ASSET MANAGEMENT BASED ON OPERATIONAL AVAILABILITY AND LIFE CYCLE COST OPTIMIZATION ACHIEVEMENT: THE OFFSHORE PROCESS CASE STUDY

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Abstract

In order to support the asset high performance achievement throughout the life cycle the paper will demonstrate the optimization methodology based on Dynamic Programming Algorithm integrated to the apmOptimizer software which enable to predict the asset performance, such as production efficiency, operational availability, reliability and also take into account the asset configuration, maintenance, inspection policies to minimize the life cycle cost. The proposed methodology enables to optimize the asset performance based on Dynamic Programming Algorithm as part of the apmOptimizer software which enables to take into account operational availability, reliability, maintenance, inspection and spare parts. In order to demonstrate such methodology an offshore asset case will be demonstrated considering the integration of such factors to minimize the asset life cycle cost (CAPEX and OPEX) throughout the life cycle.

The final results will demonstrate the advantages of the optimized solution when compared with other solution. The final result will show the trade off analysis considering the operational availability and Life cycle cost for the usual proposal solution and the optimized one. Therefore, as part of the final solution, the best inspection and preventative maintenance time as well as spare part stock level, which enables to minimize the life cycle cost will be defined based on software simulation.

The Optimization of asset performance based on Dynamic Programming is a new approach applied to the traditional RAM analysis which predicts the asset performance based on information pre-defined. The proposed solution is a powerful tool to be applied to offshore and onshore assets during design or operation phase in order to support decision about asset configuration, maintenance and spare part policy.

1. Introduction

The Asset management has the main objective to support the assets to achieve high performance. Therefore, different methods based on reliability engineering, risk management, human reliability as well as life cycle cost must be performed in a different asset life cycle as defined by the asset management plan.

In order to manage the asset performance, different standards can be applied as guidelines such as PAS 55 and ISO 5500 and additional references such as KP3 asset integrity program and the concepts of JP 886 standards related to ILS.

The new asset management version is the standard series ISO 55000 which includes ISO 55000, ISO 55001 and ISO 55002. The ISO 55000 is related to the terms and definition. The ISO55001 is related to asset management requirement and the ISO 55002 is related to the guideline for the application of ISO 55001.
In general terms the series ISO 55000 encompass the similar aspects described in PAS 55. Therefore, the element of Asset management based on ISO 55000 is described as follows (ISO 55000, 2014):

- Context of the organization
- Leadership
- Planning
- Support
- Operation
- Performance evaluation

The context of the organization element includes internal and external context. The external context includes the social, cultural, economic and physical environments, as well as regulatory, financial and other constraints. The internal context includes organizational culture and environment, as well as the mission, vision and values of the organization.

The leadership element describes the Top management responsibility for developing the asset management policy and asset management objectives and for aligning them with the organizational objectives. Leaders at all levels are involved in the planning, implementation and operation of the asset management system.

The planning element describes the organization's asset management planning activities at different levels. The asset management plan activities are defined based on strategic objectives which are generally produced from the organization's strategic level to the bottom level and are documented in an organizational level.

The support element describes the required collaboration among many parts of the organization. This collaboration often involves the sharing of resources. Coordinating these resources and applying, verifying and improving their use should be the objectives of the asset management system. It should also promote awareness of the asset management objectives across the whole organization.

The operation element enables the directing, implementation and control of its asset management activities, including those that have been outsourced. Functional policies, technical standards, plans and processes for the implementation of the asset management plans should be fed back into the design and operation of the asset management system.

The performance evaluation can be direct or indirect, financial or non-financial Effective asset data management and the transformation of data to information is a key to measuring asset performance. Monitoring, analysis and evaluation of this information should be a continuous process. Asset performance evaluations should be conducted on assets managed directly by the organization and on assets which are outsourced.

The guideline to evaluate the asset management based on ISO 5500 elements scores is defined in the reference Calixto Eduardo et al ,2016 and support the decision about which action must take place along the different asset life cycle to improve the asset performance. Figure 1 summarizes the ISO 5500 asset management element's relation.

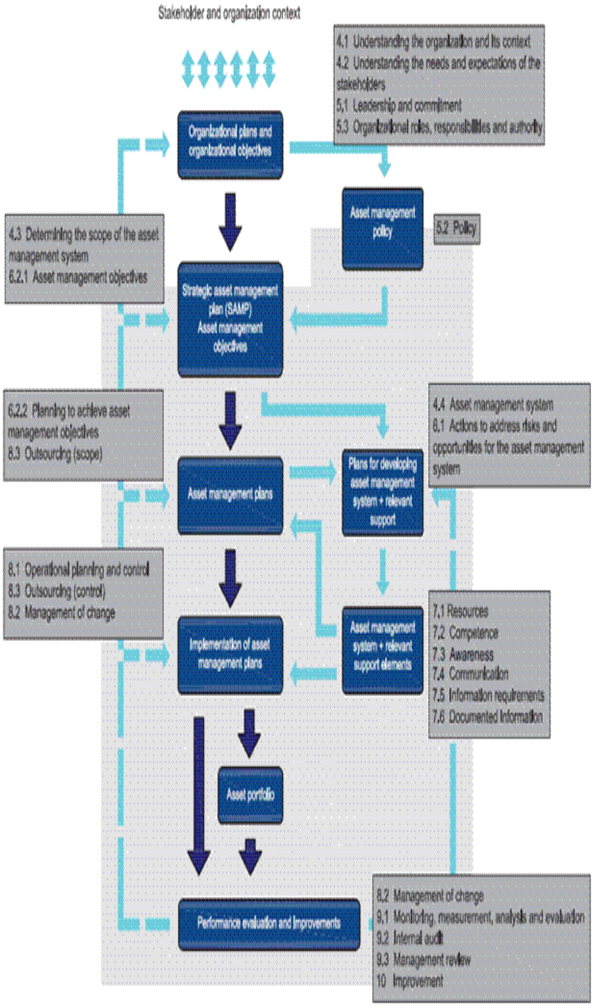

Figure 1 - ISO 55000 element relationship. Source ISO 55002

Despite of very clear asset management concept definition and standards guidelines, the achievement of the asset high performance depends on how different reliability engineering methods such as Lifetime data analysis, RAM, FMEA, RCM and RBI are implemented throughout the asset life cycle and also how the actions recommended by such methods are able to optimize the asset performance. Nevertheless, in order to achieve the asset performance optimization at least two main drivers such as performance and cost must to be taken into account. The item 3 will introduce the concept of the asset optimization and the case study will be demonstrated in chapter 4.

2. *Asset Management for Oil and Gas Industry*

Concerning the Oil and Gas industry as oil, gas and derivatives supplier the technology and market are relatively stable. Therefore, is expecting a long life cycle, which requires an asset performance optimization based on continuous improvement supported by reliability engineering, integrated logistic support and LCC.

Indeed, depends on equipment characteristic different physical asset management approach are required. In case of most of static equipment vendors, the market is stable and the technology is stable. Despite a long life cycle which requires an LCC approach, some innovation are required mostly related to materials to be robust to different operational environmental conditions. Usually, these physical assets such as pipes, vessels, towers, tanks are very reliable but requires a very good maintenance and inspection plan to certify the risk mitigation.

In case of vendors who supply electronics an electrical component, the technology and market are dynamic. Therefore, the physical asset management requires the new asset concept development and short life cycle, which implies a shorter payback time related to an economic life cycle. In this case, the asset performance optimization must to be achieved during the design phase, because any improvement during operational phase impact highly on payback and the profitability of such assets.

In case of rotating equipment vendors, the market is dynamic and the technology is stable. That means such assets have a long life cycle, but it´s always necessary to develop new asset concepts due to competitiveness and also new customers requirements. In this particular case, the life cycle profit approach is more appropriate than life cycle cost approach because each physical asset must to be addressed to the customer which requires a shot economic life cycle related to the warranty period.

Because of the complexity faced with oil a gas, oil and gas industry the asset management must to be supported by the following programs:

- Reliability Engineering program
- Asset Integrity Management program
- Integrated Logistic Support program
- LCC/LCP program

Concerning the reliability engineering program, the high performance of physical asset is achieved by the best reliability engineering method's implementation throughout the asset life cycle phases including the preventive maintenance programs with the application of RCM, RBI and FMEA which are part of reliability engineering program.The figure 2 demonstrates different reliability engineering methods to be applied throughout the asset life cycle.

Indeed, all effort starts on design phase applying different qualitative (DFMEA, RCM, RBI, HALT, FRACAS, human reliability) and quantitative (RAM, ALT, Reliability Growth analysis and warranty analysis) methods. Such methods have the main objective to identify the early life failure during design and eliminate them whenever it is possible. On an operational phase, different qualitative (PFMEA, RCM, RBI) and quantitative (Lifetime data analysis and RAM analysis) methods must be taken place to maintain asset performance until the end of asset life when must be defined when decommissioning the equipment that is supported by ORT (Optimum Replacement Time), RAM analysis and Reliability Growth analysis.

The asset integrity management is also part of Asset management, but the main objective is to achieve physical asset high performance concerning safety and environmental aspects. In fact, the risk management has been applied for all Oil and Gas companies all over the world, but even with all effort applied the major accident has not been avoided.

The Asset integrity Management requires different effort concerning risk management, reliability, preventive maintenance and human error assessment. Therefore, the pillars of Asset Integrity are “Risk Management”, “Reliability & Manintenance” and “Human factor” as shows figure 3.

The Risk Management means to define a risk target, hazard identification, incident and accident investigation, risk assessment, risk evaluation and risk mitigation, communicate the risk and prepare an emergency response plan. In order to identify hazards and assess the risk different qualitative and quantitative methods can be applied like PHA, FMEA, HAZID, HAZOP, FTA, ETA, SIL, LOPA, AQR and Bow Tie.

The Reliability & Maintenance performance index are defined in pre-feed phase to be assured in the design phase of RAM analysis, life time data analysis, accelerated life test, reliability growth analysis, DFMEA, RCM, RBI. In addition, a long operational phase, lifetime data analysis and RAM analysis are carried out to support decisions as well as RBI, RCM that will define maintenance and inspection policies to maintain asset availability and reliability a long operational phase.

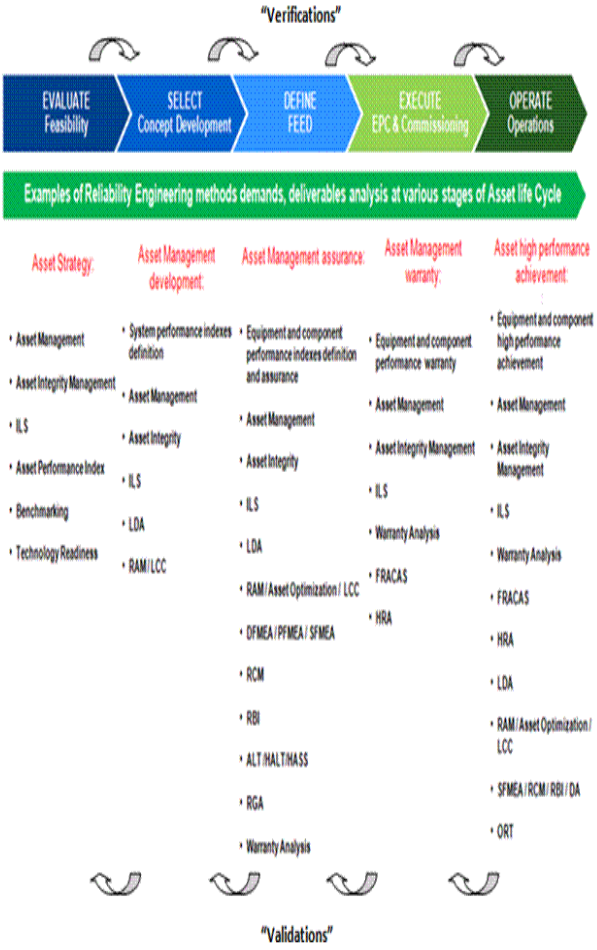

Figure 2: Asset Management life cycle.
Source: Calixto, 2013.

The Human factors are identified by human reliability analysis, which concerns all human performance factors related to all critical activities that can lead in an accident or environmental impact.

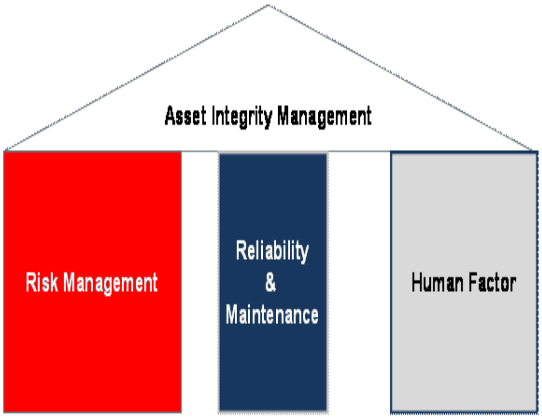

Figure 3: House of Asset Integrity Management.

The Integrated Logistic Support (ILS) has been applied to military and aerospace industries worldwide, and after some decades has proved to be a successful methodology.

The integrated logistic Support (ILS) encompasses all information from different reliability engineering methods and also includes important logistics issues such as deliver time and spare part policies which may affect asset performance. The figure 4 shows the integrated information flow, which supports the ILS.

The final program which supports the asset management is the Life Cycle Cost (LCC) which can be defined basically by the accountability of all cost involved to design, execute, operate and maintain the asset. Despite is not the scope of this paper to define deeply the concepts applied to LCC, the item 5 will demonstrate the minimization of the life cycle cost as a result of Asset optimization performance.

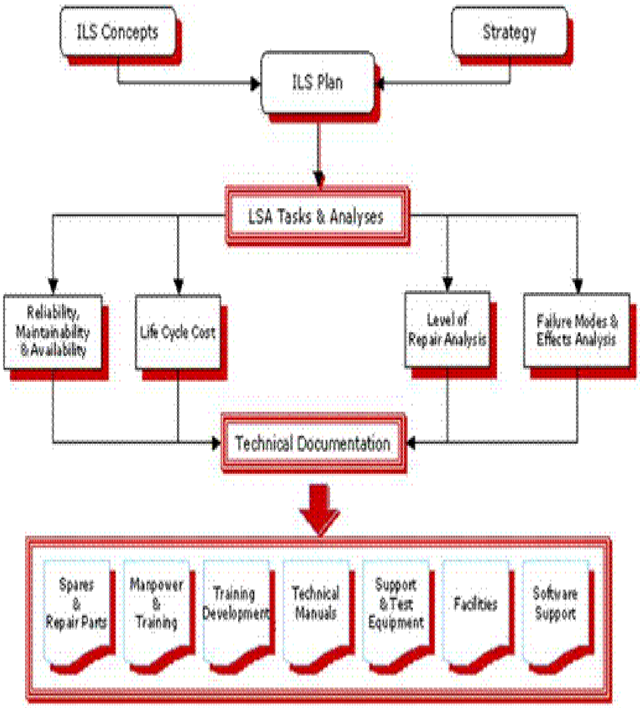

Figure 4: ILS information flow
Source: http ://www.mulkerin.com/images/

3. *Asset Optimization*

As mentioned before, in order to achieve the asset performance optimization at least two main drivers such as performance and cost must to be taken into account. Indeed, optimize means maximizing the performance, such as production efficiency and operational availability as well as to minimize the life cycle cost.

The very limitation about the implementation of reliability engineering methods is that such methods are applied at system level based on high performance achievement of individual equipment and components without considering the optimal solution for the whole system. The optimal solution defining the optimal time to perform preventive maintenance & inspections, spare part levels, best spare part locations and resources. The whole asset performance optimization is demonstrated is figure 5.

The best time to perform preventative maintenance and inspection depends on each equipment and component probability of failure, which is defined on LDA (Life Time Data Analysis) as well as degradation process.

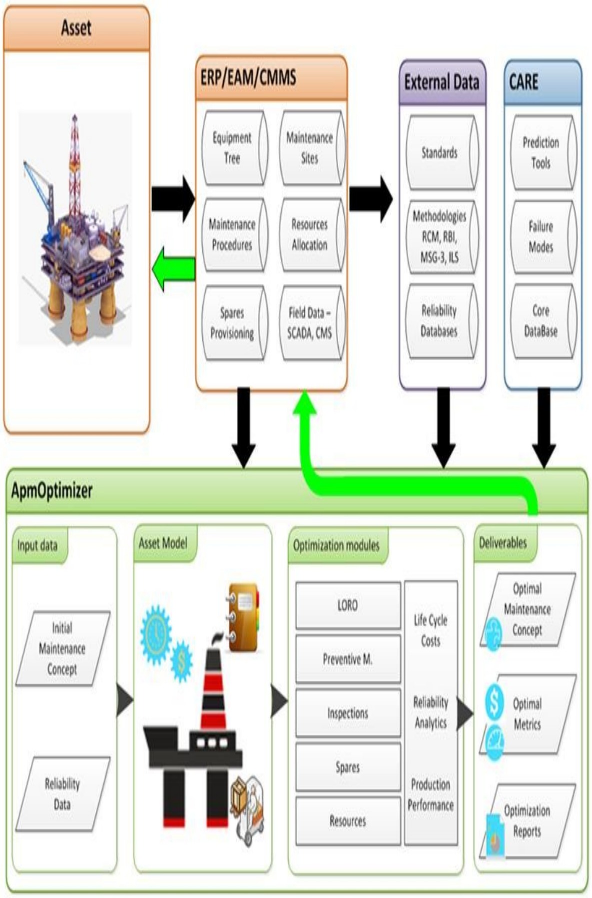

Figure 5 Asset Performance optimization (Source: Calixto.E, Bot.I 2015)

Such degradation assessment is supported by PDA (probabilistic degradation analysis) as well as RCM and RBI methods based on predictive maintenance results, standards and online monitoring data.

In addition, the spare parts will also be influential for such preventive maintenance, inspection and failure times. Therefore,in order to maximize one equipment performance, it´s necessary to first define the best time to perform a preventive maintenance for each component and further define the optimal time for the whole equipment as shows figure 6. Once definitely the best time to perform such preventive maintenance and inspection, it´s also possible to define the best time to purchase the spare part in order to minimize the stock level and life cycle cost.

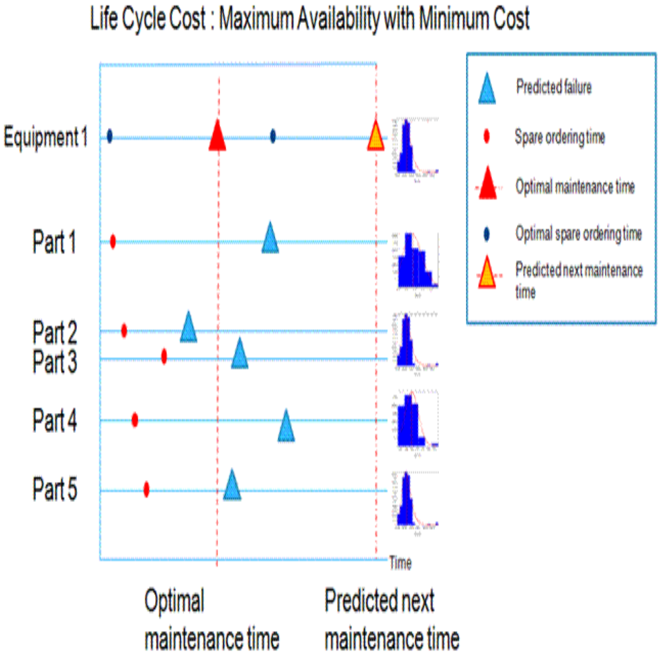

Figure 6: Equipment Performance optimization(Source: Calixto.E, Bot.I 2015)

The optimal time is such time, which allows to minimize the life cycle cost and maximize operational availability of equipment. After optimizing the equipment, the further step is to optimize the system asset considering the optimal solution defined for each individual equipment which affect this System asset performance.

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Indeed, in many cases, to optimize each equipment individually will not allow to optimize the whole asset performance. The System asset optimization takes into account all individual equipments constrains to give a better solution for the whole asset system as shows figure 7.

The challenge of optimizing the whole asset is related to the huge number of constraints such as environmental, safety, law, client, performance and cost. In addition, there are different goals which in many cases do not allow to optimize the whole asset, such as zero stock policy, minimal operational cost and minimum number of teams.
The idea of asset optimization is to support the leader's decision based on a mathematic method approach which save time and have a potential to optimize system assets performance.
The optimization methodology encompasses information such as spare parts, preventive maintenance and inspection policies, reliability and logistic parameters of many equipment and component as well as the hierarchical relation between them.

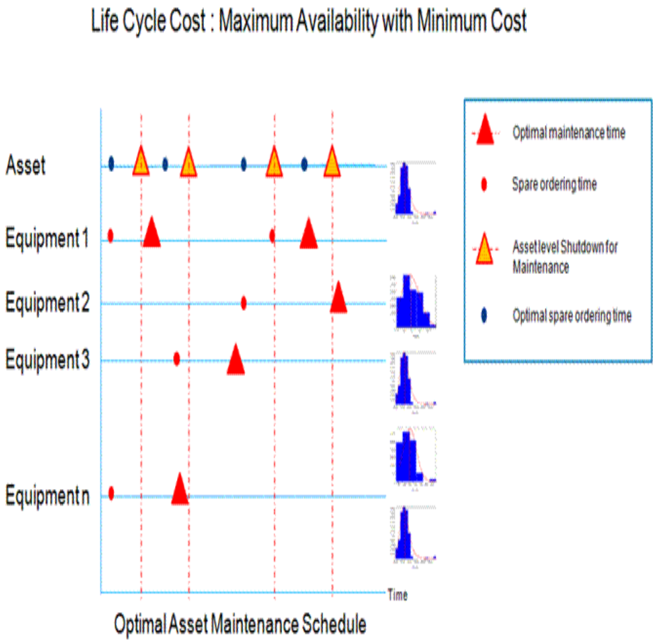


Figure 7: System Asset Performance Optimization. (Source: Calixto.E, Bot.I 2015)

For this reason, Dinamic Program (DP) is the ideal tool for this task.Gustafsson (Gustafsson, 2010), presented a DP method for maintenance optimization in which S_t and d_t represent the state of the system and decisions made respectively, at time t. Furthermore, i_t is the exogenous information that arrives at time t. φ represents the transition function and with these notations the system evolves in time according to:

$$S_{t+1} = \phi(s_t, d_t, i_t)$$

For each decision we make, a cost $C(s_t, d_t)$has to be paid. If we assume a stochastic system, the objective is to minimize the expected total cost over some planning period.
If we assume that the system is in some state at time 0, and we have to make decisions for the time horizon 0, . . . ,T , our problem is to :

$$MIN_{x_0,x_1\ldots,x_T} : E\left(\sum_{t=0}^{T} C(s_t, d_t)\right)$$

Subject to:

$$S_{t+1} = \phi(s_t, d_t, i_t)$$

The proposal DP method includes the operational availability target considering the maintenance policy decision which is described as following: For each item prepare a set of possible maintenance policies and calculate their cost and resulting item availability. Next, use these possibilities to construct a new set of possible maintenance policies for blocks each containing several items. In this way possible maintenance policies are constructed for every level in the asset hierarchy and the optimal policy is eventually chosen.
The second optimization possibility is to consider the Hierarchal System Model Optimization. The challenge is to optimize the maintenance policy for the system i.e. to find the cheapest policy subject to a requirement that system availability be larger or equal to $A_{required}$.
Suppose that the system optimal policy $P_{1,1}$ is known ($P_{i,j}$ denotes the policy for block j that belongs to level i)and it has a system availability denoted by $A_{1,1} \geq A_{required}$. Similarly, the set of policies and availabilities for the blocks of level 2 is denoted by ($P_{2,i}$) and ($A_{2,i}$). The system optimal maintenance policy is a union of optimal policies belonging to level 2 blocks:

$$P_{1,1} = \bigcup_i P_{2,i}$$

Therefore, with availabilities $A_{2,i}$, and more generally:

$$P_{m,j} = \bigcup_i P_{m+1,i(j)}$$

Where $I(j)$ denotes the indices of blocks in level $m+1$ which are children of block j. Since $A_{2,j}$ has not known a-priory, different optimal policies are constructed for different $A_{2,j}$ values, and the optimal $P_{1,1}$ is constructed by choosing the best combination of level 2 component policies. The process can easily be generalized to systems with many hierarchal levels.

In fact, there are different optimization algorithms which enable to define an optimal solution. It´s not the scope of this paper to discuss in details each individual optimization model and algorithm, but present a feasible solution which was successfully applied on Oil and Gas industry.

The optimization algorithm described above was implemented into the apmOptimizer (BQR) software for different optimization modules such as Preventative Maintenance (PMO), Inspection optimization (PIO), Spare parts (S2A), Resources (R2A), level of repair (LORO). Such application will be demonstrated in the item 4.

4. *Offshore Asset optimization case study*

In order to exemplify the Asset performance optimization, a case study applied in Oil and gas offshore assets will be presented in this section.

Producing hydrocarbons in deepwater offshore requires subsea and Topside assets such as different types of platform as shows figure 8.

The subsea production wells have been around for more than 40 years. A subsea well consists essentially of a wellhead assembly and a Christmas tree (sometimes referred to as a wet tree), which is basically identical in operation to its surface counterpart, with the primary exception of reliability refinements, to permit operation at the seabed.

The oil well is drilled by a movable rig and the extracted oil or natural gas is transported by pipeline under the sea (flow lines and flexible risers) and then to rise to a processing facility. The main subsea system and equipment are described as follows:

- Subsea production control system
- Subsea structures and manifold system
- Subsea intervention system
- Subsea umbilical system
- Subsea Flexible risers
- Subsea Flow Risers
- Subsea PLEM
- Subsea Jumpers

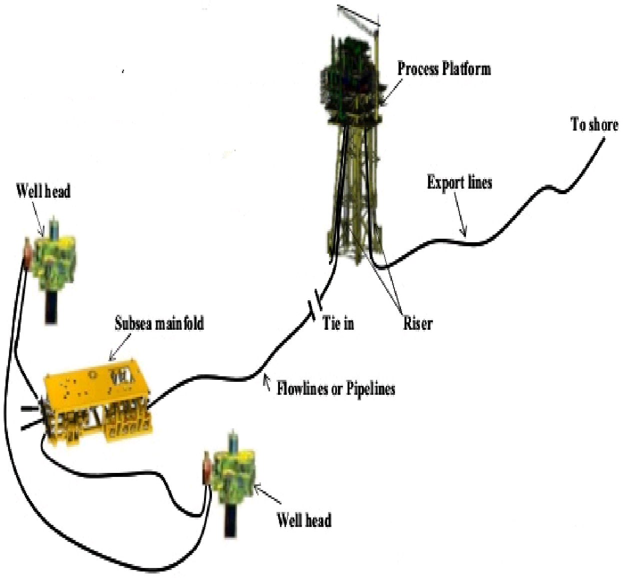


Figure 8: offshore Production flow

Subsea wells have been used in support of fixed installations as an alternative to satellite or minimum facility platforms for recovering reserves located beyond the reach of the drill string or used in conjunction with floating systems such as FPSOs and FPSs.

Depends on the type of reservoir, different configuration of platform is required to maximize the production by the asset maximum performance achievement.

Concerning Oil and Gas offshore assets, the subsea equipment is the most critical in terms of investment, safety and environment criticality. Indeed, in case of unsafe failures in flexible risers, flow lines, jumpers and PLEM a major accident with catastrophic consequences may occur. In addition, loss of production may have huge economic consequences due to lack of proper spare parts or preventative maintenance and inspections. Figure 9 shows a diagram block of a subsea system which based on RAM analysis, has achieved lower performance than expected due to human errors during design installation and maintenance.

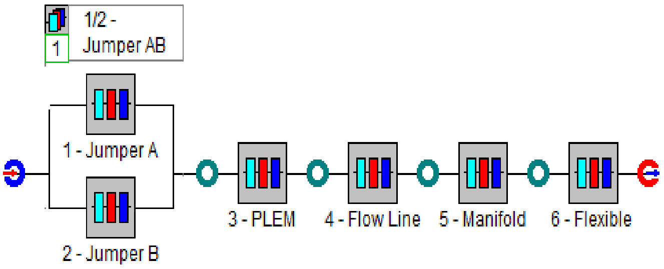


Figure 9 – Subsea RBD (BQR apmOptmizer).

The system operational availability prediction in the first 5 years is 90.34%. In order to improve the subsea system performance, it´s necessary to mitigate the human error based on installations and maintenance procedures improvement and supervision follow up. In addition the FMEA recommendation related to product specifications must be implemented during the design phase.

After all efforts to achieve high performance by implementing the recommendations, the system operational availability achieves 99.81% in 5 years. In fact, in order to achieve the lower LCC and higher operational availability it's necessary to take into account the cost of preventative maintenance, inspections and spare parts optimization. In addition, the logistic effects must be accounted for in order to have an integrated solution that ILS methodology proposes.

In order to perform complete asset performance optimization the logistic times are very important information. Table 1 considers the logistic times to deliver, test and install critical subsea equipment.

Item	Manufactoring Time (Days)	Transportation time (Days)	Test & Installation time (Days)	Total time (Days)
Flexible Riser	73	5	20	98
FLow Line	73	5	20	98
Jumper	73	5	20	98
PLEM	73	5	20	98
Umbilical	73	5	20	98

Table 1 – Subsea logistic times

In addition to logistic time, the LCC must be accounted during ILS analysis and it´s necessary to take into account the preventive maintenance and inspections of critical equipment as shown in table 2.

Item	Equipment cost ($)	Test & Installation time cost ($)	Repair cost ($)	ROV cost ($/day)*
Flexible Riser	440000	200000	640000	50000
FLow Line	420000	200000	620000	50000
Jumper	105000	150000	550000	50000
PLEM	210000	100000	310000	50000
Umbilical	420000	200000	620000	50000

Table 2 – Subsea logistic cost

Concerning the logistics, all information is incorporated into the ILS model shown on figure 10 which considers all information deployed on tables 2 and 3 and also the RBD model described in figure 5. In order to solve the optimization of ROV inspection interval to minimize the LCC. The ILS model was applied by using the apmOptimizer software as shows figure 9.

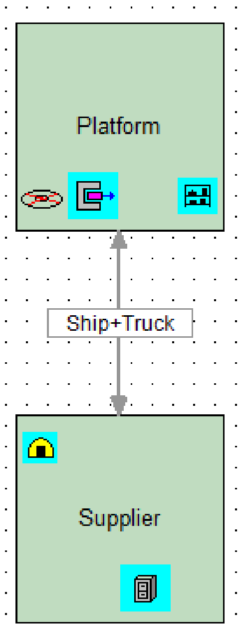
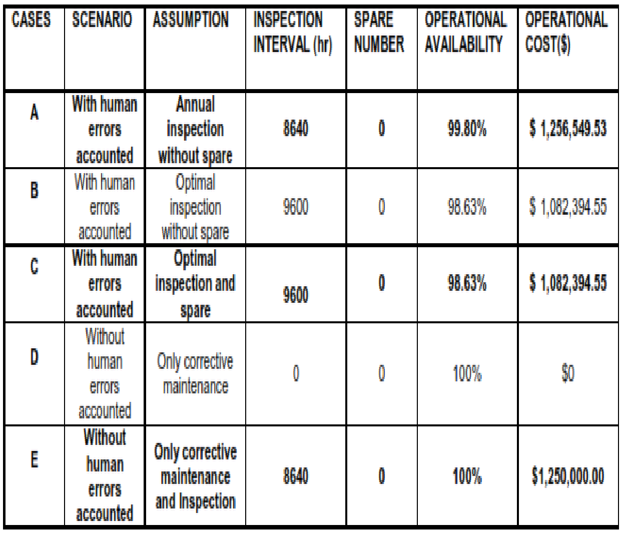


Figure 10 – ILS model

Concerning the critical subsea equipment, table 3 shows the trade off analysis which takes into account the initial annual inspection ROV and spare part policy for the flowline and also the optimal inspection interval and spare policy for 5 years.

Table 3 – Flow line optimal inspection and spare part



CASES	SCENARIO	ASSUMPTION	INSPECTION INTERVAL (hr)	SPARE NUMBER	OPERATIONAL AVAILABILITY	OPERATIONAL COST($)
A	With human errors accounted	Annual inspection without spare	8640	0	99.80%	$ 1,256,549.53
B	With human errors accounted	Optimal inspection without spare	9600	0	98.63%	$ 1,082,394.55
C	With human errors accounted	Optimal inspection and spare	9600	0	98.63%	$ 1,082,394.55
D	Without human errors accounted	Only corrective maintenance	0	0	100%	$0
E	Without human errors accounted	Only corrective maintenance and Inspection	8640	0	100%	$1,250,000.00

The first column shows the difference scenario cases from A to E.

The second column describes the scenarios A, B, C which consider human error for the first 5 years and the scenarios D and F which does not take into account human error (design, installation and maintenance).

The third columns describe the assumptions which consider the type of maintenance and inspection and also the spare part policy.

The fourth column describes the inspection interval (ROV) based on RCM and RBI analysis on scenario B and optimal time based on apmOptimizer solution described in scenarios B and C.

The fifth column describes the spare part (flexible riser) for different scenarios. On scenario A, one spare part is considered. For the other scenarios, zero spare parts policy was implemented in model.

The sixth column shows the operational availability achieved for each scenario based in each assumption.

Concerning operational availability, the scenarios A achieves the best operational availability in five years (99.80%).

The seventh column describes the operating cost for each scenario. In this case, scenario A presents the highest cost which is affected by the PM interval. Scenario D shows the lowest operating cost based on the assumption of zero human error and zero PM. Since it´s not possible to guarantee the absence of human error, the scenario C is the most realistic and the second best in terms of cost which considers the optimal solution, which means, the optimal inspection interval and spare part.

Based on table 3 results, the highest performance is achieved. The final solution applied the similar approach to others subsea critical equipments such as Flexible risers, Jumpers, Umbilical and PLEM. Therefore, the Asset peformance optimization model assessed in the apmoptmizer software enables to minimize the LCC and maximize the operational availability.

5. *Conclusion*

The asset performance optimization model proposed enables to optimize the asset performance, such as operational availability and LCC. In order to apply such methodology, plenty of failures, repair, maintenance and logistic data are necessary.

The usual reliability engineering methods such as FMEA, RCM, RBI, RAM and also AIM are essential to be used as input to the asset optimization model.

In many projects, to implement all such methods requires time and investment, but more important is the reliability and PM culture as well as the programs such as ILS as a key success factor to achieve high performance and lower LCC.

In many ILS applications, the optimal solution is not achieved because it required an optimization model to support the final decision related to PM interval, spare parts levels and resources.

The case study presented was applied to a real subsea oil and gas project achieving successfully the main objective that was considered the logistic effect on system performance and also optimize the asset performance and LCC.

The next step will be to apply this ILS optimal methodology to different Oil and Gas assets in order to support the asset management in different life cycle phases and optimize the asset performance.

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