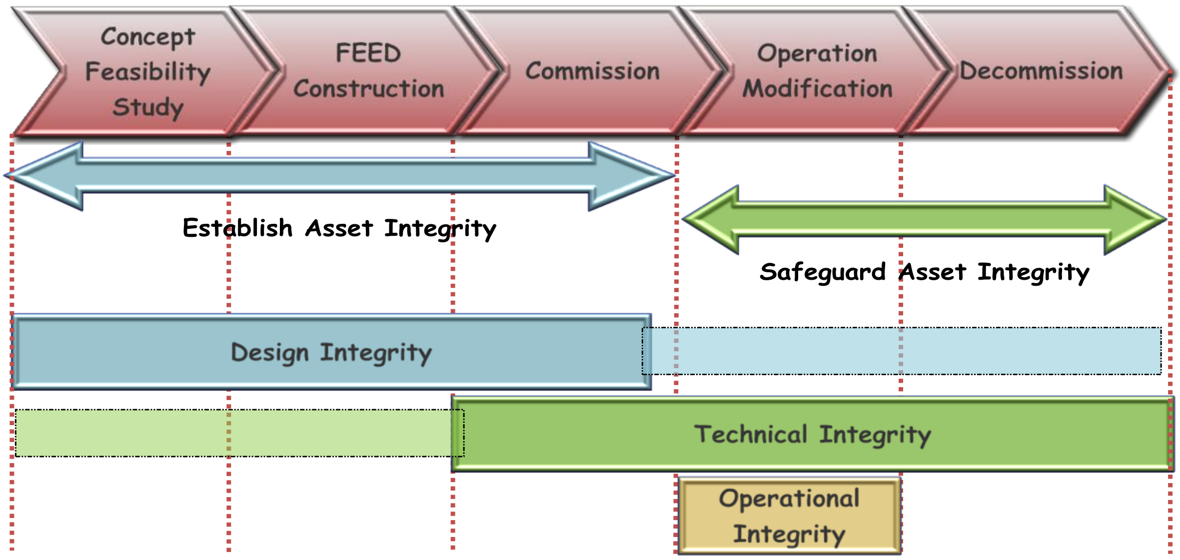


Figure 3-7 Asset Integrity during Life Cycle (Adapted from Bax, 2010)

Finally, it is clearly seen that a strong asset integrity management only can be accomplished by developing a well understanding about design, technical and operational integrity concepts. In order to keep the facility operating under desired conditions during its life time, it is essential to have a pointless integration of these elements as it is shown in Figure 3-7. This, on the other hand, is the only way to develop a sustainable and reliable industrial system. And the technical integrity is the main pathway right in front of the stable, controllable and reliable life span operations.

Process work flow coming from complex industrial systems and leading to the maintenance strategies is illustrated in Figure 3-8.

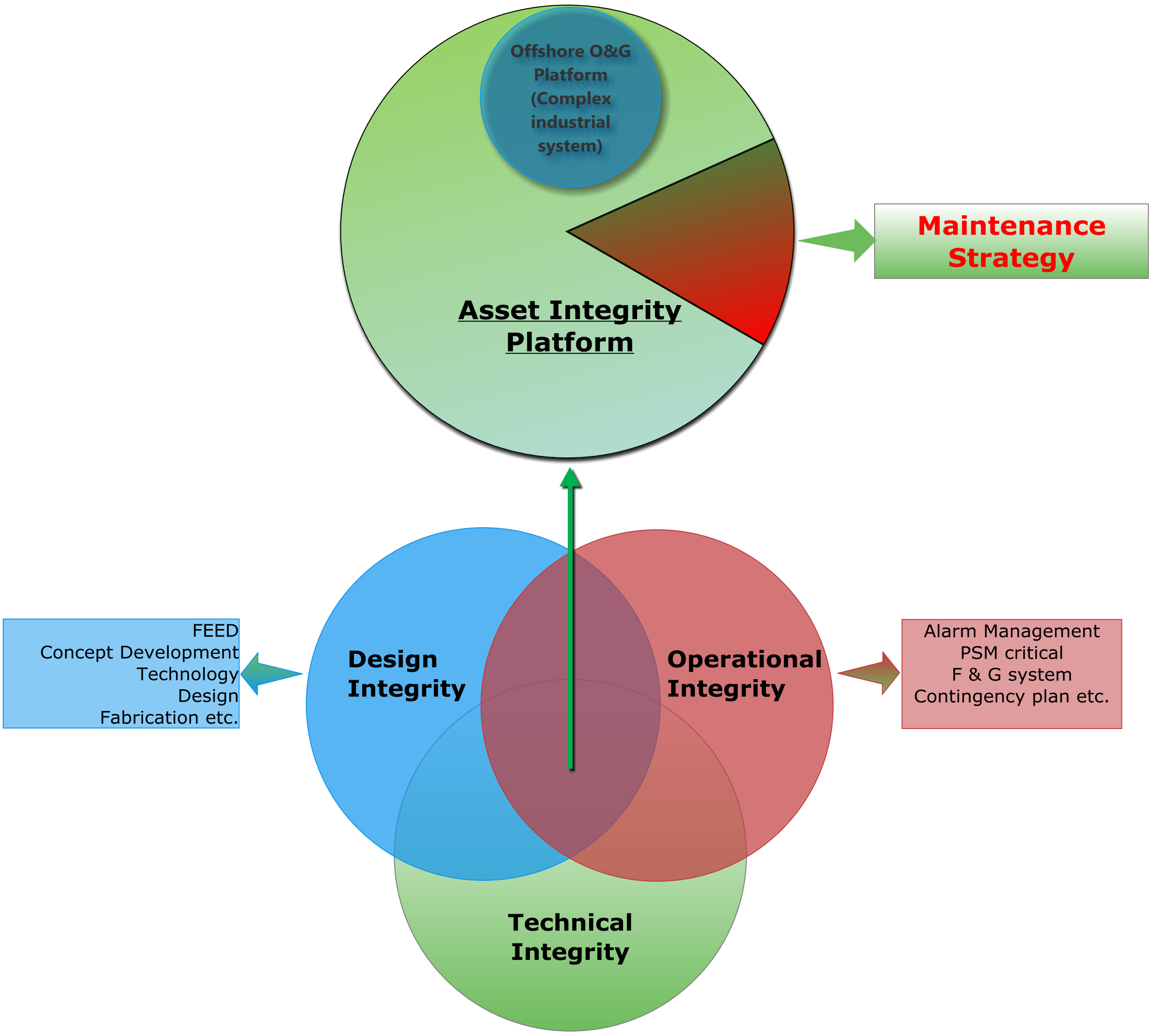


Figure 3-8 Pathway from Complex Industrial Systems to Maintenance Strategy

3.5) Challenges with respect to the asset integrity

The entire work processes mentioned earlier for asset integrity has to be HSE and cost friendly with a sustainable regularity. It has to be well understood that the plant must be operated with a harmony of HSE regulations which enforces elimination or reduction of risk as low as reasonably practicable. Maintenance is the key tool for building strong technical integrity and so working environment with reasonably low risk. Maintenance philosophies aim to prevent or limit undesired failure that might cause loss of production and/or high cost of repair action. To be able to achieve these goals, a well-structured maintenance strategy which is supposed to be integrated as a part of strong asset integrity must be applicable.

Asset integrity must be provided as a life span service and must comprise design, operation, construction, maintenance, modification and decommissioning phases. And of course, asset integrity has its own overall objectives and challenges as well as elements of asset integrity have their own challenges to achieve in order to have a sustainable safe working environment. These overall industrial challenges for the asset integrity service contractor to accomplish can be listed as below;

- Insufficient collaboration; lacking of information and experience sharing among the companies operating in the same industry
- Operating under unpredictable circumstances and various harsh environmental conditions makes it challenging to have a uniform asset integrity management paradigm.
- Regulating with various non-standardized operational regulation published by the operator companies.
- Inadequate integration of maintenance and safety work processes.(Pirie and Østby, 2007)
- Lack of required documentation and unskilled personnel.

Turning challenges into the gain also can be seen as general challenges to accomplish. According to the that paradigm, objectives that are supposed to be accomplished as end result through the industry challenges are listed below;

- Liability for regulatory requirements, HSE
- Competency
- Risk evaluation and management
- Well organized documentation
- Availability and robustness of information
- Incident investigation and life-long learning
- Performance management

4) MAINTENANCE STRATEGIES AND MANAGEMENT

Maintenance, according to the ISO 14224, is combination of all technical and managerial activities, controlling actions to be able to keep an item in desired functional state or restore it to make it perform its function properly. (British Standards Institution, 2006)

On the other hand, all of the managerial actions that first define goals of maintenance program that must be accomplished, then planning, design and utilization of available sources in order to implement a sustainable maintenance approach are defined as maintenance management. Maintenance management aims to build an organizational behavior model that involves different parties and corporation and methodologies. Only then, it becomes possible to ensure safe working conditions and enhanced productivity. (Standards Norway, 2011)

One of the important terms related to the maintenance that must be defined is the term maintenance strategy. It is defined as management methods or management concept used to achieve maintenance goals determined from the very beginning phase of the project.

4.1) Standards and Legislations for Maintenance

Oil & Gas activities -in general- that are held in NCS are regulated by Norwegian Petroleum Act of 29 November 1996 and the Norwegian Petroleum Taxation Act of 13 June 1975. (Statoil AS, 2009)

Maintenance programs regarding to the Oil & Gas industry that are held in NCS are regulated by Norwegian Petroleum Safety Authority (PSA). PSA Activities Regulations §45 is regulating all maintenance activities. Maintenance related monitoring, inspection, testing, trial and repair actions are also regulated by §45.

Classification of equipments used in the facilities according to the HSE consequences of potential functional failures is regulated by Activities Regulations §46. It is recommended to use classification as basis for maintenance activities and maintenance frequencies. Activities Regulations §46 recommends NORSOK Z-008 Standards to fulfill the classification requirements. §46 also refer to the Norwegian Standards NS-EN 13306 for maintenance terminology and ISO 14224 for reliability data of equipments (PSA, 2014a).

PSA Activities Regulations §47 enforces a maintenance program for the fault modes that lead to HSE risks defined through §46. Maintenance Program is to have activities such as monitoring and controlling performance, failure mechanism and technical conditions.(PSA, 2014b) §47 regulate the maintenance program with the aid of some other international standards and guidelines such as ISO 20815 for HSE frame, ISO13702 and OLF70 for safety systems, IEC 61508 for emergency shutdown system. In addition to the regulations mentioned above §48 and §49 also regulates Planning and Prioritization and Maintenance Effectiveness respectively.

4.2) Basics of maintenance strategies

Maintenance strategies can be in many different forms depending on the prospects of outcome, assets that need to be maintained and cost, of course. It can be said that maintenance cost generates the big portion of operation cost during the last few decades. According to the Mobley (2002) maintenance cost is between 15% and 60% of entire operation costs during the life time of manufacturing or process plants. However, it is obvious that consequences of not having a proper maintenance strategy or lack of maintenance management may cost much more. On the other hand beside the cost of not having such maintenance strategy, there is also great risk for health, safety and environment due to any probable failure.

Within this chapter, we will briefly present information about the maintenance strategies, main goals, motivations, concepts and their deficiencies. Maintenance strategy categorization is illustrated in Figure 4-1.

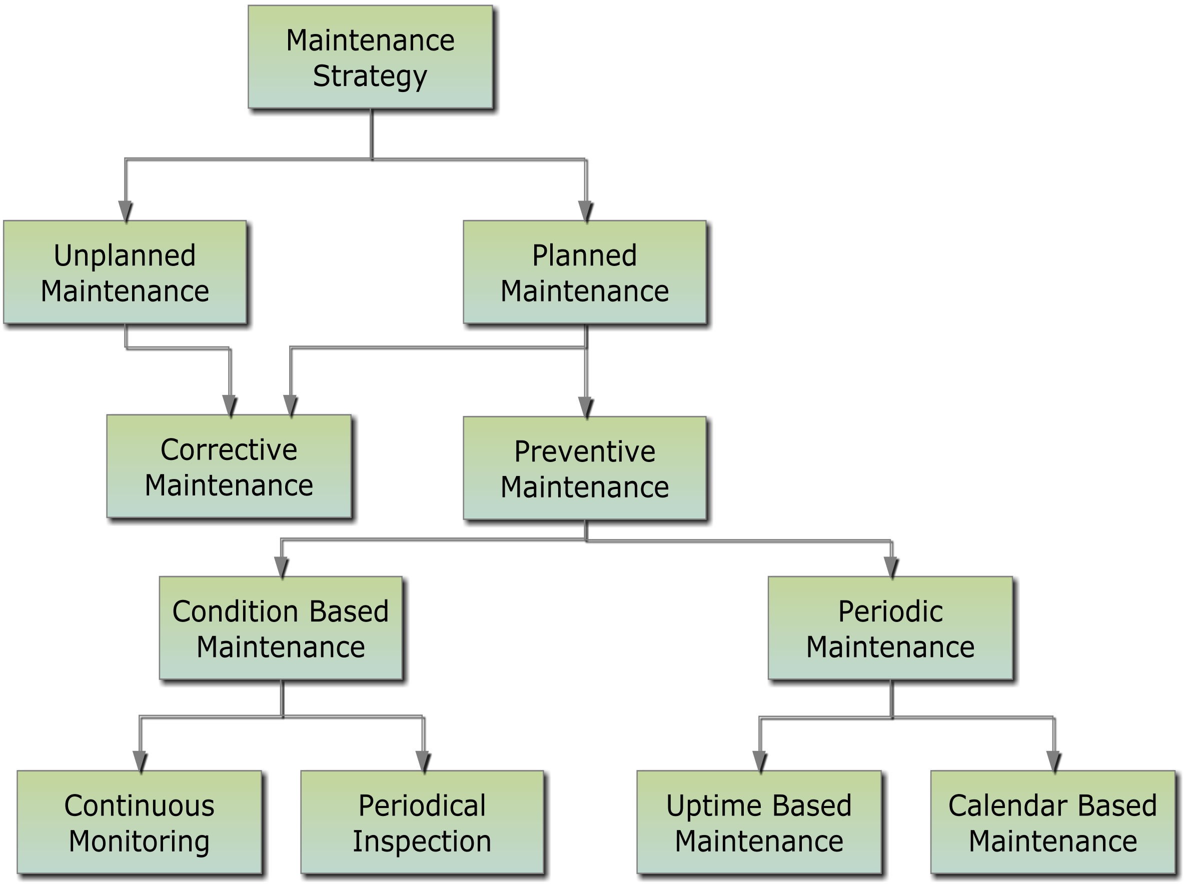


Figure 4-1 Maintenance Strategy Overview (Coetzee, 2004)

4.2.1) Corrective Maintenance

Corrective Maintenance, which is also known as *"Run to Failure Management" or "Reactive Maintenance"* or *reactive maintenance can be* called the simplest maintenance strategy. In fact, there is no maintenance strategy to talk about in such approach. In this strategy, simply it is waited to take any maintenance action until the machine or the equipment fails. Failure point is also the time to make decision whether to repair or replace the equipment. By its nature, it is expected to take immediate action in case of failure in plant. That can be only possible with an extensive spare part inventory and qualified workers that are available in the plant all the time. In addition, of course there is a huge additional economic effect due to probable operation loss or the cost of immediate spare part supply. Researches show that average corrective maintenance cost can be three times higher than the scheduled or preventive maintenance approaches. (Mobley, 2002) it is only acceptable if the equipment is not critical and has no critical consequence in case of failure.

4.2.2) Preventive Maintenance

Preventive maintenance, simply as its name implies, is used to prevent a potential failure of equipment and significant damage might happen regarded to the failure. Moreover, the way that approach is implemented is always time-driven. Mainly there are pre-determined fixed time intervals and procedures to help maintenance engineers to take the required maintenance action. No matter the time intervals are based on mean-time-to-failure (MTTF) statistics of equipment or suggestion from manufacturer or even based on the experience of maintenance operator, time intervals are not fixed as they are anticipated, moreover they definitely change, mostly they extend. This is because of the desire to stay on safe side while implementing the preventive maintenance strategy and the nature of equipment as it is understood from the bath-tube curve. As we know bath-tube concepts indicates that a new machine can fail during the very first weeks after installation just because of some installation issues. It works well afterwards for a period and then most likely starts to give some failures as a result of operation duration. Bath-tube curve is given in Error! Reference source not found..

Preventive maintenance intervals, as a state of nature, can show big differences. Intervals may differ from daily basis to once in a ten year duration regarding to the function of assets and its criticality.

Main goal of preventive maintenance can be pointed as identifying the upcoming failure with the aid of time-driven maintenance actions the way before it occurs and arrange the necessary maintenance sources such as repair part, skilled workman etc. to take the required maintenance action within the best time for plant working schedule. Otherwise, unseen failures can turn into catastrophic consequences.

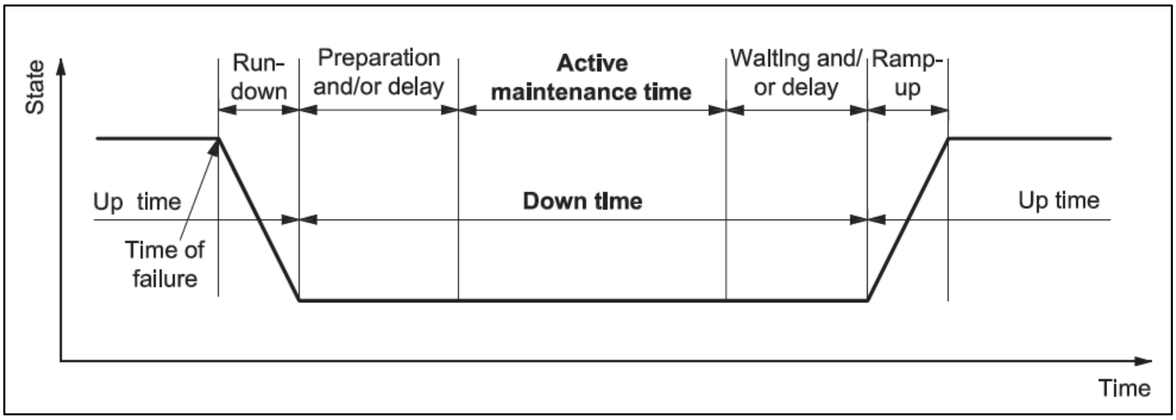


Figure 4-2 Bath-tube approach for probable failures during life-time (British Standards Institution, 2006)

From this point of view, we can say that the main difference between preventive maintenance and corrective maintenance is the ability of arranging the required sources and the ability of scheduling the repair time regarding to the impact of downtime. (Mobley, 2002)

However, in order to have time to be able to arrange sources and to take the maintenance action on the very best time for operation is the optimistic case even for preventive maintenance concept. The reason of that is hidden in the data that is used for planning preventive maintenance interval. Such data like MTTF, mean-time-between-failures MTBF, and manufacturer suggestions are all based on some assumptions or experiments that naturally have some certain limitations regarding to the operating circumstances, conditions and workloads. Consequently, not having certain information can cause some catastrophic failures because of late taken action as well as the fact that there might be some unnecessary maintenance actions.

Some of the most important advantages of preventive maintenance

- Management Control
- Spare part management control
- Cost-benefit relations
- Quality management

On the other hand, preventive maintenance has some deficiencies as we mentioned before, here we list some of the most important disadvantages of preventive maintenance strategy,

- Infant mortality
- High Initial Costs
- Using more parts than needed
- Highly exposed to the human errors (Mobley, 2002)

4.2.3) Condition Based Maintenance

Condition based maintenance (CBM) is a maintenance strategy that depends on the condition monitoring. Monitoring and evaluating the condition of maintainable assets continuously or in a regular schedule constructs the backbone of this strategy. This maintenance policy is also known as predictive maintenance.

As we mentioned under the preventive maintenance topic, the inefficiencies of PM due to being a time-driven maintenance approach, which provides maintenance action mostly depending on the historical reliability data and does not consider the current condition of the asset, is well handled with condition base maintenance strategy. Thus, with the help of condition driven maintenance strategy, it becomes easy to find out early degradation of asset and becomes easy to manage optimization of downtime duration of facility efficiently. Moreover, maintenance action is taken almost on the exact time when asset needs maintenance. To be able to determine the exact maintenance time, CBM mainly uses non-destructive testing methods including visual inspection, performance benchmarking techniques and degradation analyses. (Lee et al., 2006)

Consequently, the basic idea beyond the maintenance strategies is getting benefits summarized as follows:

- Reducing the downtime and improving availability.
- Extending life time of plant
- Increasing total safety
- Reducing cost
- Compensating of unreliability and loss of quality
- Avoiding the adverse effect of human errors
- Providing optimum operation conditions
- Minimum spare part inventory
- Ability to react as fast as possible
- Reducing risk as low as reasonably practicable

Furthermore, if we basically try to map algorithm for proper maintenance strategies, we can categorize it under four main categories depending on the state and the importance of assets. Here what we mean with *state* and *importance* is the condition and the function of the assets respectively. A visualized definition for this concept is shown in Table 4-1. This preliminary matrix can help us to select or at least to have an idea about the suitable maintenance strategy. (Schneider et al., 2006)

4.2.4) Reliability-Centered Maintenance (RCM)

Reliability Centered Maintenance (RCM) is defined as a systematic and detailed maintenance evaluation to be able to indicate and prioritize preventive maintenance activities according to the safety parameters. In other words, systematic analysis of system functions with reliability perspective and their effects on failures, where generic maintenance concepts are not sufficient to determine such detailed information. RCM is one of the advanced maintenance concept which involves risk management and ensures reliability of equipment during all its operation.

RCM concept is considered only when criticality of equipment, function-wise, is medium or high. Because that criticality levels requires in-depth analysis and information, while preventive maintenance strategy is used for low criticality equipment. RCM decision logic for maintenance selection process can be seen in Figure 0-1.

To be able to successfully implement RCM concept, principles described below must be well understood and applied. (Conachey and Montgomery, 2003)

1. Identifying the system.
2. Defining the system functions and related performance standards.
3. Define the failures that may cause the functional failure.
4. Conduct the Failure Modes, Effect and Criticality Analysis (FMECA)
5. Foresee the consequence of the functional failure.
6. Determine the measure that can prevent the failure
7. Consider the functional failure based worst case scenario and develop the actions that must be taken under worst case scenario

Table 4-1 Maintenance Strategies (Schneider et al., 2006)

		IMPORTANCE	
		Not Considered	Considered
CONDITION	Not Considered	**CM** **Corrective Maintenance** ♦ No inspection or maintenance until breakdown	**TBM** **Time Based Maintenance** ♦ Fixed time intervals for inspections and maintenance
	Considered	**CBM** **Condition Based Maintenance** ♦ Continuous or occasional monitoring ♦ Maintenance when required	**RCM** **Reliability Centered Maintenance** ♦ Priority list ♦ Connection of condition and failure effect ♦ Risk management

4.2.5) Failure Modes, Effect and Criticality Analysis (FMECA)

Failure Modes, Effect and Criticality Analysis is a qualitative analysis method that is used to prevent failures, define and mitigate their effects. According to the Mobley (2002) FMECA is a bottom-up method which consider every single component in the equipment and their failure with their impact on equipment and so consequences. Occurrence frequency and the possible failure causes are the main inputs for such analysis. As it is understood by that brief information, FMECA is highly detailed and sensitive analysis methodology; hence it is only applied to the equipment with high criticality.

4.3) Maintenance Management

The work flow that has been described so far through Chapter2, 3 and 4 for developing a concept that allows a complex industrial system, an offshore oil platform in this case, to be operated under desired functional conditions needs to have a maintenance management philosophy in order to have a great control over the assets, technical conditions. Maintenance activities etc. from this perspective it is easy to define maintenance management as a set of activities used to determine the maintenance objectives, priorities, strategies and responsibilities first and then utilize them by means such as maintenance planning, control, supervision and also improving methods for economic and organizational aspects. (British Standards Institution, 2010a)

Maintenance management philosophy takes place to provide sustainable reliability during the life span of facility. That philosophy was developed by Norwegian Petroleum Authority during 1990s and was illustrated in Figure 3-6 Maintenance Management Process.

A well implemented maintenance management model can be evaluated under three main conceptual phase called resource (input), process (maintenance verification) and results (outputs). Verification phase is divided into seven different processes that runs in a sustainable loop through the life cycle of facility. These processes and their key elements is described briefly below;

- Defining and updating the main goals and requirements
    - Risk, production and cost are mainly concern parameters.
    - Regulatory requirements have to be satisfied.
- Selecting maintenance program
    - PM, CBM, CM, RCM, FMECA, failure causes etc.
- Planning and preparation of maintenance activities
    - Method, required time, activities needs to be taken, prioritizing of activity
- Execution of maintenance program
    - Work permits, safety requirements and reporting.
- Reporting on performance maintenance, technical condition. Cost and risks

    - Considers maintenance data, performance data, sets KPIs
- Analyzing of feedback data by mapping improvement potential
    - Analyzing feedback data of maintenance actions, root cause analysis
- Development measures for strategic improvement.
    a. Improving system in terms of safety, barrier management, cost effectiveness. (Lundin Norway AS, 2012)

4.3.1) Maintenance Management Challenges

Requirements for maintenance and maintenance management are set according to the health, safety and environment regulations frame. Therefore maintenance activities have to be in compliance with HSE requirements as well. This can be said as overall challenge related to maintenance and maintenance management.

According to the supervision of Norwegian Petroleum Safety, some of the issues that are seen challenges and need to be improved are compiled as follows from (PSA, 2014c)

Challenges regarding to the ineffective management

- Classification insufficiency and not having systematic choice of priorities
- Ineffective reassessment of maintenance actions and frequencies as if equipment is not aging.
- Lack of know-how development, competences and resources

Challenges regarding to preventive maintenance

- Insufficient reliability data for the equipments
- Creating project basis technical libraries, in other word, reliability databases regarding to maintenance.
- Keeping safety critical barriers functioning whenever they are needed
- Insufficient reporting, reports without failure causes, failure mode data.

Challenges regarding to the safety and aging

- Not having a comprehensive method for detecting mal-function equipment or hidden failure.
- Lack of information reliability data, mean-time-between-failure (MTBF), mean-time-to-failure (MTTF), mean-time-to-repair (MTTR) data regarding to the aging equipment.

5) ESTABLISHING MAINTENANCE MANAGEMENT PRACTICE

A sufficient maintenance program for a production plant, by nature of matter, includes more than one maintenance strategies that was mentioned earlier in this chapter at the same time. Different maintenance strategies are applied to difference kinds of equipment depending on the risk factor that is related to the equipment. It is a challenging task to determine risk factors related to the equipment and it can be accomplished by carrying out risk analysis methods. To be able to implement risk analysis methods successfully to the entire plant, information regarding to the plant and maintenance strategies must be collected correctly and must be utilized to map relationship between equipments and systems. Information that has been gathered must be evaluated efficiently. For easy utilization of the methodology, Maintenance Management Practice is illustrated in Figure 5-1.

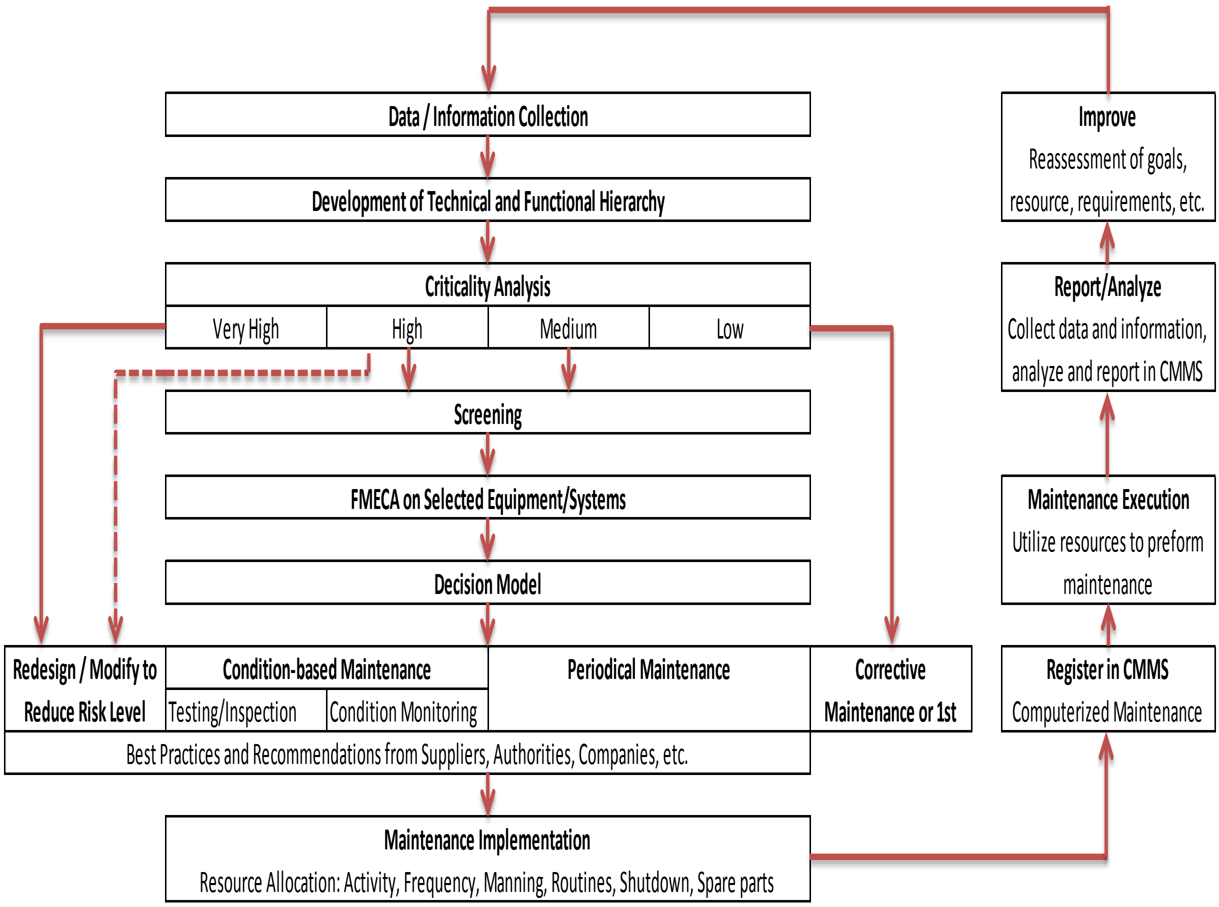


Figure 5-1 Maintenance Management Practice (Markeset and Kumar, 2005)

Hence, the first step for establishing a maintenance program starts with collecting data regarding to the maintenance program. Data that is collected is to be used for construction of the technical hierarchy for entire plant as a starting point.

5.1) Technical and Functional Hierarchy

Technical hierarchy creates an overview with in-depth technical details for entire plant. Both of information that is handled through the technical hierarchy and outcome are supposed to include every single item in the facility such as main equipments, components, instruments etc. Technical hierarchy should be established at an early phase of the project due to technical integrity concerns. Hierarchy is obtained by breaking entire plant into systems, subsystems, main functions and sub-functions regarding to the equipment itself and its function, of course. (Standards Norway, 2011) Moreover, technical hierarchy provides very essential information about technical dependencies of the installation, tag systems, documents and related drawings. As it is a necessity to define tag hereby, according to the Norsok standards tag is defined as “a unique code that defines the functional location and function of a physical component within a facility.” (Standards Norway, 1996)

Technical hierarchy is the backbone of maintenance program and by gathering information about tags belongs to the various components of the plant and evaluating them regarding to the maintenance strategies, it aims to fulfil the completion of final maintenance program.

Establishment of Technical hierarchy

As we know it very well, we need to inspect drawings and documents belong to the systems in order to start to implement technical hierarchy. And identifying the main system equipments as it is shown in Figure 5-2 .

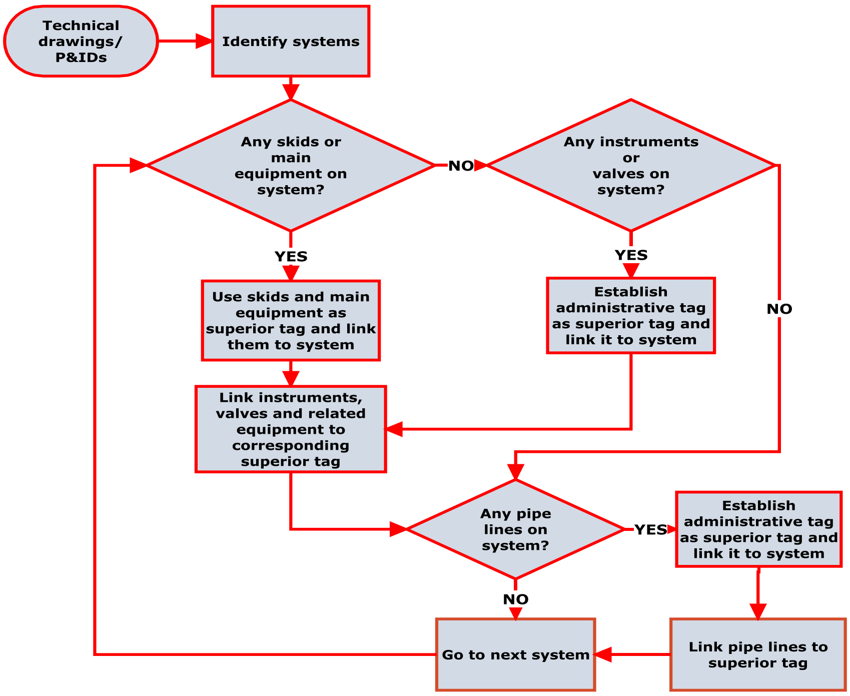


Figure 5-2 Technical Hierarchy Work Process (Standards Norway, 2011)

Biggest challenge for preparing technical hierarchy is lack of documentation at the very beginning phase of the project. Documentation issues may be fixed by time later on, however since technical hierarchy is sort of starting point for maintenance program, it should not cause any delay because of lack of documentation. To successfully overcome of this situation, it is highly recommended to have quality control check for documentation the way before the technical hierarchy kicks off.

Another challenge for technical hierarchy could be forming hierarchy visually to be able to do quality checks efficiently and building up infrastructure for consequence classification technically. Following figures are scripted and developed within the scope of master thesis to be used in Monitoring (Control) Interface (go to Chapter 7.2).

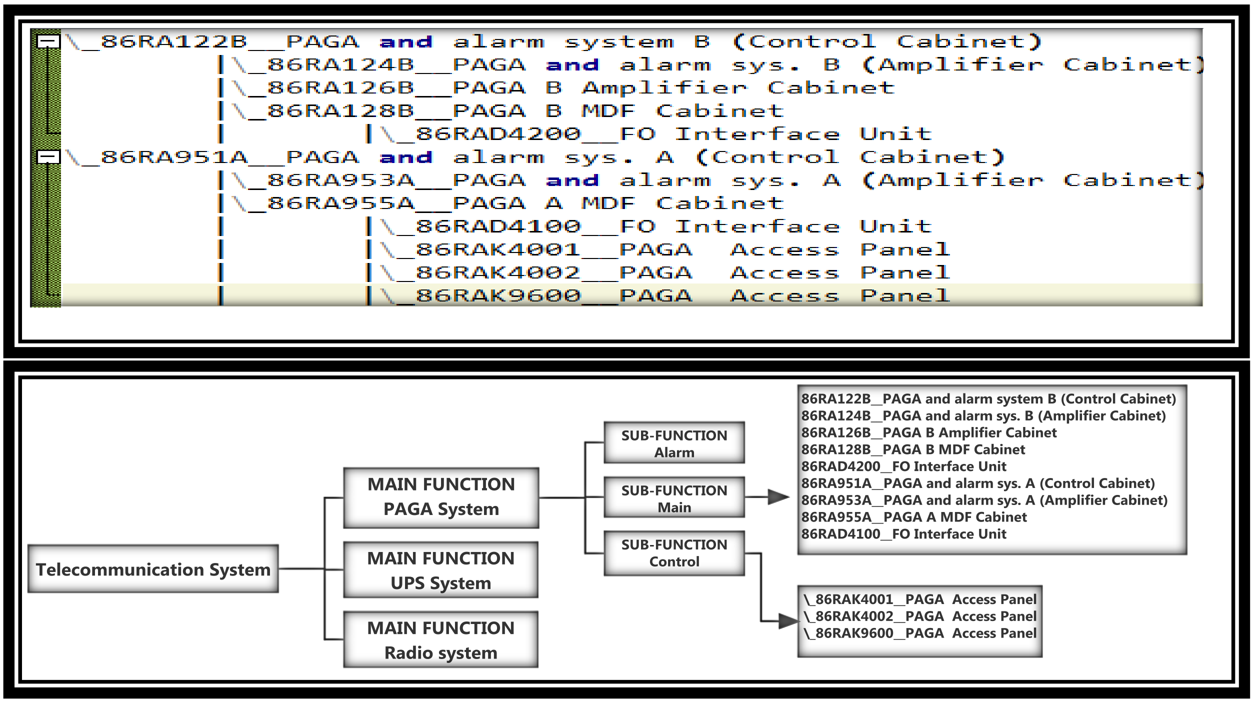


Figure 5-3 Technical (up) and Functional (down) Hierarchy Structures

Establishment of Functional hierarchy

Contrary to the technical hierarchy, functional hierarchy does not care about the physical relationship among the equipments; it is much more about the linking equipments depending on their functional features and abilities. Each systems which have been determined through the technical hierarchy are broken down into main and sub-functions. There is usually a link between main equipments and main function. And each main function has several levels of sub-function. According to the Norsok standards, it is normal to have two or three sub levels more for sub-functions. It is possible to have more detailed sub-functions but indeed it might be seem futile. And all tags and components are to be categorized underneath of a sub-function regarding to their functions. With the aid of this hierarchical functional approach, it is easy to define the critical equipments and creating base for the consequence classification. (Standards Norway, 2011)

5.2) Consequence Classification

Consequence classification process is utilized to register the probable consequences in case of a main function failure depending on the output of functional hierarchy. Failure modes and their frequencies that might cause to either a partial or a complete mal-functioning are identified through consequence classification process. Assessment is to be done according to the both assumption of partial and complete failure situation. (Standards Norway, 2011) A Risk matrix that is identified according to the HSE concerns, business strategy and acceptance criteria of the operator company is used for classification of consequences. A sample risk matrix is presented in Annex Figure 0-2 (Apply Sørco AS, 2014b)

Consequence classification creates base and starting paradigm for Preventive maintenance initials, RCM/FMECA/RBI analysis, and preparation of generic maintenance concept, work order prioritization, design and spare part evaluation. (Standards Norway, 2011)

In compliance with Norsok Z-008 guidelines, work flow in Figure 5-4 is representing entire process of consequence classification step-wise.

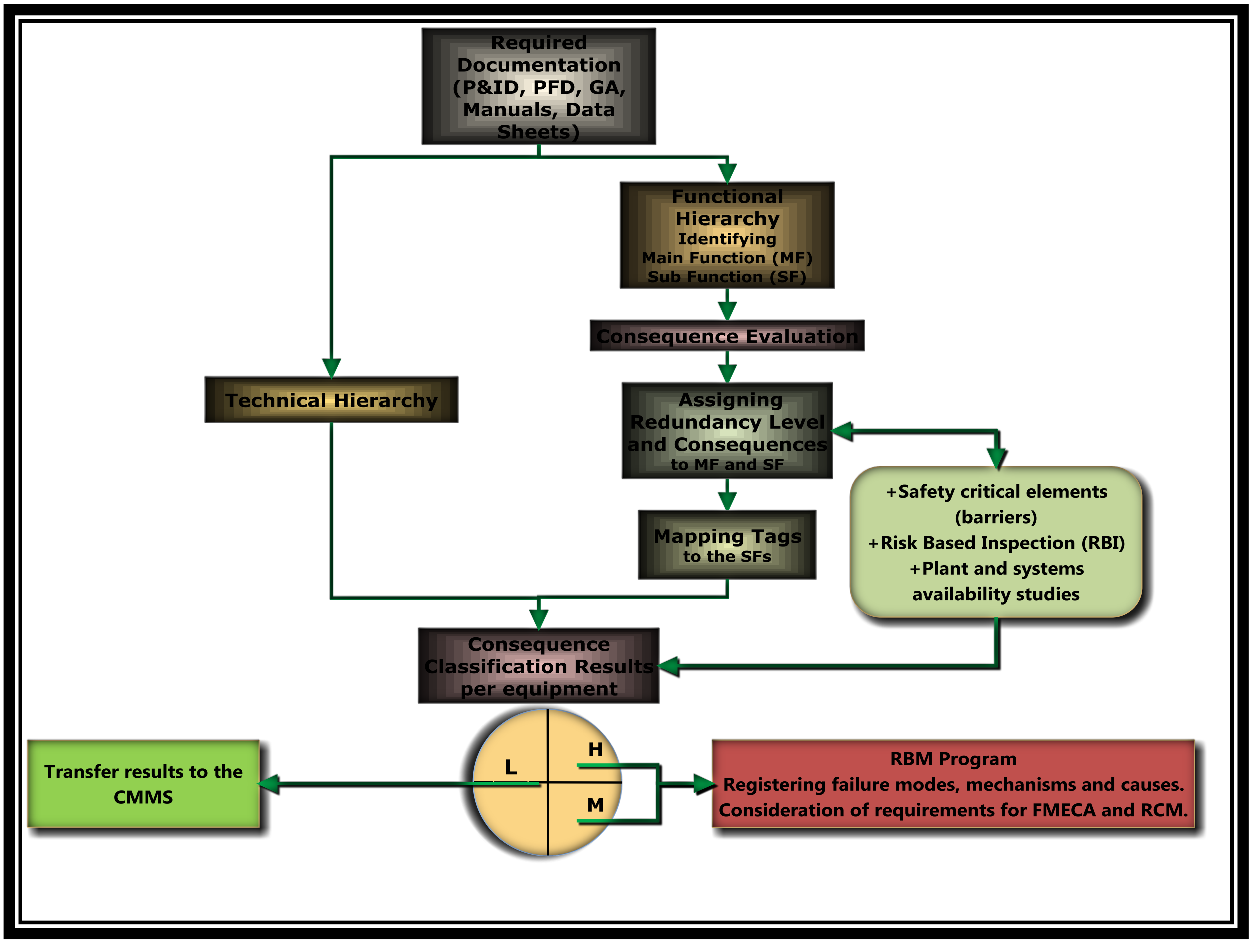


Figure 5-4 Consequence Classification Work Flow (Standards Norway, 2011)

5.3) Work Flow for Establishing Preventive Maintenance Program

According to the results of consequence classification, in case of no further detailed risk analysis method required for considered equipments or in other word specified equipments have low level of consequences, a preventive maintenance program including preventive maintenance routines should be implemented. Preventive maintenance programs and preventive maintenance routines are highly utilized maintenance concepts that must be developed in compliance with the risk assessment principles in order to implement effective and efficient maintenance activities. (Apply Sørco AS, 2014b)

As we know that while PM program specifies the maintenance activities to be carried out and time intervals between maintenance activities, PMRs describes how to maintain equipments that are registered with tag number in detail. For a set of equipments, having one preventive maintenance program but many different preventive maintenance routines is a usual practice.

A guiding preventive maintenance work flow that is drawn according to the Norsok standards is presented in Figure 0-4 Work Flow for Establishing Preventive Maintenance Program at the Appendix.

5.4) Risk Evaluation for Maintenance Decisions

According to the results of consequence classification, there will be either generic maintenance concept or more detailed risk evaluation to be able to make decision about maintenance activities to apply to the considered equipment.

Generic Maintenance Concept is defined as a group of cost effective maintenance actions that is prepared by taking RCM data into account for a known type of equipments. According to the Norsok standards for safety and production systems "Offshore Reliability Data" (OREDA®) is recommended as a recognized data source to use regarding to the generic maintenance concept (Standards Norway, 2010). In addition to that HSE requirements are always in consideration for this kind of maintenance programs as well. Generic maintenance concept can be seen as a collection of the best practices for the equipments that has similar design, similar failure modes, similar failure rates and similar operating conditions.(Standards Norway, 2011) Generic maintenance concept is usually applied to the equipments whose consequence classification shows that it has low level of consequences.

On the other hand, FMECA, RCM, RBI analysis method shall be used and maintenance program should be prepared according to the output of these analyses if the equipment does not have a familiar design with any of the equipments that company experienced so far or has a new technology or does not have sufficient reliability data or have medium or high level of consequence. Generic failure data from similar equipments can be utilized in accordance with ISO, 20815 Annex E.2. (Standards Norway, 2011)

5.5) Spare Part Evaluation

As a part of the maintenance program, a spare part program is to be developed according to the regulations. Spare part program is enforced by PSA Activities Regulations §46 and PSA Technical and Operational Regulations §59 and guided by NORSOK Z-008. All regulatory requirements emphasize importance of HSE and require the evaluation by considering HSE concerns.

Spare part program is anticipated to maximize availability and reliability of equipments that are utilized in plant and to minimize equipment down-time by:

- Identifying needs for operation and maintenance of high and safety critical equipments during operational life span.
- minimizing equipment downtime due to unavailability of spare parts
- planning and determining stock level of spare parts
- Identifying maximum and minimum re-order level for each type of equipment(Apply Sørco AS, 2013)

Spare part evaluation is required to be done based on the results of consequence classification. It must be a detailed evaluation that considers crucial parameters such as quantity, store location, lead time, redundancy, plan for operations, availability, etc. Before presenting the spare part evaluation process, it should be better to mention about spare part categories and some important parameters in order to draw the starting point for evaluation.

Spare part categories

- Capital Spares are known as having long lead time, high cost and low failure rates. These spares are crucial for the function of the plant. Decisions are usually made on case by case basis.
- Operational Spares are used to secure daily basis operations. They are required to maintain the safety capabilities of the equipments during the life time.
- Commissioning Spares are used during commissioning phase; left over spares can be used during the operation phase as well.
- Consumables are spares for non-repairable items. They have usually high demand rate and low cost.(Standards Norway, 2011)

Store Location

Depending on the results of consequence classification and demand rate, spare parts belong to the plant may be stored at various locations. Location is the output of risk based spare part evaluation. Risk matrix that is designed with demand rate and consequence parameters, determine the location and min or max value of spares to be stored. A sample risk matrix for spare part evaluation is presented in Figure 0-5 at the Appendix.

Re-order level and order quantity

It is very important to determine re-order level and order quantity to develop an cost-effective spare part program and not to fall into neither under-stocking nor over-stocking situation. Re-order level is calculated with a safety factor due to uncertainty. Calculation is based on demand rate and delivery duration. On the other hand order quantity is calculated based on demand rate, cost per order and storage cost.(Standards Norway, 2011)

Consequence Classification for Spare Part

Consequence classification for spare part is the evaluation of possible consequences in case of non-available of spare part. Similar to the consequence classification process, here we also have high, medium and low level of consequence classifications. An example for consequence classes for spare part evaluation is as follows:

- **High** – Equipment of a system that shall operate in order to maintain operational capability in terms of safety, environment and production
- **Medium** – Equipment of a system that have installed redundancy, of which either the system or its installed spare must operate in order to maintain operational capability in terms of safety, environment and production
- **Low** – No consequence for safety, production or environment

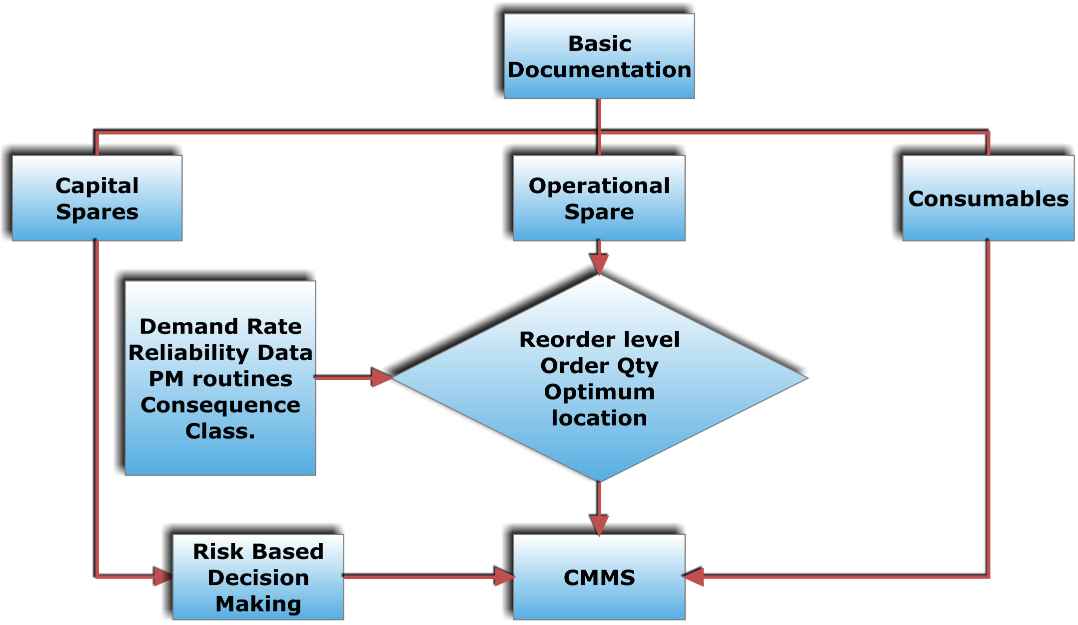


Figure 5-5 Spare Part Work Process

6) IT TOOLS FOR ASSET INTEGRITY ASSURANCE

6.1) Background

Maintenance concepts and practices that are mentioned in the previous chapter are very essential to obtain a successful asset integrity structure and to reduce the risk during the life span of facilities. However, achieving such integrity is always a challenging task for the companies operating in oil and gas industry due to the complexity of industry and the possibility of human errors regarding to that complexity.

With aid of the technological improvements in computer sciences during the last a few decades, highly efficient IT tools were started to be utilized in order to have a solid technical and financial control over the complex industrial systems such as oil and gas industry.

From the technical point of view, the main overall benefits of using such IT tools is extensively reducing human errors and increasing ability to access to the required information and to organize them. As a result of these benefits, it is easy to say that with the aid of the IT tools utilized, it is easier to provide much higher level of risk reduction and consequently better health, safety and environmental conditions.

6.2) Case Study: Asset Integrity Assurance Tools by Apply Sorcø

With respect to the advancements mentioned above, it turned out to a global trend and a must to develop and improve asset integrity tools to be able to manage cost effective projects in the industry and increase the efficiency while keeping safety concerns and human errors at acceptable levels. In that perspective, Apply Sorcø has developed its own asset integrity assurance tools called “Structured Information & Management System (SIMS)” to ensure high quality deliverables with less human errors and to provide a complete and reliable asset integrity solutions in compliance with the regulation mentioned in both of Chapter 3 and Chapter 4.

Structure Information & Management System (SIMS) consists of several separate modules which are dedicated to accomplish a part of integrity requirements. In this chapter we will review the maintenance management process that was introduced in Chapter 3 in technical integrity sub-heading, modules of SIMS, their structures and functional location within the maintenance management process.

To be able to proceed systematically, we need to develop a logic platform on which we can briefly introduce modules of SIMS, describing their functionalities and matching them to the requirements of maintenance management process. Figure 6-1 provides such platform and points asset integrity services and matching maintenance management activities. Asset integrity services were drawn starting from the point one and moves clock-wise same as maintenance management cycle taken from Figure 3-6 (Maintenance Management Process) and illustrated in the center does.

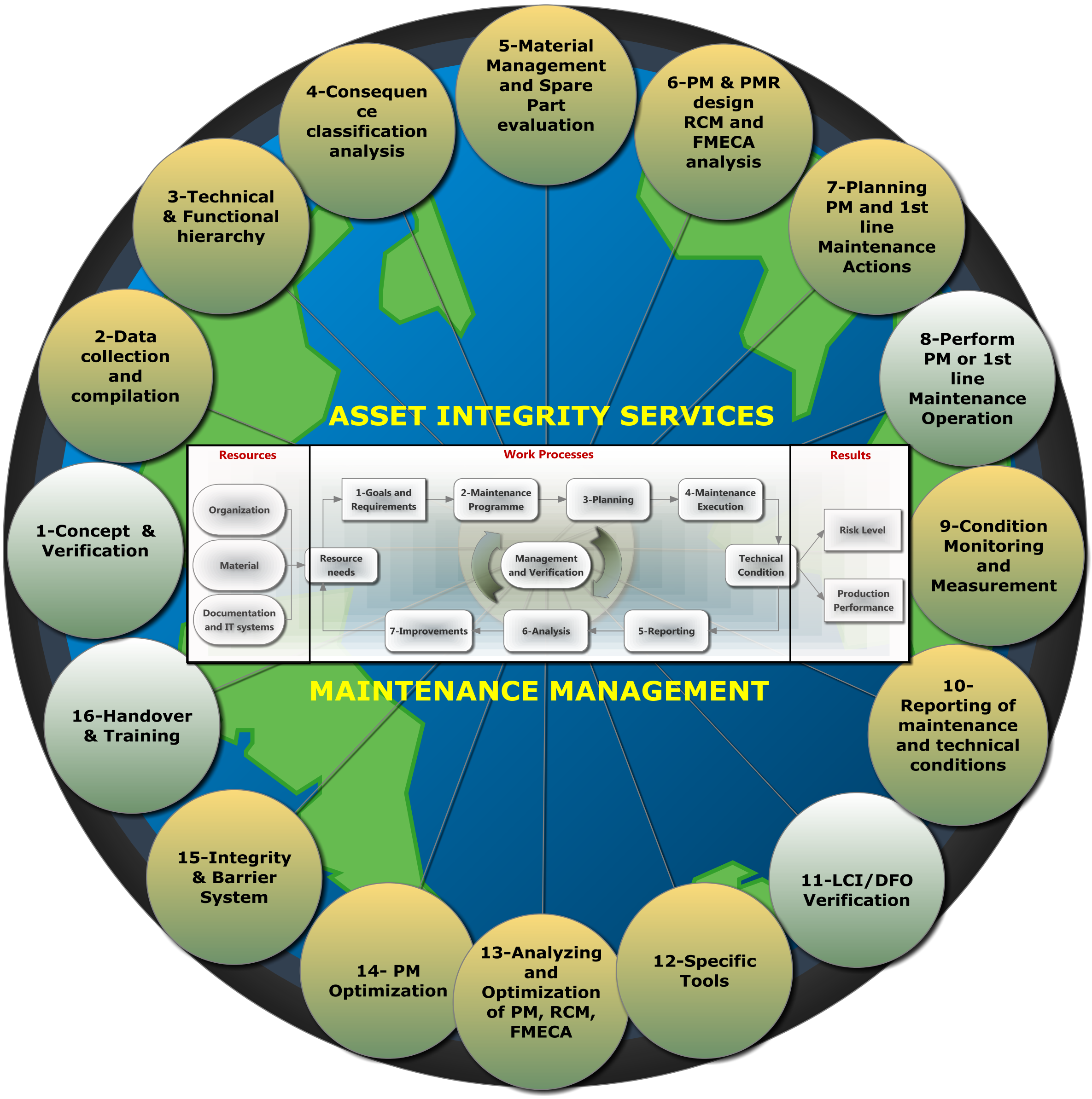


Figure 6-1 Asset Integrity Tools and Maintenance Management Cycle

6.2.1) Tag Management Module (TMM)

"Tag" or "**Tag Number"** can be identified as a unique ID that is given to every single physical equipment or component used in the facilities. Tags basically define functional location and functions of equipments and components. (Raza and Ratnayake, 2012)

To be able to build and sustain the documentation integrity in small or large-scale maintenance or modification projects in complex industrial systems and to coordinate documentation and data belong to the equipments, components or even systems amongst different involved parties during life span of the project, it is a must to use a dedicated tool.

Tags store a wide range of important information starting from basic supplier data, front-end engineering design information to risk evaluation results. In other word, it takes active role from very first day of the project kick-off after concept and verification phase until the project completion. Tag management module starts to deliver integrity requirements illustrated in 2.step in Figure 6-1. This step is matching with resource section of maintenance management cycle.

Table 6-1 Basic Information Registered on Tags

Element	Description
Flag	Status flag
Location	Tag location
Tag	Tag name
Tag_cat	Tag category
Description	Tag description
Area	Area code
System	System code
Parent_tag	The tags parent tag (one level above in the hierarchy).
Loop	Sequence/ loop number
Suffix	Suffix
Function_code	Classification of tag
Pono	Purchase order number
Resource	Resource/Equipment number
Individual	Individual (Serial Number)
Contractor	Contractor code
Site	Construction site
Safety_crit_elem	Safety critical element
Comment	Comment

Tag Management Module has been developed to manage tag and technical information regarding to the tags in large and small maintenance & modification projects as it is mentioned above. It facilitates the tag administration process, ensuring that all tag related technical information is available at the right time in a project execution process.

Tag management module, depending on the project contract, either starts with importing tag data from the operator company's database or starts with creating tag database as a standalone tag generator on its own to be used in project during the life cycle in compliance with NORSOK standards Z-001, Z-003 and NS5820. Module registers all required tag information such as documentation, master equipments, tag categories, status, descriptions, and location and specific client requirement if there is some, and finally establishes a web based access for multiple users to start work with tag required maintenance activities. Figure 6-2 shows overall layout from the TMM.

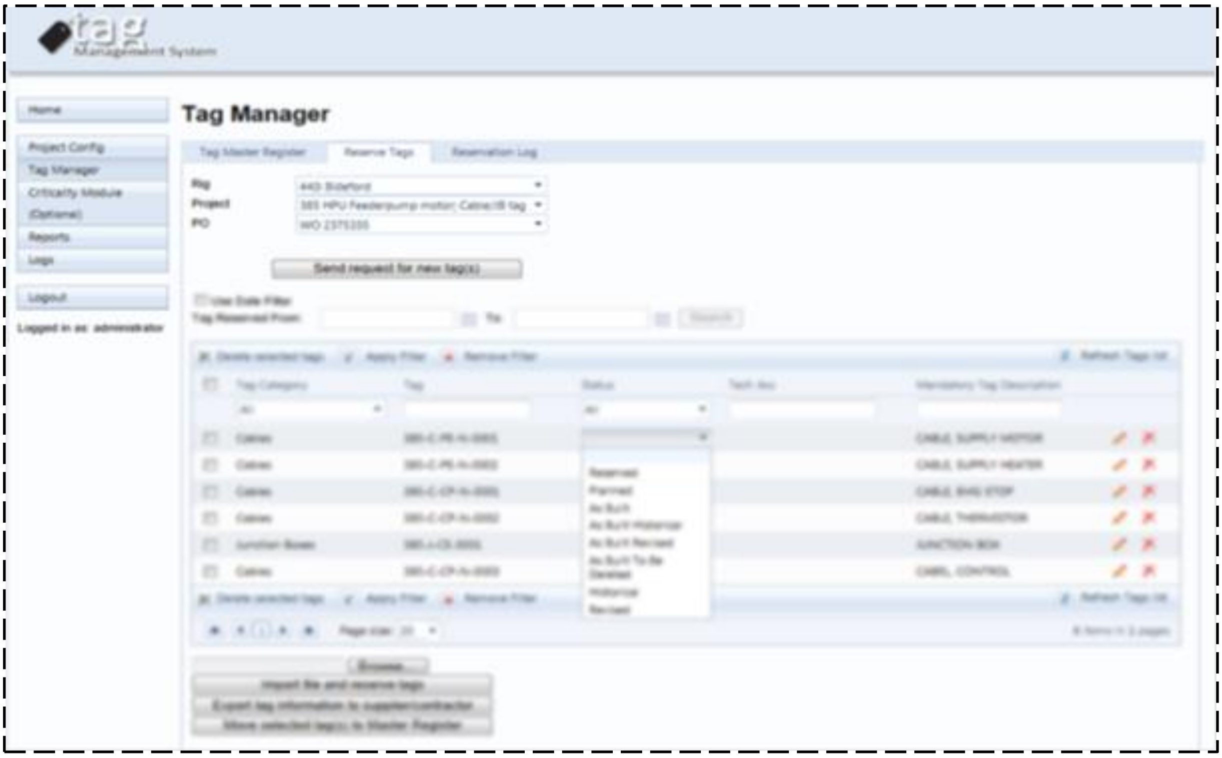


Figure 6-2 SIMS Tag Management Module (screenshot from Apply Sørco AS, 2012) **(Blurred in purpose)**

6.2.2) Consequence Classification Module (CCM)

Consequence classification module delivers integrity requirements illustrated as step 3 and step 4 in Figure 6-1. These two steps are registered underneath of "Objectives and Goals" and "Maintenance Programme" steps (1st and 2nd) of maintenance management process (Figure 3-6). Technical and Functional hierarchy can be categorized under "Objectives and Goals" that is summarized below:

Objectives and Goals: (Standards Norway, 2011)

- Determining safety critical equipments, their availability and technical conditions
- Defining failure modes and failure mechanism
- Determining the maintenance strategies to utilize.
- Compliance with regulatory requirement, must be confirmed for every as set in the facility.

Consequence classification module is developed to build technical hierarchy, functional hierarchy and consequence classification in compliance with NORSOK Z-008. The process for establishing technical and functional hierarchy can be started simultaneously in CCM.

Tag (Technical) Hierarchy Process

In compliance with NORSOK-Z008, this module helps to build an efficient, time and cost effective technical hierarchy. And technical hierarchy process creates a "tag tree" simultaneously in order to check technical hierarchy and control work flow visually.

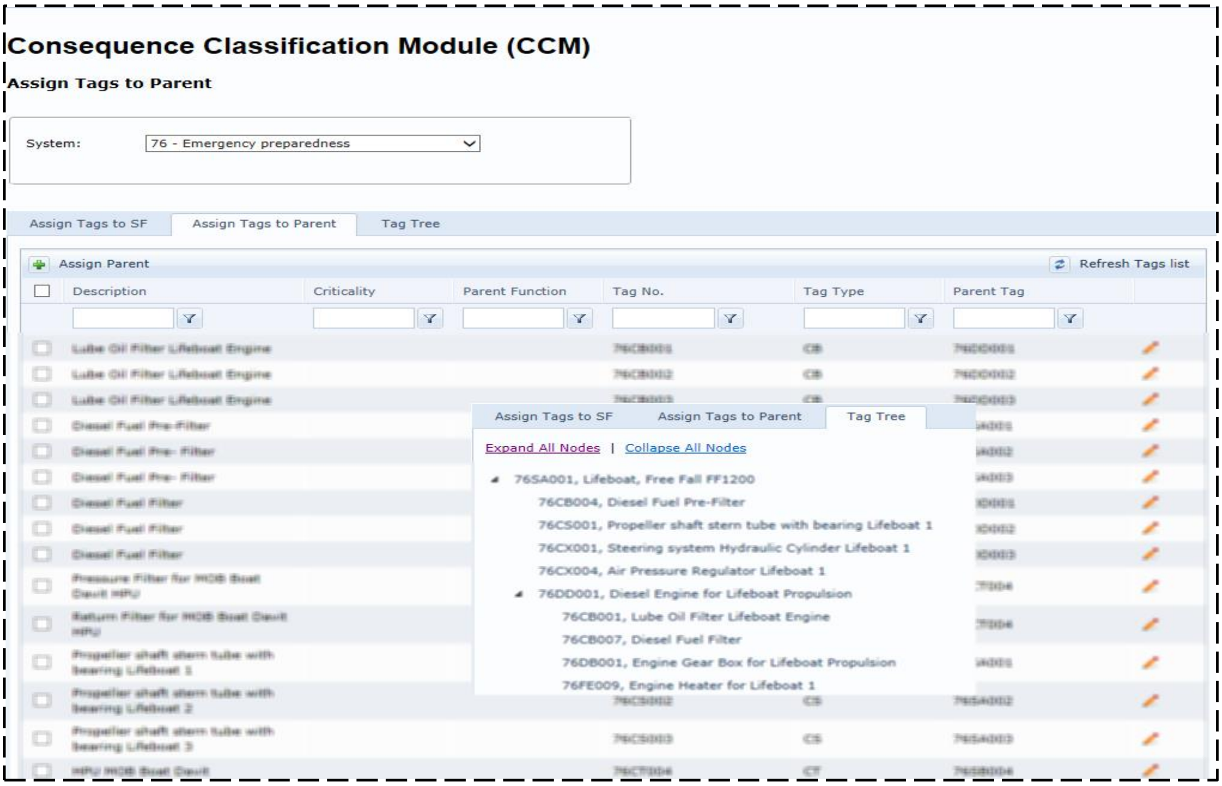


Figure 6-3 SIMS Technical Hierarchy (screenshot from Apply Sørco AS, 2012) **(Blurred in purpose)**

Function Register Process (Functional Hierarchy Process)

Functional hierarchy process helps to register main and sub functions in system levels in the facilities and let the user easily assign tag numbers to those already defined main or sub functions. As it was addressed earlier, sample main functions according to the NORSOK standard is shown in Figure 0-3. Sub-functions are defined according to the goals and objectives of the operator company. On the other hand, as we explained about it in Chapter 5.1), functional hierarchy is being done in compliance with NORSOK Z-008 standards and according to the regulations there are some standard sub-functions to assign to the equipments. These are listed in Table 6-2 and also a layout view from functional hierarchy process is shown in Figure 6-4.

Table 6-2 Standard Sub-functions

Alarm	Monitoring
Control	Controlling
EQSD	Equipment Shutdown
ESD	Emergency Shut-down
IND	Local Indication
Main	takes its description from the main function at system level
PSD	Process Shutdown
PSV	Pressure Relief
PV	Containment, Process, Vapour
Valve	Manual Shut-off

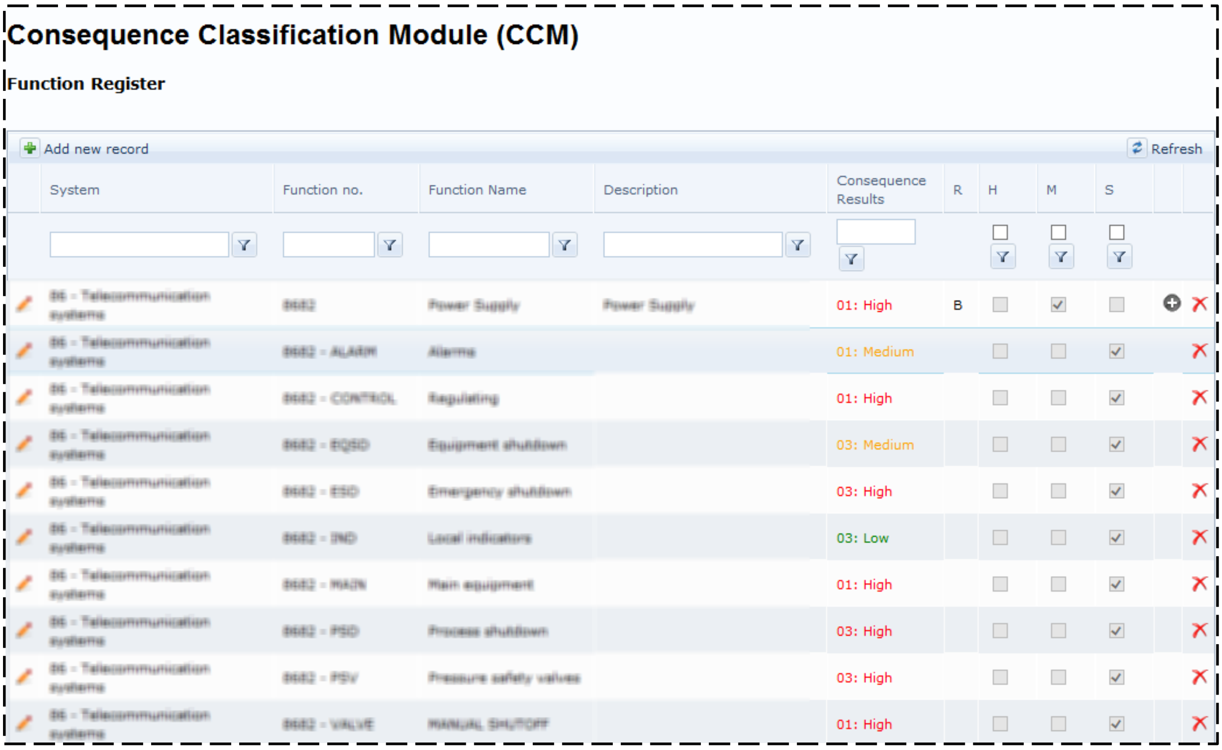


Figure 6-4 SIMS Functional Hierarchy (screenshot from Apply Sørco AS, 2012) **(Blurred in purpose)**

Consequence Classification Process

Consequence Classification process is categorized under the "Maintenance Programme" step of maintenance management process that was illustrated in Figure 3-6. According to the NORSOK Z-008, followings activities have to be done under this requirement step.

Maintenance Programme (Standards Norway, 2011)

- Performing consequence classification for main and sub-functions.
- Developing failure mode, failure cause and the connected maintenance programme for equipments representing high consequence in case of failure.
- Identifying safety functions, defining reliability requirements for the functions and testing.
- Determining maintenance program update criteria, safety critical system failure analysis basics and developing a regular basis update schedule.
- Defining maintenance intervals, preparing maintenance procedures, preparing various components within the plant and testing.

Consequence classification process helps to register consequences as it was described in Chapter 5.2), consequences of probable failure modes should be registered for both of the main functions and the sub-functions in compliance with the regulations. At that point consequence classification process helps to register failure modes and to assign registered consequences to the required main and sub functions respectively. Figure 6-5 shows overall layout from SIMS Consequence Classification process.

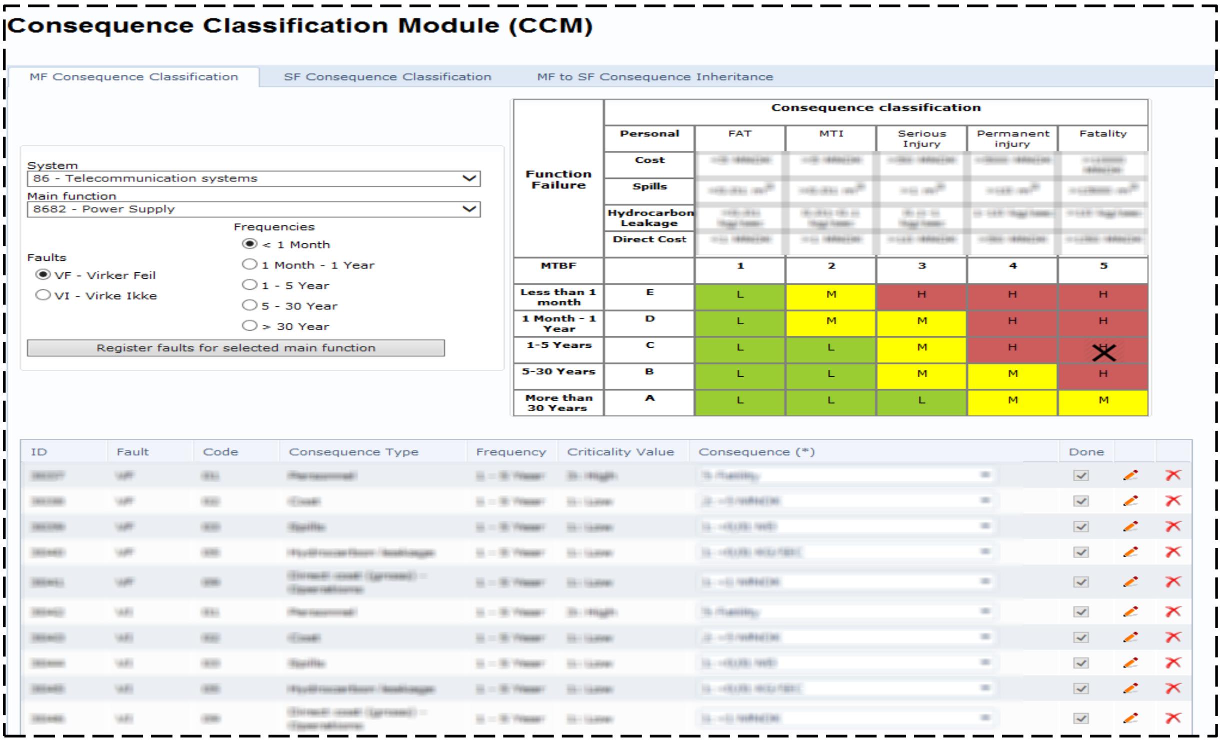


Figure 6-5 SIMS Consequence Classification (screenshot from Apply Sørco AS, 2012) **(Blurred in purpose)**

6.2.3) Spare Part Evaluation (SPM)

Material Management and Spare Part evaluation Module delivers integrity requirements illustrated as step 5 in Figure 6-1. That integrity requirement can be registered underneath of "Maintenance Programme" step of maintenance management process (Figure 3-6).

Material Management Module (MMM)

MMM is used to facilitate codification of "Spare Parts List and Interchangeability Records (SPIR)" (Figure 0-6 Sample SPIR Form), provided by the equipment supplier to be able to track the spare parts required by the plant. Since there is a huge number of different suppliers in a complex industrial system such as oil and gas industry in our case, standardization of SPIR lists is the main challenge of spare part evaluation process. On the other hand quality control of the content that is provided in the SPIR lists, cataloguing of spare parts, creating search databases can be said as work scope of SIMS material management module. This module has a solid integration with SPM module and hence it will not be considered a separate SIMS module in the workflow charts.

Spare Part evaluation Module (SPM)

SPM utilizes the spare part database that is created by material management module and helps with the required assessments to achieve spare part evaluation end results. Methodology in compliance with NORSOK Z-008 was described in Chapter 5.5). Evaluation aims to obtain minimum-maximum quantities, re-order levels, store location and cost benefits using the criticality information coming from the Consequence classification module and planned maintenance module(PMM). Spare Part evaluation Module is finally utilized to create bill of materials depending on the spare part lists and evaluation that is done under control of the spare part experts. Consequently, it can be simply said that SIMS SPM creates a digital platform as it is shown in Figure 6-6 to populate, evaluate and register these data flow.

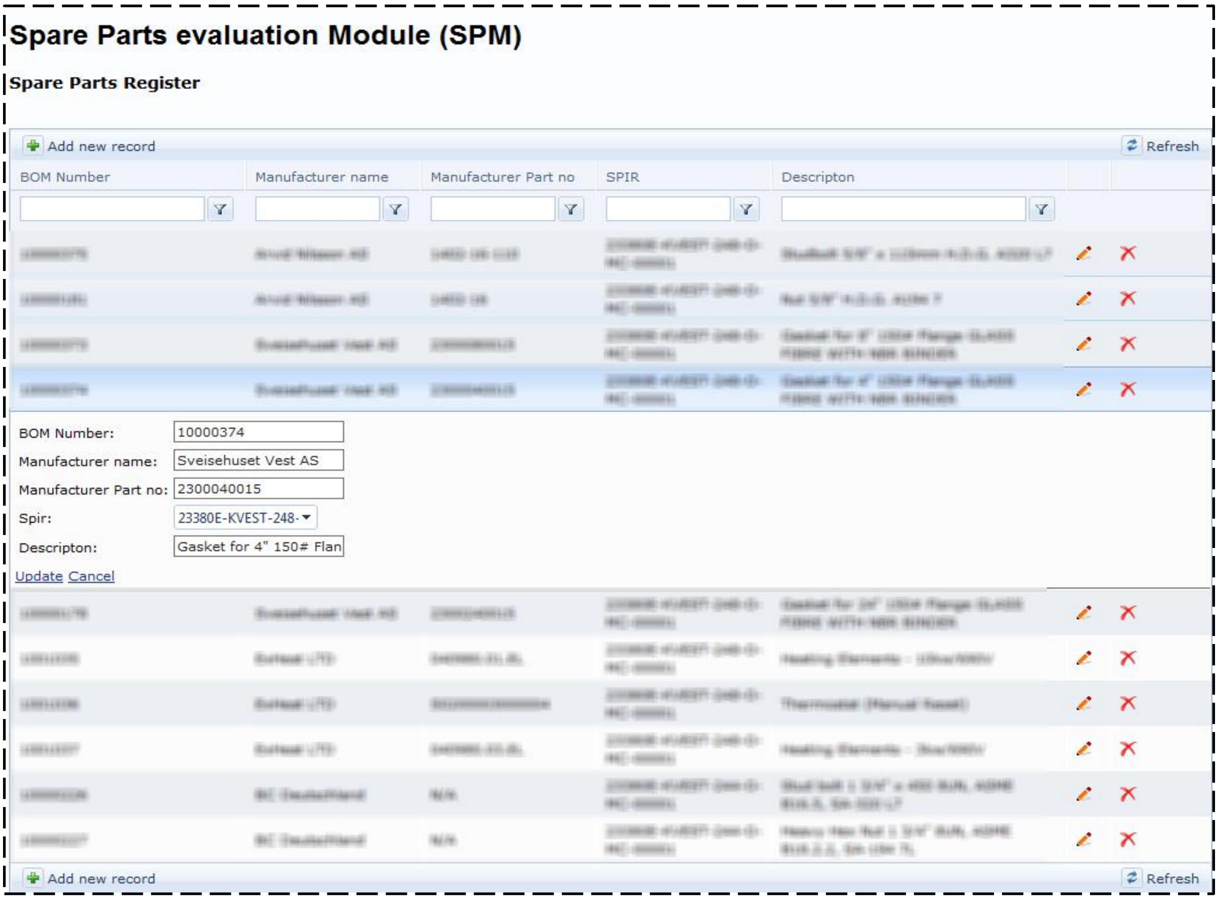


Figure 6-6 SIMS Spare Part evaluation Module (screenshot from Apply Sørco AS, 2012) **(Blurred in purpose)**

6.2.4) Planned Maintenance Module (PMM)

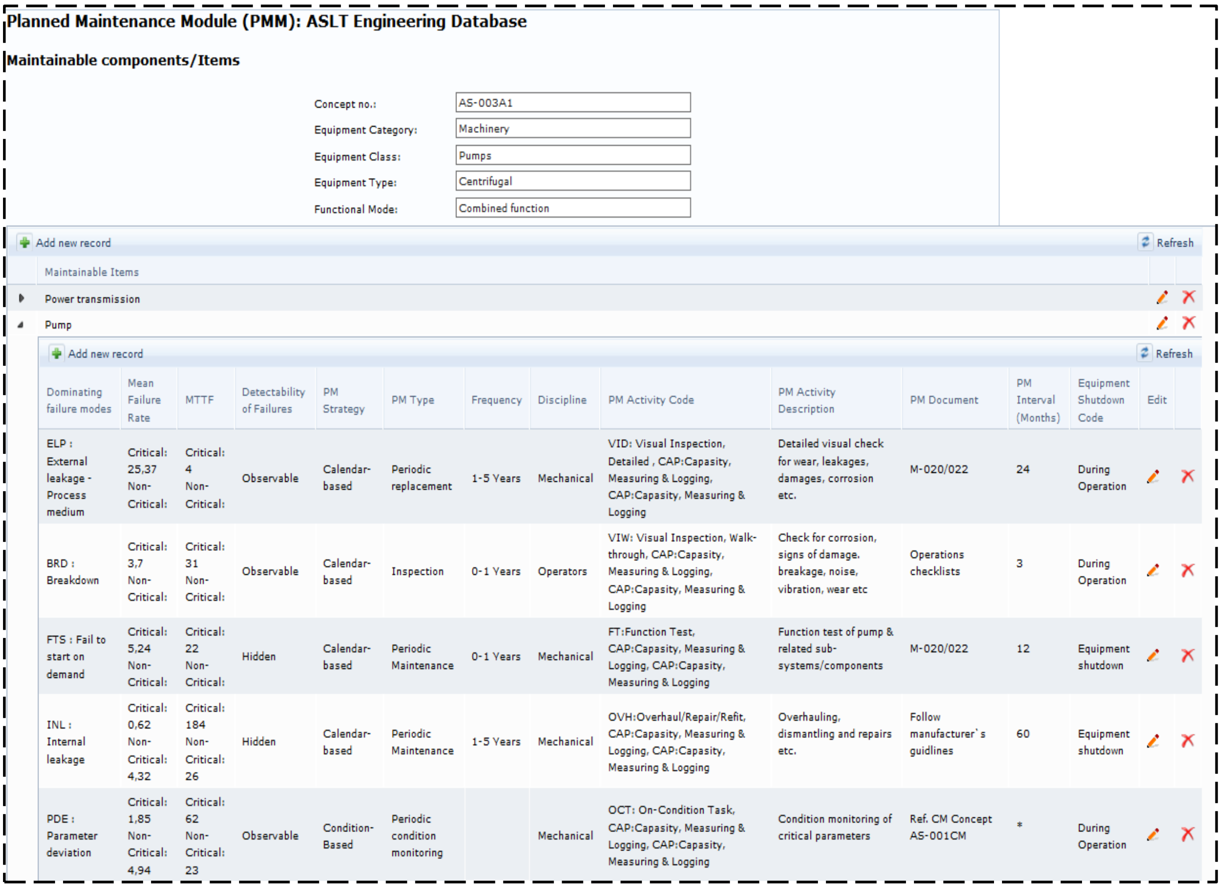
Planned maintenance module delivers integrity requirements illustrated as step 6 in Figure 6-1. That integrity requirement can be registered mostly underneath of "Maintenance Programme" and partially under "Planning" phase of maintenance management process (Figure 3-6).

Planning (Standards Norway, 2011)

- Developing a method and criteria for planning and prioritizing of both preventive and corrective maintenance work based on their impact on HSE and production.
- Monitoring and reviewing the plans regularly for efficient maintenance management

Planned maintenance module is responsible to comprise maintenance concepts in compliance with the regulations, assisting in selecting the compatible maintenance activities, determining maintenance activity intervals depending on experienced or vendor recommended reliability data and planning of preparation of maintenance routines. To be able to achieve a successful PM program, it is essential to have comprehensive knowledge on reliability data and control over the equipments, this is actually the main motivation of such IT tools.

To be able to have sufficient control over the preventive maintenance concept, a dynamically integrated technical library which depends on OREDA database is developed underneath of the module specifically for each independent project when it is needed. Technical library is such an integrated reliability database which is built on RCM logic and identifies critical failure modes, failure mechanism and suitable maintenance activities for standard equipments. PMM with technical library provides more cost effective and safety oriented solution to the preventive maintenance activities that should be taken during the life span of the facility.


Planned Maintenance Module (PMM): ASLT Engineering Database

Maintainable components/Items

Concept no.: AS-003A1
Equipment Category: Machinery
Equipment Class: Pumps
Equipment Type: Centrifugal
Functional Mode: Combined function

Add new record | Refresh

Maintainable Items
- Power transmission
- Pump

Add new record | Refresh

Dominating failure modes	Mean Failure Rate	MTTF	Detectability of Failures	PM Strategy	PM Type	Frequency	Discipline	PM Activity Code	PM Activity Description	PM Document	PM Interval (Months)	Equipment Shutdown Code	Edit
ELP : External leakage - Process medium	Critical: 25,37 Non-Critical:	Critical: 4 Non-Critical:	Observable	Calendar-based	Periodic replacement	1-5 Years	Mechanical	VID: Visual Inspection, Detailed , CAP:Capasity, Measuring & Logging, CAP:Capasity, Measuring & Logging	Detailed visual check for wear, leakages, damages, corrosion etc.	M-020/022	24	During Operation	
BRD : Breakdown	Critical: 3,7 Non-Critical:	Critical: 31 Non-Critical:	Observable	Calendar-based	Inspection	0-1 Years	Operators	VIW: Visual Inspection, Walk-through, CAP:Capasity, Measuring & Logging, CAP:Capasity, Measuring & Logging	Check for corrosion, signs of damage. breakage, noise, vibration, wear etc	Operations checklists	3	During Operation	
FTS : Fail to start on demand	Critical: 5,24 Non-Critical:	Critical: 22 Non-Critical:	Hidden	Calendar-based	Periodic Maintenance	0-1 Years	Mechanical	FT:Function Test, CAP:Capasity, Measuring & Logging, CAP:Capasity, Measuring & Logging	Function test of pump & related sub-systems/components	M-020/022	12	Equipment shutdown	
INL : Internal leakage	Critical: 0,62 Non-Critical: 4,32	Critical: 184 Non-Critical: 26	Hidden	Calendar-based	Periodic Maintenance	1-5 Years	Mechanical	OVH:Overhaul/Repair/Refit, CAP:Capasity, Measuring & Logging, CAP:Capasity, Measuring & Logging	Overhauling, dismantling and repairs etc.	Follow manufacturer`s guidlines	60	Equipment shutdown	
PDE : Parameter deviation	Critical: 1,85 Non-Critical: 4,94	Critical: 62 Non-Critical: 23	Observable	Condition-Based	Periodic condition monitoring		Mechanical	OCT: On-Condition Task, CAP:Capasity, Measuring & Logging, CAP:Capasity, Measuring & Logging	Condition monitoring of critical parameters	Ref. CM Concept AS-001CM	*	During Operation	

Figure 6-7 SIMS Planned Maintenance Module (Apply Sørco AS, 2012)

6.2.5) Barrier Monitoring Module (BMM)

There are several definitions for the term "barrier" in the industry. According to the NORSOK standards, barriers are defined as physical measures that reduce the probability of an accident or a hazardous situation and limit the consequences of the accident (Standards Norway, 2008). On the other hand according to the ISO standard barriers are defined as measures which reduce the probability of potential hazards and reduce its consequences. (British Standards Institution, 2002) Basically both definition is almost same and shows the logic beyond the barriers. Even if there has been NCS practice for a long time for barrier management and regulated by PSA § 5 Barriers and OLF 070 (OLF Guideline, 2004), most of the biggest operator companies such as Statoil, Total, BP etc. have their own extended barrier management guidelines.

Barrier Monitoring Module delivers integrity requirements illustrated as step 15 in Figure 6-1. That integrity requirement can be registered underneath of "Maintenance Programme", "Execution" and "Analysis" steps of maintenance management process (Figure 3-6).

Legislation for Barrier Management: PSA 5 Barriers and OLF070 (OLF Guideline, 2004)

Execution (Standards Norway, 2011)

That step in maintenance management process simply includes preparations, work permits, carrying out work and reporting.

- Verifying quality of work executed
- Reporting the condition of equipment and defined reliability targets for barriers and failure data after executing maintenance activity in order to help analysis and optimization work.

With respect to the industry practices, barrier monitoring module helps to facilitate safety barriers in compliance with the regulations and dynamic requirements of the oil and gas industry. BMM module helps to assign barrier functions and sub-functions to the related tags (equipment) in a hierarchical way same as tags connected to each other via technical hierarchy process. BMM mainly integrates barrier elements, tags in this case, with barrier functions. Layout from Barrier Monitoring Module is given in Figure 6-8.

Analysis and improvement (Standards Norway, 2011)

Analysis phase of the maintenance process basically considers historical maintenance data and unwanted incidents related to the maintenance activities.

- Defining trigger values, analysis technique and responsibilities that will be used in analysis process.
- Determining performance requirements and risks that are included in maintenance programme for individual systems or key components.
- Identifying improvements that should be taken into account and parameters that should be monitored.

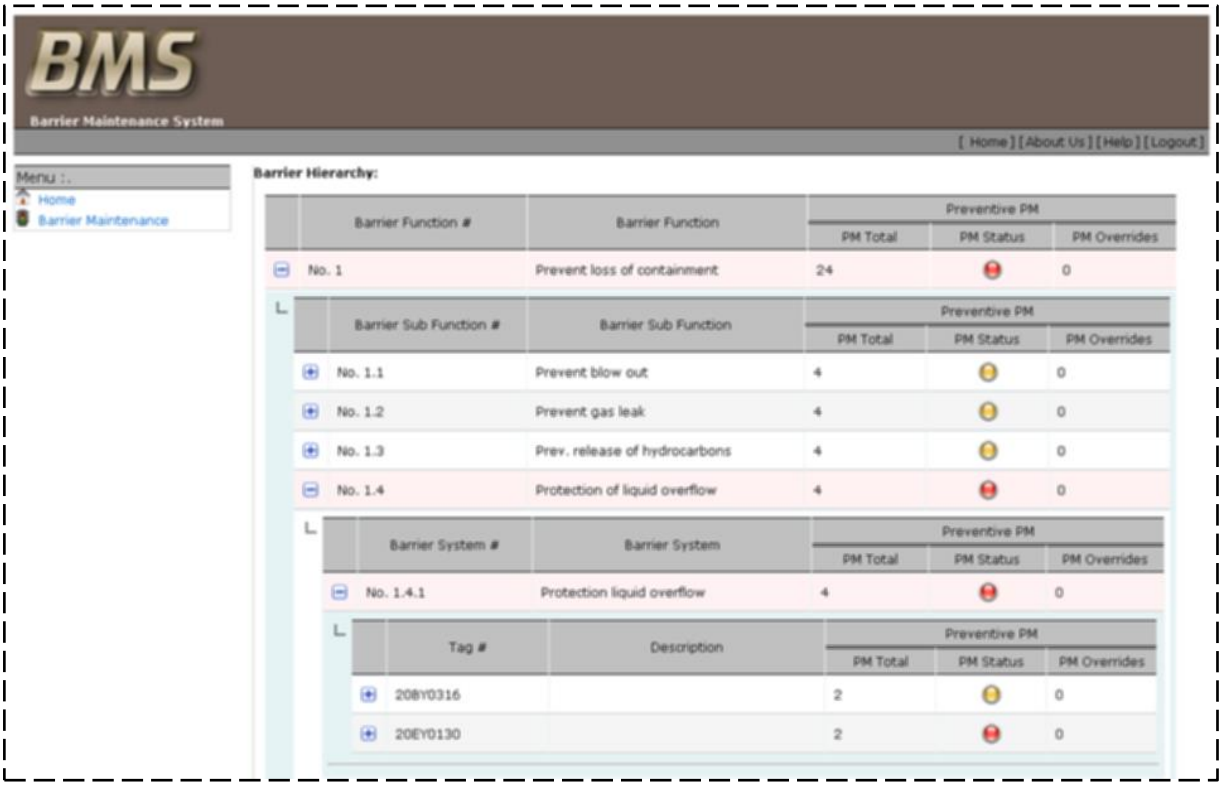


Figure 6-8 Barrier Monitoring System (Apply Sørco AS, 2012)

6.2.6) Mapping and Integration of SIMS

Following figures have been put in order to show on which phase of the project current SIMS modules are being used(Figure 6-9) and how they interact with each other during project life time (Figure 6-10).

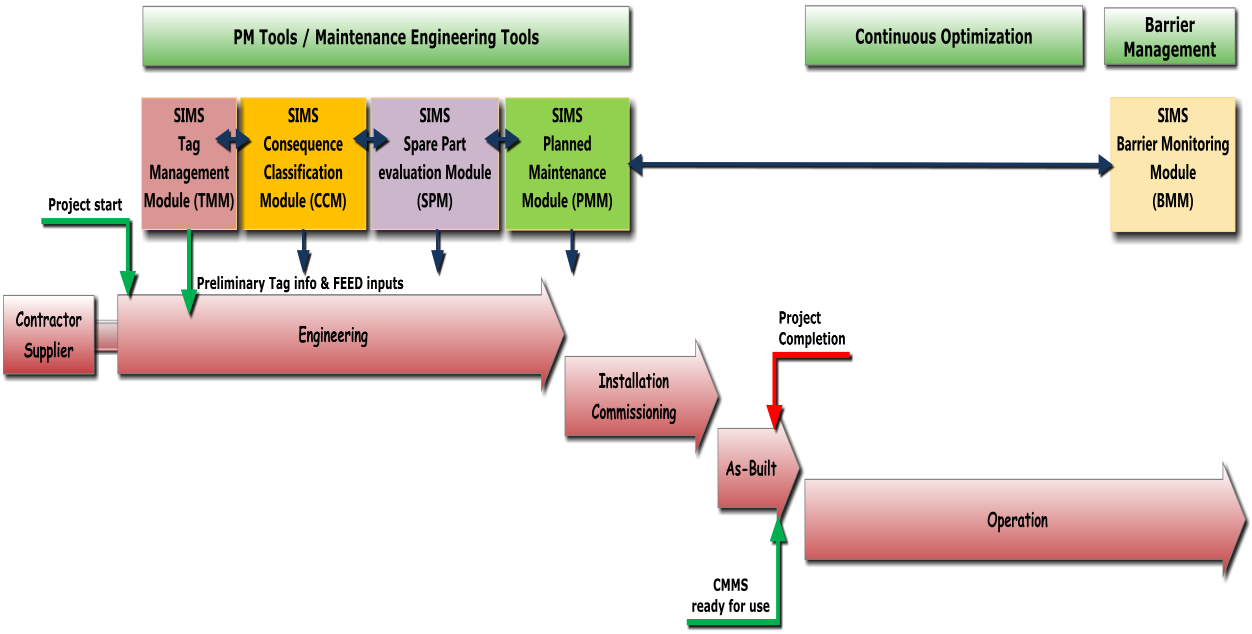


Figure 6-9 SIMS Modules on Project Execution Model (current)

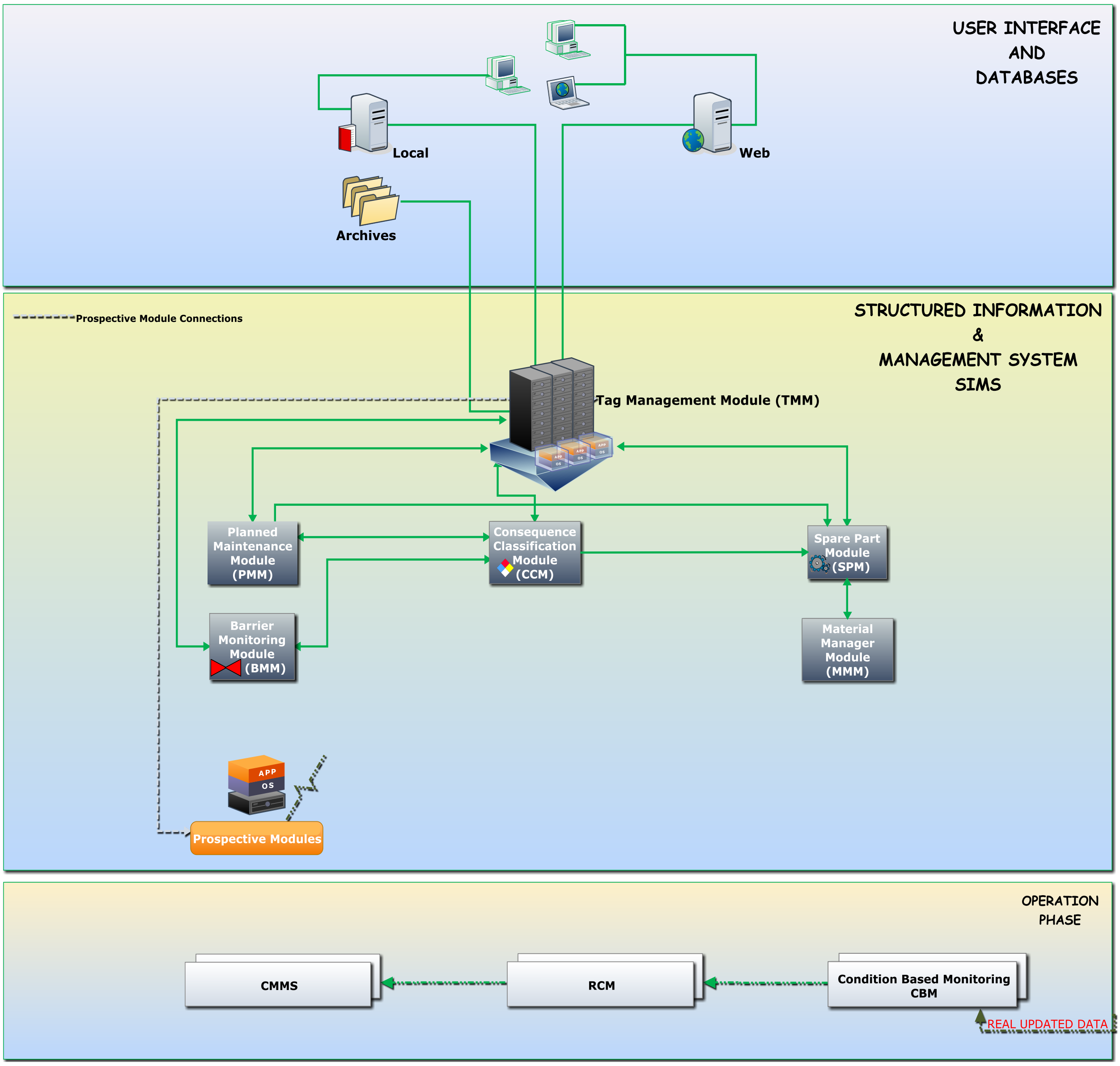


Figure 6-10 Integration of SIMS modules (current)

As it can be seen from the illustration above, there is actually no connection between Structured Information & Management System (SIMS) and operation phase of the maintenance management processes. SIMS mostly focuses on establishing a maintenance program in compliance with the regulations.

6.3) Prospective Modules and Integration Developments

There are also some asset integrity services and maintenance management requirement that are not fulfilled in the scope of the current asset integrity assurance tools. Hence, it is decided to develop such AI assurance tools that are capable to provide required missing services. These AI assurance tools are categorized as prospective modules (asset integrity assurance tools). These modules will be developed to strengthen the asset integrity and to fulfill the industrial requirements and regulations.

In this sub-chapter we explained possible prospective modules, their conformity with the regulations and finally integration to the current modules.

6.3.1) Optimization Module (OM)

Optimization Module aims to deliver integrity requirements illustrated as step 13 and step 14 in Figure 6-1. That integrity requirement can be registered underneath of "Reporting" and "Analysis" phase of maintenance management process (Figure 3-6).

Optimization Module simply is utilized for optimization of existing preventive maintenance tasks / routines and helps to implement FMEA/FMECA/RCM analysis. Optimization work depends on the technical feedbacks that are taken during the operation of facility. With the aim of this prospective module, it is intended to revise existing PM or RCM program and make it more compatible to the given plant equipments. In other words, it is sort of taking the right maintenance action at exactly optimized time for the exact equipment depending on the equipment condition and historical data.

Reporting

Reporting step of maintenance management process aims to collect and analyze maintenance data and to present these data in form of pre-defined indicators such as KPIs, cost versus goals/budget and PS. (Standards Norway, 2011) main reason to do so is continuous improvement.

According to the recommendation of ISO standard, following maintenance data should be reported.

Table 6-3 Maintenance Data to be Reported (British Standards Institution, 2006)

Reporting of Maintenance Data	
Corrective Maintenance Failure Mode Failure Cause Failure Mechanism Equipment Down time Spare parts used Man hours for activity Start and finish time of repair	Preventive Maintenance Condition of equipment before PM work Man hours for activity Spare parts used Start and finish time

Additionally, OM includes two additional modules called “Condition Monitoring Module” and “Reliability Centered Maintenance Module” that are categorized under it.

Condition Monitoring Module (CMM)

Condition Monitoring Module aims to deliver integrity requirements illustrated as step 9 and step 10 in Figure 6-1. That integrity requirement, in addition to the OM requirements and categories, can be registered underneath of “Maintenance Program” and “Technical Condition” phase of maintenance management process (Figure 3-6). Due to the concept logic of condition based monitoring approach, condition monitoring module evaluates the assets whether needs to be monitored, helps to develop monitoring strategy, evaluates the technical data gathered from the assets and offers analytical solutions according to the asset condition and performance.

Analyzing of technical feedbacks, optimizing condition based maintenance depending on the prediction of reliability, estimating remained useful life and developing either preventive maintenance or corrective maintenance actions depending on the estimation that is done are the core objectives. Another consideration to make decision at that point can be the comparison results of cost of preventive maintenance action and corrective maintenance action.

CMM starts to be implemented and developed during engineering and operation phase of the project respectively. Creating a selection algorithm for the asset to monitor depending on the reliability and criticality analysis is the starting point for CMM. Hence it is a must have a solid integration with both of consequence classification and RCM methodologies. Finally CMM aims to improve the maintenance program and starts to deliver its dedicated work in operation phase depending on the technical information taken from the equipment, failure mode.

Reliability Centered Maintenance Module (RCMM)

Reliability Centered Maintenance Module aims to deliver integrity requirements illustrated as step 6 and step 13 in Figure 6-1. That integrity requirement, in addition to the OM requirements and categories, can be registered underneath of "Maintenance Program" and "Analysis and Improvement" steps of maintenance management process (Figure 3-6).

As we discussed in Chapter 4.2.4), RCMM is utilized to improve PM tasks by conducting FMECA/FMEA analysis using reliability data of the standard equipments in order to improve efficiency of PM program and reduce the cost. RCMM should be developed according to the following work orders (Rausand and Vatn, 1998)

- System selection
- Critical item selection according to the Consequence Classification results
- FMECA analysis
- Defining the maintenance intervals

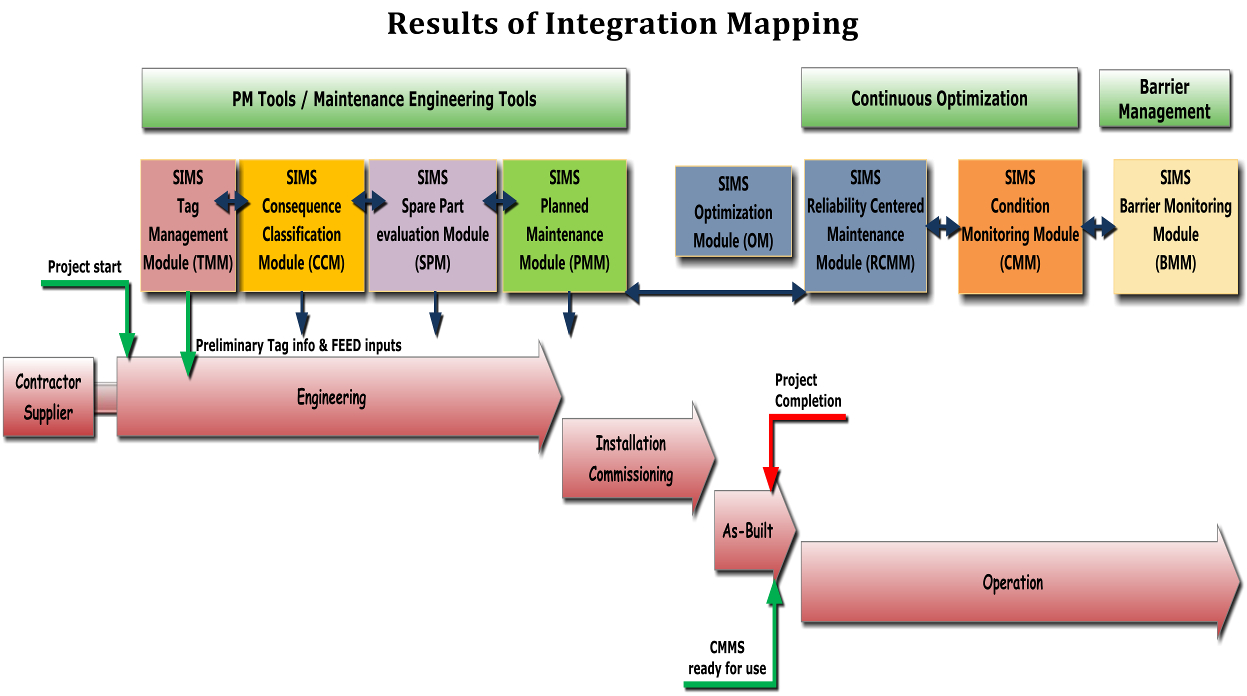


Figure 6-11 SIMS Modules on Project Execution Model (prospective concept)

Figure 6-11 (above) explains on which phases of PEM SIMS modules (prospective concept) are being used and Figure 6-12 shows how they are integrated with each other during project life time.

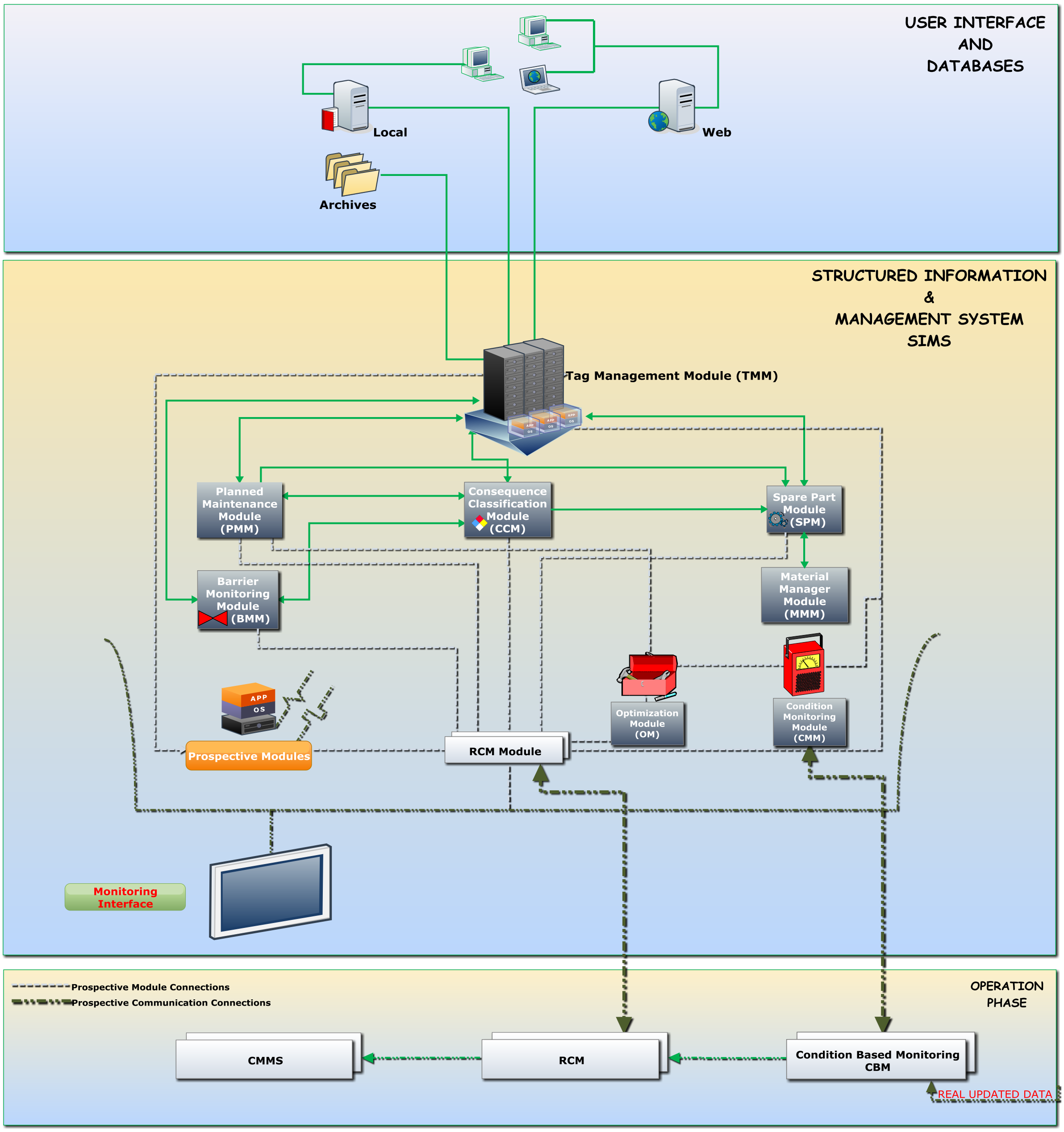


Figure 6-12 Integration of SIMS modules (prospective concept)

****Monitoring interface that is shown in Figure 6-12 will be mentioned in Chapter 7.2).**

7) INTEGRATED APPLICATION STRUCTURE AND DEVELOPMENT OF DIGITAL PLATFORM (TEST GUI)

As previously discussed in previous chapters, it is very essential to have a comprehensive and extended control over the assets in the plants with asset integrity perspective and so developing and utilizing advanced IT tools that were introduced within previous chapter for such control level is widely accepted by the industry. However it is also essential to have an integrated platform for such IT tools' themselves, as well, in order to monitor and inspect the activities that have been done during the development of the project whenever it is needed. Having a compact and all-in one interface is a very important advantage to follow up even a small detail in the entire work flow.

Since all the modules of SIMS designed in respect to modular flexibility, it has been acknowledged that an integrated digital platform with a compact Graphical User Interface (GUI) could be very useful. What we meant with modular structure is that all modules can be integrated with each other as a complete package solution or can be used as a standalone unit or it must be allowable to make various combinations. And it is very important to achieve that feature with the digital platform as well. That sort of application architectures is very important to the service companies due to contract flexibilities in the industry and helps them to offer tailor made solutions. In other word, modules and digital platform should be constructed in a puzzle algorithm according to the requirements of the project. Sample visualization for modular structure is given in Figure 7-1.

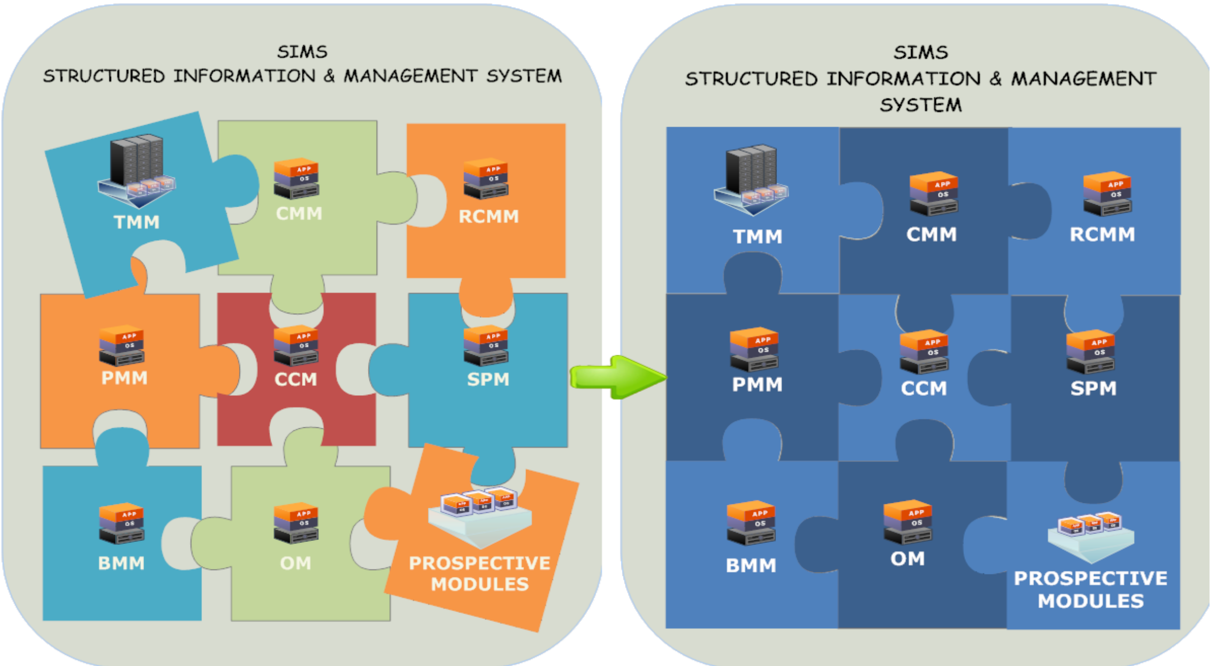


Figure 7-1 SIMS Modular Structure

Hence, regarding to the modular architecture of SIMS, digital integration platform also has to consider that feature and must have a modular structure GUI as well. In addition to this, overall achievements from view point of users for any kind of application can be listed as follows:(Antcheva, Brun and Rademakers, 2014)

- Simplicity: Only the basic functions of modules seem on the main application.
- Consistency: Easy to use and bug-free, simple and elegant design.
- Freedom: Allow users modify their own working environment within GUI.
- Forgiveness: Protect system from human error and make them feel secure.
- Manipulation and feedback: Give immediate feedbacks in respect to the actions taken and do not let user confuse about the works that is active in background.
- Descriptive: Having detailed descriptive information about the modules and "how to" index.

7.1) Design and Development Progress

It is a widely accepted fact that building up any application, GUI or website etc. generally has two part job. Design and development is the general key elements of building any IT solution same as it is in any other construction industries.

In design phase, the designers simply are deciding and creating visual outputs. For our case, in design phase it was decided how GUI will look like and what sort of features it will have finally. Design process is started by gathering functions and sketches that are needed within the scope of GUI, breaking final imagined GUI into small parts and trying to make that parts look attractive and effective in addition to the requirements mentioned previously. If we consider that GUI is sort of a connection between users and programmers, hence the design of it must be very clear for both users and programmers.

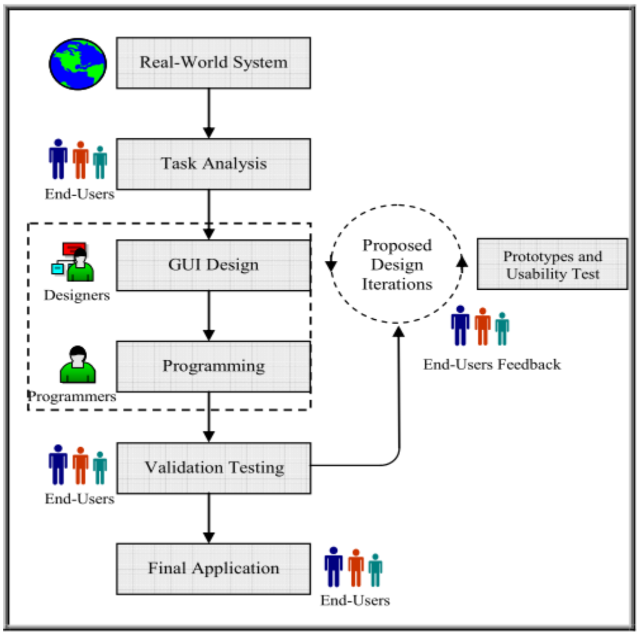


Figure 7-2 Design and Development Progress (Antcheva, Brun and Rademakers, 2014)

In development phase, programmers (developers) take the design and make it work functionally and visually. There are many different programming languages in use, but one thing is common to consider responsiveness or, in other words, performance of the application. As anybody acknowledges that nobody wants to use an application that is really slow and not functional at all, even though it has outstanding visuals and features on design paper.

Within the scope of the thesis, it is intended to create a GUI as digital platform that includes all the modules in SIMS and integrate them visually and functionally in one place. Following steps in roll have been followed during design and developing phases:

1. **Real World System:** It has been started with an industrial research to see similar application that are used in the industry and to decide what sort of GUI it could be efficient and what sort of features we do actually need.
2. **Task Analysis:** An Internal electronic questionnaire has been conducted amongst the users of the SIMS modules in the company. As it can be been seen in the appendix 2, questions are mostly focused on the performance of SIMS and additional features that are wanted to be seen within SIMS. Depending on the survey, it has been decided to develop some extra outputs as they are listed below:
   - Exporting technical hierarchy visually into the excel
   - Equipment grouping depending on the some specific criteria to be used in PM activities and exporting into excel.
   - A monitoring (Control) unit that is able to gather all the results generated by the different modules of SIMS in one place and make it easier to access and to check any individual tag with all the information registered on.
3. **GUI Design:** Initial design sketches have been drawn and discussed with the developer of SIMS and main users. Finally it has been decided to have separate home pages for every single main module with extended features added on and descriptions about legislations and sources that can be utilized. Prototype developed.
4. **Programming:** Python 3 (Python Software Foundation, 2014b) has been chosen as the programming language due to its high performance structure for fast and robust prototyping and open-source license.
5. **Validation Testing:** Proposed design iterations is still in progress
6. **Final application**

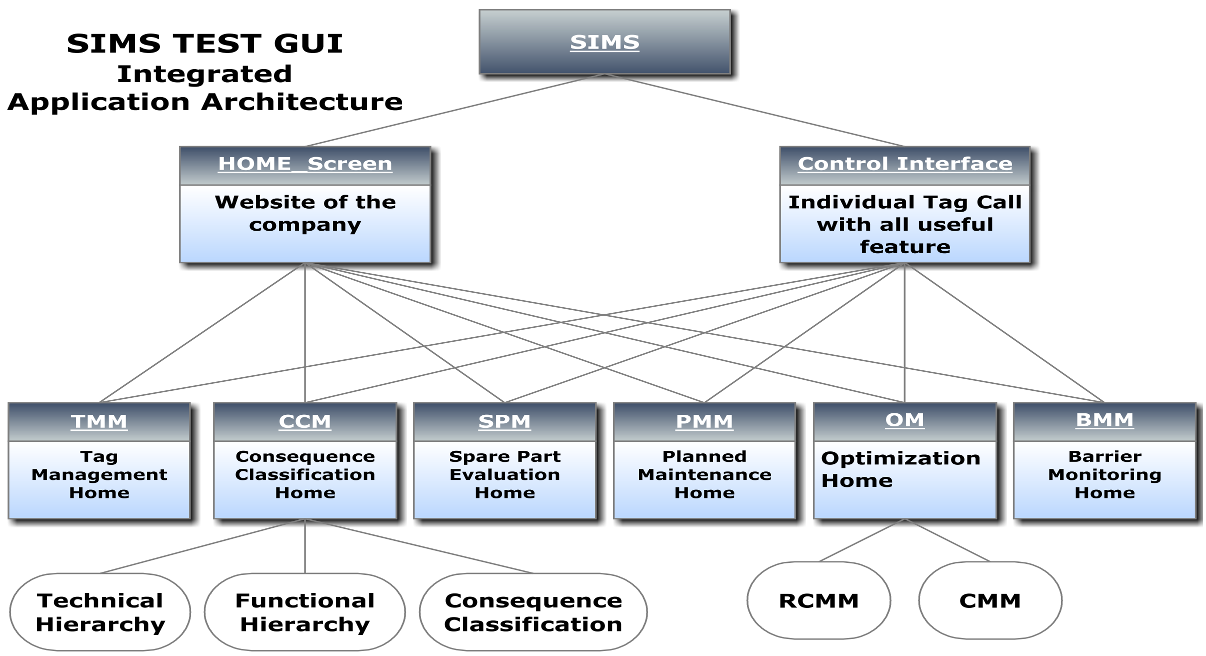


Figure 7-3 Architectural Design of Digital Platform (Test GUI) for SIMS

7.2) Monitoring (Control) Interface

Monitoring (Control) Interface has been developed as a part of the digital integration platform regarding to the requests that was taken with questionnaire same as the other request. One of the most important task of the integration of SIMS modules is actually integrating information that are populated through all modules and combining this information set in one screen to be able to make it easy and efficient to follow a tag with all necessary information registered on it. This monitoring Interface tool has been developed and integrated into the SIMS GUI to help monitoring tag data shown in Table 7-1. And

Table 7-1 Tag Features to Monitor in Control Interface

Tag Features to Monitor	
TMM Data	
Tag Number	
Description	Tag Description
System	System Description
Area	Tag location
Category	Tag category
CMM Data	
Parent Tag	Parent Tag (one level above in the hierarchy, if available)
Child Tag	Child Tag (one level above in the hierarchy, if available)
Criticality	Result of Consequence Classification
Parent Function No	Main System Function
Parent Function Description	Main System Function Description
Function No	Tag Function No
Function Name	Tag Function Description
SPM Data	
Package	Package Number that involve the tag
SPIR Name	SPIR Form name that involves that Tags
Spare Part List	All Spare part list that belongs to that tag.
RCM Data	
Reliability Data	Reliability Data from technical library and site.
CMM Data	
Monitoring values	Last monitored values from tag
BMM Data	
Barrier No and Name	Barrier name that implemented for the tag

In the current situation the user has to check every single module one by one in order to retrieve specific information that is stored in the related SIMS module. As it can be easily acknowledged, this is a time-consuming and ineffective way to do it in such complex systems. In order to be able to have a comprehensive control all over the assets, it is very essential to have integrated information center such as Monitoring Interface, here it has been developed within the scope of the master thesis as a part of SIMS.

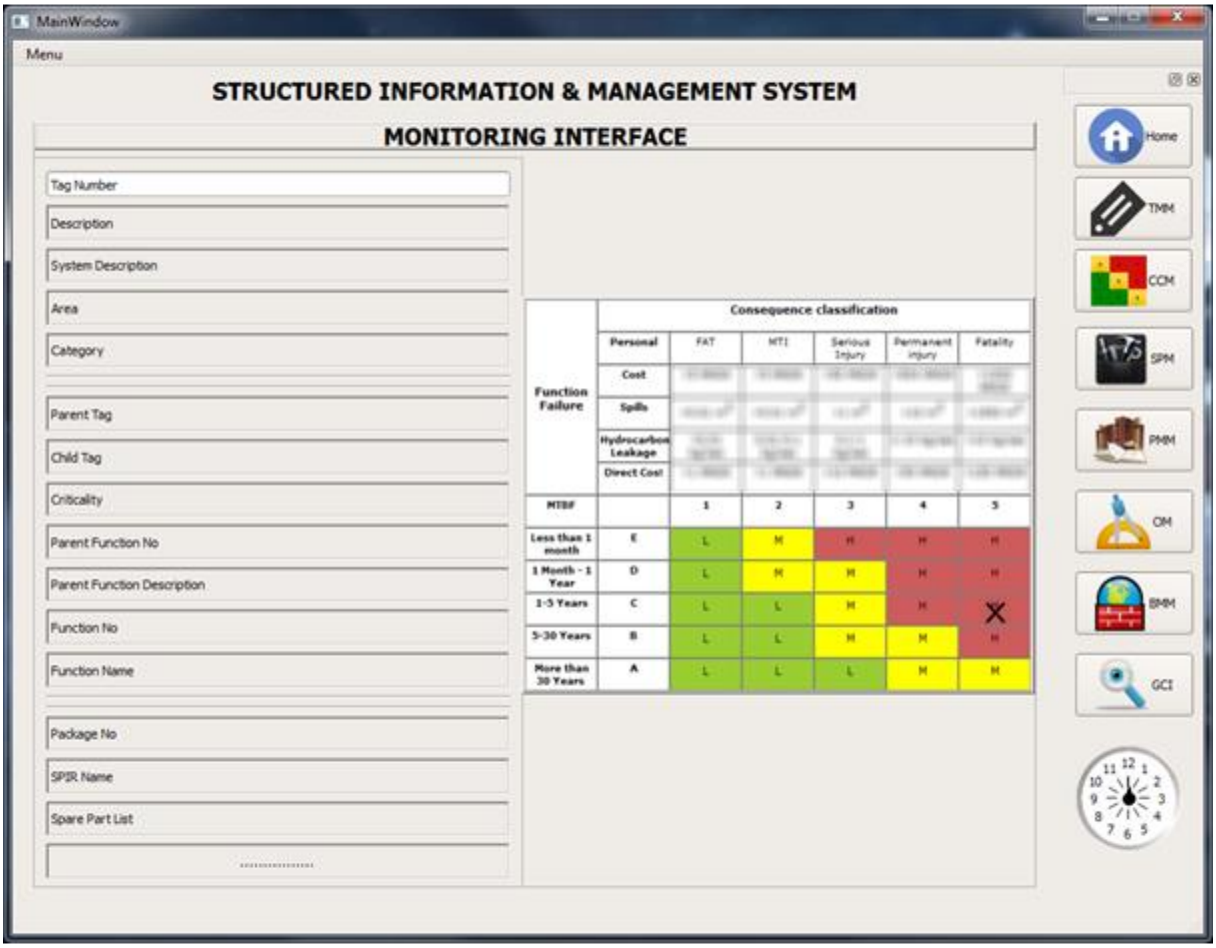


Figure 7-4Monitoring Interface Tool Screenshot

Following screenshots can be seen as both of architectural design of application and overview of GUI. There are total eight pages including monitor (control) interface and homepage. The tool box that is shown on right-hand side of the window above is internal control center for the digital platform and make it possible to go through the pages and control overall visual properties. And also the tool box has flexibility to be located on the left hand side depending on the users' desire.

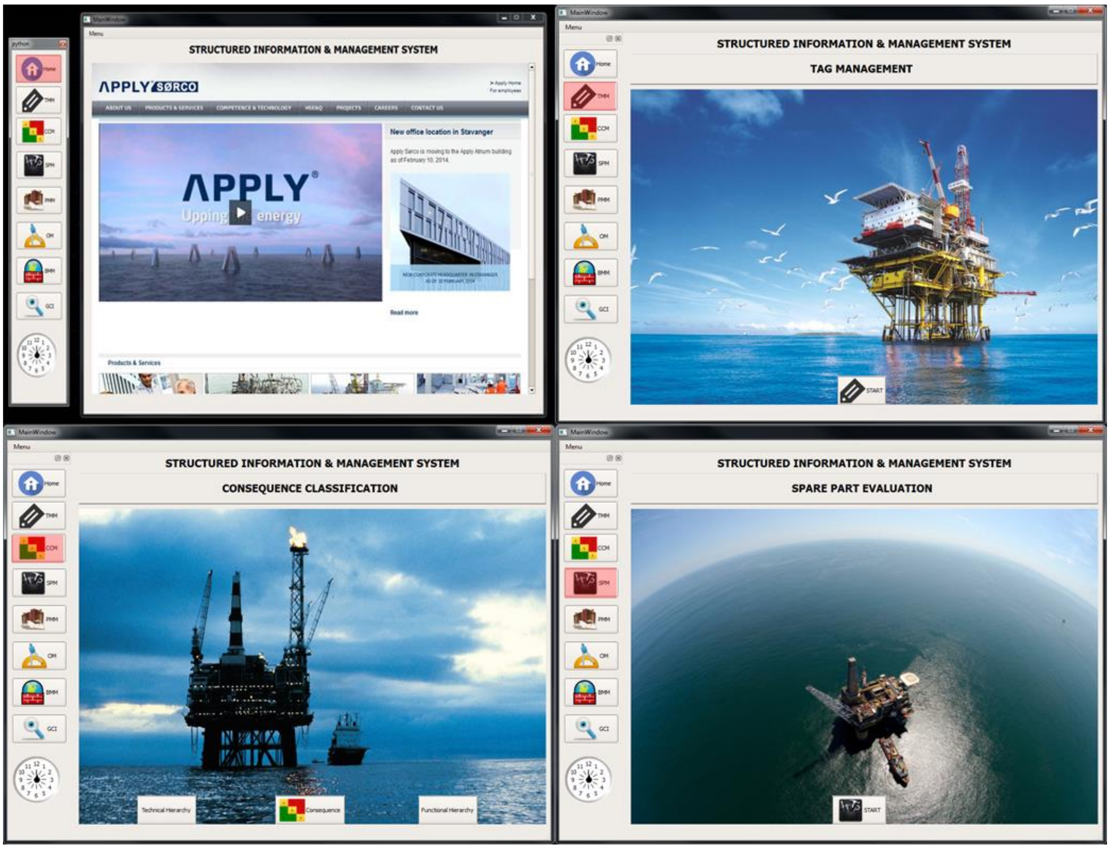


Figure 7-5 Test GUI: Home (up-left), TMM (upright), CCM (down-left) and SPM (downright) pages

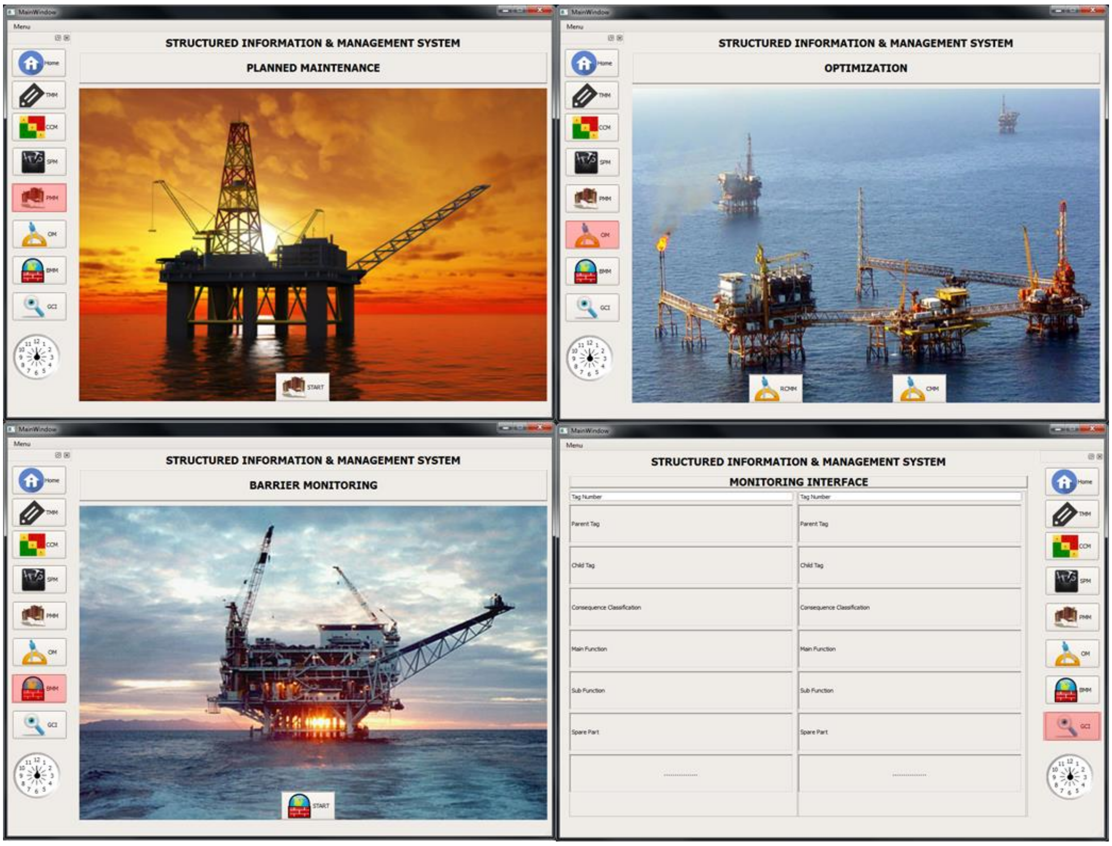


Figure 7-6 Test GUI (cont): PMM (up-left), OM (upright), BMM (down-left) and Monitoring Tool pages

8) DISCUSSION

Introduction

Asset Integrity Assurance tools that are dedicated to reduce cost and human-errors and increase the productivity and efficiency with the aid of the advancements in computer sciences and industrial expectations provide reliable and continuous solutions.

As it was pointed earlier, some of the root causes of having such asset integrity assurance tools in complex industrial systems are summarized with the following questions:

- How long will the complex system continue to be operated under the conditions it has, as it was new-built? (Mina, Braha and Bar-Yam, 2006)
- How can it be achieved to have a comprehensive and continuous control all over the assets in the industry?

The questions above are also presenting the biggest challenges faced in the complex industries as it does in O&G, as well. To be able to deal with these challenges;

- Tasks must be well mapped on a framework, in which these tasks are well handled,
- Tasks must be broken into small parts which makes it easier to see the specific solutions for each small detail,
- Find solutions for small parts with the aid of asset integrity assurance tools,
- Link related solutions to each other at the end and
- Integrate the solutions that are found out for each of the small part of the task during the implementations as one complete solution.

Asset integrity assurance tools are proposed in various ways as an efficient solution to achieve the tasks mentioned above by different companies that provide asset integrity services in oil and gas industry on NCS. Different companies may provide different tools, different application structures but eventually all the asset integrity assurance tools (that are provided by the various sources) aim to accomplish the same challenges pointed with above questions.

However at this point, there is always another big challenge about the asset integrity assurance tools each of which focuses on one dedicated job during the life span of the project. Challenge with AI Assurance tools is that these tools also must accomplish the integrity for themselves and to offer robust and continuous integration with each other same as they offer for each of the asset used in the facilities.

Therefore, an integrated digital platform that combines all the asset integrity assurance tools and involves the entire asset integrity concepts in one tool or application or software must be the most efficient solution to accomplish desired risk, cost and performance parameters within the asset integrity structure scope in the complex industrial systems.

What have been learned

It has been learned that every complex industrial systems consist of a set of subsystem, equipment, components and that every small part of the entire complex system might have great impacts on the system level if sufficient care is not paid on them. Asset integrity concept takes place as a platform, which integrates all the equipment with each other and controls and maintains them effectively. Asset integrity offers various strategies such as maintenance strategies, management strategies and performance strategies etc. to be able to provide the desired HSE and business conditions.

As already implied earlier, integration of asset integrity assurance tools on a digital platform matters for asset integrity as much as the asset integrity matters for complex industrial systems.

Python Programming language (Python Software Foundation, 2014b) has been learned and used with its dependencies. Python dependencies that are learned and used within the scope of the master thesis are listed below:

- *Pandas module;* to be able to handle database infrastructure that is used by the asset integrity assurance tools provided by the case study company,
- *DataNitro* (DataNitro, 2013) *, Xlsxwriter, Xlrd* and *Openpyxl modules*(Python Software Foundation, 2014a)*;* to be able to integrate the database infrastructure with MS Excel.
- *PyQt4 module* (Riverbank Computing Limited, 2014) *to be able to develop application with graphical user interface.*

Processes through developing an application has several steps starting from creating design layout to programming the final application after a lot of testing and validation sessions. And there are also many challenges through that pathway:

- Limited information for this kind of tailor made application,
- Dependency on various project requirements,
- Lack of documentation standard,
- Different database structure
- Insufficient quality control for the documentation received from the equipment supplier.

Beside the challenges mentioned above and the way beyond learning how to implement necessary IT knowledge and programming skills, in order to be able to develop such application, the entire technical framework from complex industrial system to asset integrity management, from asset integrity management to maintenance management practices must be learned and special attention must be paid to integrate technical process first. Afterwards it must be implemented in an IT application with the way they were integrated in real life.

Recommendations and Future Developments

As it was pointed in Prospective Modules and Integration Developments sub-chapter, there is Condition Monitoring (CMM) and Reliability Centered Maintenance modules (RCMM) decided to be developed and integrated into the current structure. By the nature of the concepts behind these modules, which are condition based maintenance and reliability centered maintenance that were mentioned in Basics of maintenance strategies sub-chapter, requires two-way communication and data transfer continuously during the life time of the asset. Hence these modules requires in-depth analysis in term of technical framework and IT development in order to implement an efficient life cycle improvement and maintenance management through the two-way data transfer process.. It is highly recommended to conduct another study just on the implementation of these modules both in technically and IT wise.

On the other hand, as previously mentioned in Design and Development Progress sub-chapter, a seven step procedure that are listed below has been followed during design and development phase of the Test GUI and monitoring interface.

1. *Real-World System,*
2. *Task Analysis,*
3. *GUI Design, (Prototype and Usability Test and required design iterations)*
4. *Programming,*
5. *Validation and Testing,*
6. *Final Application,*

However, due to the time restrain and ongoing developments, the progress is waiting at Validation and Testing step and needs to be finalized by providing final application to the end-user after implementing performance and function tests and providing beta version to be used for a while.

9) CONCLUSION

The main goal was assessing the asset integrity assurance tools that are provided by the case study company with regards to the risk involved in the O&G industry and creating an integrated digital platform for such applications.

Even before identifying the main reasons to integrate asset integrity assurance tools in an integrated digital platform, reasons to have such tools must be identified., it would be insufficient workflow without defining the underlying risk based reasons to have such asset integrity tools, main functions of such tools, main activities what we use them for and challenges make us to look for such solutions.

Hence, the environment has been identified (Complex Industrial Systems) first with its challenges and asset integrity management has been offered as a platform to accomplish challenges of complex industrial system, which it is O&G industry for our case.

Asset integrity has been categorized in order to be able to map the asset integrity services and solutions that can be used to accomplish the challenges regarding to the both of complex industrial system and asset integrity management. It has been seen that technical integrity offers the solutions and services to manage the risk involved in complex industrial system and asset integrity management.

Establishing a solid technical integrity through the life span of a project can be possible only if a sustainable maintenance management approach is applicable. According to that finding maintenance strategies were examined according to the NCS practices, regulations and guidelines.

A sample maintenance management practice has been established in order to show the required work flow to be able to accomplish the challenges regarding to the technical integrity. Asset integrity assurance tools are identified and described in detail with respect to the maintenance activities and asset integrity services. AI assurance tools that are currently in use have been mapped to be able to show the interactions between each other. The maintenance requirements that are not fulfilled by the current asset integrity assurance tools are identified as prospective asset integrity assurance tools (modules) and decided to be developed by the company. Due to the development that has been decided by the company, updated version of mapping study including prospective modules and prospective interactions has been done. Thus, asset integrity assurance tools have been identified with the underlying reasons.

The main reason to integrate the AI assurance tools is identified as to:

- Have a comprehensive and extended control all over the assets
- Reduce the risk related to the complex workflow,
- Simplify the complexity,
- Enhance the performance of maintenance management design process,
- Decrease the workman hours and so cost
- Increase data transfer quality amongst the different parties involved in maintenance operations
- Increase traceability
- Increase accessibility

In addition to the findings regarding to the challenges in industry, a survey (see Appendix A: Survey) conducted amongst the current user of SIMS and asked about the desired improvement, features and usability issues. According to the following considerations:

- Result of the survey
- Findings regarding to the challenges in the industry
- Finding during the design & development study for creating an integrated digital platform

it has been decided to develop an integrated digital platform with GUI, in other words, an application with GUI that includes;

- All the asset integrity assurance tools that are in use now with the current usability standards
- Prospective asset integrity assurance tools with the aid of the mapping study that has been done within the scope of this study in Chapter 6.3).
- Monitoring (control) interface that includes all the relevant information regarding to the maintenance activities.

As a result of the thesis, an integrated digital platform in compliance with the findings starting from the very first reasons for having such asset integrity assurance tools to the findings listed above, have been designed and developed within the scope of the thesis.

Finally, it is very essential to conclude that the main objective and sub-objectives of the master thesis have been accomplished successfully by mapping asset integrity assurance tools in compliance with the regulations and developing an integrated digital platform.

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APPENDIX A: SURVEY

University of Stavanger (UIS)
Apply Sorco AS
Stavanger, Rogaland
Norway

Print Form | Submit by Email

STRUCTURED INTEGRITY MANAGEMENT SOFTWARE SURVEY

1 - If you are not a SIMS user,Please write the IT tool that you use often and the main activity you use it for.

Excel? ProArc? Word?
Thank you for participating. (delete field first)

2 - Please check the SIMS module you are using:

- ☐ Tag Management Module (TMM)
- Consequence Classification Module
  - ☐ CCM Tag Hierarchy
  - ☐ CCM Functional Hierarchy
  - ☐ CCM Desicion Risk Model
- ☐ Spare Part Module

3 - Not in the list above? Please write it below.

>>

4 - How easy do you think it is to access SIMS?

5 - Do you think you have all the necessary information about TAGs in SIMS? If NO, please write what sort of information you usually need

>>

6 - Is there any Tag feature you haven't used in SIMS?

>>

7 - How user-friendly do you think the user interface of SIMS is?

8 - Please rate how easy it is to find data you look for

TMM			
CCM Tag Hierarchy		CCM Functional Hierarchy	
CCM Desicion Risk Model		Spare Part Module	

9- Do you use any complementary IT tools with SIMS? Please write its name and the purpose you use it for.

>>

10 - Do you think SIMS have barriers to prevent human errors? If no, please write possible human errors might occur?

>>

11 - Do you think is it easy to track and fix any probable human errors afterwards as a user?

12 - How comfortable are you with using SIMS?

13 - Do you experience any bugs or crashes and How often do you experience ?

14 - Do you need to export your work that is in SIMS for another IT tools? Please write the external IT tool and work type.

>>

15- What kind of challenges are you facing while using SIMS?

Is there no challenge? Sure? (delete field first)

16-What key features would you like to see in SIMS?

Isn't there any? Sure? (delete field first)

17 -How satisfied are you with with using SIMS?

- ○ Very satisfied
- ○ Somehow satisfied
- ○ Neither satisfied nor dissatisfied
- ○ Somehow dissatisfied
- ○ Very dissatisfied

APPENDIX B: COMPLEMENTARY FIGURES FOR MAINTENANCE PROGRAMME

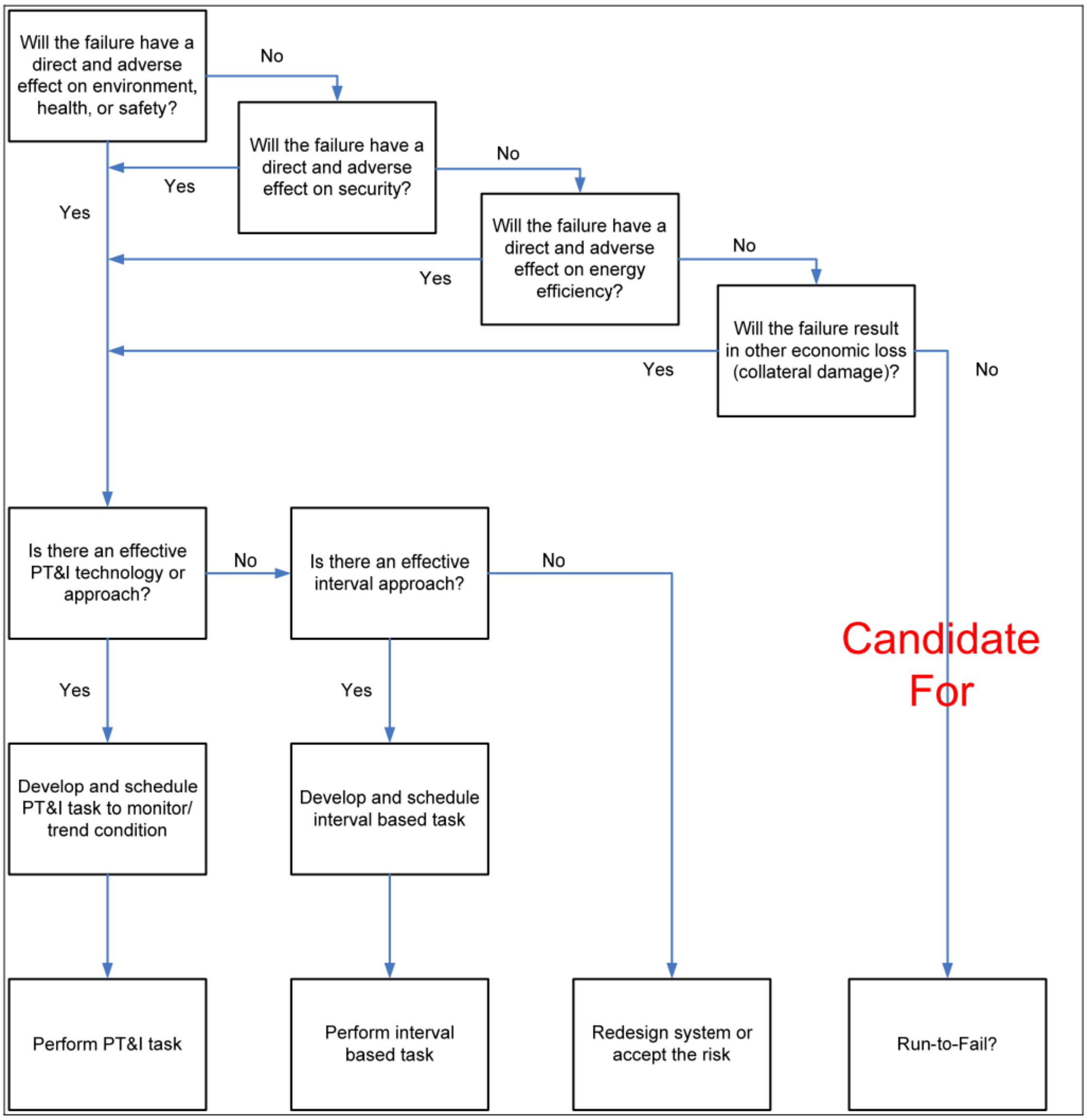

Figure 0-1 RCM Decision Logic for Maintenance Selection Process (NASA, 2008)

FUNCTION FAILURE	Consequence classification					
	Personnel	FAT	MTI	Serious injury	Multiple serious injuries or permanent injury	Fatality
	Cost	< 5 MNOK	> 5 MNOK	> 50 MNOK	> 500 MNOK	> 1000 MNOK
	Spills Oil, red or black chemicals	<0.01 m^3	>0.01 m^3	>1 m^3	>10 m^3	>1500 m^3
	Hydrocarbon Leakage	<0.01 kg/sec	0.01-0.1 kg/sec.	0.1-1 kg/sec. or brief leakages >1 kg	1-10 kg/sec. or brief leakages >10 kg	>10 kg/sec. or brief leakages >100 kg
	Operations Direct cost [Gross]	< 1 MNOK	> 1 MNOK	> 10 MNOK	> 50 MNOK	> 150 MNOK
MTBF (Mean Time Between Failures)		1	2	3	4	5
Less than 1 month	E	L	M	H	H	H
1 Month- 1Year	D	L	M	M	H	H
1-5 Years	C	L	L	M	H	H
5-30 Years	B	L	L	M	M	H
More than 30 Years	A	L	L	L	M	M

Figure 0-2 Consequence Classification Risk Matrix (Standards Norway, 2011)

MF description	Sub title, examples
Accumulation	Instrument/plant air, heating/cooling medium
Cementing	
Circulating	Heating/cooling medium
Compressing	Gas export/injection
Cooling	
Detecting	Fire and gas
Distributing	(Main/emergency) power, hydraulic, tele
Drying	Air, gas
Expanding	
Filling	Lubrication oil
Filtering	
Fire fighting	Sprinkler, deluge, water spray, foam, aqueous film foaming foam, hydrants
Generating	(Main/emergency) power
Heating	
Injecting	Chemicals, gas, water
Life Saving	Mob, lifeboat, basket, raft, escape chute
Lifting	Deck crane, personnel, goods
Logging	Well, production, mud
Manoeuvring	
Metering	Fiscal (gas/oil), CO_2
Pumping	Oil/gas export, bilge, seawater
Regenerating	Glycol
Scrubbing	
Separating	Production, test, cyclone- (water/sand/oil), centrifuge
Storing	Chemicals, potable water, lubrication/seal oil
Transferring	Oil/gas pipe (riser)

Figure 0-3 Main Function Descriptions (Standards Norway, 2011)

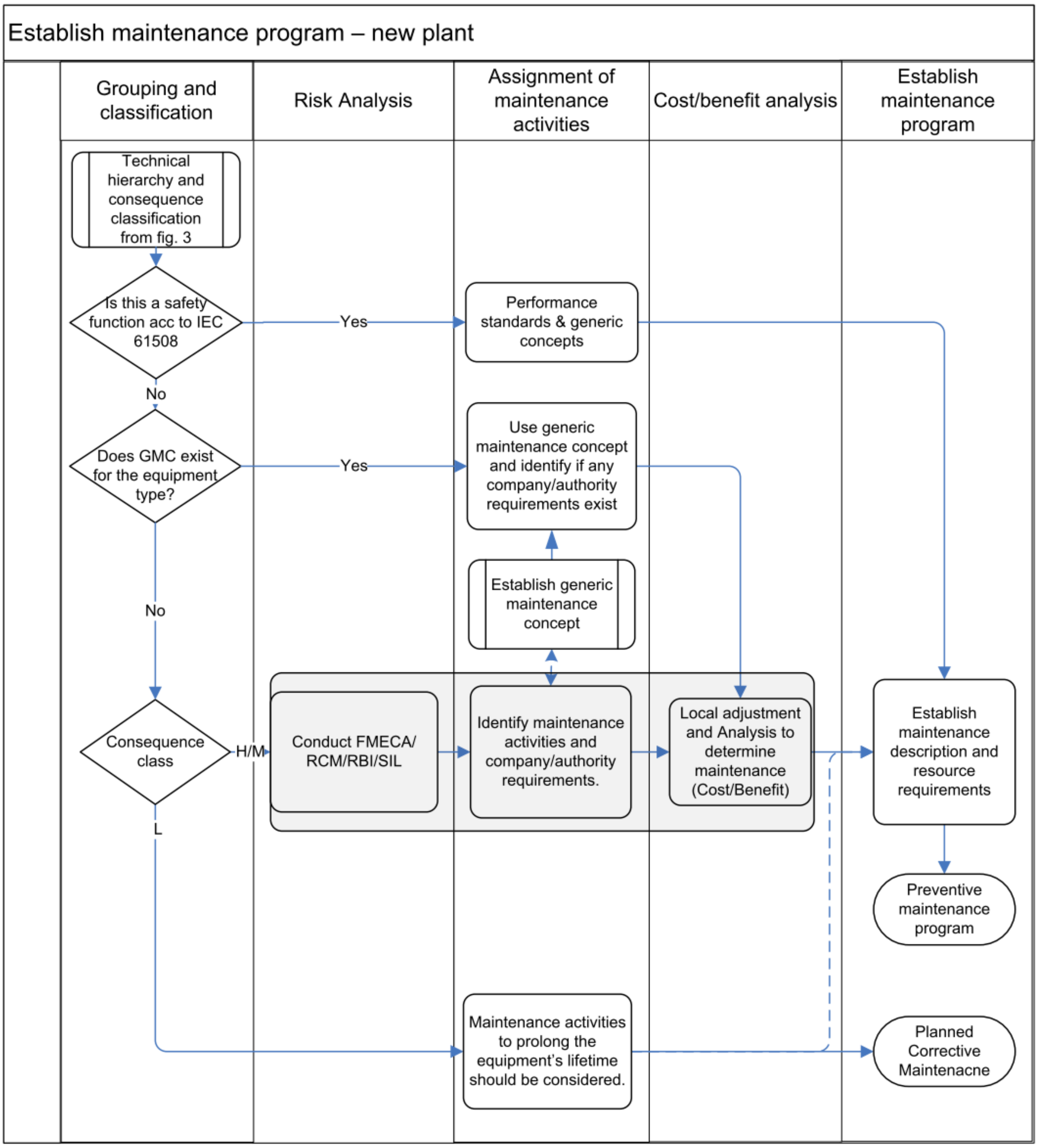

Figure 0-4 Work Flow for Establishing Preventive Maintenance Program (Standards Norway, 2011)

Consequence / Demand rate	Low	Medium	High
First line spare parts, frequently used.	Minimum stock at site	Minimum stock at site and any additional spare parts at central warehouse	Adequate stock at site
Not frequently used.	No stock	Central warehouse, no stock at site	Central warehouse and minimum stock at site if convenient
Capital spare parts. Seldom or never used.	No stock	No stock	Holding optimized by use of risk assessment case by case

Figure 0-5 Spare Part Evaluation Risk Matrix (Standards Norway, 2011)

SPARE PARTS LIST AND INTERCHANGEABILITY RECORD (SPIR)

THE EQUIPMENT CONSISTS OF THE FOLLOWING UNITS / COMPONENTS

26 COMMISSIONING SPARES		27 OPERATING SPARES	
Quantity in column 18 authorized for purchase by:	Req. No.:	Quantity in column 21 authorized for purchase by:	Req. No.:
	Spare part P.O.:		Spare part P.O.:
	Project spares req. on site date:		Operational spares req. on base (

31 General information:

MATERIALS DATA

3 Manufacturer model/type no. / 2 Tag No. / 4 Manufacturer serial no.	Deluge / AFFF Valv 71XX001 1203-200	Deluge / AFFF Valv 71XX002 1203-300	Firewater Hosereel 71SQ501....518 1203-500	Firewater Hydrant 71SR001... 1203-400	Portable Extinguish 72SP001....006 1203/017	Portable Extinguish 72SP101....106 1203/017	Mobile Foam Unit 72SX020....023 1203/017	Smoke Hood Cabin 72SX030....033 1203/017	Item Number	Total Number of identical spares installed	Spare Unit	Description of Recommended Spare Parts	Drawing ref. Detail Dwg. No./ Data sheet no.	Drawing ref. Item ref.	Material	Supplier's Part no.	Real Manufacturer's Part	
5	1	1	1	1	1	1	1	1		8	6A	9	10	11	12	13		
6 Quantity of spare parts per unit / component	2	2							1	4	P	8" Elastomer flow control sleeve c/w 'O' ring spares	3203-T-IMC-R-XD-71-0001-01	1203-200-1	Natural Rubber	1203-200-1	64/70058	Angus Fire
	2	2							2	4	P	6" Elastomer flow control sleeve c/w 'O' ring spare kit	3203-T-IMC-R-XD-71-0001-01	1203-200-2	Natural Rubber	1203-200-2	64/90121	Angus Fire
	4	4							3	8	P	Kit Service Pilot Control Valve	3203-T-IMC-R-XD-71-0001-01	1203-200-1/2	Natural Rubber/SS	1203-200-1/2	64/90118	Angus Fire
	2	2							4	4	P	Spare Kit for 4" Butterfly Valve	3203-T-IMC-R-XD-71-0001-01	1203-200-5	Buna	1203-200-5	BFV-L-100-C-TI	Tecofi
	8	8							5	16	P	Spare Kit for 6" Butterfly Valve	3203-T-IMC-R-XD-71-0001-01	1203-200-4	Buna	1203-200-4	BFV-L-150-C-TI	Tecofi
	6	6							6	12	P	Spare Kit for 8" Butterfly Valve	3203-T-IMC-R-XD-71-0001-01	1203-200-3	Buna	1203-200-3	BFV-L-200-C-TI	Tecofi
	4	4							7	8	P	Solenoid Valve	3203-T-IMC-R-XD-71-0001-01	1203-200-10	Titanium	1203-200-10	Y123BA3H1B3023	FCx Thompson Valves Ltd.
	4	4							8	8	P	Pressure Transmitter	3203-T-IMC-R-XD-71-0001-01	1203-200-6	Hastelloy C	1203-200-6	3051TG4A2B31KBK8Q4M6	Emerson Process
	1	1							9	2	P	Pressure Indicator	3203-T-IMC-R-XD-71-0001-01	1203-200-102	Titanim	1203-200-102	SM 316/SMC-G 10.100 0-25 BAR, TF100G Titan, 1/2" NPT-M	Skotselv Instrumentering
			18						10	18	P	Firewater Hosereel, nozzle	3203-T-IMC-R-XD-71-0004-01	1203-500-3	Chrome Plated Brass	1203-500-3	1310s-0	Rauplan Oy
				22					11	22	P	Hydrant Valve	3203-T-IMC-R-XD-71-0003-01	1203-400-2	Bronze BS 1400 LG2	1203-400-2	Bailey Class-F	Bailey
				44					12	44	P	Layflat Hose	3203-T-IMC-R-XD-71-0003-01	1203-400-6	Rubber	1203-400-6	Guardman 38mm x 15m	Mandals Reberbhan
				22					13	22	P	Style #372-BC Nozzle, Capacity: 475 lpm @ 7 barg	3203-T-IMC-R-XD-71-0003-01	1203-400-7	Brass	1203-400-7	Style #372-BC Nozzle	Protek
					36				14	36	P	Portable Fire Extinguisher, Dry powder	NA	NA	NA	1203/017-1	BS12MED	Cosalt
						6			15	6	P	Portable Fire Extinguisher, CO2	NA	NA	NA	1203/017-2	BC5MED	Cosalt
							4		16	4	P	Mobile Foam Unit	NA	NA	NA	1203/017-4	POK 150L	Cosalt
								4	17	4	P	Smoke Hood Cabinet	NA	NA	NA	1203/017-9	JB58	Cosalt
									18	15	P	Eye Wash Bottles n Cabinet	NA	NA	NA	1203/017-8	Eye wash station	Cosalt
									19	15	P	Torch	NA	NA	NA	1203/017-11	Wolf TS 24	Cosalt
									20	2	P	Firemans Cabinet	NA	NA	NA	1203/017-5	JB17.600	Cosalt
									21	4	P	Safety Shower	NA	NA	NA	1203/017-10	STD-H-15KS/11KS	Cosalt
									22	2	P	Safety Station Cabinet	NA	NA	NA	1203/017-6	JB38	Cosalt
									23	2	P	CO2 Wheeled Extinguisher	NA	NA	NA	1203/017-3	NWC9	Cosalt
									24	2	P	First Aid kit	NA	NA	NA	1203/017-7	First Aid kit	Cosalt
									25	550	P	HV Nozzles K=40	NA	NA	Naval Brass	1203/029-1	HV Nozzles K=40	Tyco
									26	40	P	HV Nozzles Narrow Flow K=40	NA	NA	Naval Brass	1203/029-2	HV Nozzles Narrow Flow K=40	Tyco
									27									

Figure 0-6 Sample SPIR Form