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Abstract

The Oil and Gas industry operating on the Norwegian continental shelf is entering the tail-end phase of oil and gas production. This cause an increase of the operational unit costs due to reduction in production volumes and increasing costs related to operation and maintenance activities. In order to extend oil and gas production lifetime, operators and involved parties had to investigate alternative solutions. This challenge is solved either by increasing production volumes from reservoir and/or reduce operational costs through improving/optimizing operation and maintenance performance for the production facility, which enable the operators to extend the oil and gas production period. Optimizing operation and maintenance performance can be achieved by optimizing service delivery processes. Thus the operator improves the effectiveness, efficiency and quality of deliverables, which will leads to improve the company profit.

This thesis attempts to understand and design maintenance strategy that could be used for oil and gas production lines consisting of functional products/performance based service delivery. Different service delivery strategies are presented, with respect to product and service delivery, and characterized each of these service delivery strategic models. Critical challenges related to maintenance strategy of performance based service deliveries are presented, in order to identify influence factors of maintenance strategy design. Maintenance management system for functional products is suggested and established in order to achieve operation and maintenance objectives.

A case study on Offshore Mobile Drilling Unit is carried out in order to understand how to design maintenance strategy of performance service delivery. In addition, responsibilities of operating company and contractor are defined, with respect to the operation, maintenance activities including service support system. The case study is divided into four parts. A basic offshore rotary rig is presented in the first part. Drilling and well professionals are presented in the second part. Semi-submersible mobile rig unit contract is presented in the third part while conducted guided interview performed, and questionnaire is answered by interviewee can be found in the fourth.

Acknowledgements

The lord Jesus said “Peace I leave with you; my peace I give you. I do not give to you as the world gives. Do not let your hearts be troubled and do not be afraid.” (John 14:27)

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Abbreviations

Abbreviations	Wording
AOC	Acknowledgement of Compliance
BAT	Best Available Technology
BOM	Bill of Materials
BOP	Blowout Preventer
CAPEX	Capital Expenditure
CBM	Condition Based Maintenance
CENELEC	European Committee for Electrotechnical Standardization
CMMS	Computer Maintenance Management System
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode, Effect and Criticality Analysis
FTA	Failure Tree Analysis
HSE&Q	Health, Safety and Environment, and Quality
KPI	Key Performance Indicators
LCC	Life Cycle Cost
MODU	Mobile Offshore Drilling Unit
NCS	Norwegian Continental Shelf
NPD	Norwegian Petroleum Directorate's
O&G	Oil and Gas
O&M	Operation and Maintenance
OPEX	Operational Expenditure
PSS	Product-Service System
RAMS/S	Reliability, Availability, Maintainability, and Maintenance Supportability/Safety
RCM	Reliability Centred Maintenance
TBM	Time Based Maintenance
TPM	Total Productive Maintenance

Definitions and Terms

Authorities

It means all government, state and municipal authorities, agencies and bodies entitled to give rules, regulation, directions, instructions, approvals and/or consents in relation to the product, off-onshore facilities, and/or performance of the work.

Availability

It is ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided (ISO 14224, 2006)

Drilling unit

It means all appurtenant items, equipment, materials, associated services, replacement, and spare parts thereon of whatsoever nature provided by contractor and used in connection with the work.

Facility

It means the physical products, off-onshore based and all onshore property, offices, accommodation, storage areas, working equipment, temporary works and things of whatsoever nature to be provided by contractors, subcontractors and service provider for the performance of the work.

Generic maintenance concept

It is a set of maintenance actions, strategies and maintenance details, which demonstrates a cost efficient maintenance method for a defined generic group of equipment functioning under similar frame and operating conditions (Norsok Z-008, 2011)

Maintainability

It is design characteristics which should be implemented in design stage, or in the installation stage that determines the ease, economy, safety, and accuracy with which maintenance action can be performed, also, the ability to restore a product to service or to perform preventive maintenance within required limits (Industrial service compendium, 2010).

Maintenance supportability

It is the ability of a maintenance organization to have the correct maintenance support at the right place to perform the required maintenance activity when it is required (NS-EN 13306).

Operating company

Operating company is the financier of the industries. They are the main users of the services delivered by contractor and service companies / supplies / service providers. An operating company called simply an operator.

Operational integrity

It is defined as the ability of the asset to meet today's functional requirements (Rolstadås et al., 1999).

Operations

The combination of all activities, including administrative and supervision actions, intended to start up, run, monitor and shut down equipment and systems in accordance with intended purpose and design specifications.

Subcontractor

It means a third party who has entered into agreement with contractor for the performance of part of the work.

Technical integrity

It is defined as the ability of the asset to fulfil its functional requirements in the future (Rolstadås et al., 1999).

Third party

It means any party other than company and contractor.

Well

It means a single hole to be drilled to a predefined final geological target, including any remedial deviations, side-tracking and/or deeping to reach the geological target, including testing and completion.

1 Introduction

Operating companies in oil and gas industry are moving from products orientation business strategy model towards service orientation business strategy model. This change took a place when O&G fields in the Norwegian continental shelf begin to enter the tail-end phase of production, the phase unit of operational costs started to increase due to reduction in production volume and increasing in O&M activities cost. Therefore, it was necessary for operator and the involved parties to investigate alternative solution in order to deal with this challenge. There are two alternative solutions presented, it is either to increase production volume and/or reduce operational expenses by optimizing performance. The identified solution of optimizing performance can be achieved by optimization service delivery process, which leads to increase the effectiveness, efficiency and quality of deliverables.

Service business delivery strategy models are mainly consist of three concepts in term of product and service delivery:

- First concept is a conventional product the traditional delivery of a physical product such as machinery or equipment;
- Second concept is delivery integrated service into the manufactured product as a total offering from manufacturer or service provider (Neu, 2005);
- Third concept is functional products concept delivery performance of the physical product (Markeset and Kumar, 2005).

A conventional product should be understood as a physical product, the manufacture or service provider sells and transfers the physical products' responsibility to customer. Thus the manufacturer has limited or no responsibility regarding the Operation and Maintenance (O&M) of the physical product. It could be some contractual agreements of O&M activities such as guarantee periods, maintenance recommendations, and training, but the product is still owned by the customer/buyer/(operator) and the functional performance is in the hands of the product owner the customer. The value creation from customer perspective is to generated maximum profit from product that give high quality output at minimum life cycle cost O&M. the creation value from manufacture perspective is the generated profit from selling the product, selling service support system (service to support the physical product and the customer) (Markeset and Kumar, 2005).

A functional product or performance based service delivery is unlike conventional product idea of selling a physical products and transferring responsibility to the customer/buyer, delivery of functional performance in term of availability of the product instead of selling the product itself. The customer/buyer pays only for the functional performance and does not pay for the physical product. Manufacture owns the physical product and has total responsibility for the physical product and service support system such as operation and maintenance

elements. The value creation is the customer and manufacture will have the same focus on process optimizing of the performance because the manufacture will be responsible for the total cost (Markeset and Kumar, 2005).

The interesting basis for this thesis is defining maintenance strategy for offshore O&G production line consisting of functional products. Since there are two or more organizations that have to share the responsibility and the risk of process production facility, new influence success factors need to be studied and implemented to secure the functional performance delivery of the functional product.

1.1 PROBLEM DESCRIPTION

The Norwegian oil and gas industry has been combining different business strategy models in order to design, construct, install, operate and maintain oil and gas production, offshore drilling units, oil and gas refinery, etc.

Customer/buyer/operator is often used to operate, control and maintain the functional performance of offshore O&G production system. They have their own (O&M) organization that is involved in the daily O&M activities in order to secure the production line's safety and stability. In addition, they have their own maintenance system to manage maintenance activities. For the large, complex, automated and integrated system in the production line (e.g. gas turbines, production control systems, and etc.) the operator owns the system and has their own maintenance system and strategy. This requires service support system from manufacture/contractor such as maintenance, service, decision support, and knowledge (full service).

In the functional performance delivery strategy, the customer pays only for the functional performance of the physical product, the responsibility of the physical product are not transferred to the customer and manufacture/service provider has to guarantee for availability, performance rate and quality of the physical product.

The main challenge of a customer/an operator is to secure high performance of using functional product and minimum the cost of buying functional products. Markeset and Kumram (2007) have identified factors that have influence on performance based service strategy. Maintenance strategy is one of the factors presented. This factor is high rated influence on the performance of the functional products service delivery, securing good design of maintenance strategy of the functional product for specific facility will lead to successful and satisfied operator/customer.

There are currently few functional product deliveries/performance based service delivery for offshore O&G production line system that consist of functional products. The integrated product-service system delivery/full service delivery is the most common service strategy delivery. The author will look into the performance based service delivery in the future.

1.2 OBJECTIVE AND SUB-OBJECTIVES

The main objective of this thesis is to contribute to the understanding of designing maintenance strategies and control mechanisms for a production line system consisting of one functional product system/two functional products systems in order to secure operator's efficiency, productivities and competitiveness, and improve management performance through visualization of responsibility among different parties.

Sub-objectives:

- 1- Define and describe what conventional product concept is?
- 2- Define and describe what functional product concept is?
- 3- Define the characteristics of the functional product vs. conventional product?
- 4- Describe a technical system that consists of functional products?
- 5- Describe an organization system that consists of operators and contractor/service providers of functional products?
- 6- Identify factors that influence performance of the functional product
- 7- Investigate and suggest how to create maintenance strategies for functional products in one production process line where different suppliers are responsible for delivering the performance from "their" units

1.3 METHODOLOGY

The first part of this report is based on a comprehensive literature survey and a field study of service delivery business strategy, with focus on performance-based delivery and design of maintenance strategy for performance based maintenance.

The second part is based on a case study conducted to map current practices with respect to performance based delivery, to understand the design of maintenance strategy for functional product from operating company and contractor perspective. Data have been collected through face-to-face interviews, phone interview, an e-mail questionnaire, available documents from the industry and a literature survey.

1.4 LIMITATIONS

The work presented in this thesis is limited to the topside assets (administrative, managerial, and contractual) in the Norwegian offshore industry.

2 State of the art in design maintenance strategy for functional products

In order to design maintenance strategy for functional products/performance based service delivery, the author has decided to introduce different types of service strategies. Conventional and functional products service strategies have defined and characterized, generic technical and administrative systems have been designed for O&G production line consist of functional products, advantages of performance based delivery have been identified. Thereafter various challenges have been identified based on qualitative assessment on the manageability and consequences on the HSE, regulation and costs. Finally, suggested maintenance management system for functional products is established.

2.1 INTRODUCTION TO SERVICES DELIVERY STRATEGY

Grönroos (2000) states “*service is a complicated phenomenon*”. There are many definitions of service that can be listed up, but the key words are an attempt to define the term which should include processes and activities, consumed and simultaneously produced. A clear definition of service will enable both operator and service provider to know what is service offered, expectations, cost, quality, how to purchase service, and how to get help (University of California Santa Cruz, 2012).

Grönroos (2000) has written regarding services, manufacture changes their focus of business-to-business concepts from selling products to providing solutions. Different industries have the last decades changed their service delivery strategy from offering physical products to offer combination of physical products plus full service to fulfill the total need of their customers. The development in the service delivery strategy and the shift to service perspective is partly customer driven, competition driven, and technology-driven.

The manufacturers/contractors have started to offer services that support customer activities, (e.g. within operating and maintaining production line or processes). They had to learn about the given task and operational requirements of the operator, and became more involved in providing integrated solution and essential parts of the operator’s operations (Brax, 2005, Baines et al., 2009).

The operators became more interested in outsourcing their parts of operation instead of performing and investing in products themselves (Gebauer, 2008).

The development of the service delivery business strategy started when manufacturers and/or contractor decided to take the step toward offering different solution of functional products such as “total care solution” and “solutions selling” that accommodate the total need of their operators (Kumar and Kumar, 2004).

Manufacturer/maintenance service companies such as ABB provides robots, maintenance strategies, and spare parts strategies to achieve 95% uptime to the provided system as a total care solution. Audit, tax and transaction service companies such as KPMG AS and KPMG Law provide audit, tax, transaction and advisory services to their operator in Norway (KPMG, 2014).

2.2 DEFINITION AND CHARACTERISTICS OF CONVENTIONAL PRODUCT CONCEPT

The conventional product or traditional service concept can be defined as manufacturers/service providers/contractors sells physical products and provides after sale service to customer/buyer/(operator) with limited responsibility regarding the operational and maintenance of the physical product. This concept is characterized by [Table 2.1](#) (Markeset and Kumar, 2005):

Table 2.1 Conventional product characterization

Parameters	Conventional product characterization
Ownership	<ul style="list-style-type: none"> - Ownership of physical product is transferred to the operator. - Ownership of spare parts is transferred to the operator.
Operation and Maintenance	<ul style="list-style-type: none"> - Operation and maintenance responsibility is transferred to the operator. - Operator responsible for lifecycle commitment for the owned product. - Operator responsible of optimizing the availability of the total production system.
Financing	<ul style="list-style-type: none"> - A payment model is made for the utilities. Contractual

	agreements between manufacture and operator of operation and maintenance such as guarantee periods, after sale service, training etc.
Retrieval and recycling	- Operator is responsible for retrieval, recovery and disposal owned product.

2.2.1 Conventional Product support

According to Marqueset and Kumar (2005) conventional product support is a traditional after sale services. Conventional product has different solutions regarding product support; it can vary from selling physical product itself to the operator till having contractual agreement of performing complex operation and maintenance tasks or providing full service including full support, training and knowledge of the product. There are three different types of service delivery strategy for conventional products as it is explained below:

1- Physical products offering

It is the oldest and most traditional approach. Customer buys, operates and maintains the physical product/system. Training, expert and spare parts may be required from manufactures/service providers.

2- Product-Service System (PSS)-(Service selling)

PSS is conventional products support service solution. It is defined as “the result of an innovation strategy, shifting the business focus from designing and selling physical products only, to selling a system of products and services which are jointly capable of fulfilling specific client demands” (Manzini and Vezzoli, 2003). The PSS business strategy approach is used in order to achieve greater revenue. It has many benefits such as achieving closer relationship between customer and manufacturer and increasing profit from manufacture products. Sundin et al. (2005) defined PSS main approaches: service provider adding value to the products life cycle; service provided “outcome, performance, or results” to the customers.

3- System, Service, Support, and Knowledge-(Full service concept)

Full service concept is defined as “...a comprehensive bundle of products and/or services, that fully satisfies the needs and wants of a customer related to a specific event or problem” (Stremersch et al., 2001). It is linked to bundle of products term, which is defined as “the offering of groups of products and/or services as a package”. Full services means that the service provider offer a combination of products, service, product support

service, and knowledge as one package or system, which fulfills all customer needs as a total system.

Stremersch et al. (2001) divided full service concept into two dimensions, first “(1) *bundling strategy (a bundle of products and/or services)*” and second, “(2) *extension in customer need fulfilment (that fully satisfies the needs and wants of the customer related to specific event or problem)*”. The full service concept is illustrated in Figure 2.1.

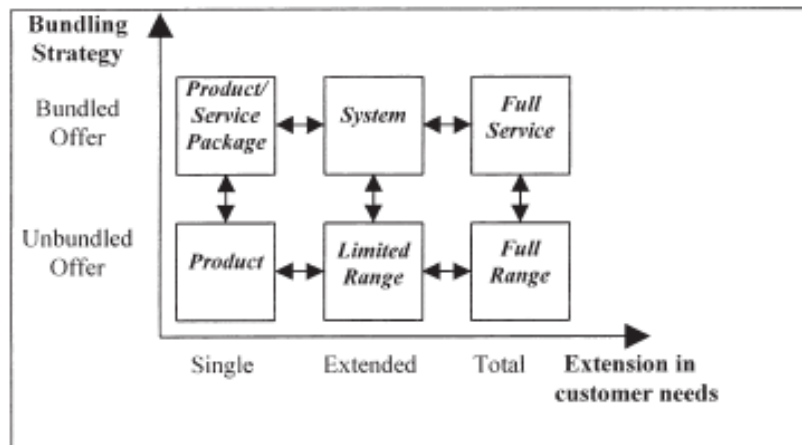


Figure 2.1 Definition of full service concept (Stremersch et al., 2001)

2.3 DEFINITION AND CHARACTERISTICS OF FUNCTIONAL PRODUCTS CONCEPT

Sundin et al. (2005) introduced business concept of the Functional Sales as “... *reference to the customer value, to optimize the functional solution from a life-cycle perspective*”. Sundin and Bras (2005) have explained main idea of this concept as the freedom of the service provider to decide the way to deliver the functional requested by operator.

Markeset and Kumar (2005) introduced concept of the functional products as “... *the customer buys the performance, not the product and the related service*”. Functional products are known as performance-based service delivery. It is a service delivery strategy where manufacturers/contractors/service providers sell performance of the system/product in term of availability instead of selling the system itself. In this approach the contractor focus on optimizing the same processes that an operator is interested in optimizing.

The contractors provide hardware and software, and support service system to keep the physical product operable. The support service system/customer support is refereeing to the

“*service*”, and it is more than maintenance activities, it includes decision-making, operational planning and etc. (Alonso-Rasgado et al., 2004, Markeset and Kumar, 2005).

This concept is characterized by (Alonso-Rasgado et al., 2004, Markeset and Kumar, 2005) in the Table 2.2:

Table 2.2 Functional product characterization

Parameters	Functional product characterization
Ownership	- Ownership of physical product and spare parts is not transferred to the customer.
Operation and Maintenance	- Operation and maintenance responsibility is not transferred to operator. Contractor is responsible to perform operational services and managing maintenance functions. - Contractor responsible for lifecycle commitment for the owned product. - Contractor responsible to optimize production of the process facility (reliability, availability, maintainability, and maintenance supportability (RAMS)) of the delivered products.
Financing	- A new payment model and contractual agreements assigned between contractor and customer based on incentive contract, this will be presented in section 3.3.3.
Retrieval and recycling	- Contractor is responsible for retrieval, recovery and disposal for their owned product.

2.3.1 Functional product value creating

The manufacturer owns the physical product, and takes responsibility of functional performance including operation, maintenance and service support. The manufacturer will focus on the design of the physical product to ensure maximum performance rate in term effectiveness and efficiency “at minimum LCC and maximum profit”. To be able to reach the mentioned target the manufacturer have to face the following challenges (Kumar and Kumar, 2004):

- 1- Cost reduction of O&M
- 2- Design-out the product weaknesses to ensure low service activities that need to support the product
- 3- Optimization all of RAMS, functional characteristics, performance of operation and maintenance processes, and product support

- 4- Interfacing and coordination between the process owner of customer production department and the manufacture.
- 5- Manufactures' resources priority and coordination in case of offering functional product to several customers.

Alonso-Rasgado et al. (2004), Markeset and Kumar (2005) listed up main value creating points of the functional products:

- 1- The manufacture will gain knowledge about the operation and maintenance performance of the production line.
- 2- The manufacture and customer will have the same aim to optimize the performance of the functional product which is a part of the production line.
- 3- The manufacturer and customer profit from the result generated by the functional product performance.
- 4- The functional product and related processes have to generate maximum profit at the lowest life cycle costs.
- 5- Closer relationship long-term contract between customer and service provider/contractor.

From the customer perspective, the customer will aim to optimize the performance of the process for the production line together with the manufacturer. The cooperation and coordination between the process owner and several manufacturers will be a big challenge to ensure availability, effectiveness and efficiency of the system. Additionally, the customer will share the risk with the manufacturer. The initial cost is a dominant factor in purchasing-decision of physical products, therefore the customer prefers to choose this type of service delivery strategy comparable to other types of services. The customer will get offered guaranteed availability of the purchased system.

2.4 COMPLEX SYSTEM THEORY

Magee and Weck (2004) have defined complex system as “A system with numerous components and interconnections, interactions or interdependencies that are difficult to describe, understand, predict, manage, design, and/or change”.

It is a term used to describe a system. The system is complex when there are many parts interconnected and interactions within a specific system or other systems such as production line consisting of many products to fulfill number of functions that is interconnected, several manufactures/contractors have responsibility of their product/system, and they could have several subcontractors that constitute a functional and spatial unity.

It can add more complexity if the system is interacted with another system in the world such as an economic system. However, it does not necessarily mean that all systems are complicated system. A system giving a specific output applied to a given border condition is not necessarily a complex system.

Characteristics of the technical system can classify the level of complexity for any technical system. It is therefore necessary in this thesis to characterize the technical system of functional products for O&G production line.

2.4.1 Generic description of physical technical system for O&G production line consisting of functional products

System theory is applied to the physical technical system for offshore O&G production line. A system can be defined as “interconnected parts working in conjunction with each other in order to accomplish a number of goals” (PMI, 2000). The physical technical system for offshore O&G production line consists of three main elements Input, Conversion production process, and Output, as it is shown in Figure 2.2

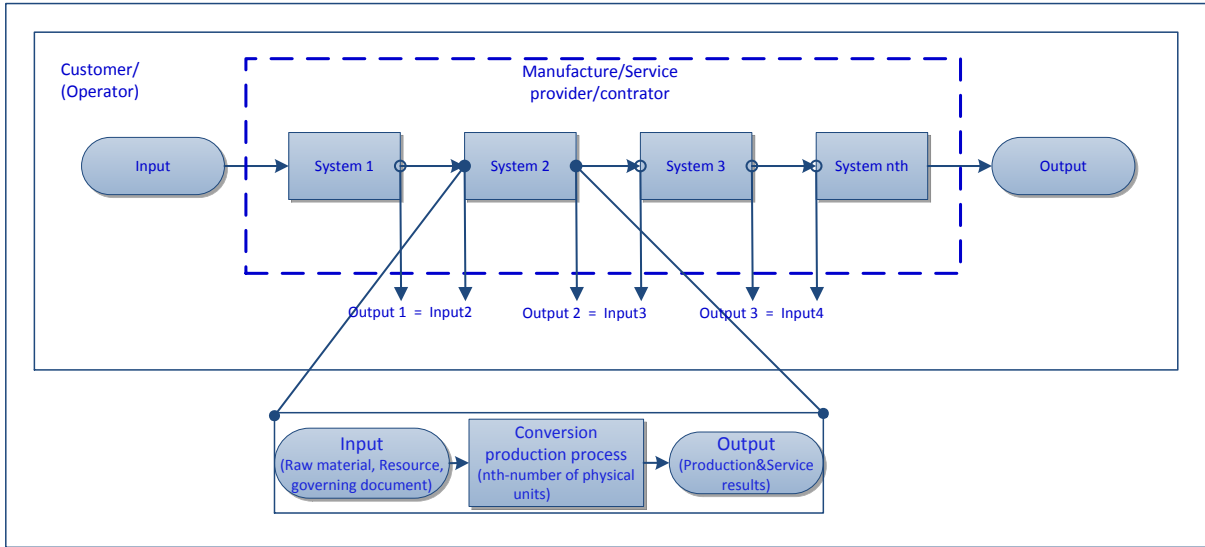


Figure 2.2 System elements for offshore O&G production line

Input: The physical system consists of incoming steam of physical objectives such as raw material (oil, gas and water), contract (a legally binding agreement between two parts, which includes information about the offer, acceptance of offer, price, requirements and regulation, terms and conditions, and etc.), governing document (includes functional requirements “*what shall be achieved*”), work processes (“*how and whom work shall be executed*”), work

requirement, organization, management and control, technical requirement (design of technical equipment, system or function). Additionally, these documents will also define design basis premises of the production line/project and the project scope and interfaces, and phases associated with decision gate processes “*design basis, concept, planning, identifying, and execution phase*” while it is passing from one phase to the next in the project development process (Samarakoon and Gudmestad, 2010)).

The conversion production process: is an operation process which converts the provided input into output. It is consisting of nth-number of systems and sub-systems. Each system is consisting of physical units such as (pump, motor, and compressor) which has their own input and output to the next system, as it shown in [Figure 2.2](#). In addition, it consists of product support service activities attached to the product as a part of the work process assuring performance of the product such as (maintenance, operating, inspection, quality controlling activities, and etc.).

Output: Operation performance of the production line will result (e.g. volume of oil by day, meter hole by day, power by hour).

2.4.2 Generic description of administrative system for O&G production line consisting of functional products

The internal elements of organization will be explained in this section such as responsibility, boundaries and interface, control, feedback, relationship, etc. for an O&G production line.

The administration system is the governing system. It is receiving, processing and giving information, and it is normally used to control a physical system or another administrative system. The organizational system model for the offshore O&G production line consists mainly of two organizations, operator organization and contractor (n-th) organization. There are two options for delivery of functional products for offshore oil and gas production line:

[Option 1: Multiple contracts \(A number of contractors sign individual contracts with responsible for delivery of their own functional product/system to operator\)](#)

[Figure 2.3](#) is illustrating offshore O&G production line consists of systems and sub-systems. The characteristic of the given systems and sub-systems will be integrated hardware, software, sensor, control system, and information technology that increase complexity of the system (Markeset and Kumar, 2005). The stippled blue line shows manufactures/contractors ownership part, and an orange line shows Customer/operator’s ownership part of the O&G production line.

The operator owns the input and output of the offshore O&G production line. Administrative, technical and functional requirements have to be defined; raw material and governing documents have to be provided to each contractor.

The contractors own functional products, they have responsibility to provide performance in term of functionality and availability of their delivery system (output). They have to manage the core process activities such as technical operation and maintenance (Hypko et al., 2010). They have responsibility to establish their own O&M objectives and maintenance program in order to secure objectives alignment across operator’s organization.

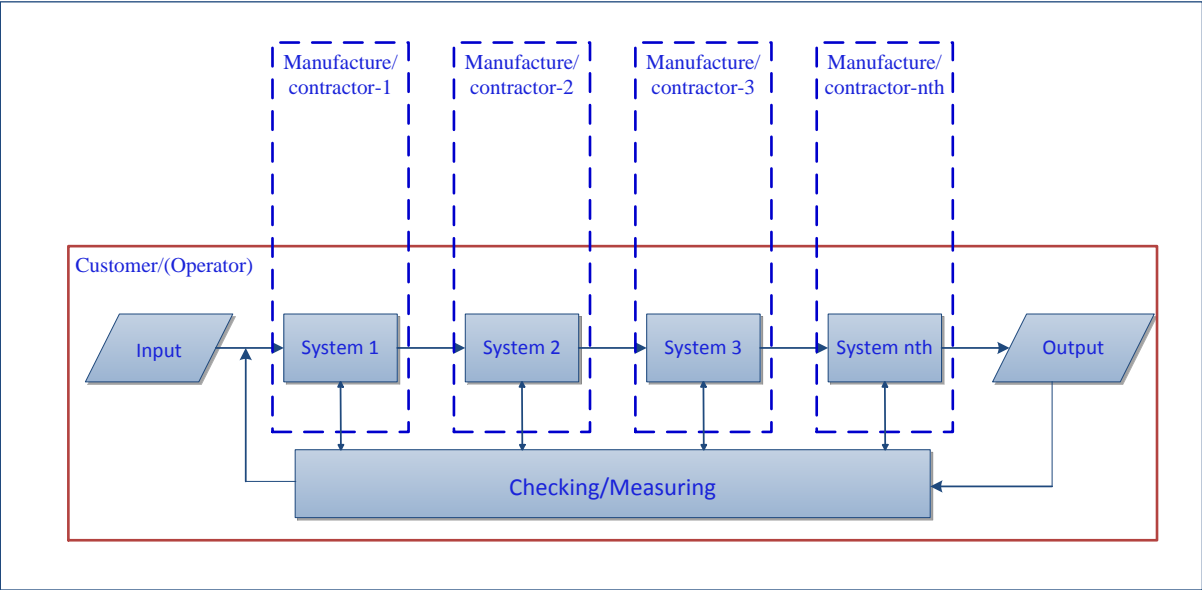


Figure 2.3 Option 1, a system perspective of offshore O&G production line

The contractors have to be responsible of establishing a proper maintenance system and plan, in order to achieve O&M objectives. In addition, they have to identify criticality of elements of the provided system, perform failure analysis, spare part inventory and data management system, and establishing their own maintenance strategy.

The operator have to inspect, control and monitor the measured performance of contractors, ensure the flow of information and interface between different systems (output for system1 “output1”, interface with input for system2 “input2”, and etc. as is shown in Figure 2.2) and ensure systematic feedback to the contractors. The operator and contractors have to collaborate and corporate to ensure safety and availability of the each system and total system for offshore O&G production line.

Option 2: Single contract (One main contractor with total responsible for the delivery of performance of the core process of the offshore O&G production line).

Figure 2.4 is illustrating offshore O&G production line consists of main contractor operator. The contractors have partner and alliance with a number of sub-contractors in order to be able to cover a wider spectrum of technical expertise, the stippled blue line shows main contractor's ownership part including the sub-contractors, and an orange line shows operator's ownership part.

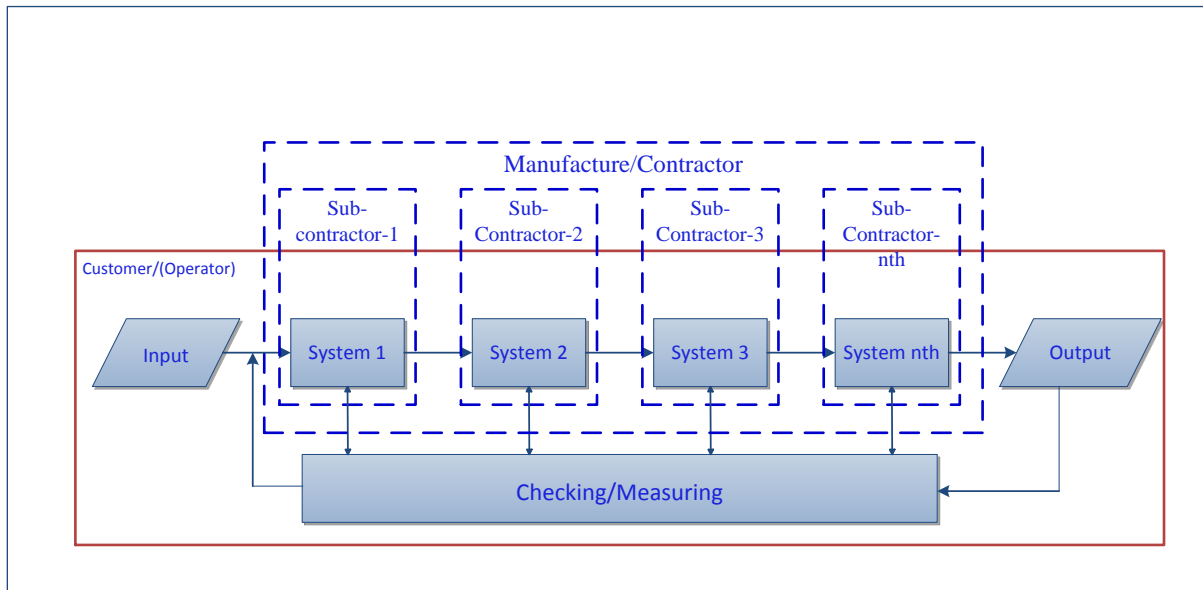


Figure 2.4 Option 2, a system perspective of offshore O&G production line

The operator owns the input and output of the offshore O&G production line. Administrative, technical and functional requirements have to be defined; raw material and governing documents have to be provided to main contractor for the total production facility.

A single contract will be established between the operator and the main contractor. The contractor has the main responsibility to deliver performance in respect with required output of the total production system (e.g. drilling hole by day).

The contractor owns the production line in alliance with other technical expertise e.g. a drilling contractor forms alliances with a number of sub-contractors to be able to cover a wide spectrum of technical expertise such as completion, workovers and well interventions, they share the risk together to delivery performance in term of functionality and availability of their system (output). They have to manage the core process activities such as technical O&M (Hypko et al., 2010). They have responsibility to establish their own O&M objectives and maintenance system in order to secure objectives alignment across contractor's organization.

The main contractor has to manage together with other partners the core process activities in order to secure performance delivery of the total system. Each contractor is responsible to deliver their own system/sub-system and establish their own O&M objectives, they will ensure that their O&M objectives alignment across main contractor’s organization.

The operator and main contractor have responsibility of controlling and monitoring performance measurement of partners’ systems/sub-systems. The main contractor has to secure for interface between system/sub-systems (output for system1 “output1”, interface with input for system2 “input2”, and etc. as is shown in [Figure 2.2](#)) and securing systematic feedback to the operator and other contractors with respect to performance measurement. Main contractor and other contractors are responsible to collaborate and corporate to ensure safety and availability of total system and sub-system of O&G production system.

2.5 ADVANTAGE OF FUNCTIONAL PRODUCTS FROM OPERATOR AND CONTRACTOR PERSPECTIVE

Advantage of the functional products-Operator perspective

There are many parameters that characterized functional products concept, advantage of buying functional products from operator perspective going to be explained in the [Table 2.3](#).

Table 2.3 Advantage of the functional products-Operator perspective

Parameter	Description
Ownership	<ul style="list-style-type: none"> - Lay et al.’s (2009) research regarding service-based business concepts and business-to-business service explained the transformation of traditional buyer-supplier into new exchanging models of delivery and payments. They have provided a set of parameters from different scientific papers in the service-based business to create a common framework, and they concluded: that shifting in ownership structure from traditional business concept to performance-based delivery concept can contribute to economies of the scale and modifying the incentives of the operator. <p>Reduction information asymmetries, since the property rights of the equipment are not transferred to the operator. It is retained by the manufacture / service provider, the operator does not need to put effort to balance the information asymmetries associated with the service provider more complete knowledge of the equipment. The information symmetries regarding service quality become irrelevant since only</p>

	those parts that fulfil the quality requirements are paid (Lay et al., 2009).
Operation & Maintenance	<ul style="list-style-type: none"> - Free personnel resource for operator by transferring the responsibility of technology research, operation and maintenance activities to service provider. - Win-to-win potential due to the contractor's expertise is running their products. It leads to reduce cost and lead times.
Financing	<ul style="list-style-type: none"> - Lower CAPEX Capital Expenditures because of not investing in buying physical products will increase the capability to establish several projects parallel at the same time. - Low level of risk. Since the manufacturer or service provider is not transferring the ownership of the products and taking responsible to perform operation and maintenance process activities of the delivered products. - Reducing cost and lead time due to manufacturer's expertise is running their physical products.
Location of operation	<ul style="list-style-type: none"> - Physical products is to be installed at operator's plant
Retrieval and recycling	<ul style="list-style-type: none"> - The owner of the physical products has the responsibility for retrieving and recycling

[Advantage of the functional products- contractor perspective](#)

There are many parameters that characterized functional products concepts. The advantages of selling functional products from contractor perspective are going to be explained in the Table 2.4.

[Table 2.4 Advantages of the functional products- contractor perspective](#)

Parameter	Description
Organization	<ul style="list-style-type: none"> - Contractor builds long-term relationship with operator. - Contractor gains knowledge with respect to operator's requirements.

Ownership	- The ownership of physical products will remain with contractor, contractor will have more control in operating and maintaining their products/system which lead to improve performance rate, since they are the manufacturer of their products and they are competent for it.
Operation and maintenance	- Contractor has the same aim as operator to optimize the performance of the functional products.
Financing	- Builds long-term business relation, gives financial benefits

2.6 CRITICAL CHALLENGES OF FUNCTIONAL PRODUCTS

There are various challenges that could be raised in a maintenance perspective of functional products in different life cycles. A number of critical challenges have to be categorized based on qualitative assessment, their manageability, consequence on Health, Safety and Environment (HSE), production and cost. The given challenges below are considered critical since they have high impact and are difficult to manage for O&M of the functional products. To ensure a successful design of the maintenance strategy for functional product in an O&G production line it is necessary to meet all these challenges. The identified operation and maintenance life cycle challenges of the O&G production line are as follow:

2.6.1 Design phase:

- 1- Service support system: The design of the service support system for functional products are less established in the literature and practice by the contractors, in compare to physical products which are well established in literature and practice (Alonso-Rasgado et al., 2004).
- 2- Mind-set change in operator organization from traditional business concept to performance-based service concept of functional products. Operator prefers to have in-house maintenance and operation organization for better control of assets and availability, but with some exception operator outsources maintenance activities that requires specialized knowledge such as turbines, inspection of subset structures, etc.

2.6.2 Operation phase:

- 1- Operator's process facility has own maintenance system to manage maintenance activities, all operation data, contractor has own maintenance system where they are able to manage maintenance activities separated from operator's maintenance system, this lead to decrease the effectiveness, efficiency and quality of the total operating system.
- 2- From contractors' perspective, contractors have to manage two maintenance systems if contractor's maintenance system is integrated into operator's system. Additional if the contractor is committed to deliver functional performance to more than one operator. This can lead to conflict and decrease effectiveness, efficiency and quality of the contractors' performance.
- 3- Operator's process facility has long experience and big O&M organization with respect to personnel, procedures and strategy in order to following up, control and monitor process facility. The contractors have difficulties to meet operator's requirements with respect to process facility because of contractor's limited size of operation and maintenance organization.
- 4- Poor following up and control mechanism from operator perspective with respect to maintenance performance activities because of few and not competent personnel, who has influence on the optimization of operation work performance of the functional products.

2.6.3 Maintenance phase:

- 1- Maintenance strategy: Large number of physical products owned by operator and contractor's functional products will be installed in the operator's production line for processing oil/gas. The functional products will be connected to the operator's process system. Contractor's maintenance system should be integrated to accommodate those integrated high-end operator's maintenance system. Contractor maintenance personnel will face challenge to operate with two different systems, operator personnel will face challenge to define extensive preventive and predictive maintenance strategy that suit with overall system needs. Additionally, there are other factors that have influence on maintenance strategy which is explained below.

HSE: it is the most critical factor because of the large, complex, automated and critical integrated system, and many personnel involved to work in hydrocarbon zone (e.g. secure sub-contractor's focus on HSE).

Implementation and execution: implementation and execution of maintenance strategy with respect to performance of work, responsibility, control and interface activities.

Spare parts: spare parts management for the functional products should be managed carefully since contractor and operator has to different maintenance systems.

Logistic: logistic management, including the five elements information, transportation, inventory, and warehousing, material handling, and packaging for functional products. Additional, to develop a logistic plan would be critical factor given a big number of interface partners and activities.

Interface: Interface management, different maintenance systems for different contractor will cause big challenge in cooperation and exchange of experience and information between operator and contractors organization.

Controlling: Operator's challenge in following up and implementing control mechanism with respect to maintenance performance activities because of few and not competent personnel who has influence to optimize maintenance work performance of the functional products activities (e.g. if the operator is planning common preventive maintenance strategy in term of planned shutdown to perform maintenance activities simultaneously on all functional products, each year in three weeks. How can the operator control and measure it).

Information technology: Operator's difficulties to get access to contractor's database with respect to maintenance activities.

Short duration service delivery: according to operator's estimations and experiences for short duration service such as well drilling, it cost three time for operator to buy performance service delivery of drilling unit, than it cost to buy, operate and maintain of drilling unit. Operator is in doubt if it is profitable to implement performance based delivery for production line, when Operational Expenditure (OPEX) is going to be continually high over the whole production time.

Long duration service delivery: payment model is a critical factor, how to calculate

Operator's challenge that contractor secure high maintenance performance and competence of contractor's personnel in operator's process facility.

2.7 MAINTENANCE MANAGEMENT SYSTEM

The purpose of defining maintenance management system is to secure and contribute to safe, reliable and efficient operation of functional products for O&G production line. It enables the operator and contractor to comply with external and internal requirements. As well as it supports contractor maintenance performance through high quality decision making, fast and precise execution, control of maintenance actions and continuous improving and learning.

According to EN13306 (2010) maintenance management is defined as “all activities of management that determines objectives, strategies and responsibility and implement them by means such maintenance planning, maintenance control and supervision, improvement of methods in organization including economical aspects.”. Maintenance management function consists of following:

- 1- Planning maintenance activities,
- 2- Organizing/scheduling maintenance activities,
- 3- Implementing and execution maintenance activities.

It involves two main groups of activities, the first group is addressed to be aware of the requirements, state of assets, implementation of actions and decisions in respect to maintenance, and the second part involves maintenance supportability.

Maintenance supportability is defined as “*ability of a maintenance organization of having the right maintenance support, at the necessary place to perform the required maintenance activity at a given instant of time or during a given time interval*” (EN13306, 2010).

The contractor have to implement the structure of the maintenance management system for O&G production line and its associated functional products’ two aspects:

- 1- Maintenance management process.
- 2- Maintenance management techniques framework.

2.7.1 The maintenance management process

The main purpose of maintenance management process is to ensure that required functional products such as availability, reliability, and integrity levels are achieved, at an acceptable cost level (maximum profit). It is a course of action by following a series of stages in order to manage and control maintenance activities properly for an asset.

Maintenance management process is a continuous process based on quality management system. Quality management system is defined as organization’s work steering with respect to product and service quality which is includes processes, documents, resources and monitoring systems (ISO 9001, 2000).

The contractor organization has to establish document to carry out and maintain quality management system to meet ISO's 9001 requirements and has to perform two main activities in order to meet ISO's 9001 requirements:

- 1- Document quality policy, quality objectives and quality manual.
- 2- Carry out procedures, plans and operations to describe how product and service quality is achieved.

The contractor organization's size, activities type, or process complexity are deciding detail, quality, and form of documentation. The contractor has to define quality policy in order to achieve main quality management objectives. The quality policy has to be:

- 1- Suitable to contractor organization's purpose.
- 2- Committed to meet requirements with respect to legal, regulatory and operator.
- 3- Able to create a background to establish quality objectives.
- 4- Communicated throughout operator and contractor organizations.

The contractor organization has to define measurable quality objectives in order to support quality polices.

Maintenance management process consists of the following groups as it shown in [Figure 2.5](#):

- Maintenance management sequence.
- Maintenance resource management.
- Measurement, analysis and improvement.

A sequence of management process have to be carried out by contractor, starting with defining maintenance policy and objectives, planning operations, assigning resources, execution and following up by monitoring. The contractor has to manage maintenance resource of physical elements such as human resource, spare parts, spare parts stock and preservation, and information safety, etc. The different stages of the management sequence will create managerial actions on the physical elements of contractor's maintenance organization. During execution stage of the maintenance operations on the assets, a process of measurement, assessment and improvement have to be started by contractor, and have to be compared with the operator's objectives and requirements. After the explained processes above, implementation tasks can be carried out by using a set of managerial tools and techniques such as failure mode and effect analysis, etc. In the next section, the maintenance management techniques framework will cover the implementation stage and suggested techniques.

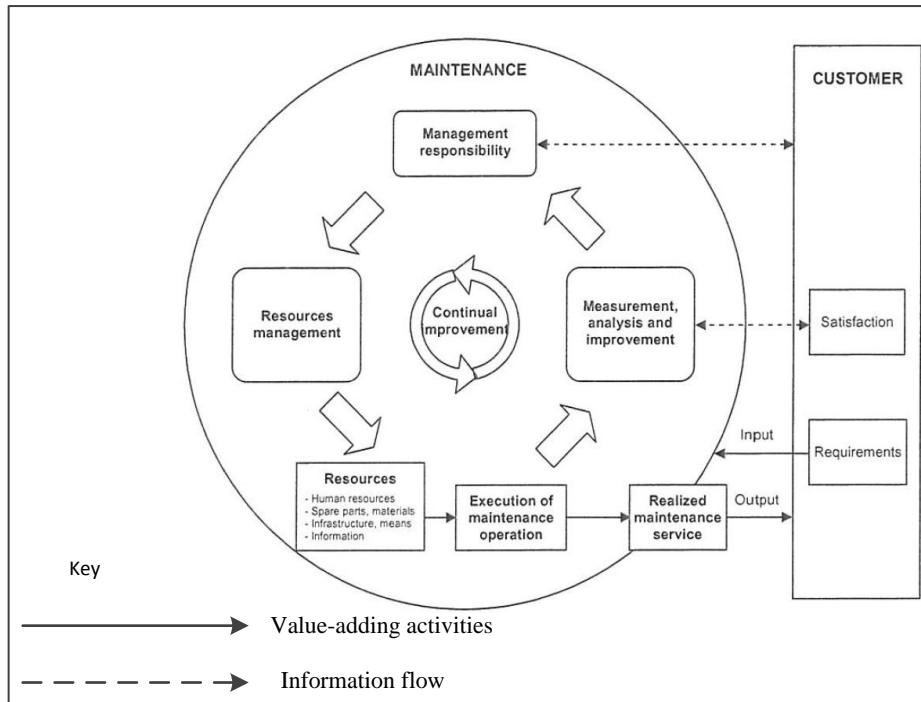


Figure 2.5 Model of organization maintenance management process adapted from (ISO 9001, 2000)

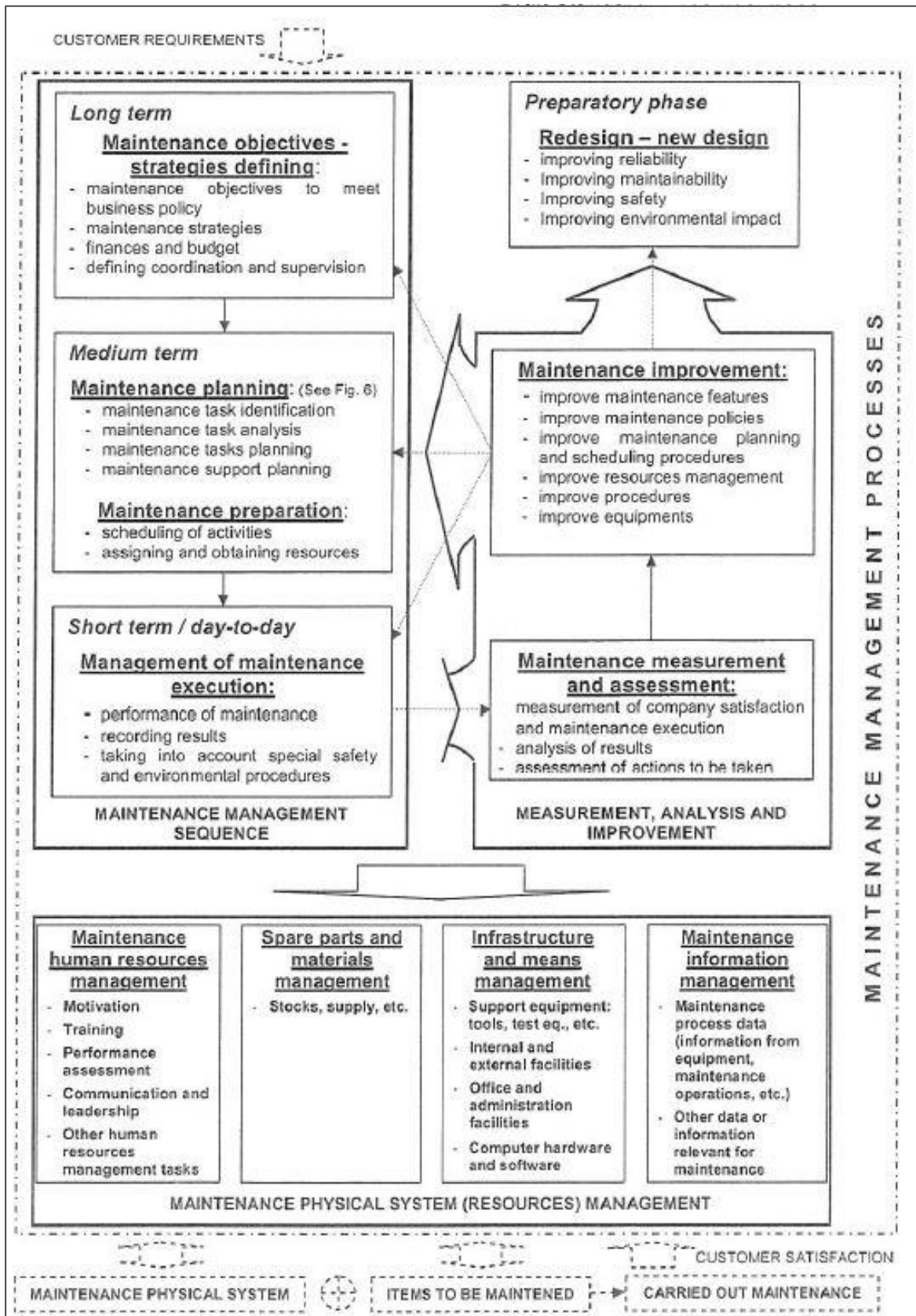


Figure 2.6 Maintenance management processes (ISO 9001, 2000)

2.7.2 Maintenance policy

The contractors and subcontractors have to establish a maintenance policy to guide planning, execution, assessment, analysis and improvement of maintenance to meet Norwegian Petroleum Directorate's (NPD) and operator's requirements.

The maintenance objectives of functional products have to be developed and established from corporate policy and requirements. These objectives may include safety, security, availability, performance and maintenance cost and should be communicated throughout contractor's maintenance organization.

The action plan should be developed from the maintenance objectives. It provides basis to ensure operator's requirements are fulfilled. Improvements can be planned based on accepted user and maintenance oriented performance measures. The plan may include type of maintenance that should be applied to each asset, replacement, overhaul, service support, etc., or improvement new tool and method to monitor the operation, implementing better information management or more efficient work management processes (ISO 9001, 2000).

2.7.3 Maintenance objectives and strategy defining

The maintenance strategy requires maintenance strategic objectives definition for functional products. It provides a clear guidance and direction which represents the success factor of the maintenance, and secures effectiveness of implementation of the maintenance plans, schedules, controls and improvements. Maintenance objectives can be divided into three categories presented by (Crespo Márquez, 2007):

1- Technical objectives for functional products:

- Safety operation and environmental friendly-zero accident, low/reduction of the harmful emission that may have effect on the environment, avoiding oil spill and disturbing the ecosystem in the surround area.
- Secure integration of the functional products into operator's process facility.
- Secure availability of functional products/system in the operative state with non- failed state and high level of availability
- Secure reliability, maintainability, and supportability of functional products/system.
- Secure operability of functional system.
- Secure effective of the production performance which is depending upon maintenance plan implemented to each technical system/functional system-maintenance management.

2- Mandatory regulations:

- Secure that provided functional products/system has fulfilled the existing regulation to obtain maintenance objectives.

3- Financial objectives

- Minimum cost of buy functional performance and minimum cost of offering functional products including service support system to satisfy given technical objectives.

The contractor has to determine RAMSS of their system, in order to set up an optimal maintenance and inspection plan. The European Committee for Electrotechnical Standardization (CENELEC), and standards EN 50126, EN 50128 and ENV 50129 are inputs to the RAMSS requirements. Problems that could arise from malfunctions of functional products/systems should be determined. Failure mode, Effect and Criticality Analysis (FMECA) can be used for failure analysis. Thereafter maintenance and inspection types and intervals should be determined. In principle each failure mode should be combated by maintenance task. A proactive maintenance such as Reliability Centred Maintenance (RCM) has to be applied, where different maintenance strategies combined. By analyzing the system of the functional products used in the production line system, the functional products can be divided into different groups based on different maintenance approaches which are mentioned in maintenance strategy section 2.9.2. Implement and develop of different components of the maintenance physical system should be carried out. In addition, it should decide to implement different elements of the management techniques framework such as Computer Maintenance Management System (CMMS) in order to secure the efficiency of the management with respect to produce minimum waste and unnecessary effort.

2.7.4 Asset maintenance planning

There are two main groups of actions and decisions process which is illustrating maintenance management process model as shown in [Figure 2.6](#), it is listed below:

2.7.4.1 Maintenance planning:

- Maintenance asset identification
- Maintenance asset analysis
- Maintenance asset planning
- Maintenance support planning

2.7.4.2 Maintenance preparation:

There are two main items under maintenance preparation:

- Scheduling of activities
- Assigning and obtaining resources

The maintenance organization have to carry out asset maintenance planning by identifying asset, prioritizing the asset according to maintenance strategy, identifying asset's performance requirements according to strategy, evaluating the asset's performance, planning for asset maintenance.

The contractor has to identify maintenance activities by combining different approaches in order to ensure their detailed maintenance planning and prioritizing of asset (Crespo Márquez, 2007), it is necessary to incorporate the following:

- Adopting manufactures' recommendations document related to maintenance and operation;
- Using maintenance engineering technique such as RCM based on the FMECA method, to analysis assets;
- Study and analyzing technical documentations for each prioritized asset
- Considering regulatory requirements for safety condition of asset operation, environmental regulations for the asset, etc.

Additionally, they have to perform maintenance activity analysis in order to determine the specific information and resources for maintained asset. According to (ISO 9001, 2000) planning for maintenance should consider the following requirements for each asset:

- Operator requirements regarding availability objectives and targets such as productivities, capacity, effectiveness operational costs, etc.
- Operator and authority requirements related to safety, environment and regulation;
- Methodology for maintenance optimization
- Management and organizational responsibility for maintenance activities
- Support resource involved and time required performing maintenance activities
- Inspection, monitoring and measurement should be done
- Availability of the support resources
- Review procedures to verify that maintenance activities are successfully completed

Maintenance task definition and the maintenance capacity planning can be finalized when given process above applied on all assets.

2.7.5 Maintenance Schedule

The contractor has to document system for maintenance planning activities. They should have enough time and resources to schedule maintenance activities. Maintenance schedule can be achieved by ensuring the following activities:

- Assigning competence personnel
- Acquiring products and spare parts from inventory
- Total support services including tools, transport and lifting are available
- All necessary procedures with respect to safety, operating, maintenance and work plans should be prepared
- Identifying availability of external resources
- Identifying communication resources
- Providing personnel training.

2.7.6 Management of maintenance execution including information gathering and processing

The contractor has to perform maintenance activities carefully regarding disassemble, cleaning, repairing, refurbishing, replacement, reassemble, and testing of the physical product. Information should be recorded regarding inspection and measurements required. It is necessary to consider the following list below before applying preventative maintenance program (IEC 60300-3-4, 2007):

- Store of the performed tasks/activities (e.g. technical data and activities description)
- Securing spare parts and testing equipment
- Securing service support system such support product and service personnel
- Securing inspection activities are carried out in respect to plan
- Securing recording information

2.7.7 Assess maintenance

The contractors have to perform assessment of preventive and corrective maintenance activities either after a major failure or on periodic basis in order to review performance of prioritized asset for certain of time (IEC 60300-3-4, 2007). They have to establish and use of computerize maintenance information system, in order to collect data, analyzing data and interpreting results. The assessment of preventive maintenance should cover technical aspects of maintenance activities, availability of resource and operating, effectiveness of maintenance, safety and environmental procedures. The assessment of corrective maintenance should cover the major failure, major costly failure, and major HSE issues in order to carry out fully investigation to identify preventive and corrective actions.

2.7.8 Ensure continuous maintenance improvement

The contractors have responsibility for improvement of support system. An improvement planning has to be done according to operating company's overall plan. This can be achieved by having available management support, effective process throughout sharing knowledge, collaboration and good communication between different organization's levels and subcontractors, improvement in maintenance level and procedures, spare parts logistic, safety and environment procedures, maintainability of an asset, skills and training of personnel, integrate new technical, operational and organizational barriers, etc..

2.8 MAINTENANCE MANAGEMENT TECHNIQUES FRAMEWORK

The function of maintenance management techniques framework is to support the structure of the maintenance management system which becomes a part of the organization structure (Crespo Márquez, 2007). Maintenance management techniques framework consists of many different techniques, methods, knowledge and managerial tools which are necessary for the maintenance management to reach its objectives. These activities are only management activities or tasks that should be applied on the assets that should be maintained. The physical actions on the assets are not included in this part (ISO 9001, 2000).

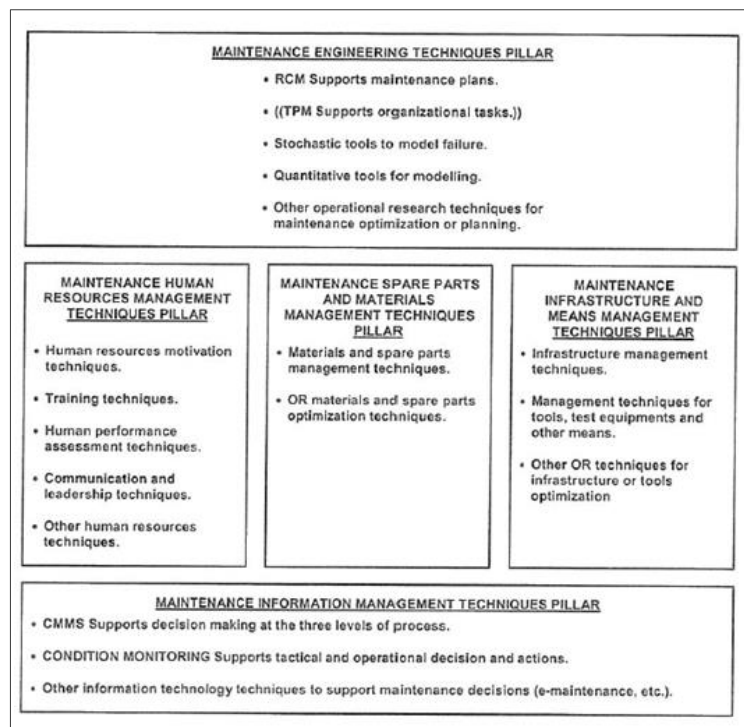


Figure 2.7 Maintenance management techniques framework (ISO 9001, 2000)

The structure of the maintenance management techniques framework consists of five main areas of managerial tools as it shown in [Figure 2.7](#):

- Maintenance engineering techniques.
- Maintenance human resource management techniques.
- Maintenance materials and spare parts management.
- Maintenance infrastructure and means techniques.
- Maintenance information management technique.

[2.8.1 Maintenance engineering techniques](#)

There are many engineering techniques and methodologies which are used to support maintenance management processes within maintenance and operation plans and schedules, policies, optimization maintenance policies, maintenance decisions, etc.

RCM supports maintenance plan

RCM is engineering technique used by maintenance management organization to support design of maintenance plan and policy.

Total Productive Maintenance (TPM) supports organizational tasks

TPM is engineering technique used by maintenance management organization to support design of maintenance related to overall equipment effectiveness.

[2.8.2 Maintenance human resource management techniques](#)

Maintenance human resource management techniques such as SAP software aim to optimize performance of maintenance personnel and general maintenance personnel working activities. It assures the best interface among different personnel discipline within organization and among external organizations, personnel motivation, leadership, inter personnel communication, etc.

[2.8.3 Maintenance materials and spare parts management](#)

Materials and spare parts management software is one of the most important software program (e.g. SAP software) that can be used in projects. It aims to manage spare parts and services (buying, supplying, handling, storing, planning, controlling, analysis of service and spare parts, etc.) for an asset. It can be used to monitor internal and external contractors and subcontractors including service procurement, contractor and subcontractor management.

2.8.4 Maintenance infrastructure and means techniques

The purpose of these techniques is to implement maintenance operations for different assets. These techniques are not used for maintenance but it is directed to subjects such as tools, maintenance workshop equipment and test equipment, maintenance building, installations, etc.

2.8.5 Maintenance information management techniques

The purpose of these techniques is to support maintenance management processes and implementation of the other techniques. These techniques are related direct to maintenance activities in term of data management such as CMMS.

CMMS is a management tool consisting of hardware and software packages. The purpose of using this tool is to manage the maintenance of equipment and the facility. Using CMMS can reduce costs and improve work efficiency. There are several function modules in CMMS as it is listed below:

- Equipment identification and Bill of Materials (BOM): identification of functional products can be integrated with operator's system of production line facility, which will allow control for maintenance, recertification, and repair.
- Planning and scheduling: planning and scheduling for manpower, time, and cost for optimizing.
- Work order management: requirement, scope of work, and information of the task in stored in work order system. Production facility has a lot of activities that needs to be prioritized using this system.
- Preventive maintenance: using predictive and preventive maintenance of production facility (e.g. condition monitoring for functional products).

2.9 MAPPING MAINTENANCE STRATEGY

To be able to map maintenance strategies of functional products for an O&G production line, the author had to identify maintenance systems and maintenance strategies. Thereafter, section 2.9.3-to-2.9.11 presented factors that influence on the design of maintenance strategy for functional products based on the given maintenance objectives and critical challenges of functional products which are presented in section 2.7&2.7.3:

2.9.1 Maintenance system

The maintenance system have to be based on an evaluation of the equipment and functions to ensure that critical equipment in respect with safety, production/regularity and cost receives the highest priority, that can be identified and included in contractor's management system. The maintenance system should be managed by the following activities:

- 1- It is necessary to define clear maintenance objectives by contractor based on operator's objectives.
- 2- Responsibility for planning, implementation and following up of maintenance should be defined.
- 3- Equipment classification should be identified including all data necessary for identification of the individual equipment items, which helps to generate system analyses and statistics from experiences with equipment failures, problems, and malfunctions.
- 4- Overdue planned maintenance and corrective maintenance for critical equipment with respect to safety, regularity and cost should be recorded and evaluate.
- 5- Collecting user experience for the purpose of improving functionality, reliability and safety of equipment and operations.
- 6- System's capability to integrate maintenance program, spare parts, and able to purchasing and finance in a common system.

2.9.2 Maintenance strategy

Functional products maintenance strategy can be defined as a direction and recommendation how to achieve maintenance objectives. These objectives should be reached through continuous efforts to improve effectiveness and optimization maintenance.

In order to achieve effective maintenance, it is necessary to plan, identify and analyze equipment history. The following steps give effective and optimized maintenance for equipment:

- 1- Failure detection.
- 2- Failure Tree Analysis (FTA).
- 3- Failure Mode and Effects Analysis (FMEA) and FMECA.
- 4- RCM.
- 5- Interval optimization.

Criticality and consequence classification of physical products should be established and implemented, thereafter started preparation of maintenance strategy for physical product. The criticality of physical product that might bring serious consequences is determined by use maintenance historical data. Critical physical products can be defined as equipment or system's failure. All O&G production line physical products must be classified based on

consequence of failure. Consequence of failure can be classified in the following categories:
 1) HSE; 2) production; 3) Costs, as it is shown in [Table 2.5](#).

Table 2.5 Criticality and consequence classification

	Consequence categories			
		HSE	Production/regularity	Cost
Consequence class	High	Potential death, severe personal injury. Equipment that is critical for safety out of function. Potential major environment pollution.	Shutdown or considerable reduction of production-where the value of the production loss defined limits X per day for plant	Considerable cost which exceeds Y in the current exchange plant rate
	Medium	Potential personal injury which needs medical treatment. No fire hazards in classified areas. Limited effect on safety systems	Shutdown or reduction of production where the value of production loss is less than the defined limit X per day for plant	Moderate cost between X-Y in the current exchange plant rate
	Low	No potential personal injury. No fire hazards or effects on the safety systems. No potential environmental pollution	No direct effect on production	Insignificant cost which is less than Z defined current exchange plant rate

There are different maintenance strategy approaches available for handling production line processes. In order to decide which strategy approach should be used, the contractors have to understand operator's business process as a first step, particularly as it relates to the management of maintenance needs.

[Figure 2.8](#) illustrate the most common approaches to maintenance strategy adopted by O&G industrial organizations to manage their maintenance processes. The approach can be divided into three main groups as it is explained below (Farrel, 2011):

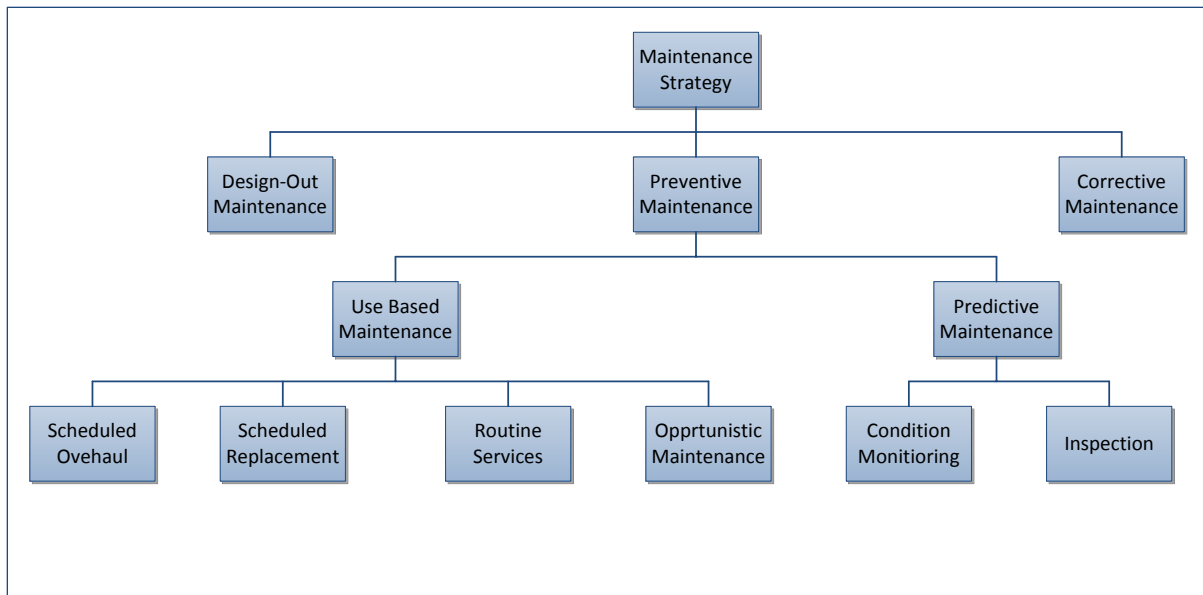


Figure 2.8 An illustration of different approaches to maintenance strategy (Farrel, 2011)

2.9.2.1 Design out maintenance

Design out maintenance of functional products for O&G production line facility is necessary strategy to secure reliability, availability, maintainability, supportability and safety (RAMSS) of O&G production line. It will influence the reliability of the operation for the O&G production line. The objective of this strategy is to manage adverse failure modes by redesigning the particular component or system in order to decrease the need for maintenance.

2.9.2.2 Corrective/Breakdown maintenance

It is known as “not doing” or “run-to-failure” maintenance. Maintenance people wait until equipment fails. Equipment runs until it is not able to deliver their intended functions and then they will be either repaired or replaced. This type of maintenance can be used when the equipment failure does not threaten safety, environment or production, and where the cost of preventing failure would be greater than the consequence of failure. The total maintenance cost will be the cost of equipment replacement or repaired, in addition to the cost of loss/deferred production due to equipment breakdown.

2.9.2.3 Preventive maintenance

It is commonly known as scheduled/planned maintenance. The maintenance on particular equipment is performed regularly/daily such as visual inspection and vibration monitoring at scheduled intervals. This type of maintenance can be used for highly critical equipment where the cost of failure is high, availability of spare parts and rapid replacement must be planned

for, and where failure has negative impact on safety or environment. This maintenance approach is divided into periodic maintenance and predictive maintenance:

Periodic maintenance is known as Time Based Maintenance (TBM). It consists of periodically inspection/routine inspection, routine lubrication, service and replacement of equipment/parts to avoid a sudden failure to occur.

Inspection: Activity can be carried out in different phases before, during and/or after maintenance activities. The purpose of inspection activities is to confirm the relevant characteristics or property of an asset by checking, measuring, observing, testing or gauging.

Predictive maintenance is also known as Condition Based Maintenance (CBM). The equipment is monitored continuously/ regular intervals depend on the nature of the failure degradation. Also, it manages the historical trends values, by measuring and analysis equipment deterioration data to predict future behavior, so maintenance can be planned in the most effective schedule and shows the necessity for known downtimes before the failure actually occurs.

2.9.3 Harmonization

It is necessary to optimize design of maintenance strategy for the O&G production line by harmonizing contractors' and sub-contractors' maintenance system with operator's overall maintenance system. This can be achieved by defining a clear maintenance objectives and strategy. All objectives established by contractors' or service providers' organization that should be coordinated, so the efforts in all areas will be directed towards a common operator's overall goal. This leads to each contractor/service provider committed to establish a goal hierarchy for their physical product, as shown in [Figure 2.9](#) (e.g. maintenance system should be integrated into high-end operator's maintenance system), (e.g. maintenance objective: availability 99%) will be a measure to achieve operator's overall objective, (e.g. a capacity of 1,000 barrels / hour) and satisfy operator's needs and expectations, and fulfill the given operator's requirements (Rolstadås et al., 1999).

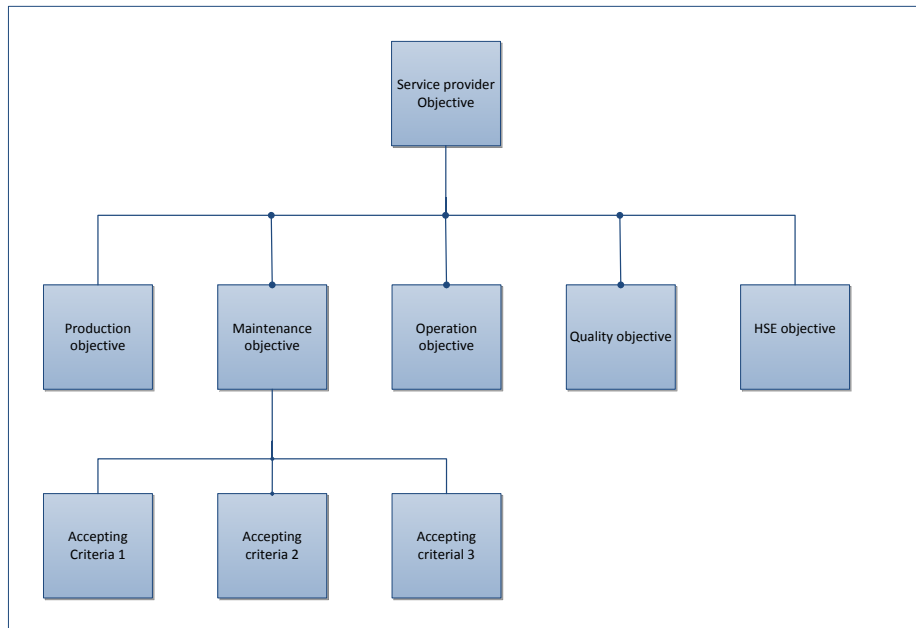


Figure 2.9 Different levels of goal hierarchy, adapted from (Rolstadås et al., 1999)

The contractors' objectives should not be considered independent objectives from the others service providers, although they lie on the same line in a hierarchy as shown in

Figure 2.10. The overall level and all functions which lie on the same line in a hierarchy will influence and depend on each other through a work process, and therefore must be harmonized.

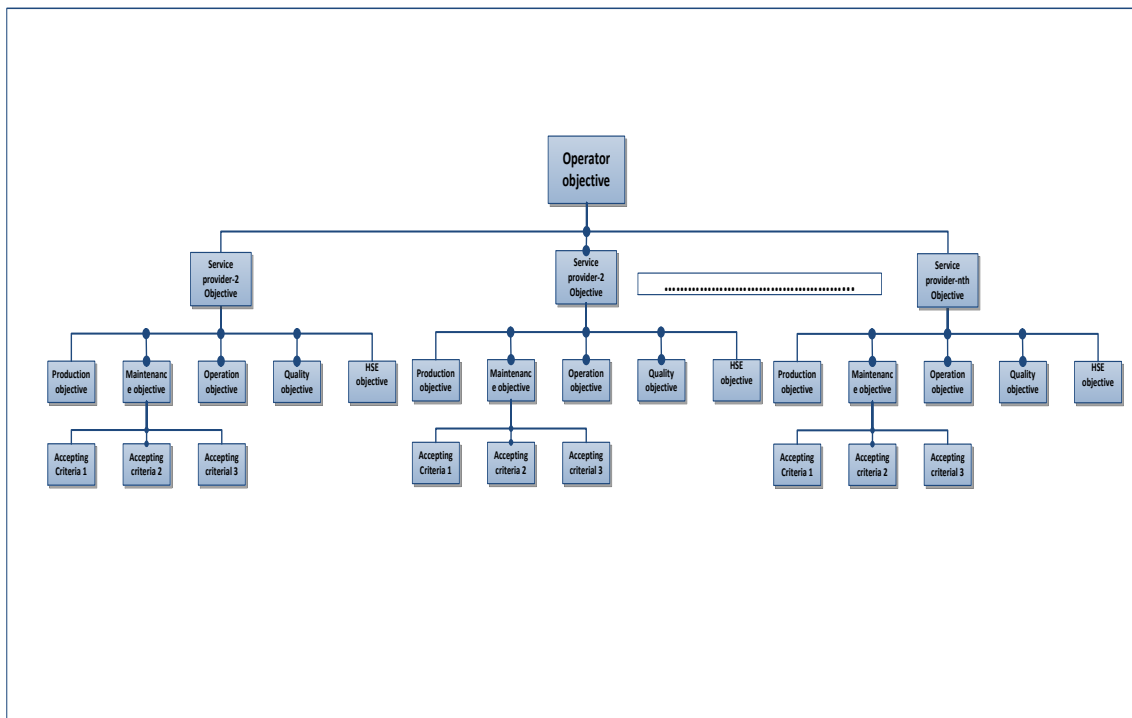


Figure 2.10 Production line system perspective on different levels of goal hierarchy

Each involved parties need to set up sub-conclusions given in the form of guidelines for how an objective for maintenance should be developed to achieve operator's overall objective (e.g. reliability should be integrated in the operator's objective to demonstrate importance of maintenance function. Operational, technical and organizational barriers should be integrated to avoid/prevent a specific chain of events could cause damage/loss for human or environment).

2.9.4 Authority requirements

Main rules and regulation have to be met with respect to maintenance. Physical product criticality and consequence classification should be defined, and type of maintenance should be applied.

2.9.5 Operator Requirements

Operator requirements regarding HSE, availability of production and resource, capacity, cost-effectiveness have to be met by the involved parties.

2.9.6 Responsibility

Management and organization responsibility should be defined for maintenance activities, since there are many parties involved in process facility.

2.9.7 Operational profile

Operational profile should be defined by contractors based on operator's requirements. It is a critical factor that should be considered to secure a common maintenance strategy for different parties (e.g. yearly and 6 monthly planned main overhaul, inspection and maintenance jobs on equipment, and should be scheduled to the summer season.).

2.9.8 Design of functional product

Conceptual phase: operator has to set up technical basis for the O&G production line and each functional product. Manufacture/contractor has to challenge the given concept in order to

meet at the most optimal concept. Many meetings have to be held to agree on specific concepts. Each involved party has to carry out concept optimization through close communication and collaboration with the operator.

Design phase: the operator has to set up a design basis document for the O&G production line including the functional requirements (e.g. producing, exporting, and receiving oil/gas). Each involved party has to identify all project needs of hardware and software, and service support. Interface factors have to be solved and identified by the operator and contractors, since there are many parties involved, these parties have a big influence on project performance. The interface factor divides into two aspects:

- 1- Physical interface aspect: It is important to create schedule studies interface by identifying the interface between physical products (e.g. create plant interface, tie-in, and etc.).
- 2- Organization interface aspect: It is important to create a communication strategy between involved parties, and to create control and monitoring functions for the project.

Alonso-Rasgado et al. (2004) have established a method for functional product design with a main focus on service support systems, since there is a lack of literature and methods as they have stated, while the hardware is well defined in the literature and practice. There are five phases that have been defined in the design of service support systems for functional products, as listed below, it is shown in Figure 2.11:

- 1- Concept creation.
- 2- Identification of sub-system (e.g. innovative sub-system, an existing sub-system, adaptive existing sub-systems).
- 3- Integration of the subsystems that together have to provide service performance.
- 4- Modelling of the proposed system.
- 5- Testing, implementing and execution.

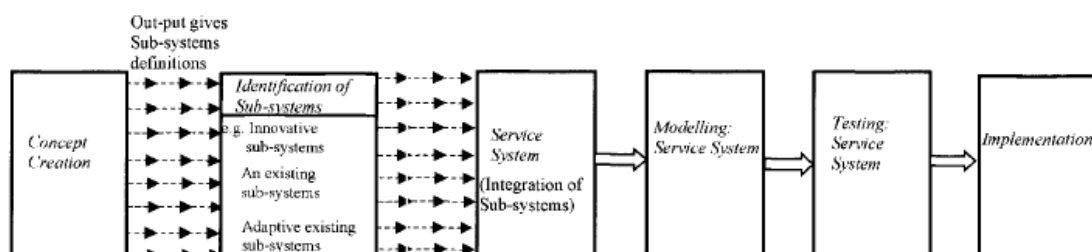


Figure 2.11 Five phases of service support design (Alonso-Rasgado et al., 2004)

The designed service system has to include all activities and actions which is required to ensure a certain function of equipment. The service system called total support system that covers the following:

- Spares provision, operation, on-site activities support, and remanufacture
- Decision-making and forecasting
- Training of users and service provider

2.9.9 Life Cycle Cost (LCC) analysis for functional products

The LCC analysis is an engineering and economical optimization technique to determine cost of the functional products over its entire life span. It is used to compare the cost of various alternatives of an equipment or system and to secure reliability, maintainability, and supportability of the functional products (Alonso-Rasgado et al., 2004). Additionally, it is necessary for the manufacture/service provider to include service support system design calculation in this phase in addition to the hardware design calculation.

LCC analysis calculation will secure functional products, operation, and recycle design optimization to generate the benefit of total system value. LCC analysis includes calculation of Capital Expenditure (CAPEX), OPEX, and cost of deferred production (production downtime). The general principles simplified block diagram of LCC is shown in [Figure 2.12](#).

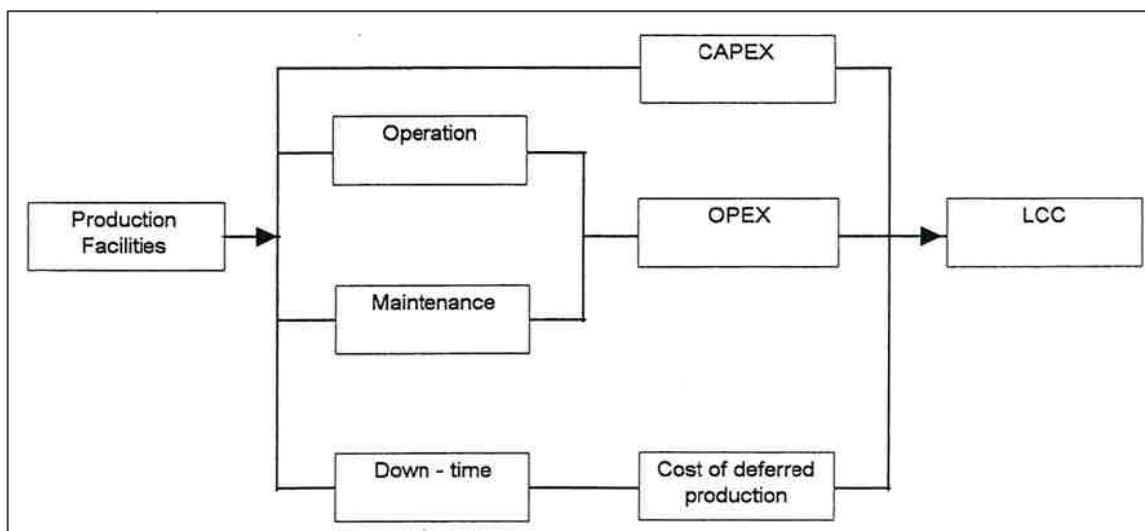


Figure 2.12 LCC Analysis for functional products (Odland, 2012)

Functional products, installation, and commissioning cost are calculated under capital category, required man-hours for total service support system (operating and maintaining the equipment, spare parts, and repair) cost is calculated under operational category.

2.9.10 Spare parts philosophy

The maintenance elements that are related to availability, operational, performance and reliability can be achieved through contractors' spare parts management philosophy.

Each functional product should have sufficient number of necessary spare parts available for an emergency condition and possible repair. The need for spare parts shall be determined for each system based on the following activities:

- Risk rating and assessment
- Failure, damage and repair event scenarios
- System specific factors

The contractors and subcontractors should meet operator requirement with respect to spare management. Contractor's spare parts management should be approved by operator in order to secure availability of the spare parts equipment.

Functional products of the O&G production line will require spare parts for the addressed list below:

- All contractors and subcontractors equipment need spare parts to minimize the risk of obsolete part of equipment through its life cycle
- Long delivery time of spare parts for critical functional products
- Secure the lowest cost and safety for the part during operation and installation activities for O&G production line to guarantee the reliable operation of the field

In order to manage spare parts logistic and inventory by contractors, it needs to implement a robust inventory control system and procedures to ensure the efficiency of the operation and maintenance O&G production line.

By determining quantity and type of the spare parts, the contractors can fully utilize the use of production facility place and avoid unnecessary cost for storing parts and to preserve it. The availability of the spare part is an important factor to avoid downtime and loss of the production (e.g. spare parts for routine maintenance have always to be immediately available to secure maintenance performance). Additionally, there are many other issues have to be consider to ensure the efficiency of the O&M such as location, inventory control, obsolete part, replace vs. repair philosophy, criticality, and rate of consumption.

There are some standardized methods can be applied to manage spare parts, logistic, and inventory of functional products operation as it is explained below (Niebel, 1994):

- ABC classification system for inventory, it can be used to identify and categorize parts for periodic maintenance, in order to avoid overstock or understock, avoid losses due to spoilage and obsolescence and obtain the best turnover rate on all items in term of cost. ABC classification for contractors can be integrated with the operator's equipment.
- Computerized maintenance inventory control, integration computer of maintenance inventory control for functional products to secure flexibility capability to control of spare parts for operation during its late life.
- Inventory record system
- Safety stock and lead times, buffer stock is important to secure uncertainties in supply critical parts on time.

2.9.11 Incentive contract

It is a type of contract that is used to control the performance service delivery/functional products. There are different aspects that are covered by contract such as condition and requirements, scope of work, payment method, etc.

Incentive contract is a powerful method used in order to get the contractors to collaborate with operator. This type of arrangement will motivate contractor's personnel to optimize performance of functional products and to save resource and costs. The cost savings of functional product's operation will be split between contractor and operator on the basis of a bonus paid for achieving defined target and objectives.

The operator aims to utilize the performance of the functional products with respect to the time as efficient as possible, and to achieve that the operator would use incentive contract to increase the efficiency of the operations process activities.

3 Case study

This case study aims to provide a broad picture and an understanding of the maintenance design strategy of a performance based service delivery. A case study was carried out using a semisubmersible Mobile Offshore Drilling Unit (MODU), operated on the Norwegian continental shelf. The MODU plays a central role in the well construction processes, and many parties are involved to deliver technology, equipment, knowledge and services to the operator company.

[This chapter is divided into four parts:](#)

The first part: This part of case study presents the basic offshore rotary rig to get an overview of main systems and equipment which is involved in well drilling operation. The main system and equipment are delivered by drilling rig contractor and sub-contractors,

The second part: This part of case study presents the drilling and well professionals in O&G companies to get an overview of well construction processes, responsibility sharing between different organizations: operator, drilling rig contractor, subcontractor and service company's organizations.



Figure 3.1 Semisubmersible rig (Seadrill, 2007)

The third part: Presents semi-submersible mobile rig unit contract to get an overview of the complexity of performance based contracts for drilling well operations. The main focus in contracts is directed toward rules and conditions, work performance, responsibilities and control mechanisms (e.g. payment method model) to ensure performance of the drilling rig unit.

The fourth part: The author conducted guided interviews and questionnaire with management and operative personnel from operator and contractor involved in setting up contracts and managing drilling rig facilities for MODU. This has been done in order to understand how operator and contractors are defining maintenance strategy for functional products, when contractor has the responsibility to deliver functional performance, and how it can be considered of installing/buying functional products in operator's process facilities.

3.1 THE BASIC OFFSHORE ROTARY RIG

In this section the author presents the basic offshore rotary rig. The basic offshore rotary rig is employs five different/basing systems (Jahn, 2008):

3.1.1 The hoisting system

A typical hosting system is made up of the mast/derrick, drawworks, crown block, traveling block and the wire rope drilling line, as it is shown in Figure 3.2.

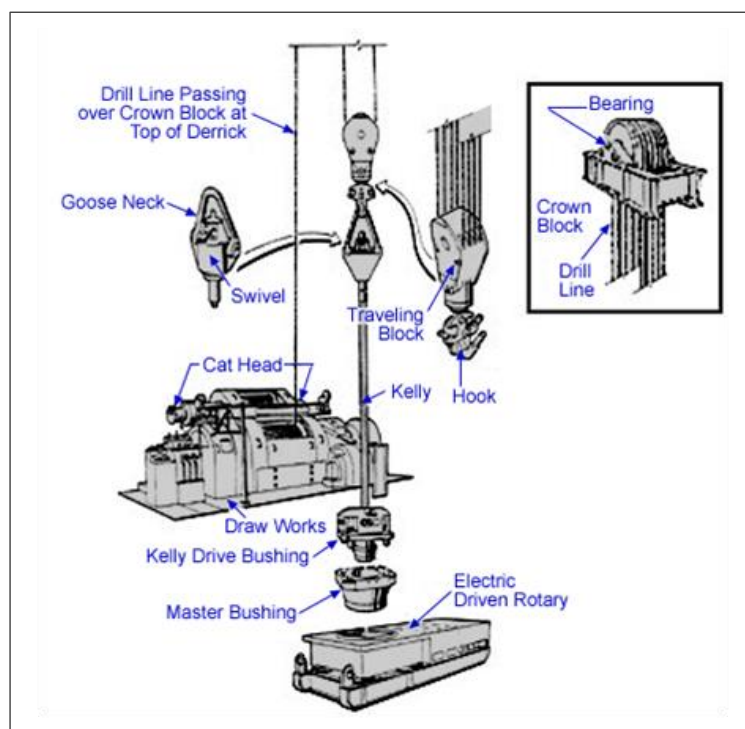


Figure 3.2 Hoisting system (Nguyen, 1996)

Masts and derricks are steel beam tall towers which has average height 60 meters. It is designed to support the blocks and drilling tools, as is shown in Figure 3.3. A mast is a portable derrick that can be raised and lowered as a unit. A standard derrick is requiring

personnel to assemble and disassemble it, piece by piece. They cannot disassemble as a single unit. Currently, most rigs use masts because of flexibility and speed to rig up and down compare to the standard derricks. The drilling area is divided into three areas, the drilling floor area, heart of drill rig where the derrick is located on, pump floor area which is located below drilling floor area and drill string floor area above the drilling floor area which consist of different equipment to handle, store and operate the drilling string.

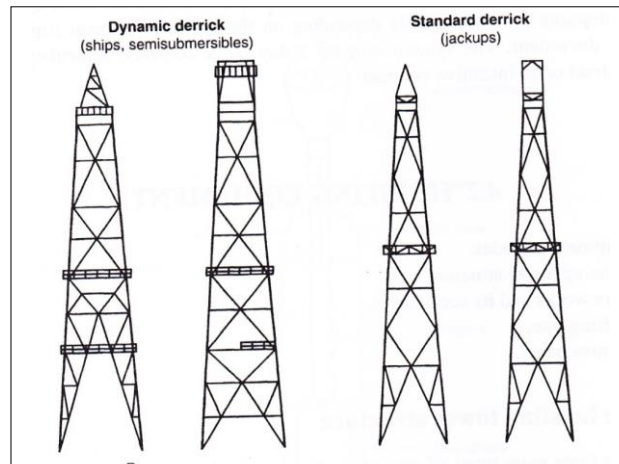


Figure 3.3 Derricks steel beam for ship, semisubmersibles and jack-ups rig (Nguyen, 1996)

A cathead is a winch, or windlass, on which a line, such as rope, cable, or chain is coiled. Under active position, a cathead reels in the line with great force. Pulling on a line is vital to screwing and unscrewing drill pipe. Typically, there are four cathead mounted on the catshaft of the drawworks, and two on each end (Jahn, 2008).

Automated pipe handling: The manual work on the rig floor has largely been replaced by a hydraulic system which picks up pipes from the rack, and transports it up to the drill floor and inserts it into the drill string. This process is controlled by the contractor's drilling rig crew.

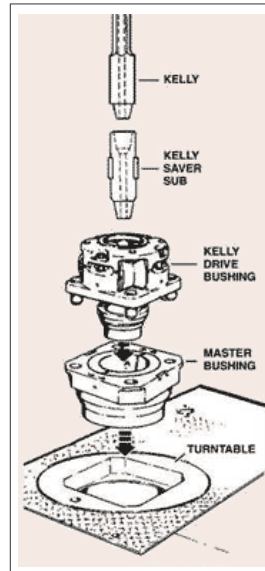
The rotating system: Torque is transmitted from a power source at the surface through a drill string to the drillbit. There are three different parts involved in this operation explained below (Jahn, 2008):

- Rotary table and Kelly
- Top Drive
- Down-hole mud motor

3.1.2 Rotary Table systems

A rotary table with turntable: a stationary heavy-duty rectangular steel case houses the rotating turntable. The turntable is round in shape and is near the middle of the case as it is

shown in [Figure 3.4](#). The turntable produces a turning motion that machinery transfers to the pipe and bit. The case also holds gears, bearing, and other components on which the turntable rotates. An electrical motor or gears and chains from the rig drawworks power the turntable. Additional equipment transfers the turntable's turning motion to the drill pipe and attached bit (Jahn, 2008).



[Figure 3.4](#) Rotary table (Nguyen, 1996)

[A master bushing](#): a bushing is a fitting that goes inside an opening machine, as it is shown in [Figure 3.4](#). A rotary table master bushing fits inside the turntable. The turntable rotates the master bushing. The master bushing has an opening through which contractor's personnel run pipe into the wellbore. A tapered bowl fits inside the master bushing. This bowl serves a vital function when the pipe and bit are not rotating. When the driller stops the rotary table and uses the rig's hosting system to lift the pipe and bit off the bottom of the hole, it is often necessary for crew member to suspend the pipe off bottom. To do so, they place a set of segmented pipe gripping elements called "slips" around the pipe and into the master bushing's tapered bowl. The slips firmly grip the pipe to keep it suspended off the bottom (Jahn, 2008).

[Kelly Drive bushings](#): the third piece of rotary equipment is the kelly drive bushing as it is shown in [Figure 3.4](#). The kelly drive bushing fits into master bushing. Two types of master and kelly drive bushing are available. One master bushing has four drive holes. Strong steel pins on the bottom of a kelly drive bushing made for this type master bushing fit into the holes. When the master bushing rotates, the pins engaged in the drive holes rotate the kelly drive bushing. Another type of master bushing has a square opening and no drive holes.

The kelly: the fourth major part of a rotary-table system is the kelly. It is 12 meters long pipe, although an optional length of 16 meters is available. A kelly is a special length of pipe as it is shown in [Figure 3.2](#). The kelly is not round like conventional pipe. It has four or six flattened sides that run almost its entire length. The kelly's flat sides mate with a corresponding square or hexagonal opening in the kelly drive bushing.

The Swivel: the fifth principal part of a rotary-table system is the swivel. The swivel interfaces the rotary system with the hoisting system. A heavy –duty bail, similar to the bail, or handle, on a water bucket but much larger, fits into a big hook on the bottom of the traveling block. The hook suspends the swivel and attached drilling string, as it is shown in [Figure 3.2](#).

To summarize the kelly-and –rotary-table system (Jahn, 2008):

- The turntable in the rotary table rotates the master bushing.
- The master bushing is rotates the kelly drive bushing.
- The kelly drive bushing rotates the kelly.
- The kelly rotates the attached pipe and bit.
- The swivel suspends the pipe, allows it to rotate, and has a passage for drilling mud to enter the kelly and pipe.

Top drive: most rigs are now fitted with a system whereby the drill string is rotated by a drive mechanism in the mast rather than by the rotary table at rig floor level (Jahn, 2008). Thus 27 meters sections can be drilled before connections need to be made, and the drill string can be rotated while pulling out of the hole in 27 meters section. This improved system, which speeds up the operation and allows better reaming of the hole, is known as a top drive. Latest rigs allow running of 36 meters section and equipped with two derricks, one to drill the well, and the other to concurrently pre-assemble drilling string.

Like the regular swivel, a top drive hangs from the rig's large hook and it has a passageway for drilling mud to get into drill pipe. The tope drive comes equipped with a heavy duty electrical motor. The drillers operate the top drive from their control console on the rig floor.

3.1.3 The mud treatment system

The drilling fluid is pumped from a storage unit down the drilling string and up through the annulus. The mud cools the bit and also removes the cutting by carrying them up the hole outside the drill pipe. At the surface the mud runs over a number of moving screens, the shale shakers as is shown in [Figure 3.5](#), which move the cutting for disposal. The fine particles which pass through the screens are then removed by de-sanders and desilters, usually hydrocyclones.

The mud having been cleaned and transferred into mud tanks, large treatment and storage units. A powerful pump brings the mud up through a pipe and through hose connected to the swivel forcing it down the hole inside the drill string.

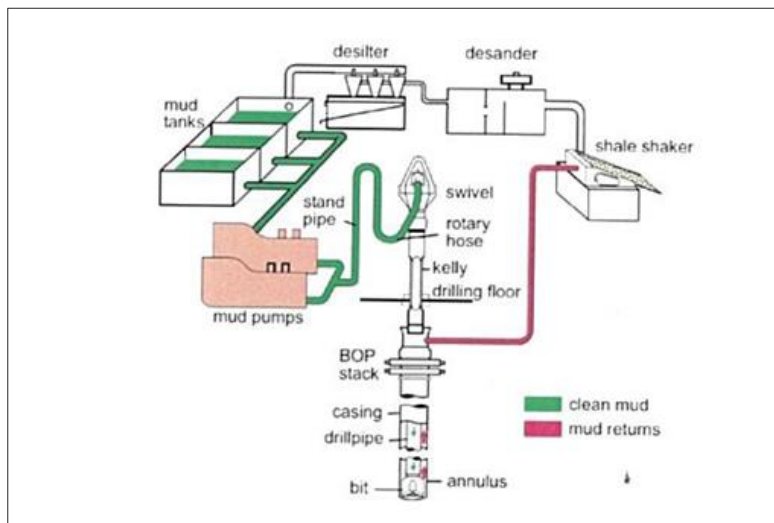


Figure 3.5 Mud treatment system (Haavik, 2013)

3.1.4 The power system

MODU needs a source of power to carry out the drilling operations (hoisting, circulating, and in many cases, the rotating equipment required to make hole) as is shown in Figure 3.6.

MODU uses internal combustion engines as prime power source, or prime move. Most rigs require more than one engine to supply the needed power and most rig engines today use diesels, because diesel fuel is safer to transport and store than other fuels such as natural gas, LPG, or gasoline.

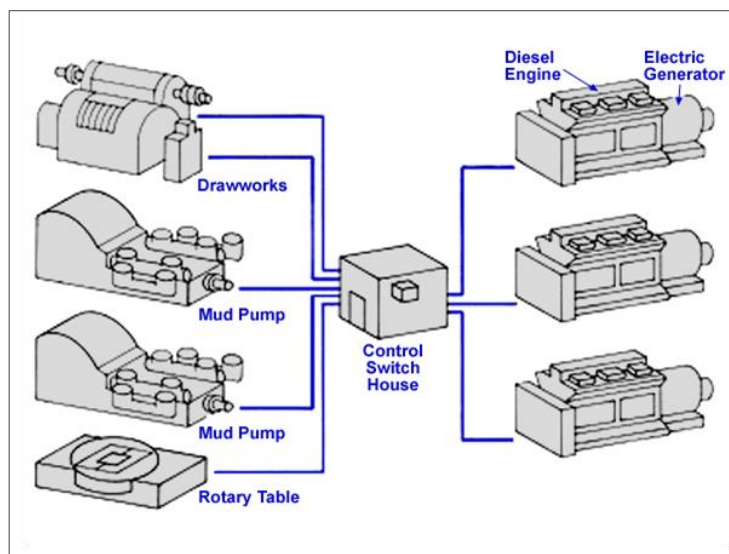


Figure 3.6 MODU Power System (Nguyen, 1996)

Electrical generators or as diesel electrical rig is driven by powerful diesel engines are used to drive most rig components. These generators produce electricity that flow through cables to electrical switch and control equipment enclosed in a control cabinet. From the control gear, electricity goes through more cables to electric motors. The manufacturer attaches the motors directly to the equipment to be driven such as the drawworks and mud pumps.

3.1.5 The well pressure control system

The surface pressures above and within the hydrocarbon bearing strata are controlled by the weight of the drilling fluid and by large valve assemblies at the surface Blowout Preventer (BOP). The purpose of drilling mud is to supply a hydrostatic head of fluid to counterbalance the pore pressure of the fluids in permeable formations. However, for variety of reasons the well may kick, i.e. formations fluids may enter the wellbore, upsetting the balance of the system, pushing mud out of the hole, and exposing the upper part of the hole and equipment to high pressures of the deep surface. If it left uncontrollable, it can lead to a blowout, a situation where formation fluids flow to the surface in an uncontrolled manner (Jahn, 2008).

BOP is a series of powerful sealing elements designed to close off the annular space between the pipe and the hole through which the mud normally returns to the surface. By closing off this route, the well can be shut in and the mud and/or formation fluids are forced to flow through a control the pressure that reaches the surface and to follow the necessary steps for killing the well, i.e. restoring a balanced system.

3.2 DRILLING AND WELL

Drilling and well professionals are involved in different phases of a well construction processes. Seismic mapping is the first step in well construction process of the overburden formations and the reservoir containing the hydrocarbons. The seismic mapping task will give images of the formations. The captured data would be served as input information for the planning of well. The well construction phases consist of the following (Haavik, 2013):

1- Well planning phase

Conceptual phase: the well planning team runs the conceptual planning of the well. The well planning team consists of different disciplines from operator side, reservoir engineer, geophysicist, petrophysicist, evaluation geologist, operation geologist, program well engineer, program drilling engineer, production engineer, well project coordinator, and service companies, drilling rig contractor and sub-contractors. The drilling and well coordinator

representative are responsible for detailed planning and engineering for this phase. The main activities of this phase are defining well target, well bath and method selection.

2- Well operations phase/Execution phase

The operation phase starts when drilling plans and the well construction are formally approved in term of drilling program. The planning well team will hand over their responsibility to the well operations team. The well operation team is presented in the [Table 3.1](#).

Drilling rig organization is divided into operator organization, drilling rig organization which includes sub-contractors and service companies' organization. Service companies can be defined as independent companies who they hired in by the operator to operate and maintain operator's owned equipment on the rig, while sub-contractors are independent companies who they are sub-supplier of the drilling rig contractor.

Table 3.1 Drilling rig organization

Operator drilling team	Drilling contractor team/ rig team	The service companies
<ul style="list-style-type: none"> - Onshore-Drilling engineering team - Offshore-Drilling leader - Offshore-Drilling engineer - Offshore-Operation geologist 	Drilling organization: <ul style="list-style-type: none"> 1- Drilling leader/drilling superintendant 2- Driller 3- Assistant driller 4- Derrickman 5- Roughnecks 	<ul style="list-style-type: none"> 1- Direction driller 2- Mud logger 3- Mud engineer 4- Cementer 5- Operation geologist
	Stability organization: <ul style="list-style-type: none"> 1- Barge Engineer 2- Assistant barge Engineer 3- Crane operator 4- Roustabout 	

	Technical/maintenance organization; 1- Technical leader/maintenance supervisor 2- Maintenance Engineer 3- Electrical supervisor 4- Engine room operator 5- Motorman 6- Mechanic 7- Welder 8- Electrician 9- System technician 10- SAP planner	
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Operator drilling team consists of following:

- 1- On-offshore drilling engineering team: Operator representatives, a number of engineers have responsible for well drilling of a specific well and follow up the operation when the plan comes to execution.
- 2- Offshore-Drilling leader: Operator representative head of MODU, who has main responsible to follow up the drilling operation in cooperation with the drilling rig contractor's representative drilling rig manager.
- 3- Offshore-Operation geologist: Operator representative has responsibility to secure the entire drilling operation offshore by analyzing potential sites for the oil and gas content with respect to potential risks associated with drilling.

Drilling contractor team/ rig team: Drilling rig contractor-organization consists of three sub-organizations: Drilling organization; Stability organization and maintenance organization.

Drilling organization: It consists of different technical expertise (e.g. drilling manager, drilling leader, driller, assistant driller, derrickman, and roughnecks). Drilling manger has overall drilling rig responsibility including the operation and personnel responsibility. Drilling

leader has main operation responsibility of drilling rig together with other disciplines such as driller assistant, driller, etc..

Stability organization: It consists of different technical expertise (barge engineer, assistant barge engineer, crane operator, roustabout, and etc.). They have overall responsibility of marine activities that is carried out in accordance to authority rules and regulations.

Maintenance organization: It consists of different technical expertise (e.g. maintenance engineer, SAP planner, electrical supervisor, mechanic, motorman, and etc.). They have overall responsibility of daily operation, detect safety-critical and maintenance activities of the rig equipment, and report direct to the contractor drilling rig manager. Additionally, they have administrative responsibility of maintenance management system with respect to spare parts, logistic and coordination of maintenance activities.

Drilling contractor team has the overall responsibility to supervise and manage the drilling and well control during the drilling operation. They have to ensure a safe operation of the drilling by including all other technical expertise from different parties (e.g. service companies) and organizations. They have to manage different rig systems during the drilling operation (e.g. drilling control system, drawworks, pipe handling systems, mud circulation systems and BOP) in accordance with authority and operator requirement which is specified in the contract/operating procedures.

5- Well evaluation phase/Conclusion phase

The well drilling program is compiled in this phase, detail operations procedures are to be filled in, daily drilling reports are to be completed, and etc. The well data have to be evaluated by geophysical and petrophysical. After this phase the drilling and well organization has completed its task and can hand the well over to the operator's production organization.

3.3 MARINE DRILLING CONTRACT

In this part the author decided to present semi-submersible mobile rig unit contract in the Norwegian Continental Shelf (NCS), in order to get overview of complexity of performance based contract for drilling well operation of performance based delivery conditions contract for MODU, the focus is directed to responsibilities, planning, requirements, control mechanisms, payment method, cooperation, etc.. Thereafter, the author summarized the case study throughout interviewed participants' responses from operator and contractor perspective.

The contract was mainly consisted of the following chapters:

- 1- Condition of contract
- 2- Scope of work
- 3- Method for payment
- 4- Administrative requirements
- 5- Functional requirements

3.3.1 Condition of contract

Main rules and responsibilities

The operator/operating company has defined the work performance as following:

- The work has to be executed in accordance with International standards. As part of such performance, the contractor has to give priority to safety in order to protect life, health, property and environment, cooperate with operating company's representative, and comply with drilling-, operations-, and safety procedures.
- The contractor has the sole of responsibility of the entire performance of the work, and management and direction of the drilling rig unit and all associated equipment, materials, personnel and Subcontractors.
- The contractor has to give first priority of the safety of the drilling rig unit to provide safe working condition, and to comply with operating company's safety requirements at any time and to comply with contractor's own drilling, operations, and safety procedures.
- The contractor has the responsibility to inform operating company and provide full details in the event of encountering well problems such as loss of circulation, abnormally high pressure, or accidents, incidents, near misses and well control situation, or other instances in which it fails perform the required work.
- The contractor has to implement and document system for quality assurance, in accordance with the administration requirements.
- The operating company representative and their personnel owns the right to undertake quality audits and verifications of contractor's and any subcontractor's quality

assurance system, and have to inform the contractor if such audits identify a deviation from the requirements of the contract.

Authority and Classification requirements

- The drilling rig contractor has to keep itself informed of, complied with and documented its compliance with applicable laws and regulations, requirements and orders of the Authorities and Certifying Agencies. In addition to the operating company's governing documents.
- The drilling rig contractor, subcontractor has to submit all information, documentation or certificates for the contractors work performance.

Default and Delay

- The contractor has to inform operating company and take corrective actions, if the drilling rig is unable to perform the drilling services according to scope of work given in the contract, or the performance of the drilling services is delayed due to repairs, maintenance and/or modification to the drilling rig. The corrective action has to be completed within agreed number of days from occurrence of the applicable event.
- The contractor has right to x number of hours for repair and maintenance of the drilling unit and will be paid for such time at the operating rate. Any hours excess the agreed number of hours, the contractor have to be compensated at no payment of rate.

3.3.2 Scope of work

The operator has specified the required activities that should be performed by drilling rig contractor and subcontractors as following:

- The drilling rig contractor has responsibility for the planning, coordinating the moving and towing of the drilling unit to or from and between shore and well locational, and carrying out all marine operations of the drilling unit including operations such as anchor handling, positioning, and etc.
- The drilling rig contractor has responsibility to perform drilling, completion and intervention work with drilling rig.
- The drilling rig contractor has responsibility to pay at its expense to provide the drilling unit, personnel, equipment, material, consumables and all services required for performance of the work.
- The drilling rig contractor has responsibility to provide and maintain the drilling rig in good working order and in a safe and fully operational condition in compliance with contract.

3.3.3 Method for payment

The payment was based on incentives payment method, fixed price and daily rates. The well costs can be categorized as following:

- Fixed prices for the period of the contract, (e.g. casing and tubular, logging, cementing, drill bits, mobilization charges, rig move)
- Daily Rates Preambles consist of the following:

Operating Rate: the operating rate should be paid during operation period.

Standby Rate: the standby rate should be paid during periods, when the contractor performance work is delayed due to the waiting on weather including time for pulling or installing the drill string, BOP and Riser, or waiting while the drilling unit is modified as a result of variation to the work.

- Incentive, The drilling rig contractor agrees with operator for the well specifications, then operator determine the cost based on historic data of the average performance of similar wells that have been drilled. The contractor will be entirely in charge of drilling the well while cost saving achieved will be split between operating company and drilling rig contractor.

3.3.4 Administration requirements

The operator has defined contractor's responsibility as following:

- To establish and use their own internal methods, routines and procedures in implementation and administration of the contract.
- In case if/when the contractor have to carry out the work within operating company's organization, operating company's methods, routines and procedures have be adhered to. Whenever it is required, the drilling rig contractor should adapt its methods, routines and procedures in order to accommodate contract requirements and to achieve the necessary work quality and safety.

This section of administration requirements is divided into the following:

3.3.4.1 Quality assurance

- Overall management system has to be established and implemented by drilling contractor. The operator requires a quality system that should be based on NS-ISO 9001, as it is presented in section 2.7.1. Additionally, the system has to be documented

in a quality assurance manual and has to be approved and signed by contractor's top management.

This system is reflect how contractor have to ensure continuous improvement in planning and ongoing operations, and any change or deviations in the quality system, the operating company should be informed.

- The operator required establishment of a contract quality plan for drilling rig work. The plan has to incorporate the requirements of NS-ISO 9001 and ensure the fulfillment of contract requirements. It has to be considered as contractor's governing document for the performance of the work. The established quality plan has to describe the control and interface activities in relation to subcontractors and third party companies. The quality plan for contractor performance for the work had included the following elements, as a minimum:
 - Progress, time and resource schedules for performing all activities associated with work.
 - Plans for verifications, internal audits and audits of subcontractor.
 - A documented management system that ensures document control, status, traceability and continuous improvement
 - Descriptions showing how the individual activities or work processes have to be controlled, performed and checked. The description included the activities and operational interfaces and organizational barrier philosophies associated with the contract, maintenance and supervision and modification of the drilling unit and equipment used in connection with the work, progress planning, following up and reporting; communication with and reporting with operating company, use of Best Available Technology (BAT).
- Competence: the operator is required that contractor has available HSE personnel in a quantity and with professional skills to control and monitor all aspects related to health, working environment, technical and operational safety, the environment and security.
- Measurement: the drilling rig contractor has responsibility to measure for fulfillment of contract requirements.

3.3.4.2 Continuous improvement

- The operator required a plan of drilling activities and operations from drilling rig contractor. Additionally, they have to implement a planning process to obtain technical limit in all operations, in order to describe how the contractor and sub-contractors take ownership of the planning process, and how the contractors'

personnel onboard are involved in operator's planning work onshore per assist, review and workshops.

- The drilling rig contractor has to take ownership and perform all measurements of Key Performance Indicators (KPI), which is described in operator's governing documents. Additionally they should make the (KPI) visible and utilize them actively in the daily work to improve operations.

3.3.4.3 HSE delegates

The drilling rig contractor has responsibility to document systems for planning, execution and following up and improvement of all HSE aspects. They have to ensure that requirements for HSE and HSE documentation are defined in subcontractor and purchase orders regarding all machinery, equipment and services. The following reports required from drilling contractor:

- Reporting to the public authorities: the drilling contractor has responsibility for ensuring that authority receives the information required by law. The drilling contractor has to ensure that all subcontractors in descending line report to authority in accordance with relevant laws and regulations. All products classified as hazardous and/or harmful to the environment have to be registered with the appropriate authority, together with a copy of such registration to operator representative, whether pertaining to contractor's own reports or to reports from any subcontractor in a descending line.
- Report to operating company: the drilling contractor has to perform all HSE and quality reporting according to operator's requirements and in a format that operator requires.
- Daily drilling report: the drilling contractor has to give input to the daily drilling report in a format required by operator.
- Weekly report: the drilling contractor has to submit a weekly report in a format as required by operator. The report may contain status of maintenance, coming period maintenance tasks, critical operations in coming period, problem areas, etc.
- Monthly reports: the drilling contractor has to analyze trends of the KPI and focus on deviations according to agreed targets. The report has included the following:
 - 1- Recommendation of corrective actions for areas where target are not achieved.
 - 2- HSE and quality activities for the period such as HSE activities, operational efficiency, quality and non-conformance.
 - 3- A statistic presentation both for the actual month and in total. The statistic presentation will include for each subcontractor in these two reports. It means subcontractors will not report directly to operating company.

- Yearly report: the drilling contractor has to submit a yearly report for the work. The report is described the following:
 - 1- Summary of contractors' yearly action plan for HSE&Q activities.
 - 2- Recommended action plan with targets for HSE&Q activities for the coming year.
 - 3- Proposed improvements (equipment, systems and operations)
- KPI parameters measures have to be set up according to HSE, operational, quality and non-conformance categories, as it is presented in Appendix A.

3.3.5 Functional requirements

The operating company has to provide relevant governing documents for the work. The contractors have to comply with these provided governing documents. The drilling rig contractor and subcontractors have to be responsible of systems on the drilling rig unit, and they have to cooperate and provide assistance and facilities in respect of services provided by operating company.

3.3.6 Documentation

The drilling rig contractor has to be responsible for providing, updating and maintaining all relevant documents and certificates related to the drilling unit and operation of the drilling unit under the contract. Requirements and criteria related to equipment and operations of significance to safety have to be specified, the conformity with specifications has to be documented. Electrical installations have to be planned, designed, manufactured and operated in accordance with the technical provisions contained in applicable regulations for electrical installations in maritime installations.

3.3.7 Maintenance System

The operator required that all maintenance activities including classification, program, planning and execution have to be in accordance with relevant governmental regulations and guidelines, maintenance has to be based on an evaluation of the equipment and functions to ensure that critical equipment with respect of HSE, regularity and cost is given the highest priority, as it is presented in section 2.9.1. All required criticality and risk analysis has to be carried out by drilling rig contractor, contractors and sub-contractors.

The drilling rig contractor has to document and implement system for maintenance of the drilling unit and its associated equipment. The maintenance system has to comply with latest NPD requirements, for the particular technical and operational provisions in NPD requirements for relevant operational activities. Equipment and facilities have to be organized

systematically in maintenance program, which has to document the preventive maintenance, corrective maintenance and condition based maintenance.

3.4 INTERVIEW OPERATOR (A) AND CONTRACTOR (B&C) PERSPECTIVES

The author conducted guided interviews from three different companies, operator (A), drilling rig contractor (B) and drilling rig contractor (C) who were involved in managing performance base service delivery for MODU. Two participants from operator (A) were interviewed: Manager MODU facility with 23 years of experience within maintenance and operation and Principle engineer MODU facility verification experience within operation, maintenance and modifications of process production facility and MODU on the NCS. Drilling rig contractor (B) with one participant: Technical Leader for MODU with 19 years of experience within maintenance and operation. Drilling rig contractor (C) with one participant: Technical maintenance-Motorman for MODU with 9 years of experience within maintenance and operation.

All interviewee are introduced to the same questionnaire in this study, as it is shown in Appendix C. The interview started by presenting functional products/performance based service delivery and its characteristics. A system perspective for offshore O&G production lines and main objectives of the thesis are explained. Thereafter, the interviewee answered the given questionnaire. The answers/results is presented and discussed below, based on interviewee and chapter 2- “State of the art in design maintenance strategy for functional products”:

3.4.1 Functional performance service delivery- Question (1)

The operator (A) is considering MODU service contract as functional performance service delivery, because drilling contractor and service providers sell performance of the product in term of availability instead of selling the product itself, as it is explained in section 2.1. The operator (A) is adding one additional characteristic or condition to the functional products that is “incentive arrangement/scheme”, the operator (A) does not consider MODU service contract “Daily rate arrangement without incentive scheme” as functional performance delivery, since the main focus will be directed toward availability measures of the system and does not focus of performance effectiveness measures. In addition, functional performance delivery is focusing on performance process optimization, where contractor(s) and operator have same interest to optimize the process of the work, while this type of contract does not meet customer needs and satisfaction.

Operator (A) “the principle engineer” specified that there are differences between buying performance based delivery for process production facility and drilling facility as MODU:

- 1- The operator has significant big O&M organization for process production facility including all procedures and routines for O&M
- 2- The operator has to establish different strategies to follow up functional product deliveries than conventional products.
- 3- The contractor has to integrate and manage their maintenance system into operator’s system.
- 4- The contractor has to integrate and manage their maintenance system into operator’s system.
- 5- The MODU drilling facility has small O&M organization compare to operator’s O&M organization, and they use their own maintenance system.

The contractors (B&C) could not answer on this question since they are not familiar with functional products “term”.

3.4.2 Type of functional products delivery “Option 1&2”- Question (2 &3)

All four interviewee gave the same answers. The operator signs multiple contracts for well drilling operations (option (1) section 2.4.2). The signed contract will cover all technical expertise (e.g. logging, cementing, fluid circulations, and etc.) to perform the required job. In addition, the operator is responsible for the design and the plan of well which is secured through operator’s own drilling and well organization.

According to author and operator (A) single contract with drilling rig is preferable in order to get delivered functional performance for the total system, instead of having multiple contracts which requires more resources involved to secure interface and collaboration issues. The operator has to sign multiple contracts because the drilling rig contractor does not have the capacity and competence to cover all technical expertise.

3.4.3 Responsibilities- Question (4)

According to all four interviewee, the contract is the key element of defining responsibilities. The contract gives a full overview of responsibilities, interface, scope of work, performance of work, conditions and regulations, subcontractors’ responsibilities, and functional and technical specifications of the MODU.

The operator (A) has specified the following: The operator has to define responsibilities of all participated parties. The authority has a major influence of contractor’s maintenance management system while the operator has to confirm that maintenance strategy of the contractor is complying with the given requirements. In addition, the operator to has to verify,

monitor and follow up well drilling operations and maintenance activities through daily, weekly and annual inspections and reporting.

The contractors (B&C) have specified the following: The drilling contractor has responsibility to establish maintenance management system, defining their maintenance strategy and has to comply with operator's requirements as described in section 2.7. Responsibility to report prioritized maintenance of critical equipment in order to secure availability, reliability, supportability and safety of their facilities.

According to the contract and author, the drilling rig contractor has the main responsibility of their products regarding maintenance system including total support system. In addition, they are responsible of the following:

- Authority approval
- Authority classification approval (covers technical requirements).
- The operated MODU on NCS must be designed, constructed, installed and surveyed in compliance with class society ABS (Maritimelink, 2009).
- Verification activities of operation MODU must be done in compliance with the application regulatory requirements according to Norwegian Petroleum Act.
- Acknowledgement of Compliance (AOC) from Petroleum Safety Authority Norway.
- All maintenance activities of products
- Continuous feedback on performance related to quality of service and products. In addition, the given information must be fact based and documented.

The contractors have to establish, implement and document their maintenance system of the drilling unit and their associated equipment. They have responsibility to maintain their equipment and secure maintenance of the third party/service provider's equipment which is connected to the drilling unit equipment. Additionally, they have responsibility for their personnel, other contractors, service providers and operating company's personnel.

Contractor's technical manager have to schedule a meeting every second week with operator's drilling leader and contractors drilling leader to get overview of maintenance activities, critical equipment maintenance activities list and operational consequence with respects to maintenance activities. The aim of these meetings is to secure operating company's operational plan for drilling in case of performing maintenance activities.

The operating company's equipment that going to be used under drilling operations have to be inspected and approved by the contractor. The service provider has the responsibility to deliver services in term of maintenance and operation of operating company's equipment.

3.4.4 Existing of maintenance organization- Question (5)

According to operator (A), the operator does not need a maintenance organization for the performance-based contract for the MODU. This is a cost saving factor for the operator.

According to contractors B and C, the contractor needs a maintenance organization with respect to functional products deliveries.

3.4.5 Maintenance strategy philosophy- Question (6)

The operator (A) has specified the following regarding maintenance and maintenance strategy of the operator: the operator has to define overall strategy plan that includes all contractors' strategy plans, all necessary requirements and work performance descriptions. The operator (A) specified that good planning and scheduling is the key to success of the operator's operations. The operator's strategy is based on risk based decisions, measuring work performance based on given acceptance criteria, and ensures continuous process improvements as presented in section 3.3&Appendix B.

The contractors (B&C) have defined their maintenance strategy based on criticality and type of equipment. The criticality of equipment is defined base on safety-critical factors, which is scaled from 0-4 (low-to-high safety criticality). Additionally, they have defined different maintenance approaches which are used in order to maintain the technical integrity of equipment:

- 1- Preventive maintenance/ planned maintenance, based on fixed time intervals and running time.
- 2- Operation-based maintenance.
- 3- End-of-well maintenance which is applied after the well drilling operation is carried out/ended.
- 4- Manufacturer's recommendations and defined regulations (NMD/IM0/DNV/NOG). In addition, contractor C claims that fixed maintenance intervals should be used.

3.4.6 Control mechanism of functional performance delivery- Question (7)

According to operator (A), the contract is key the element of control mechanism for functional performance delivery that could enable the operator to follow up and monitor the contractors. The contract has to be based on incentive agreement to secure contractor's performance as it described in section 3.3. Contractors have to define their maintenance objectives based on operator's requirements and to define the maintenance strategy for drilling rig by prioritize critical assets and plans for maintenance activities, and ensuring availability of the support service system.

The operator ensures establishment and implementation of monitoring philosophy for drilling operations based on their policies, maintenance objectives and strategy. They have systematic methods to daily, monthly and annually monitor the drilling rig unit.

According to operator (A), there are several tools which are used to monitor and manage planning, implementation and execution of operations (e.g. some of the following tools are used: project planner, compass: managing well bath, KPI planner, risk matrix, drilling and well estimator to calculate time, cost and complexity, etc.). The methods/tools used during the execution phase are daily, weekly, monthly and annually reported, including the following:

- Registering drilling contractors' downtime by calculating incidents and downtime for operation and project planner.
- Daily status regarding equipment testing, logging and planning activities.
- Operation status for service, failure categories, equipment type and part to enable the operator to identify which equipment is failed and contributed to downtime; etc.

According to contractors B and C, it is necessary to set up a computerized maintenance management system where it keeps historical maintenance database (per equipment serial number) which automatically generate efficient maintenance planning based upon the historical database combined with actual equipment condition. Thus, it is imperative for the contractor and operator to work closely in sharing these knowledge and information.

3.4.7 HSE-Question (8):

According to operator (A), the drilling and well operations that are highly exposed to safety, environment and economic risks. The activities must have a high level of cooperation between all involved parties to perform the drilling operation. Therefore the operating company prioritizes HSE first, and it considers planning activities for drilling operations and maintenance strategy during design and execution phases are success factors to perform drilling operations. The drilling rig contractors and service providers have responsibility to establish maintenance system for their equipment. In order to secure contractor's and subcontractor's personnel, the operator has to monitor, inspect, and verify maintenance activities. The contractors and subcontractors have to comply with HSE requirements.

According to contractor (B), the contractor can secure the health and safety of the subcontractor's personnel through the following activities:

- 1- Ensure working methods and a good safety culture.
- 2- Measure results by statistics.

- 3- Common reporting systems for safety observations that form a basis for statistics and analysis.
- 4- Continuously safety improvement actions based on the performed measures.
- 5- Good safety culture leading to the desired results can be rewarded, and oppositely can accidents lead to reactions in relation to losing contracts or other negative effects.
- 6- Coursing and guidance in relation to safety matters can also lead to a common understanding of risks that will lead to a higher level of safety and fewer future incidents

3.4.8 Critical challenges & Alternative solutions- Question (9&10)

The operator (A) specified many challenges and alternative solutions related to functional performance delivery, the author will present some of these challenges below:

The main challenge is how to establish requirements and guidelines including technical and functional specifications for drilling contractors and other contractors because the operator will sign many contracts that cover the needs of all technical expertise. This challenge can be achieved to openly communicate plan and schedule with the contractors. The contractors need a proper time range to prepare their equipment, ensure proper planning and scheduling for operations, and standardizing of drilling operations, equipment, planning and execution of well drilling operations.

According to operator (A) (the principle engineer) the main challenge regarding operability of the MODU is that the current performance has been approximately 60%, even using performance based service delivery. The alternative solution is that the operator has to use incentive scheme where the contractor has to meet the operational requirements and the operator has to check and verify the delivered functional products routinely according to the requirements.

According to contractors (B&C) the main challenge is to maintain the system integration. The operator has its own maintenance system - while the contractor has to establish their own maintenance system that need to be integrated to operator's system. This cause the contractor has to operate more than two maintenance systems to integrate their system into the operator's system. If the contractor has to provide functional products to several customers, conflicts may arise because they have to operate with several systems for different customers. The alternative solution is standardization and harmonization of maintenance system between different contractors and operators.

4 Results and discussion

The main objective of this thesis is to understand and design maintenance strategies and control mechanisms for O&G production line consisting of one or two functional products. The main challenge of the functional products maintenance is how to define factors that influence performance of the functional products and the total system performance consequently.

Maintenance of the functional product is depending on the right maintenance strategies being applied on asset at the right time. Maintenance management system has to be established to manage the process in the maintenance organization. Clear objectives, requirements, maintenance strategies and responsibility should be defined and implemented to design and integrate support systems. In addition, support of the technical and operational processes of maintenance activities such as maintenance planning, maintenance control and supervision, and continuous improvement process, as it explained in 2.7 has to be established. The operator has to face the main challenge of organizing and cooperation between different contractors/service providers which are led by different service provider managers. This challenge can be achieved by requiring strategy plans for each involved party, approving these strategies and implement it across O&G production line organizations, measure and monitor performance process continually and apply corrective actions in order to secure optimal performance and maximize the value creation of contractors and sub-contractors.

The manufacturer/contractor has to meet guidelines defined by government and the operator regarding all maintenance activities that include classification of equipment, maintenance program, maintenance planning, and maintenance execution as it is explained in section 3.3.1. It is necessary to evaluate functional products/assets to ensure the criticality of the assets with respect to HSE, production and cost, which has the highest priority. It is of crucial important to carry out criticality and risk analysis continuously to ensure performance of the production process facility.

There are many factors that influence on design maintenance strategy for functional products which should be considered. In addition, the main principles of designing maintenance strategy for conventional products should be taken into consideration. Clear maintenance objective have to be defined. The criticality and consequence classification of an asset should be established and implemented. Equipment with high criticality and that can be rapidly replaced need to be prioritized through the planning process to ensure availability of service support system. Preventive and predictive maintenance approaches can be applied for the equipment/asset with high criticality.

The main factors that influence on design maintenance strategy for functional products need to be secured to achieve overall maintenance strategy for O&G production line. The following factors are defined and discussed below:

4.1.1 Authority requirements

It is necessary to comply with authority requirements regarding HSE in order to protect life, health and environment. It can be achieved through cooperation and good communication with operator, and by complying with operator HSE requirements.

4.1.2 Design

It is necessary to optimize design of functional products for maximum performance rate and high quality. This can be achieved by design out maintenance to decrease the need for maintenance and establish a service support system to secure equipment/system availability. In addition, it can be achieved through implementing/incorporating operator's required technical specifications and functional requirements, and by selecting LCC analysis to secure reliability, maintainability, and supportability, as it is presented in section 2.9.2 & 2.9.8

4.1.3 Availability

Functional product's availability can be achieved through a holistic approach to maintenance of all systems by:

- Improving the preventive maintenance planning and service support system strategy, good planning of maintenance in cooperation with operator's personnel, and early/adequate follow up on emerging challenges.
- Carry out consequence classification of spare parts, logistics and well planning of spare parts is necessary to keep needed spare parts in stock as presented in section 2.9.10.
- Assigning personnel with competence to maintain and repair components available, the downtime can be reduced if anything unforeseen could occur.

Improving knowledge of technicians, engineers, operations and maintenance personnel. This can be achieved by setting good competency requirement for related skills and conducting required training, as it is presented in section 2.7.8.

4.1.4 Harmonization

To secure all O&G production line regularity, safety and cost optimization, it necessary to provide all equipment replacement and repair strategies. This can be achieved by operator's overall maintenance objectives "maintenance strategy" which has to be harmonized with contractors and subcontractors maintenance strategy to secure all equipment replacement and repair strategies. This can be achieved by ensuring a high level of cooperation, communication and planning. The physical products that are owned by different parties have to be equally and adequately maintained at all times. An important factor have to be considered for all involved parties: to use the same maintenance systems, or to cross refer to maintenance being performed so that management can keep track of and have control of and to be able to plan overall maintenance that have to be performed at suitable times, as presented in section 2.9.3.

4.1.5 Operability

The operability of the functional products can be secured through adequate maintenance of the functional products and monitoring of running parameters so that maintenance can be performed when it is needed. This can be achieved by correct operation of the equipment and to ensure that it is operating within optimal running parameters.

4.1.6 HSE

HSE factors are of crucial importance to avoid any accidents that may influence damage or loss to personnel or environment. This factor/objective of functional products can be achieved through integrating technical, operational and organizational barriers, giving priority to the safety, complying with operator's safety requirements, securing working methods and good safety culture. It has to be measured by statistics and having/creating one common reporting system for safety observations that forms a basis for statistics and analysis. Using these measures, each involved parties can carry out safety improving actions. A good safety culture that leads to the desired results can be rewarded and, oppositely, accidents may lead to reactions in relation to losing contracts or other negative effects. Training, coursing and guidance with respect to safety matters will secure the different parties a common identification, understanding and reduction of risks that will lead to a higher level of safety and fewer incidents.

4.1.7 Maintenance information management

Maintenance information have to be monitored, controlled and managed with respect to planning, scheduling, inventory, history, store's inventory and usage and cost information record for O&M. This can be achieved by efficient utilization of CMMS and integration contractor's maintenance system into operator's overall system. Different work orders for

different parties should be performed and reported in a common system, and based on these work orders, trends can be carried out, where the spare parts should be connected to the work orders. This information should automatically be reordered to stock based on preset max/min stock level. The corrective work orders should be created and planned if needed. The work hours used by the respective worker performed maintenance should be reported in the work orders, in order to secure easy track of labor related cost.

4.1.8 Contract

It is a key element to control the performance of the functional products, by defining conditions and requirements for the involved parties, rules and responsibilities (operator vs contractors), and scope of work to secure functional performance delivery. The incentive scheme method is a crucial important factor that has significant influence on performance and collaboration of the contractors, as explained in section 2.9.11.

5 Conclusion

To achieve optimum design of maintenance strategy for O&G production line consists of functional products, the influence success factors need to be considered in overall project development phases.

The rules and regulations given by the authorities have to be met regarding HSE, and should be achieved through cooperation with operator's requirements. Responsibilities and roles have to be defined and explained in the contract in order to reduce uncertainty in the project, as described in in contract section 3.3.1.

Clear maintenance objectives and technical requirements with its acceptance criteria have to be defined in the design phase. For the production phase it should be redefined to a "dynamic" acceptance criteria based on operator's objectives with respect to the production level, quality, profit, etc.. Availability of the functional product should be defined (e.g. high level of availability for equipment and resources with non-failed state).

The operability/functional products' ability to sustain production rate of the O&G production line is an important element. High level of availability and reliability of functional products are supported by an adequate level of operability (Coetzee, 1997), and as explained in section 4.1.5.

Availability have to be achieved through establishing a holistic approach to maintenance of all systems, harmonizing maintenance planning, improving the preventive maintenance planning, establishing maintenance program including spare parts in store, consequence classification of spare parts and logistic, training of maintenance and operation personnel, and improving resource availability including service support system.

Maintenance management system ensures the required reliability of functional products. This can be achieved through implementing/incorporating operator's required technical specifications and functional requirements, and prioritized maintenance of critical equipment.

Reliability of production facility has to be achieved through optimization the design of functional products 4.1.2, improving communication and collaboration between the involved parties, ensure optimized spare parts management system (e.g. using SPIR), operating functional products within specifications and ensuring redundant design for the designed system.

Maintainability has to be achieved through optimization production facility design, communication and collaboration between involved parties, and ensuring accessibility.

Maintenance supportability can be achieved through optimization of spare parts, efficient utilization of CMMS and integration contractor's maintenance system into operator's overall system.

Incentive contract is a crucial important factor which should be considered by operator to secure the performance service delivery and design of maintenance strategy consequently.

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Appendix A

HSE- Activities KPI

- Number of fatalities
- Serious incident frequency
- Number of lost time injuries
- Number of case of restricted work injuries
- Number of incidents with high loss potential
- Number of recordable injuries excluding first aid cases
- Number of falling objects specified in high, medium and low risk.

Operational efficiency- Activities KPI

- Tripping speed.
- Running speed.
- Run –pull BOP.
- Run-pull anchors.
- Run time x-mas threes, tubing hanger and three cap.
- Overdue number and hours of critical maintenance.

Quality and non-conformance- Activities KPI

Contractor shall submit to operating company all non-conformance reports each stating how and when the non-conformance was identified, consequence(s) and suggested preventive and corrective actions. Non-conformance shall mean deviations from procedures, specifications, standards and contract requirements as well as authority requirements. All suggested actions shall be subject to operating company's acceptance before implementing them. The following shall be described:

- 1- Reporting of quality losses including recommended corrective actions
- 2- Quality cost.
- 3- Verifications of sub-contractor.
- 4- Status yearly action plan.

Appendix B

Risk-based decision

Risk-based decision making is “ A process that organizes information about the possibility for one or more unwanted outcomes into a broad, orderly structure that helps decision makers make one informed management choices” according to (ABS, n.d.).

Risk-based decision making is a process of series basic steps. The result of these steps will add value to “almost any situation” and especially to the situation that has possibility for serious or catastrophic outcomes.

Example, by implementing factors such as “harmful effect on safety, health, and environment”, “property loss”, or “mission main” in engineering risk-based decision will add more value to any engineered system or activity.

Implementing this process in each level of organization will provide the decision maker information needed “real risk” in systematic way.

Risk-based decision making is more than “just risk”, it is orderly decision analysis process that consider cost, schedule, requirement, etc. that provides decision maker smart choices.

To conclude, risk-based decision making process helps people to make better logical choices without complication. but, it is not enough in creating competitive performance if it is used “separately”.

It needs to be combined with other tools and strategies for performance improvement such as (The balanced Scorecard) BSC, (Plan, Do, Check, Action) P-D-C-A “Total Quality”, Benchmarking process, continuous performance improvement process, and opportunity-based process to add the value of making better logical and smart choices that will lead an organization to competitive performance.

Appendix C

The interviewees are introduced to the functional products/performance based service delivery and its characteristics. A system perspective for offshore O&G production line and main objective of the thesis are explained. The table below lists the answers of each interviewee:

Questions		Answers			
		Manager MODU facility (Operator A)	Principle engineer MODU facility verification (Operator A)	Technical Leader Contractor (B)	Technical maintenance-Motorman contractor (C)
1.	Does operator/contractor consider MODU service contract as functional performance service delivery?	Yes, it dose	Yes, it does- additional it depends on contract type: If it is based on daily rate/Turnkey contract, it is not functional performance service delivery. If it is based on incentive contract, it is functional performance incentive.	N/A- not sure.	N/A. not sure.
2.	What type of functional products delivery singed for well drilling operations, is single or multiple contract? To cover all different technical expertise (option1&2-reference section 2.4.2)?	Option 1: (multiple contracts) A number of contractors signed individual contracts with operator to delivery total functional performance for well drilling.	Option 1: (multiple contracts) A number of contractors signed individual contracts with operator to delivery total functional performance for well drilling.	Option 1: (multiple contracts) A number of contractors signed individual contracts with operator to delivery total functional performance for well drilling.	Option 1: (multiple contracts) A number of contractors signed individual contracts with operator to delivery total functional performance for well drilling.
3.	What do operator prefer regarding the type of functional products delivery (reference	Operator wish to sign one single contract to get delivered functional performance for the total system, but drilling contractor does not has	Operator wish to sign contract to get delivered functional performance for the total system, but drilling contractor	Operator wish to sign contract to get delivered functional performance for the total system, but drilling contractor	Not- sure.

	section 2.4.2)?	capability and competence to deliver total system including all technical expertise.	does not has capability and competence to deliver total system including all technical expertise.	does not has capability and competence to deliver total system including all technical expertise.	
4.	Who has main responsibility of maintenance activates of MODU?	<p>Contract is key element of defining responsibilities. It gives full overview of responsibilities, interface, and scope of work, performance of work, conditions and regulations, subcontractors' responsibilities, functional and technical specifications.</p> <p>Managing of maintenance activities of functional product is under</p> <p>Operator checks that contractor has maintenance strategy comply with requirements.</p> <p>An authority has more influence on the maintenance activities of the MODU than the contract, because of the authority's verification.</p> <p>Monitoring and following up responsibilities.</p> <p>Contractor has responsibility to apply approved maintenance system for their functional product.</p>	<p>Contract is key element of defining responsibilities. It gives full overview of responsibilities for different parties.</p> <p>No-direct responsibility regarding maintenance activities of MODU.</p> <p>Contractor(s) has responsibility of securing maintenance activities of MODU.</p> <p>Operator will verify, monitor and follow up maintenance activities through daily, weekly and yearly reporting.</p> <p>Operator has responsibility of maintaining and managing drilling well operation.</p>	<p>Contractor has main responsibility of establishing maintenance management system, to manage maintenance activities and cooperation with operation personnel to support work process including:</p> <p>Operating, maintain, securing availability, reliability, supportability and safety of their facility.</p> <p>Responsibility to report prioritized maintenance of critical equipment in order to cooperate with drill operations.</p>	<p>Contractor has main responsibility of establishing maintenance management system, to manage maintenance activities Direct responsibility of all maintenance activities and cooperation with operational personnel to support work process including (spare parts availability, planning, logistic, etc.).</p> <p>Reporting responsibilities.</p> <p>Securing availability of the equipment.</p> <p>Securing optimizing equipment performance.</p>
5.	Existing of maintenance organization?	Operator has no maintenance organization with respect to functional products delivery.	Operator has no maintenance organization with respect to functional products delivery.	Contractor has maintenance organization with respect to functional products delivery.	Contractor has maintenance organization with respect to functional products delivery.
6.	What type of maintenance	Maintenance strategy for MODU is	Maintenance strategy for	Different strategies are	Different strategies are

	strategy philosophy is applied for functional products-MODU?	based on risk assessment/risk based decision.	MODU is based on risk assessment/risk based decision.	<p>applied, mostly based on the criticality and the nature of the different equipment.</p> <p>Criticality of equipment has defined based on safety-critical based on scale level from 0-4 (low-to-high) safety-critical.</p> <p>Preventive maintenance is planned and performed based on either running hours or fixed time intervals to maintain the technical integrity of equipment.</p> <p>Operation-based maintenance.</p> <p>End-of-well e.g. maintenance of BOP after the operation is carried out.</p> <p>Using two different data bases to monitor drilling operation and maintenance activities of drilling activities.</p>	<p>applied, mostly based on the criticality and the nature of the different equipment.</p> <p>Preventive maintenance is planned and performed based on either running hours or fixed time intervals to maintain the technical integrity of equipment.</p> <p>Maintenance activities is performed based on the intervals given by regulations (NMD/IM0/DNV/NOG) /and recommendations from manufacturer.</p>
7.	How operator/contractor able to secure and control maintenance information and activities?	<p>Planning for operation.</p> <p>Setting up KPI-target.</p> <p>Monitor/Measure operation performance “results”-analyses</p>	<p>Planning for operation.</p> <p>Setting up KPI-target.</p> <p>Monitor/Measure/check and verify equipment and</p>	<p>It is needed to setup a computerized maintenance management system where it keeps historical maintenance database (per equipment serial number) and it is able to</p>	<p>It is needed to setup a computerized maintenance management system where it keeps historical maintenance database (per equipment serial number) and it is able to</p>

		Feedback with corrective action it is necessary	operation performance “results”-analyses the results. Feedback with corrective action it is necessary	automatically generate efficient maintenance planning based upon the historical database combined with actual equipment condition. Thus, it is imperative for the contractor and operator to work closely in sharing these knowledge and information	automatically generate efficient maintenance planning based upon the historical database combined with actual equipment condition. Thus, it is imperative for the contractor and operator to work closely in sharing these knowledge and information
8.	How to secure that contractor and subcontractor safeguarded health and safety in work environment for their personnel?	Through contract’s conditions and regulations requirement. Monitor check and verification activities. Contractors are responsible to meet HSE requirements	Through contract’s conditions and regulations requirement. Monitor check and verification activities. Contractors are responsible to meet HSE requirements	Contractors’ personnel should follow approved maintenance procedure to ensure equipment integrity. Ensure their personnel use proper and approved tools Contractor to establish expert support for their technician to provide guidance and thus minimize error.	Ensure working methods and good safety culture, and measure this by statistics can be a good way of ensuring this. Common reporting system for safety observations that form basis for statistics and analysis. Based on this measures can be taken and safety improving actions can be performed. Good safety culture leading to the desired results can be rewarded, and oppositely can accidents lead to reactions in relation to losing contracts or other negative effects. Coursing and guidance in relation to safety matters can also lead to a common understanding of risks that will lead to a higher level of safety and fewer incidents.

9.	What are critical challenges for functional product's maintenance and operation?	<p>Main challenge is "contract" upset.</p> <p>Establish requirement and guideline including technical and functional specifications for drilling contractor and other contractors. Since the operator will sign in many contracts cover the needs of all technical expertise.</p> <p>How to organize and the different contractors?</p> <p>Implementation and execution of the contract for functional product Ensure contractor is using and/or updating its operation and maintenance procedure.</p> <p>Ensure standardization across their requirements, work process, and equipment fleet regarding buy functional performance for production facility.</p> <p>Disadvantage: Price to get performance service delivery of functional product is three times higher of performance of owned equipment to perform the same task.</p>	<p>Main challenge is Operability: Currently today "performance of MODU- y-axis with respect to time x-axis" it has been 60% of performance even it is functional product – because of contract not based in incentive agreement.</p> <p>Trust between operator and contractors, since there is gap in reporting maintenance information and real status.</p> <p>Regarding process facility for fixed installations (e.g. production platform):</p> <p>Maintenance system integration, operator has own maintenance system- contractor has own maintenance system for their functional product that need to be integrated to operator's system.</p>	<p>Different parties with different priorities for maintenance activities.</p> <p>Spare parts availability. Logistic planning. Logistic of spare parts</p> <p>Regarding process facility for fixed installations (e.g. production platform):</p> <p>Maintenance system integration, operator has own maintenance system- contractor has own maintenance system for their functional product that need to be integrated to operator's system.</p> <p>Contractor has to operate more than two maintenance system in case of integration their system into operator system- and if they are delivery functional products to more than one operator- they have to operator with more than two systems</p>	<p>Different parties with different priorities for maintenance activities.</p> <p>Spare parts availability. Logistic planning. Logistic of spare parts.</p> <p>Regarding process facility for fixed installations (e.g. production platform):</p> <p>Maintenance system integration, operator has own maintenance system- contractor has own maintenance system for their functional product that need to be integrated to operator's system.</p> <p>Contractor has to operate more than two maintenance system in case of integration their system into operator system- and if they are delivery functional products to more than one operator- they have to operator with more than two systems.</p>
10.	Alternative solutions for given challenges	Openly communicate plan and schedule to contractors to ensure contractors have proper time range to prepare their	Incentive contract. Meet operational	The alternative solution is standardization and harmonization of maintenance	The alternative solution is standardization and harmonization of maintenance

		<p>equipment.</p> <p>Operator to set up clearly defined guidelines and requirements.</p> <p>Standardizing of drilling operations, equipment, planning and execution of well drilling operations.</p> <p>There is need for contractor to set up computerized maintenance management system-that can be integrated to operator's system.</p>	<p>requirements.</p> <p>Competence maintenance personnel from operator's organization</p> <p>Contractor has to report the correct status of their system.</p>	<p>system between different contractors and operators.</p>	<p>system between different contractors and operators.</p>
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