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Integrated Operations—A Key Enabler to Operational Excellence in Maintenance Management of FPSO's

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Abstract

Teekay Petrojarl Production (TKP), the largest operator of Floating Production, Storage and Offtake (FPSO) vessels in the North Sea, has an ambition to retain its leading position as FPSO contractor in harsh environments while also expanding its business into benign waters worldwide. One of the important measures to attain this is by establishing and implementing best practice within E&P operations business worldwide. Several projects have been started to support TKP's effort to reach operational excellence. This paper is concerned with one of the projects, "Integrated Operations – A Key Enabler to Operational Excellence in maintenance Management of FPSOs". The main objective of this project is to enable TKP to take a step further into operational excellence by implementing more effective work processes, and developing new theory, methods and tools for maintenance optimization. TKP regards Integrated Operations (IO) as an important instrument to reach this objective. The research project focuses on three activities; 1) Describe and analyse future work processes for strategic and tactical analyses, 2) develop tools and methods to support strategic and tactical maintenance decisions, and 3) implement and verify work processes, tools and methods. Cases are used to develop, test and verify work processes, tools and methods prior to implementation, and have proven essential to create consensus. Recent experience shows that challenges with IO are more related to organisation and competence than technology itself. The Man, Technology and Organisation (MTO) focus is chosen when developing new work processes to meet the challenges related to competence and organisation. Close cooperation with onshore and offshore staff is critical when developing the new work processes. The main challenge for the development of tools and methods is related to balancing simplicity and theoretical basis. It is seen that many of the new tools and methods may be feasible just because the IO setting enables the use of onshore centralised expertise. The project has clearly seen that a successful implementation of IO, to reach operational excellence in maintenance management, requires full attention to balancing personnel competence, technology complexity and organisation (MTO), and ensuring management ownership (visions, maintenance strategy, measurable goals).

Introduction

Teekay Petrojarl Production, TKP is the largest operator of Floating Production, Storage and Offtake (FPSO) vessels in the North Sea with a combined production capability of 339,000 barrels of oil per day and a crude storage capacity of more than one million barrels.

TKP has an ambition to retain its position as the leading North Sea FPSO contractor through redeployment of existing units in core areas (harsh environment) and actively seek new projects. With nearly 50 years of accumulated operating experience – from test production to tail end production - TKP has a strong reputation and market position within FPSO operation in harsh environment.

A typical characteristic for TKP is that the company supplies a service for the oil companies in terms of oil/gas production from wellhead to refinery. Regularity has key implications on income, whereas operational cost is the most critical factor for company revenue. High regularity combined with re-deployment and safety track records in operation of FPSOs call for a strong focus on technical condition, technical integrity and maintenance efficiency.

Establishing and implementing best practice within the E&P operations business worldwide shall be recognised as the ultimate goal. In acknowledging the capabilities of integrated operations, the maintenance management strategy and system (with its supporting tools and work processes) shall be sufficiently robust and flexible to effectively adapt to anticipated evolutions, and defend this position for the next 20 years.

In order to elevate the best practice, TKP has a range of ongoing projects to enable TKP to take a step further into operational excellence. One of these projects, “Intergated Operations – A key Enabler to Operational Excellence in Maintenance Management of FPSOs”. This is a research project funded by the Norwegian Reseach Council, TKP, Marintek and SINTEF., and touches upon its interaction with the other projects.

The structure of the paper is as follows. We start with a description of the activities of the research project, followed by a brief description of the cases we have established to both analyse work processes and to test the tools and methods we develop in the research project. Next, we describe the results from the project so far. Finally, the conclusion describes the general experience, challenges and the way forward.

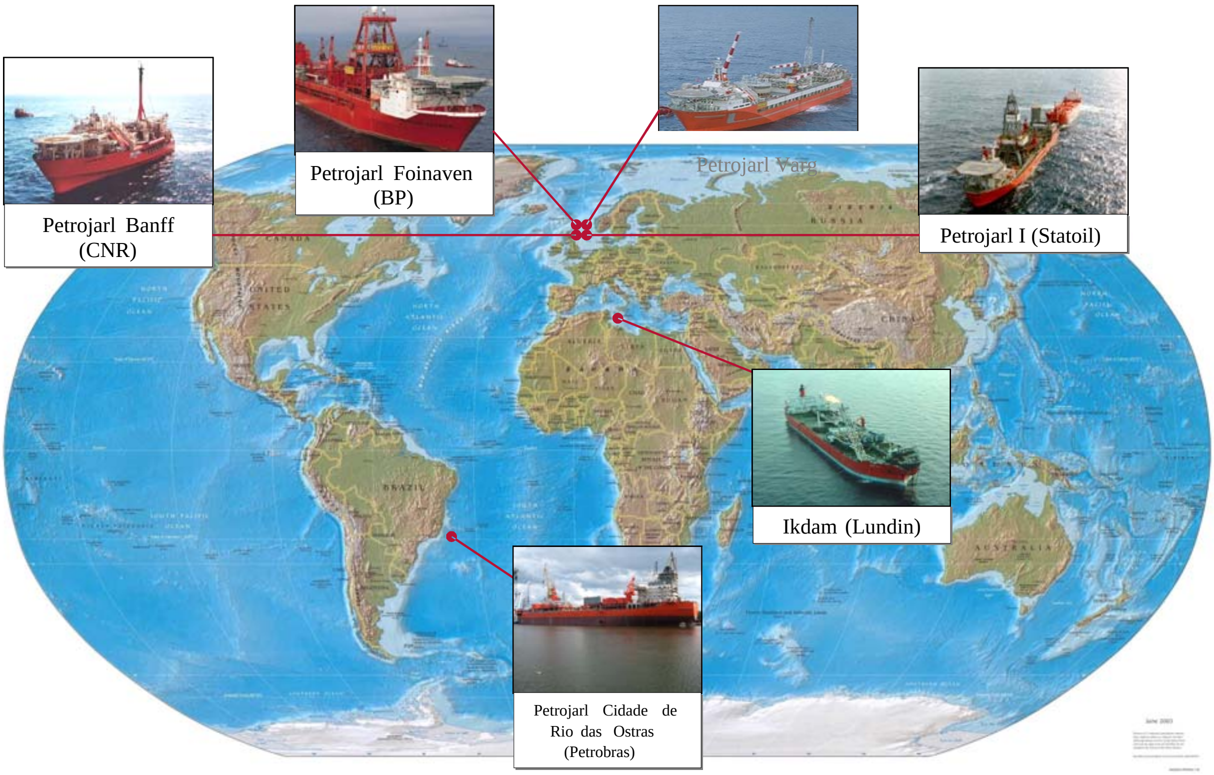

Figure 1 The TKP FPSO fleet

Research project description

Integrated Operations (IO) as a concept was initially applied to support drilling operations. It has later moved into the areas of reservoir management, production management and process management.

When it comes to supporting maintenance management, onshore operation centres are increasingly being used to share data and information for certain equipment types and perform condition monitoring and diagnosis analyses of these units. The overall integrity and maintenance management, however, has not yet become a commonly known IO work practice.

More recent experience shows that the challenges are more organisation and competence than technologically oriented – see Hocking et. al. (2004). Central challenges to succeed in IO are:

- How to improve the decision processes in integrated teams?
- How to obtain common goals and integrated thinking?

- How to communicate across disciplines, organizations, cultures, onshore/offshore?
- How to succeed in the cooperation between companies and the suppliers?
- How to draw on the knowledge and expert networks in the company?

The principal objective of the research project is to enable TKP to take a step further into operational excellence in maintenance management. TKP regards IO as an important instrument to reach this objective and has therefore launched this research project to meet the challenges outlined above.

Operational excellence will be obtained by developing new theory, methods, and tools. Further, the project will implement more effective work processes to continuously improve maintenance strategies and optimise maintenance for a world wide fleet of floating production units.

Sub-objectives are:

- Develop work process and supporting infrastructure for strategic and tactical maintenance analyses in an integrated operations environment
- Develop methods and tools to facilitate better strategic and tactical decisions in an integrated operations environment
- Implementation and verification of new work processes, tools and methods
- Document unique capability in managing technical integrity of production units in an outstandingly safe and cost effective way.

The results from the research project will contribute to increased safety, regularity and cost-effectiveness of floating production units in an integrated operations environment. Further, highly cost effective maintenance management is seen as a critical success factor to maximise the recovery from end of field life operations and development of small HC discoveries in distant areas by redeployment of mobile units.

With respect to current best practice, a significant improvement potential is seen from developing and implementing an overall maintenance management concept that aims at balancing safety, environmental impact, production losses and costs by applying formal methods for maintenance optimisation.

TKP has in its development of a new maintenance strategy established three maintenance steering loops to describe the different steering processes involved in maintenance management. The steering loops represent three different work processes in maintenance management;

- Strategic (Maintenance engineering and planning)
- Tactical (Change control/continuous improvement)
- Operational (Maintenance execution)

The work processes are illustrated in Figure 2 below.

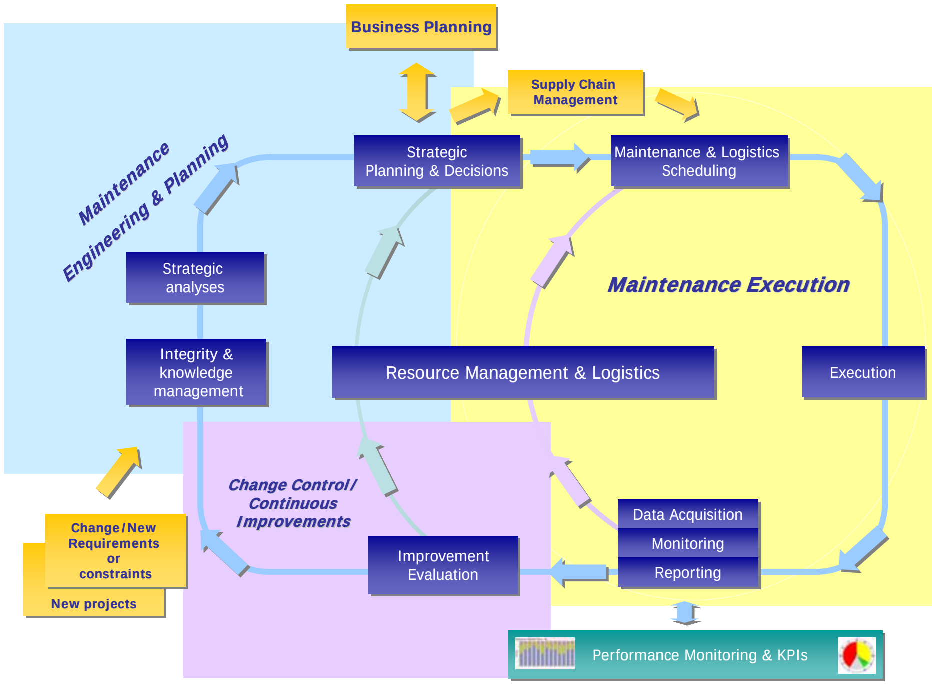

Figure 2 TKP maintenance steering loops.

Research project activities

The research project comprises the following activities:

1. Describe and analyse future work processes for strategic and tactical maintenance analyses in an integrated operations environment.
2. Develop tools and methods to support strategic and tactical maintenance decisions in an integrated operations environment
3. Implement and verify developed work processes, tools and methods, and data infrastructure

The activities are further described in the following sections.

Work processes

The work processes activity encompasses the following tasks:

1.1 Visions and Goals
1.2 Current practice
1.3 Work process and analysis
1.4 MTO measures and enablers

Task 1.1 – Visions and goals

Define the overall visions, objectives and measurable goals for the future work processes in strategic and tactical maintenance analysis. Overall visions and objectives such as safety, reliability and cost effectiveness are being addressed. Example of an objective on a high level is to reduce overall maintenance and inspection costs by 20-30 % with no negative impact on regularity, integrity and safety performance.

Task 1.2 – Current practice

Define cases for analysis and describe work processes for these cases. A selection of cases will cover the most important integrity and maintenance management decisions. Both major and minor decision situations are being be analysed. Major decisions may concern modification work/renewal while minor decisions may concern the optimal interval for preventive maintenance for a critical item. Another example of a relevant decision situation is to find the optimal maintenance action based on condition monitoring and other performance data. Coordination with production management requirements is essential to these decision situations in an integrated operation setting.

Current work processes in strategic maintenance analysis for the most important integrity and maintenance decisions will be described using a suitable format.

Task 1.3 – Work process and analysis

The work processes and the activities within the work processes will be analysed with a Man Technology Organisation (MTO) approach. Preconditions and requirements for each activity to reach the defined objective will be addressed.

Questions to be addressed in the analyses are; clarity in roles and responsibilities, what type of information is needed to perform the analysis, how can the personnel involved communicate over distance and does the right analysis models exist? The analysis will reflect both the overall objectives and the more detailed goals as described above.

Condition monitoring techniques are relatively easy to use if the condition limits (triggers) are easily identified. In practice, however, it is difficult to establish unambiguous triggers due to the complex pattern received from the different sensors and measuring instruments. A variety of actors; optimisation analysts, operating personnel etc. are required to make good decisions in an operational context. These people are often physically located at different places, e.g. some are sitting in the onshore operation room, some are operating the FPSO, and others (e.g. manufactures of the compressors, and the condition control systems) are located in different countries. To get stakeholders to work towards the same objectives, and with converging mental models of the situation and optimal management of timely prediction of failures, is a huge challenge.

The result from this analysis describes the GAP between the “as-is” (current work process) situation and the desired “to-be” situation for the strategic maintenance analysis.

Task 1.4 – MTO measures and enablers

The measures and enablers needed to change from the “as-is” situation towards the desired “to-be” situation will be described in this task. The measures will be divided in man, technology and organizational (MTO) measures.

Personnel (M) measures such as skills and competence required to conduct the new work processes will be addressed in the analysis. In addition, new technology (T) necessary to support carry out the new work processes will be identified. Finally, organisational (O) changes, i.e., the roles and the responsibilities can be changed as a result of this analysis. As an example, technical infrastructure may be described as an enabler to support the decisions needed.

The activity results in a general description of enablers needed to reach the integrated operation situation. Communication in geographically dispersed teams is one major challenge that will be addressed and discussed. To guide a smooth transfer and prevent hampering the ongoing operations, with due consideration to the gap between the “as-is” situation and the desired “to-be” situation, a strategy for implementing changes will be established.

Tools and methods

This part of the research project focuses on the development of tools and methods to facilitate better strategic and tactical decisions in TKP, taking advantage of the opportunities presented by an IO setting. Due to the end-of-field life operations and development of small hydrocarbon discoveries in remote areas, TKP operates within tight profit margins. Highly cost effective maintenance is seen as a critical success factor in this context. This implies that TKP needs to optimise the balance between maintenance cost and regularity on the one hand, and profit, long term integrity and overall asset management on the other hand.

Task 2.1 – Framework for maintenance strategies and optimisation

An optimisation approach to maintenance management requires a holistic view on tools and methods, to capture the variety of factors influencing costs related to maintenance, regularity and safety. This may be captured in a general framework that could be used both to establish reasonable maintenance strategies and to optimise the maintenance. Such a framework comprises five building blocks;

- Connect the component performance to the system performance (RAMS system model)
- Develop probabilistic models to establish the relation between component state and likelihood of failure
- Model the effect of maintenance on the component performance
- Develop enhanced models for cost of executing maintenance
- Establish regularity and cost models related to reduced system performance

These building blocks are very or reasonably well developed as single blocks, but the integration of these blocks into one overall model is rarely seen in industrial applications. One of the main objectives is therefore to establish the building blocks in such a way that integration of them enables maintenance optimisation in an effective manner. In a real application the framework is a dynamic framework that will be improved during the analysis. The framework or model could also be used for other purposes than finding optimum intervals for maintenance. The main research objectives are summarised in the following:

- Define the principal content of each building block
- Describe the development of the various building blocks during the different iterations when applying the framework
- Define the interfaces between the different building blocks
- Describe the usage of the framework from a coarse model to a more detailed model, and the level of competence required to use the model

Task 2.2 – RAM modelling

At the core of the framework model lies a Reliability, Availability and Maintainability (RAM) model. Tools for RAM modelling already exist. These are based on Monte Carlo simulation, and are excellent tools for conceptual design and for operations planning. However, in an operational context, our hypothesis is that many of the optimisation challenges may be assisted by an analytical RAM model. The advantage of using an analytical RAM model is that the results are instantly given, as opposed to the Monte Carlo based simulation models. We believe that this increases the applicability of RAM models in maintenance optimisation, e.g., through reduced time and cost expenses on sensitivity analyses. Therefore, a central activity in the project currently, is the development of an analytical RAM model. This model is in the near future to be run against a simulation based RAM model to see whether our hypothesis can be accepted.

The purpose of the RAM model is to analyse the effect of different component maintenance options on system regularity. The system regularity figures can, in turn, be utilised to assess regularity costs, and be fed into the maintenance cost modelling framework. Thus, the RAM model will be crucial in maintenance, incl. spare parts optimisation.

Task 2.3 – Probabilistic models

To fully utilise the potential of such a RAM model, it needs to be dynamic in the sense that it will be able to take into account the likelihood of component failure, based on the component state. Therefore, we need probabilistic models that can describe the relationship between component state and failure likelihood. Condition monitoring is essential for such probabilistic models. Although industry has struggled in making condition monitoring a success, we believe that condition monitoring again will become more popular due to:

- *Sensor cost reduction* – we already see a significant drop in sensor costs. This enables monitoring more equipment, and also voting (e.g., 2-out-of-3) of sensor output signals to reduce the problem of false alarms.
- *Integrated operations* – some complex process equipment (e.g., compressors) often require expertise to assess the condition. Rather than having experts on each vessel, IO enables monitoring of equipment across all installations by experts onshore.
- *Diagnostic and expert advice* - services offered by equipment manufacturers and suppliers.

In addition to providing input to the RAM model, the negative effect on system regularity from too much maintenance or inefficient maintenance can be revealed by combining condition monitoring and probabilistic models.

This type of condition monitoring may also form one of the bases for continuous improvement. Here, good triggers are essential. Critical equipment could be followed up using trending on condition monitoring. A trigger is when the technical condition falls below a given acceptance limit. Thus, in this project we also aim to define appropriate triggers for some critical equipment at TKP.

Task 2.4 – Planned maintenance (PM) program optimisation

Another vital element of the maintenance optimisation framework is the optimisation of the PM program. Traditionally, vendor recomendations or Reliability Centred Maintenance (RCM) is often used for PM program establishment. Expert judgements and historical data are used to estimate PM intervals. We will attempt to model the effect preventive maintenance has on the component performance, in terms of, e.g., failure rate. Again, this information can be fed into the RAM and maintenance cost models described earlier to assist in interval optimisation.

Having established an optimal PM program, the next challenge is to group PM tasks. This is a matter of optimising cost. On the one hand, when a PM task is carried out too early, it obviously incurs extra cost as the component in consideration could have run longer before PM. On the other hand, delaying the PM task may have negative impact on the component performance if the PM interval is delayed too far from its optimal interval.

We have established a tool that assesses potential cost savings from grouping different PM tasks. This tool indicates the tasks that may reduce overall PM program costs if grouped. This model may also be used for planning of opportunity based maintenance.

Task 2.5 – Effective learning and continuous improvement

The tools and methods described above fits into the continuous improvement loops illustrated in Figure 2. However, to make such loops function in practice, supportive work processes are essential. These processes are developed and described in the work process and analysis activities. We also know that in a continuous improvement situation, strategic analyses may be required, e.g., for system modifications or renewals. Our intention is therefore to provide TKP with tools for prioritisation of equipment renewals and modifications.

Selection of cases

We have decided to use cases for the analysis of work processes. Further, the cases will be used to test the developed tools and methods. There are several reasons for this, one of the most apparent being easier to communicate with different levels in the organisation.When selecting cases, some basic criteria were applied:

- Each case shall be connected to one or more of the TKP maintenance steering loops.
- Invite to integrated decision-making.
- Have a potential for improved ship-shore interaction.
- Must be recognisable on all production units.
- Invite to introduction of improvement using new analysis tools and methods.
- Have a significant potential for improvement (“low hanging fruit”).
- If possible, involve suppliers or service partners.

We have chosen the following cases for work process analysis:

- Establish new/revised maintenance program for an installation
- Condition based maintenance – gas compressor
- Continuous improvement – maintenance of Pressure Safety Valves (PSV)

The two latter are described in more detail below:

Condition based maintenance – gas compressor

We have chosen compressors which are vital for production – a shutdown of a gas lift compressor may lead to complete stop in production. Two of the four installations are equipped with reciprocating processors and the other two with centrifugal compressors.

The compressors are equipped with various degrees of monitoring, from on-line vibration monitoring connected to supplier, via on-line process monitoring, lubrication oil analysis down to manual inspection. Typical process data are transferred to shore using a dedicated data capture and presentation system. The maintenance strategies vary between the installations, however, the ambition is to convert to condition based maintenance when applicable.

The work processes entailing condition monitoring and maintenance planning of the gas compressors will involve both the operational (inner) and strategic (outer) loops of TKP's newly developed maintenance steering loops (see Figure 3 below):

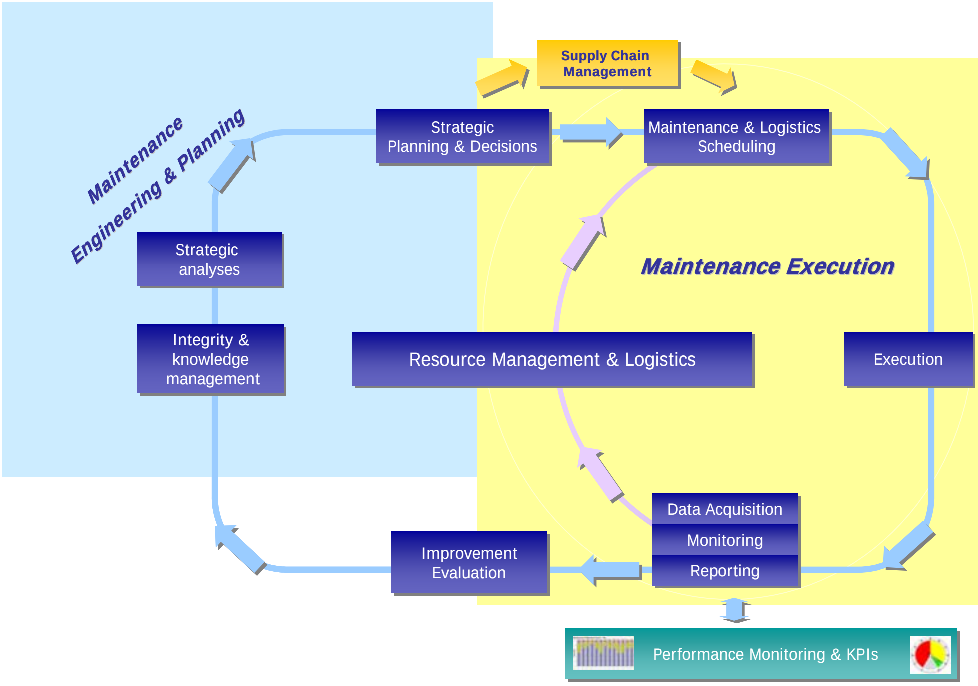

Figure 3 TKP's strategic and operational maintenance steering loops

Continuous improvement – maintenance of Pressure Safety Valves (PSV)

The regime for recertification of PSVs varies between the installations; some use third party suppliers (different suppliers for different installations) to run the testing and maintenance on a campaign basis, others perform testing and maintenance themselves. The recertification of PSVs encompasses performing tests, capture test results, inspect and investigate failing valves and recommends change in certification intervals based on test and inspection results. The degree of actively pursuing experience transfer between the third party suppliers and TKP is varying across the installations.

The work processes entailing maintenance of PSVs will involve the tactic (mid) loop of TKP's newly developed maintenance steering loops (see Figure 4 below):

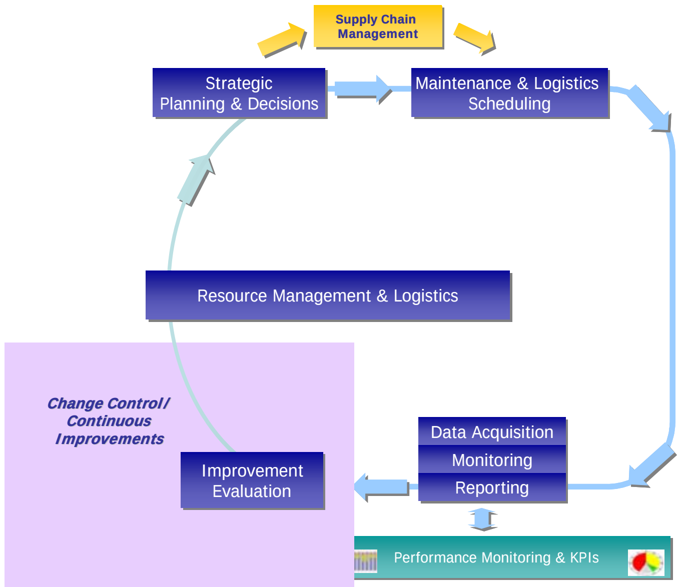

Figure 4 TKP's continuous improvement maintenance steering loop.

Results

The project commenced mid 2006 and will run until end 2009. The project can thus not show a complete set of results; however we will in the following sections describe the results so far.

Work processes

The main objective of the work processes activities has been to establish visions and goals. TKP has established its Integrated Operation Policy, which is to be regarded as the TKP IO vision and overall IO goal. Measureable goals have not been established yet. They will be established in workshops with TKP operations' management where also the desired "to-be" state will be outlined for each of the cases.

The current practice ("as-is") has been established for the cases.

Condition based maintenance – gas compressor

We first we established a general condition monitoring analysis work process (see Figure 5 below):

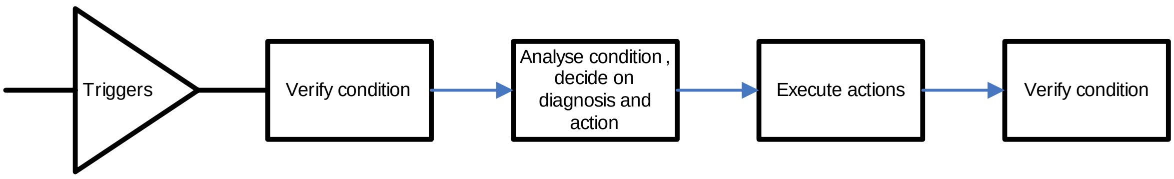

Figure 5 Generic condition monitoring work process

Each of the boxes in the generic model were decomposed into more detailed work processes (see Figure 6 below):

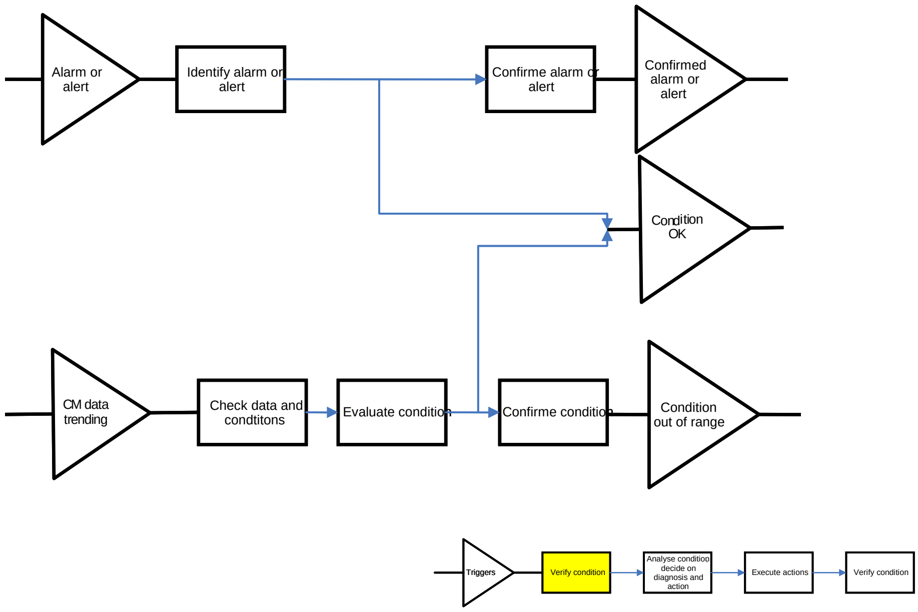

Figure 6 Generic "verify condition" work process

The outlined work processes were used in workshops/interviews with relevant on-shore and off-shore personnel for each installation. The “as-is” mapping was performed with each installation separately. The workshops mapped involved actors (including software applications) and decisions for the case, and the results were drawn in process workflow diagrams by the researchers. An example of such a workflow diagram is shown in Figure 7 below:

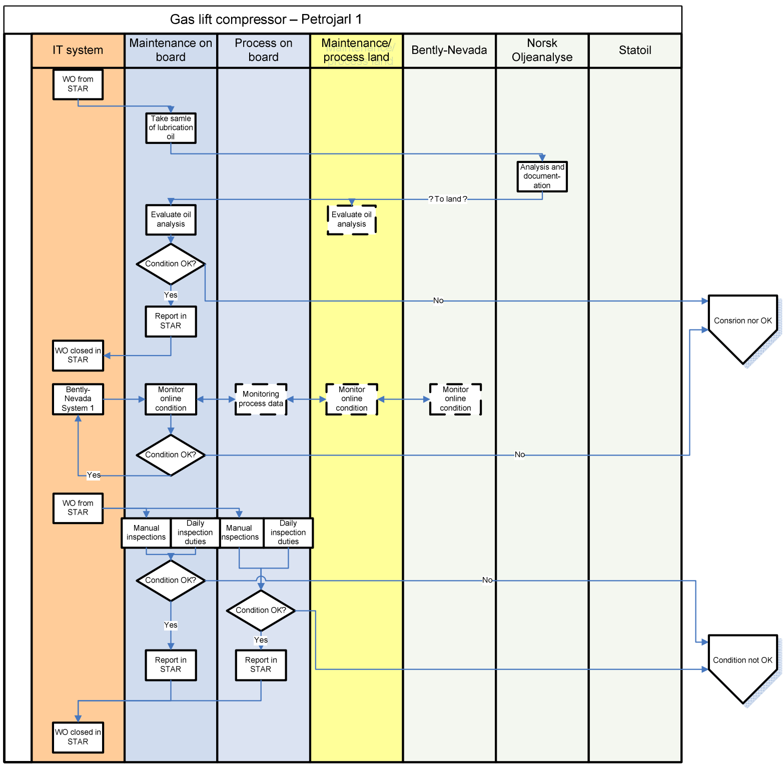

Figure 7 Example of workflow of condition based maintenance of gas compressor

The workflow diagrams have been subject to verification by the involved personnel who participated in the mapping workshops.

Continuous improvement – maintenance of Pressure Safety Valves (PSV)

As for the gas compressor cases, we first established a general continuous improvement process encompassing maintenance analysis, performance, reporting and assess work process (see Figure 8 below):

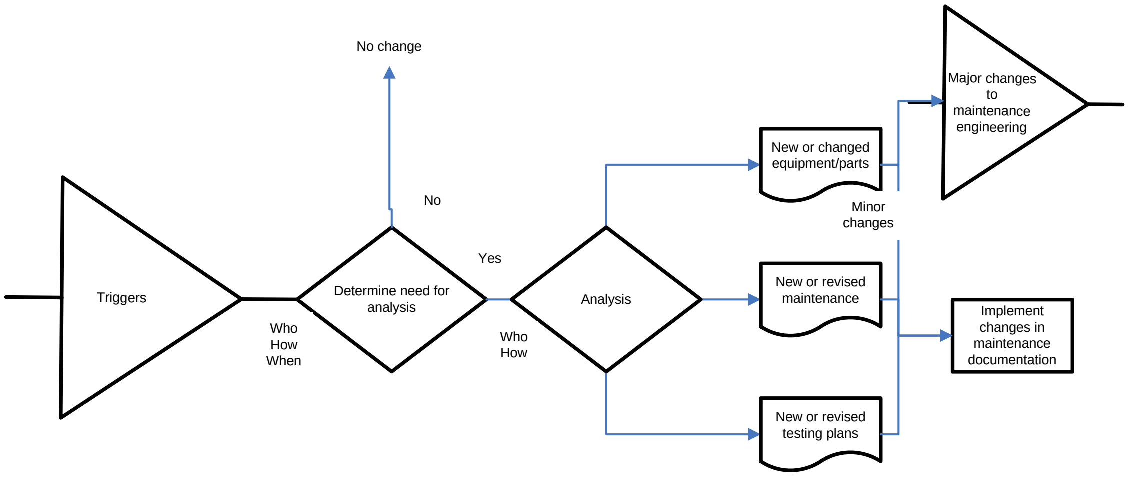

Figure 8 Generic continuous improvement process.

In this case too, the outlined work process was used in workshops/interviews with relevant on-shore and off-shore personnel for each installation. The "as-is" mapping was performed with each installation separately. The workshops mapped involved actors (including software applications) and decisions for the case, and the results were drawn in process workflow diagrams by the researchers. One of the issues addressed was:

- Decide which changes that should be done concerning the maintenance of the selected equipment? Method and intervals on:
  - Testing and recertification
  - Monitoring
  - Inspections
  - Time intervals for recertification
  - Adjustments in equipment design

An example of such a workflow diagram is shown in Figure 9 below:

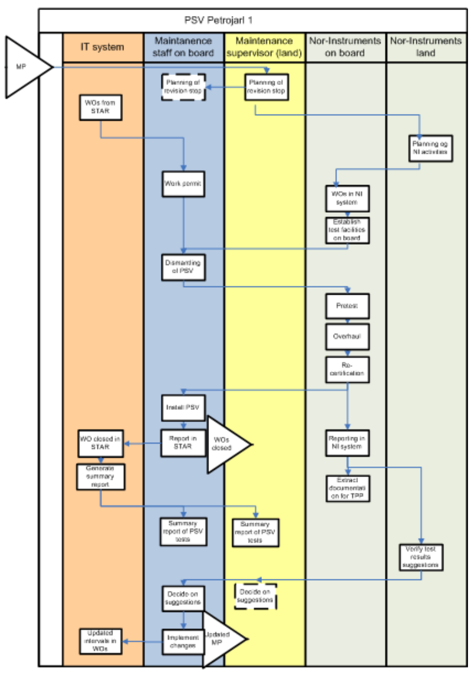

Figure 9 Example of workflow of continuous improvement of maintenance of PSVs

Tools and methods

RAM modelling

An analytical RAM model has been developed, and is under testing, however, it is too early to conclude from the testing. The intention of the testing is to see whether an analytically based model can provide sufficiently accurate results for our purposes, when comparing with a simulation based RAM model. If it does, we will have a tool that can be used more efficiently for maintenance optimisation purposes in operation.

The tool has a graphical user interface, where the reliability block diagrams of systems are established, and the failure frequencies, distributions, repair times and repair costs are stored in a database. Currently, the model is populated with OREDA data – OREDA Data Handbook (2002). The basis for the tool is a database structure, enabling future integration with the TKP Maintenance Management System (MMS), where data may be pulled from the MMS into the analytical RAM model. This requires modifications to the reporting in the MMS. Some of these modifications are to be implemented in the next version of the TKP MMS. TKP's own reliability and maintenance data will be applied to adjust and continuously improve the RAM model to be installation specific when the connection with the MMS is established.

Planned maintenance program optimisation

We have developed a model for grouping preventive maintenance tasks for a multi-component system with maintenance cost dependencies between the components, and have so far applied this to a gas lift compressor system (the model may be used for other systems). For example, there may be common set-up costs for components, and the downtime may be reduced if some of the components can be maintained simultaneously. Our model considers the situation where;

1) we can save some set-up costs and downtime costs by executing several maintenance activities at the same time, but
2) there will be an extra cost of shifting the optimal preventive maintenance interval for each component, as illustrated in Figure 10.

τ_1 and τ_2 are the optimal PM intervals for components 1 and 2 respectively, and τ_{Group} provides the optimal interval if the preventive maintenance tasks of these two components are grouped. The model groups the activities that will save preventive maintenance program costs, taking the cost-benefit considerations above into account.

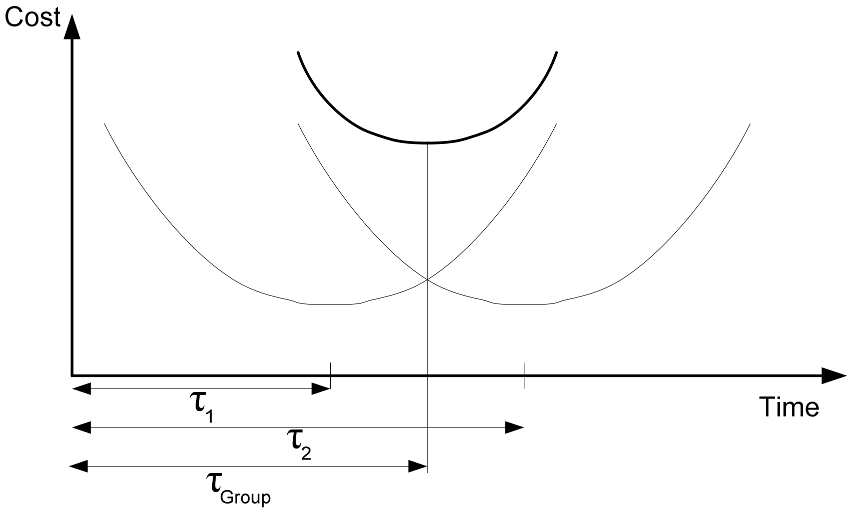

Figure 10 Optimal grouping of preventive maintenance tasks

As with the RAM model, our intention is that the data needed for the grouping may be pulled from the MMS.

Conclusions and further work

Experience so far shows that it is very important to announce the management intentions with introducing integrated operations in TKP. This is necessary to avoid misinterpretations and open for a good dialogue. The general impression from the work analysis is that it is essential to be concrete in the mapping of the case related worksflows. The analyses have revealed different ways of performing the tasks for the cases for each installation. The analyses have also shown that the operating personnel quickly came up with suggestions for improvement, a view, in our opinion, which would not have been signalled if the discussions were not so concrete. The workshops have shown a desire for more onshore support.

The planned way forward is to use the workflow diagrams to establish measurable goals for the work processes and to establish desired “to-be” situations. Central questions to be raised in this process are:

- What are the strengths/weaknesses in the currect practice (“as-is”) with regard to, e.g.;
    - onshore involvement?
    - are the processes independent?
    - relevant competence?
    - cross-discipline interaction and learning?
    - updating and traceability?
- Are the processes in accordance with the TKP IO vision and goals?
- How can the tools and methods developed in the project improve decision making in the work processes?

Aiming at excellence requires the introduction of state-of-the-art tools and methods to support the maintenance management. One of the main challenges in implementing the theoretical approaches developed are to find the balance between simplicity and sufficient theoretical basis of models and methods. In addition, it is necessary to consider the implications tools and methods have on the work processes, and whether these implications can be realised in practice. Therefore, we see that the implementation of the tools and methods we develop in the project requires a strong integration with the work process analysis’ activities of the project.

The complexity of some of the models requires centralised expertise rather than having one expert for each FPSO. Here, IO plays a crucial role, and the intention to streamline maintenance management across the FPSOs supports centralised expertise.

Another challenge related to the application of state-of-the-art tools and methods is the data needed for modelling. TKP needs to ensure a common reporting practice across vessels in their MMS, both to allow for benchmarking across vessels, and to make sure that the data is valid and consistent. In addition, some of the models require data that is not currently being registered in the MMS. A necessary activity in the project is therefore to assess if it will be feasible to collect the required data, and if the benefit of collecting can defend the extra costs of data collection. Finally, there is a challenge to continuously improve the data quality – there is no use for advanced tools and methods if the data are of poor quality.

These are some of the factors that will, in the end, influence on whether the use of the tools and methods will be a success or not. We need to further identify necessary success factors. However, we know that TKP in some cases operates in remote areas. This imposes limitations on the data bandwidth, and thus on the amount of data that can be transferred to land. There is a need for an intelligent filtering of which data is needed, and how these can be efficiently extracted from the data systems, packed and sent onshore.

In essence, a successful implementation of IO to reach operational excellence in maintenance management requires full attention to balancing personnel competence, technology complexity and organisation (MTO) and ensuring management ownership (visions, maintenance strategy, measurable goals).

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