

LEADING INDICATORS FOR THE MANAGEMENT OF MAINTENANCE PROGRAMMES; A JOINT INDUSTRY PROGRAMME

Keith Hart[1], Professor John Sharp[2], John Wintle[3], David Galbraith[4], and Ed Terry[5]
[1]Energy Institute
[2]Cranfield University
[3]TWI Ltd.
[4]Poseidon International Limited
[5]Sauf Consulting Limited

The Energy Institute has initiated and managed a Joint Industry Project (JIP) to deliver a Capability Maturity Model procedure to assist Duty Holders and contractors with the management of maintenance. The model is a generic tool which enables the assessment of the maturity of an organisation's capability to maintain facilities at offshore installations for improved safety and availability. It uses Capability Maturity Modelling as a means of measuring organisational behaviour and is aimed at the assessment of maintenance departments.

The first applications were projects for the Health & Safety Executive in the UK and the Petroleum Safety Agency in Norway and were specifically targeted at safety with elements of regulatory compliance. These have been the subject of papers in previous Hazards.

The JIP has now developed new applications with a more operational and commercial bias that have highlighted different emphases in the approaches used in the modelling technique; the modelling from the JIP describes the processes involved in the management of maintenance programmes and includes the application of the model to the different contracting strategies used in the UK oil and gas sector.

The paper will describe these most recent applications, the way in which these applications have modified the model development and how using workshops and case studies have added to our confidence in the effectiveness and applicability of the model.

BACKGROUND

The authors have been developing tools that can be used to identify and assess leading indicators; some of the applications have been presented in earlier Hazards Conferences. Through the Energy Institute, feedback from the oil and gas industry and the regulator (the UK Health & Safety Executive) has indicated that industry wanted a better mechanism to monitor and measure maintenance programmes

The industry is well aware of the impact of inefficient or ineffective maintenance on the reliability of systems essential for ensuring safety and production, and the costs and hazards of outage. This project has developed a model from which companies can assess the maturity of their capability to manage maintenance, and identified some of the steps

needed for the companies to move to a different level. The project was set up as a JIP and attracted members from the oil & gas operators, the regulator and one of the new breed of contractors who operates assets on behalf of other owners.

As described in the earlier papers, the Capability Maturity Model (CMM) describes five levels of company culture and approach; in this project, it was the culture and approach adopted for the different processes of maintenance management that was subject to capability maturity assessment. This paper describes how the maintenance model was developed and summarises some of the outcomes.

MAINTENANCE MANAGEMENT PROCESSES

Maintenance management can be broken down into a number of discrete identifiable processes. Some processes are essential for the activity and apply to every installation undergoing maintenance, and these are called the Core Processes.

There are other processes which although common are not found in every application, and these have been called Complementary Processes.

In addition, there are management processes that affect the ability to carry out the Core and Complementary Processes in the longer term, these are called Supporting Processes.

The following sections describe the anticipated Core, Complementary and Supporting Processes which the authors consider form Maintenance Management Processes.

CORE PROCESSES

For almost every situation, the activity of maintenance management can be broken down into six Core Processes and the accuracy of the definition of, the effectiveness of their integration and communication between the processes is often as important as the conduct of the processes themselves. The six Core Processes are:

1. Setting policy, targets and controls over resources
2. Strategy and planning
3. Procurement of resources
4. Effecting maintenance on site
5. Data management and record keeping
6. Audit and assurance

These six Core Processes are continuous with inputs and outputs between processes at different points. This is shown in Figure 1. In organisations with multiple assets all the processes are in progress simultaneously.

Sometimes the processes will be hard to recognise, particularly if their maturity is not high, and sometimes responsibility for the processes will be divided between several different organisations. This is discussed later in the paper.

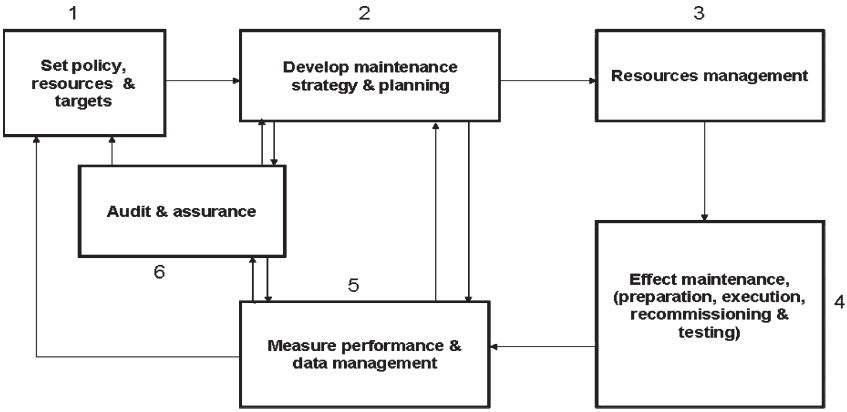

Figure 1. Core Processes for maintenance management

SETTING POLICY, TARGETS AND CONTROLS OVER RESOURCES

This process is normally undertaken at a senior level and may cover a range of assets. The policy for maintenance management would normally be expressed in general terms consistent with company objectives and values. These could cover aspects relating to maintaining the safety and reliability of the installation, the health and safety of undertaking the maintenance itself, change management, the requirement for data management and record keeping (both relating to the maintenance itself and the equipment performance), and the need for regular audit and assurance.

Targets may relate to production, availability of equipment, number of unplanned shutdowns for unscheduled maintenance, the time, duration or frequency of outages. The targets should take account of the life of the installation, the field and its characteristics, the market and the age and condition of the equipment.

A major part of this process is to define a consistent set of responsibilities for maintenance and allocate sufficient authority to purchase resources and equipment.

As part of this process, clarifying the divisions of responsibility between on-shore and off-shore staff, and the interactions between operations, maintenance and inspection, and between in-house and outsourced maintenance contractors is a key contributor to creating a positive culture.

DEVELOP MAINTENANCE STRATEGY, PLANNING AND SCHEDULES

Responsibility for this process is normally asset or installation specific and in the hands of a dedicated maintenance team or supervisor, the process should develop a general strategy or approach to be applied in planning maintenance for each asset consistent with meeting the policy and targets. The approach may depend on the type or function of the equipment

or structure being considered, and the context in which it is operated. Possible maintenance strategies could range from routine, predictive, condition based, risk based, preventative, to breakdown only.

RESOURCE MANAGEMENT

This process gets the people, equipment, tools and parts to site ready for maintenance to be put into effect. It is concerned with resource management, procurement and logistics. Inputs include detailed planning, local constraints and context, and any business arrangements that the company may have made with its supply chain. The efficiency of this process can have a large impact on productivity and cost.

For more mature organisations resource management may involve risk considerations and a spares management strategy (considered as a Complementary Process). The availability, storage and location of equipment, tools and parts are key aspects, and for offshore installations there is the issue of the resources to be stored off-shore. Arrangements for rapid transport and delivery to site are key aspects of the process.

EFFECTING MAINTENANCE AT SITE

Management of this process is largely concerned with interfacing the maintenance task with the wider operations and safety context of the installation. It involves the preparation of the equipment, local isolation and access, Permit-to-Work, inspection and assurance, and finally re-commissioning and testing. While the normal work-breakdown for the task may have been specified from the computerised maintenance management system, the maintenance team needs to be alert to unexpected conditions of the equipment being maintained, when other actions may be needed.

More mature organisations will have a seamless interface between their own staff and subcontractors on site. Creating a positive work environment and culture is key to successful maintenance. There have been several recent industry guides on how a positive maintenance culture can be achieved. The level of supervision is important, particularly where the competencies required for a task are split.

Effective management of the schedule of maintenance tasks during an outage requires a level of maturity which is at least based on company standards (that is, level 3).

MEASURING PERFORMANCE AND DATA MANAGEMENT

To become a more mature organisation requires feedback from measuring performance and learning from experience. Here the performance measured refers to both the maintenance task itself and the subsequent operation of the equipment. For the maintenance task, typical areas to record are;

- How long did it take?
- What went well and what were the problems?
- Where did delays occur?
- Were the resources adequate?

More mature organisations will have a procedure for recording these data and updating the maintenance management system.

Information about failures and unscheduled shutdowns, abnormal operations, or from condition monitoring can be analysed and trended to provide insights to guide future maintenance strategy. Evidence of the beneficial or detrimental effects from maintenance approaches and practices can be gathered in this way.

ASSURANCE AND AUDIT

Within this model, assurance and audit demonstrate that maintenance and maintenance management have been done satisfactorily, and that appropriate reports are given to senior management. It is a management process in its own right and involves reviewing, reporting and gaining assurance on the performance of the maintenance and the condition and performance of the equipment. Within the UK offshore regulatory regime there are specific requirements for a safety management system and for verification by an independent competent person.

Assurance extends beyond quality control and compliance with maintenance procedures, and requires evidence that the functionality, availability, reliability and survivability of the equipment will meet the demands for production and safety with the maintenance that is being undertaken.

COMPLEMENTARY PROCESSES

A number of Complementary Processes have been identified and these are shown, together with Supporting Processes (discussed later) in Figure 2.

Complementary Processes are maintenance management processes that are common but, unlike the Core Processes, do not necessarily apply in every application.

RECOGNITION AND HANDLING OF NON-STANDARD EQUIPMENT AND COMPLEX TASKS

At most installations there will be items of equipment whose maintenance will (by the skills and knowledge required) need the involvement of specialists or the original manufacturer.

A mature company will have systems and a culture in place for recognising and managing such equipment and tasks efficiently. A less mature company will either not recognise that special measures are required or will have the work done ineffectively. The model highlights the attributes of different maturity levels and the interactions with specialist suppliers.

PLANNING FOR MAINTENANCE IN DESIGN AND BROWN FIELD DEVELOPMENTS

Considerable economies can be obtained if the requirements for in-service maintenance are considered when designing equipment for new installations or brown field developments.

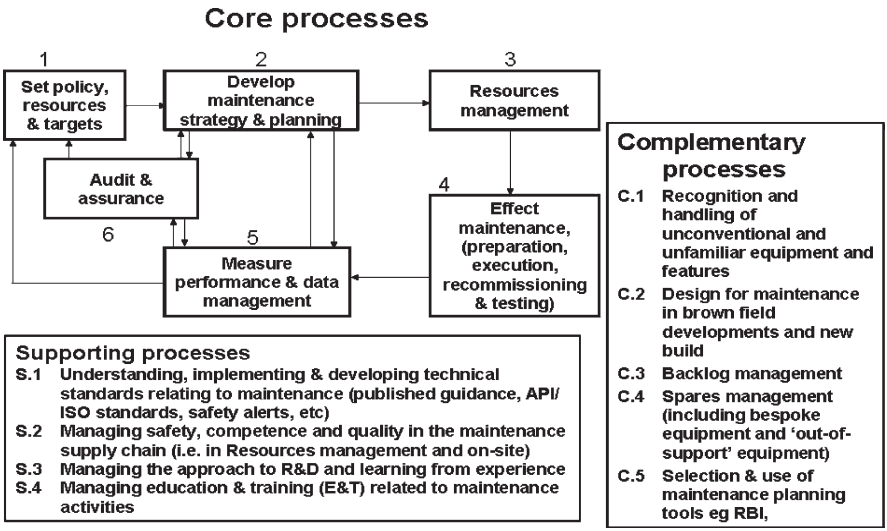

Figure 2. Core Processes together with Complementary and Supporting Processes

The process involves determining the requirements and frequency of maintenance through life, and incorporating aspects of cost, risk and availability. Planning for maintenance also involves practical issues like access and isolation.

BACKLOG MANAGEMENT

Maintenance at most installations is based on information contained and co-ordinated within a computerised maintenance management system. The system will indicate when a maintenance task is due; when a task is not completed by the due date it is registered as a backlog item.

The significance and management of backlog items is a major preoccupation of operators and regulators. The measures that a company takes to reduce and eliminate backlogs require a specialist management process which is concerned with investigating whether the requirement for maintenance identified by the system is in fact appropriate, assessing the implications of not undertaking the maintenance, and managing the scheduling and resources required to tackle the backlog.

SPARES MANAGEMENT

The issues surrounding the holding of spare equipment, parts and consumables are particularly important for installations offshore and in remote places where transport and logistics are difficult.

Relationships with the supply chain are key to successful "just-in-time" ordering. Standardisation of equipment and parts and the sharing of depots between installations and assets can be beneficial, providing it does not reduce operational flexibility.

SELECTION AND USE OF MAINTENANCE PLANNING METHODS

Deciding on the optimum maintenance strategy for an item of equipment requires knowledge and application of the various maintenance planning methods that have been proposed (e.g. condition based maintenance, risk based maintenance and reliability centred maintenance).

For example, safety and production critical equipment like gas turbines may need a different approach to say a complex pipe work system or the painting of the structure.

SUPPORTING PROCESSES

Supporting Processes underwrite the Core Processes and affect the ability in which they can be carried out. The Supporting Processes take place over a longer period of time, and while failure to undertake them may not have an immediate impact, it will have a detrimental effect on the Core Processes in the longer term.

INTERACTION WITH TECHNICAL STANDARDS

The awareness and use of technical standards is a characteristic of organisations operating at maturity level three and above.

More mature organisations will understand the basis and limitations of applicability of the general industry standards, and will be developing their own internal standards based on experience of their particular equipment. They will also be active in supporting industry standards committees and gaining insight from a wider global experience base.

MANAGING SAFETY, COMPETENCE AND QUALITY IN THE SUPPLY CHAIN

Nowadays, it is common for operators and Duty Holders to sub-contract aspects of maintenance management and maintenance tasks to other organisations in their supply chain. In theory, the responsibility for undertaking these activities safely, competently and assuring quality should lie with the sub-contracting organisation, but in practice the Duty Holder cannot avoid sharing this responsibility for both legal and commercial reasons. The Duty Holder therefore has a duty to ensure the management of safety, competence and quality in the supply chain is fit for purpose.

The approach that Duty Holders take depends on the level of maturity. Lower maturity organisations will not consider these aspects at all or consider them through only general words in a commercial contract. Higher maturity organisations will insist on being involved with the supply chain. Depending on circumstances, this involvement may range from discussing the requirements for each job where the sub-contractor is weak to undertaking occasional audits of the sub-contractor where there is less cause for concern.

MANAGING THE APPROACH TO LEARNING FROM EXPERIENCE AND R&D

Learning from experience and wider longer term knowledge generation is at the heart of the maturity model. Within the field of maintenance management, more mature organisations will examine their processes and tasks and undertake work to make them safer, more reliable, and efficient. They will know that learning and process development do not always happen naturally, but need management drive and structure.

MANAGING EDUCATION AND TRAINING

Increasing the level of education and training of the maintenance workforce can have both short and long term benefits in terms of personnel having a better appreciation of the important aspects of and reasons for their work and increasing flexibility through multi-skilling.

Companies at maturity level three will ensure that their personnel have the education and training to meet the immediate needs of the job through a combination of on-the-job and formal training. Less mature companies will rely on close supervision on-the-job, where inexperienced personnel may be undertaking a task for the first time. More mature companies will anticipate the education and training needs to meet work requirements and would be interested in accreditation of their training and certification of their personnel to undertake specific maintenance tasks. They would seek to develop industry-wide standards for training and co-operate with their supply chain and other Duty Holders to provide the facilities required.

DIVISION OF RESPONSIBILITY

Traditionally, responsibility for all the processes of maintenance management lay largely within the organisation of the Duty Holder and operator. Nowadays, the oil and gas industry is more vertically segregated and responsibility for different Core Processes may be divided between different companies. Several scenarios can be identified as shown in Figures 3 to 6.

Scenario 1 (Figure 3) shows the traditional model where the Duty Holder was responsible for all the Core Processes and only called in specialist contractors for effecting certain maintenance tasks on-site.

In Scenario 2 (Figure 4), the Duty Holder retains responsibility for policy, planning/scheduling, but appoints a maintenance contractor to manage the resources required and implement the maintenance. The Duty Holder measures the performance of the maintenance and the (maintained) equipment and undertakes the audit function, but the maintenance contractor has no incentive other than to carry out the maintenance to the schedule and at minimum cost.

Scenario 3 (Figure 5) has the Duty Holder appointing a contractor to manage the asset against a policy and targets, but does not interfere other than to carry out audits against policy metrics. The asset management contactor takes the main responsibility for

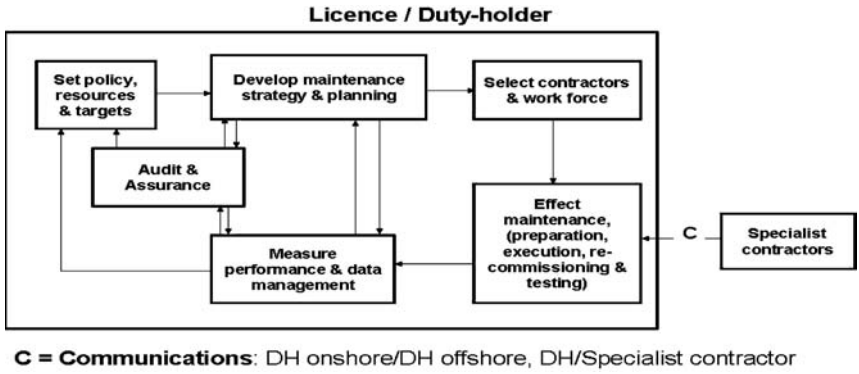

Figure 3. Scenario 1: Processes undertaken by licence/Duty Holder with specialist assistance

maintenance and can be motivated by incentives relating to the performance, availability, reliability and safety record of the equipment and the maintenance.

In Scenario 4 (Figure 6) the holder of the license (which may not be an oil company at all) has appointed an asset management contractor to undertake the role of Duty Holder and to operate and maintain the asset on its behalf. Policy and targets will be set in conjunction with the asset management contractor. The license holder's responsibility is one of due diligence to ensure that the organisation appointed has the necessary management, competence and track record to manage the assets effectively and meeting relevant

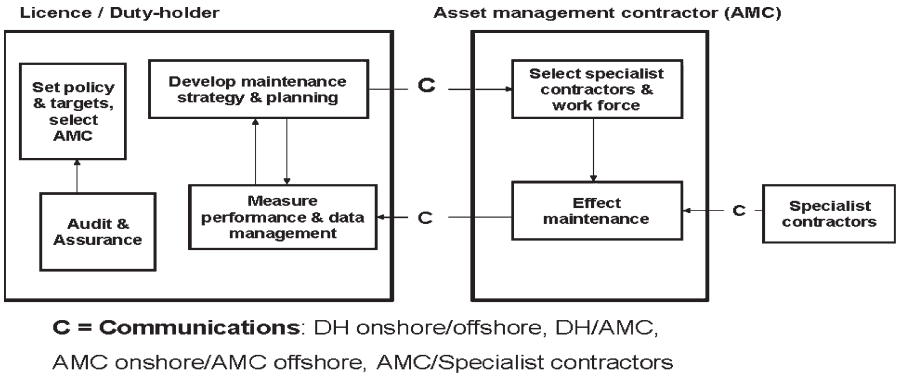

Figure 4. Scenario 2: Processes divided between licence/Duty Holder and asset management contractor

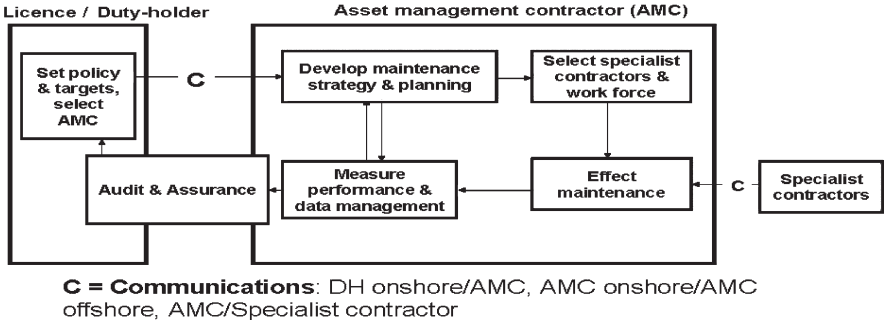

Figure 5. Scenario 3: Processes undertaken by asset management contractor except for policy and audit which are still undertaken by licence/Duty Holder

legislation. Responsibility for maintenance management is then the responsibility of the asset management contractor and the arrangement becomes similar to Scenario 1; dependent upon circumstances a separate maintenance contractor may be appointed as in Scenario 2.

It is important for personnel within companies to understand where responsibility lies. Whilst these divisions are contractually defined, training in the meaning of these agreements in practical terms is very beneficial. Long term partnering arrangements can generate understanding as experience of different organisations working together is gained.

Problems can sometimes arise when organisations within the supply chain are at different levels of maturity. Different expectations and management practices can cause

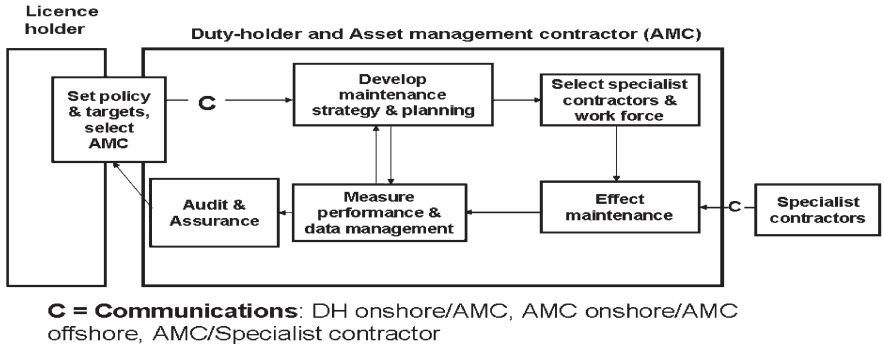

Figure 6. Scenario 4: Processes undertaken by asset management contractor except for policy which is shared with licence/Duty Holder

confusion and tension. This can occur both when the appointing company is at a higher and lower level of maturity than the supplier. In the former, the appointing company may feel a need to try to improve the maturity of the supplier through providing training as part of the supply agreement. It is more difficult for a more mature supplier to work with an uninformed Duty Holder, when the supplier must safeguard the integrity of its approach.

CAPABILITY MATURITY MODEL FOR MAINTENANCE MANAGEMENT

MODEL DEVELOPMENT AND TRIALS

The maintenance management maturity model was initially developed, based on descriptions for the five maturity levels for each of the six Core Processes. Following use of this model in a simple trial it was recognised that to enable more detail to be sought when a low maturity level was found sub-processes were needed and these were developed as indicated. Benefit was also taken from developing both Complementary Processes for particular situations where for example an installation had special new or unusual features, or where spares management had been a problem. It is not expected that all of the Complementary Processes would be included in every audit.

A more formal audit was undertaken with one of the sponsors, which involved interviews with four people with different responsibilities, ranging from the maintenance manager to the person responsible for maintenance data analysis. In general it was found that the six Core Processes worked well and were recognised by all those interviewed as representing the relevant management maintenance issues. It was also seen that inspection and integrity management are clearly relevant to several core maintenance processes and should be referred to within the model, although there is the difficulty of using the model when these two functions are separate, as they were in this case.

The trial also checked on some of the more complex Supporting Processes, but to a limited degree. Some limitations in the questions associated with maturity levels were recognised and there was a need to develop further sets of example questions. There was also a need to recognise the use and reliance placed on computer databases and management systems and to ensure that the model is consistent with their use. Overall these trials played an important part in developing and improving the model.

SPONSORS' WORKSHOP

A workshop for representatives of the sponsor's organisations was held in Aberdeen on April 20th 2007. The purpose of the exercise was to give the participants an insight into the concept and use of Capability Maturity Modelling for maintenance management by assessing the core maintenance processes. The exercise was based on an imaginary organisation which has recently taken over as operator of an early North Sea facility.

Teams of 4 or 5, who were part of an imaginary audit team, were each asked to interview a company representative (provided by members of the project team) and from the answers received identify the appropriate level of maturity for that process. After the exercise, feedback to the overall group was provided.

The exercise was well received and proved worthwhile in demonstrating the model. As a result several of those taking part felt that the model was worth trying within their own organisations.

GUIDANCE ON APPLICATION

The model is based on six Core Processes containing 17 sub-processes, together with 5 Complementary Processes and 4 Supporting Processes. These are illustrated in Figure 7. In addition there are maturity level descriptions which provide a single evaluation of maintenance management but are rather limited in the depth of analysis of the whole activity. Complexity increases with using more processes in the application of the model but this increases the value of the model in understanding the organisation's capability to perform.

The model can be used both for self assessment and for audit. In using the model it is necessary to identify the asset and identify the main organizations involved in the maintenance activities which could be the Duty Holder, asset maintenance contractor etc. From these organisations interviewees are selected, preferably at different levels in the organization. The interviews are carried out using the descriptions for each maturity level in the model.

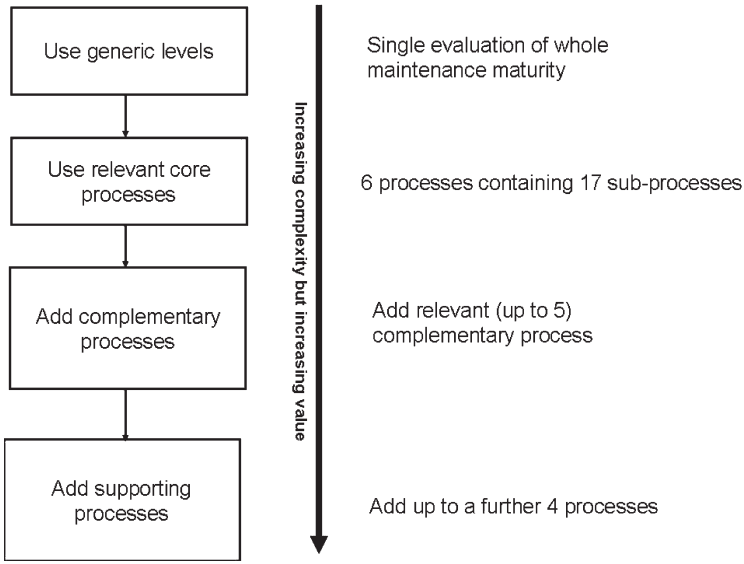

Figure 7. Outline of maturity model for asset maintenance management

The interviews would normally start with an assessment of the Core Processes. Sub-processes can be used when there is some level of concern or lack of understanding of the maturity level of a Core Process. Relevant Complementary Processes can also be included, depending on their relevance. There are also four Supporting Processes which in general are associated with longer term impact on the activity.

Information is collated for the different processes, and fed back to those interviewed, to establish the different maturity levels achieved. Depending on these results it may be necessary to recommend improvement steps to improve the maturity for some of the processes.

The project team have developed a number of audit check sheets to assist operators review their own approaches and procedures. The JIP report has a complete set of these audit sheets available to the JIP sponsors but a typical sheet is attached to this paper, see Table 1.

Table 1. Example audit sheet for Core Process 1

This table illustrates a check sheet which can be used for a maintenance management audit, this sheet is applicable to Cor e Process P1, other sheets have been developed for the Complementary Processes and Supporting Processes indicating maturity levels together with space for the auditor to record his observations.

Core Process P1	Set maintenance policy, resources & targets Provide the direction and wherewithal [Setting philosophy, policy & targets to be appropriate for condition of plant and field requirements and organization's needs, set resources {money, bed space, shut downs} to meet requirements, all based on capacity of, existing condition of and future requirements for existing plant]

Maturity levels & description	Applicability and supporting evidence
1 Management does not have any maintenance policy or targets. It leaves decisions to local staff. It may impose unconsidered resource constraints or instructions. (E.g. "Spend as little as possible." "We have an outage from production – let's do some maintenance.")	
2 Management may have a maintenance policy and targets but these may be unwritten and do not necessarily address the current requirements of the plant. Resources for maintenance are determined following previous practice	
3 Policy and targets are documented and have been based on reservoir and facility condition but are not updated to reflect changing circumstances. Metrics exist for measuring performance against targets but could be out-of-date or inappropriate.	

(*Continued*)

Table 1. (Continued)

Maturity levels & description	Applicability and supporting evidence
Management is aware of the system design and the critical factors and equipment for production, safety etc Resourcing and organisation based on policy and targets but not necessarily updated to suit current requirements.	
4 Policy and targets are updated regularly to reflect the changing production and field characteristics including condition of plant and any life extension requirements. Resources allocated appropriately. Management is aware of system design and critical factors for production, safety etc, and develops its policy taking these into account. Training is introduced to support the development of policy and targets. Performance against metrics monitored and steps implemented to remedy any inadequacies. Maintenance management developed to meet integrity assurance and system reliability requirements.	
5 The approaches to determining maintenance policy, targets and resources are optimised making use of world-wide corporate and industry knowledge. Management aware of system design and critical factors for production, safety etc, and is taking steps to introduce redundancy and diversity to eliminate or mitigate the risks. Determine optimal maintenance requirements and resolve conflicts (e.g. breakdown vs. planned preventative maintenance vs. condition based). Optimise methods of delivering maintenance (in-house and/or outsourcing) through engaging efficient and incentivized management of the supply chain Business plan and forecasting embedded into best practice policy and targets including organisational changes/adaptations as required. Performance against metrics optimised by exchange of experience and utilisation of best available global practices. Develop and improve training for key staff and the supply chain to support policy and targets.	

CONCLUSIONS

GENERAL

The team have reported on applications of the maturity modelling approach before but this application has a particular emphasis that caused extra complexity. The previous applications have had more explicit elements of regulatory requirement embedded in them and this has helped to focus on a defined level of acceptability, previously this has tended to appear as a benchmark in the Core Processes at maturity level 3. There has been no obvious need for a clear benchmark to be defined in this project; this has allowed additional flexibility in the definition of the maturity levels.

The other key area of difference with this project has been the issue of the split of responsibilities. The maintenance sector in the oil and gas industry has evolved a large range of business arrangements, any of which work very well in the right context. However, when the team have been trying to define actions and responsibilities for each maturity level, the range of contract forms has influenced our thoughts considerably. It was therefore appropriate that the range of contract forms be discussed, and these form the basis of the 4 scenarios discussed earlier.

The other development used in this project was the workshop. The team have carried out trials in all of their maturity modelling applications but this dedicated workshop using role-playing is the largest we have yet applied to maturity modelling development. The workshop was deemed very successful and it seems likely that future applications will employ a similar technique.

RECOMMENDATIONS FOR SHARING EXPERIENCE

There are potential benefits for the continued capture of experience from companies' use of the maintenance model. An opportunity to collate and share feedback would help to refine the model, particularly in identifying further improvement steps, which would assist the transfer of best practice in maintenance management across the industry. There is currently limited experience of the practical application of the model and the question set, and there would be benefit in comparing experience from different types of application, (e.g. group versus individuals interviews), and setting down some guidelines for application.

DETAILS FOR ONSHORE APPLICATION

The development of maintenance model is generic and applicable to onshore and offshore process plant. The processes that have been defined are universally applicable, as are their attributes and the associated improvement steps. However, it should be noted that for an application to a specific onshore plant there are different emphases that should be understood and accounted for; in addition, due to historical developments in the downstream sector, there will often be different tools that may be adopted to implement the processes.

The elements requiring different emphases and which may affect some processes are;

- specific onshore legislative requirements
- onshore logistical arrangements, including;
  - the available transport options for both personnel and equipment
  - the accommodation arrangements for personnel
  - the increased opportunity for rapid response teams (Just in Time arrangements)
  - increased dependency on suppliers' warranty support
- options for increased flexibility of operations in larger onshore plants, with;
  - opportunities to maintain one train whilst continuing to operate others
  - increased redundancy within some processing trains, allowing running to continue with some plant down or bypassed with an acceptable short term impact on product quality

EXTENSION OF THE MODEL

The model had to be limited necessarily to accommodate the budget allocated in the JIP but the team foresee a range of other areas of maintenance management that should be considered at some future point. These extended areas should be able to follow the basics of the model developed but will necessarily need to account for additional drivers and yet another range of contract forms and agreements. Areas the team identified for further application are;

- Sub-sea/pipeline maintenance
- Maintenance of floaters/jack-ups
- Decommissioning, failure investigation
- Shut-down/production planning, management of upgrades

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