

Technical Integrity Management: Measuring HSE Awareness Using AHP in Selecting a Maintenance Strategy

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Abstract

Global competition, varying oil and gas prices, ever more stringent environmental requirements, as well as increasing energy demands have caused changes in management approaches, product and process technologies, stakeholder expectations as well as competitive behavior in the oil and gas industry. At the same time, existing production facilities are aging and it is becoming more difficult to maintain the technical integrity of the physical assets which is the basis for energy production. Reductions in the plant technical integrity due to increasing failure rates strongly influence the health, safety and environmental risks and the ability of the plant to meet the production targets. To meet these challenges and to reduce costs as well as health, safety and environmental (HSE) risks, the companies need to establish relevant and achievable technical integrity goals and to optimize plant maintenance and operations processes and activities.

However, it is observed that there is a general lack of synergy between technical integrity management, and HSE and quality improvement strategies. Even though the employees and their managers are doing their best to make sure that things are done right, they are often not able to implement top level performance goals in their maintenance and technical integrity strategies. Normally, the companies lack good measurement approaches to assess not only weaknesses in goal awareness among the personnel responsible for technical integrity but also the degree to which high level goals are implemented in the maintenance strategies.

In this paper a model based on the analytic hierarchy process (AHP) is proposed for measuring HSE and economic awareness in maintenance and technical integrity related decision-making processes. A study is conducted for selecting an optimum maintenance strategy based on the requirements of operations on oil and gas offshore installations on the Norwegian Continental Shelf (NCS). The proposed AHP model provides an effective means to 1) determine the priorities among decision criteria and benefits and 2) assess the extent of HSE adoption in technical integrity related decision making.

Introduction

The Norwegian oil and gas (O&G) industry operates in an increasingly more challenging business environment due to the growing global competition, varying O&G prices, stringent HSE requirements, and rising energy demands as well as fast-changing stakeholder pressure on balancing financial concerns (see also Ognedal, 2008). Some operating companies are experiencing declining O&G production rates, resulting in reduced income. In addition, many of the installed offshore O&G production facilities are aging and are experiencing increasing failure rates which naturally will increase the HSE and economic risks. In spite of these challenges, the maintenance and operational activities need to be performed to achieve the ever more stringent HSE and cost performance targets and to assure the technical integrity (TI) of the plant.

The TI of a plant is a function of its technical health condition and its capability to perform its functions. However, TI is also a function of the personnel's capabilities and the management's ability to assure the condition and capability over time. Furthermore, TI assurance is dependent on the availability of quality data and information, as well as frameworks, models, tools and methods to analyze and to assist decision-making processes. Finally, TI is dependent on the plant stakeholders' and management's ability and capability to define, implement and execute operational and maintenance strategies suited to their needs. This is referred to as technical integrity management (TIM) and is the focus for this paper.

TIM is implemented by personnel who have a variety of cross-discipline expertise needed to assure the goals of the company as defined in its various policies and strategies (e.g. operational, maintenance, sourcing strategies, etc.). The TI of a plant is therefore dependent on its management and strategies, and how the strategies are implemented and executed by the experts. Thus, the TI of an installation is the result of the integrity of experts, but the integrity of the experts is not the sum or the average of the TI of an installation (also see Kaptein, 1999).

Turner (1994) has, for example, indicated that of large-scale accidents and disasters, only 20-30% are due to technical causes, whereas 70-80% are due to social, administrative or managerial causes. This is further supported by Lardner and Fleming (1999). They have pointed out that, as a rule of thumb, 80% are due to a combination of both human and organizational causes and the other 20% are due to technical causes. Furthermore, Shrivastava et al. (1988), Shrivastava (1992), TED (2003) and Shaluf (2003) indicated that organizational factors such as policy failures, inadequate resources' allocations, neglect of safety issues, communication failures, misperceptions of the extent and nature of hazards, inadequate emergency plans, cost pressures which restrain safety, etc. are also effects on failure of physical assets leading to disasters.

Hence, it is vital to measure TI performance of physical assets in terms of the performance of human assets. A comprehensive methodology for measuring the integrity performance of experts is therefore needed (see also Payne, 1994; Pearson, 1995; Giacalone and Greenberg, 1997). However, the final result of such a measurement scheme should provide a reflection of the extent to which the organization should refine its own strategies, provide necessary training to its employees, etc., in order to bridge the integrity gaps.

In this paper we propose a performance measurement model that can incorporate balanced measures based on the Analytic Hierarchy Process (AHP) framework for technical integrity management. The purpose of the proposed model is to merge data, experiences, intuitions and intentions of the experts and to propose a methodology to measure the HSE (Health, Safety and Environmental) perception of experts when making decisions related to the maintenance strategy selection of an O&G installation.

Background

There is not much written about technical integrity in industrial asset management and operation and maintenance literature, but some descriptions exist. For instance, Blackmore (2006) relates integrity to the risk of failure causing and/or contributing to major accidents and/or causing fatalities, whilst de Jong (2008) relates TI to work processes for inspection and maintenance and to data management to keep the operations available. Blackmore focuses on the consequences of low TI, whilst de Jong focuses on the maintenance processes needed to

sustain TI. Bale and Edvards (2009) relate TI to the development of the design intent with respect to safe operations. Tobi and Abri (2005) provide a view about TI in terms of life cycle perspective. He has argued that the assets have technical integrity when they are operated, maintained and abandoned with as low as reasonably practicable risk of endangering the safety of personnel, environment or asset value.

The worldwide engineering company AkerSolutions (2008) and the Canberra Act 2600 (see Defence, 2003) have also provided views about TI similar to those of Tobi and Abri (2005). In a study conducted in AkerSolutions and in the Norwegian O&G industry, Kumar et al. (2009) argue how to provide various multidisciplinary TIM services "...based on a condition-based maintenance philosophy that combines maintenance management, condition monitoring, structural integrity, inspection and other O&M [operations and maintenance] services..." which are required to "...sustain the asset's technical integrity, to operate at the required performance level, to reduce HSE risk, as well as to improve cost effectiveness and profit generation for all involved parties" in the O&M of oil and gas (O&G) production facilities.

According to the Webster Encyclopedic Unabridged Dictionary, the term "integrity" can be defined as 1) the state of being whole, entire, or undiminished; and 2) a sound, perfect, unimpaired, or perfect condition (Webster, 1996). The term "technical" carries the meaning "peculiar to or characteristic of a particular art, science, profession, trade, etc." Thorogood (1994) related TI to management and argues that "technical integrity consists of a culture as much as a set of systems and standards". Thus, in this paper, technical integrity management may be defined as "appropriate work processes for inspection and maintenance systems and data management to keep the operations available". de Jong (2008) discusses TI in a management perspective and defines it as "appropriate work processes for inspection and maintenance systems and data management to keep the operations available". In this paper, de Jong's definition reflects our understanding of TIM.

Furthermore, the frequently changing stakeholder requirements necessitated taking various factors into account (e.g. health, safety, natural environment, financial situation, etc.) when revising maintenance strategies in order to manage TI effectively. One of main difficulties is to incorporate a balanced view in defining such strategies in addressing both economic and non-economic factors. Many authors have argued the importance for minimizing the advantages over short-term gains while sacrificing long-term benefits (see e.g. Anderson et al., 1989; Eccles, 1991; Lynch and Cross, 1991; Kaplan and Norton, 1992; Liyanage, 2003, etc.). Hence, it is vital to have a mechanism for measuring performance to formally evaluate the gaps between financial interests versus HSE concerns for minimizing the traditional uni-dimensional and backward-looking nature in decision making. In addition to that, in most situations at the top level of an organization, a balanced view is incorporated within vision, mission and strategies. However, when it comes to operational or plant level, they are rarely implemented due to the domination of other priorities like meeting project deadlines, cost cutting, reducing production loss, meeting production targets, etc. (Ratnayake and Liyanage, 2007).

Furthermore, in order to manage TI it is paramount to have a methodology to measure (see Lord Kelvin, 1883; Behn, 2005) the integrity performance of those personnel who make vital decisions with regard to the TI of an O&G production facility. For example, when it comes to equipment management, also called maintenance management, then performance is measured by utilising various condition monitoring techniques. However, an O&G production facility is

inherently a complex socio-technical system that requires frequent human intervention apart from fast technology evolution. In addition to that, as stated by Koch (2008), human intelligence can not be replaced with technologies, technological systems or technological subsystems. His argument was further supported by Shrivastava (1992) with the quotation: “...operators control technological subsystems and coordinate interactions between subsystems. Managers supervise the operators and make decisions that directly affect ... technological disasters...” Therefore, when the TI of physical assets is to be managed, then it is paramount to measure the awareness of the personnel to make sure that they are fully aware of what the organizational strategy, documents and procedures state, to what extent the decisions comply with external and internal stakeholders’ demands, etc. (see also Shrivastava et al, 1988; Shrivastava, 1992; Colling, 1990; Kletz, 1993; Meshkati, 1991).

Based on the previous discussion, the TI of a production facility or plant depends on the extent to which the organization has succeeded in maintaining its physical assets with well trained/competent personnel (i.e. frequently changing top level requirements are correctly understood) in accordance with sound recognized practices and procedures to make sure predefined threshold limits are unimpaired. Hence, in this paper, TI management (TIM) is defined as, “the management of physical assets with well trained (competent) personnel in accordance with sound recognized practices and procedures whilst predefined threshold limits are unimpaired through protecting societal health and safety, and natural environment whilst optimizing the return on investment” (see also Thorogood, 1994).

The concept of technical integrity management (TIM)

Some of the major challenges of TIM are: implementing the organizational strategy, maximizing the availability and efficiency of equipment, controlling the rate of equipment deterioration, ensuring safe and environmentally-friendly operations, and minimizing the total cost of the operation. These challenges are multifaceted and arise from different levels within the organizational hierarchy. Figure 1 illustrates the way TIM crosses over the levels of the organizational hierarchy.

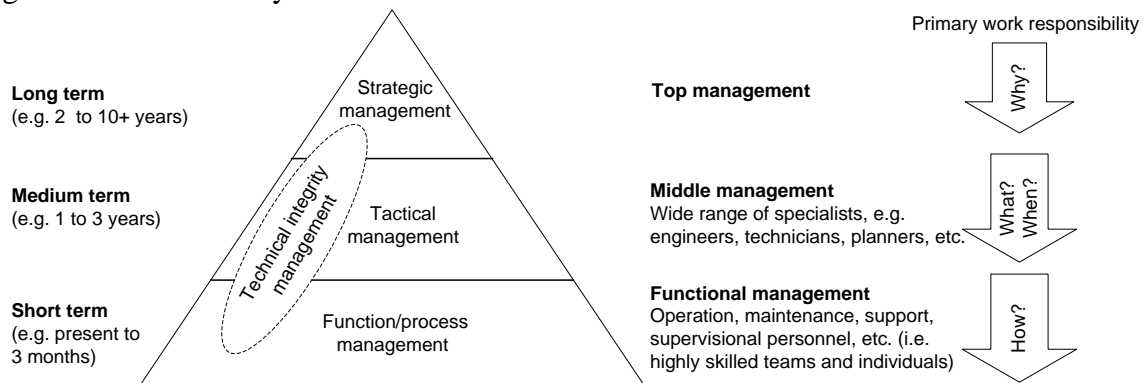


Figure 1: The scope of TI Management

However, a self-sustained success of TIM is achieved when the top-down managerial direction, priorities and performance goals are clearly aligned with the bottom-up delivery capabilities, and middle aligned with behaviors and organizational factors. Figure 2 suggests how different components with regard to TI are to be addressed (i.e. “top-down, bottom-up and middle aligned” (BSI PAS-55 1&2, 2004). These are also the ‘enablers’ of personnel factors that become subsequently important as every company has established continuous improvement habits, but these may not have translated to operational levels (Ratnayake and Liyanage, 2007).

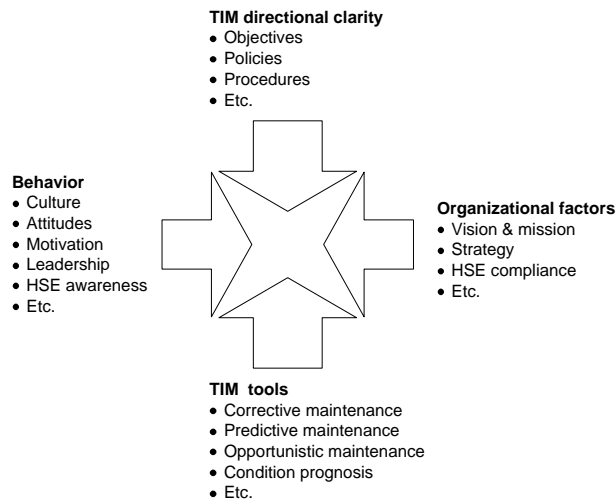


Figure 2: Top-down, bottom-up and middle aligned (adapted from BSI PAS-55 1&2, 2004)

Most managers find that this is the critical bit as the tools and techniques, reorganizations and performance measures all support making the company desires possible, but ultimately it is personnel that make them happen. So alignment through the awareness, minds, and collaborations, etc., of personnel is vital for achieving a higher degree of TI.

The major challenge in the O&G industry is to achieve a higher degree of TI through availability and lower costs while safeguarding HSE. This necessitates an effective integration of TIM and HSE concerns so that physical assets are designed and operated in a manner that safeguards their integrity throughout the life cycle. However, the changing needs of the physical assets and equipment over time have put tremendous pressures on TIM to adapt proactively to meet the fast-changing requirements of the production systems. Physical assets management has passed through significant changes in recent times. One such an approach is the PAS (Publicly Available Specification) 55 1&2, which suggests an interpretation of physical assets through an asset management point of view as shown in Figure 3.

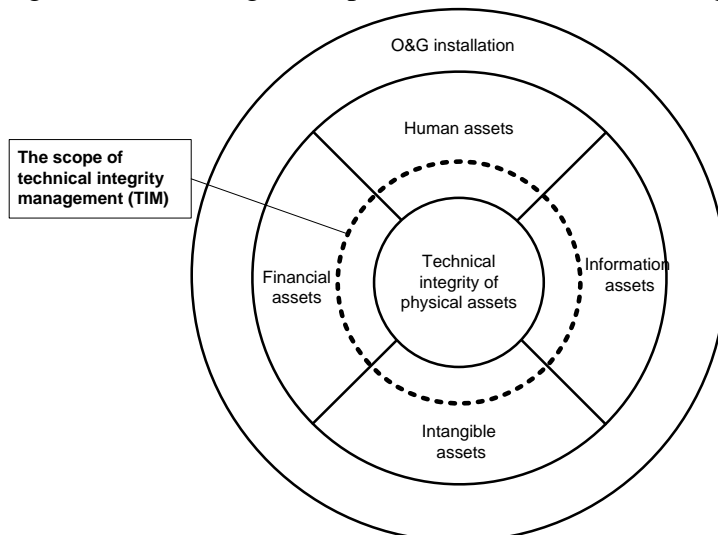


Figure 3: TI management in relation to physical assets and the other critical categories of assets (adapted from BSI PAS-55 1&2, 2004)

The scope of TIM is more than management of the physical assets (i.e. the production facility, plant, the equipment, machine, system, etc.). TIM also involves management of human, financial, information and intangible assets. What constitutes these assets often overlaps and

has influence on each other. For example, investment in physical assets such as spare parts is also a financial burden which results in the binding of capital, and many extra work processes need to be in place to manage the spare parts. Any accidents or serious HSE incidents may have an impact on intangible assets such as company goodwill and reputation. When maintaining physical assets one also collects a huge amount of information about the health and condition of the plant. This information constitutes an asset which will provide a basis for plant management and therefore it constitutes an information asset. Lastly and maybe most importantly, excellent technical integrity management requires a well trained workforce and experts and they are often the central means of achieving high performance in the organization. Hence, when considering TIM one simultaneously must consider these other critical categories of assets as well.

However, the TIM function can be considered as a wider concept that also contains maintenance management. Murray et al. (1996), for example, suggest that the scope of maintenance management should cover every stage in the life cycle of technical systems (plant, machinery, equipment and facilities), specification, acquisition, planning, operation, performance evaluation, improvement and disposal. When perceived in this context, the maintenance function is considered as the management of the TI of physical assets. Wireman (1990) observed that there has been a general lack of synergy between maintenance management and quality improvement strategies in the organizations, together with an overall neglect of maintenance as a competitive strategy. Hence, TI management provides breeding grounds to mitigate formerly mention negligence. Ahuja and Khamba (2007) contend that it “has been accepted beyond any doubt that maintenance, as a support function in businesses, plays an important role in backing up many emerging business and operation strategies”. The TIM function can be considered as a roadmap for directing emerging business and operations strategies directing into the maintenance functions. Thus, in this study TIM, in general, is considered to play an essential role in backing up business and operation strategies.

TIM and Performance measurement

In the context of management a generally accepted norm is “when an organization can measure its own performance then it can be managed” (Behn, 2005). When gaps are identified through measurement of agreed parameters, management becomes a matter of bridging the gaps using management techniques. The end results of such measurement provide directions to TIM and to processes for filling the gaps. However, performance measurement systems within an organization can be designed on the basis of several different disciplinary approaches (Brown, 1996 and Dixon et al., 1990) such as:

- the engineering approach, which relates expected output to specified input at each stage in the value chain and thus measures the input/output ratio;
- the systems approach, which sets objectives for each work unit or individual and measures the achievement of these objectives;
- the management accounting approach, which measures the achievement of a set of financial results by each cost/performance center;
- the statistical approach, which extends the engineering approach by providing empirically tested information on the strength of relationships in the input/output process;
- the consumer marketing approach, which measures consumer satisfaction; and
- the ‘conformance to specifications’ variant of quality management approaches which advocates the use of a checklist of attributes of a product or service together with its service delivery system.

Salminen (2005) explains that the basic performance concept is a function of ability, efforts, and opportunity. However, according to Tsang (2002), performance is the ability of an organization to implement a chosen strategy and achieve organizational objectives. The organizational performance reflects through the performance of individuals and groups involved. Performance can be examined from different perspectives, such as the customer, financial, process, employee, safety, and environmental perspective, etc. (Feurer and Chaharbaghi, 1995).

Performance measurement is the process by which a company manages its performance, and the performance measures are the set of metrics used to quantify the efficiency and effectiveness of actions (Neely et al., 1995; Bititci et al., 1997). Rationales for measuring performance are, for example, that the results should provide management and employees with feedback on performed work (Andersen and Fagerhaug, 2002).

Moreover, Dixon et al. (1990) and Maskell (1991) identified that performance measurement had to be coherent with low-level action taken within the business. This initiated the development of processes to implement performance measurement systems (Neely et al., 1996; Bititci et al., 1997; Bourne, 1999). Performance measurement includes hard financial metrics (e.g. cost of production loss, inventory, maintenance, etc.) and non-financial metrics (e.g. research and development, health, safety, societal and environmental concerns, etc.), as well as soft metrics like employee attitudes, and covers both processes and results (Salminen, 2005). Measurement provides the foundation for an organization to evaluate how well it is succeeding in its predetermined objectives, and helps the organization to identify areas of strength and weakness and decide on future initiatives, with the goals of improving organizational performance (Amaratunga and Baldry, 2002; Rouse and Putterill, 2003).

Organizational performance depends on the way in which the decisions are made from top to bottom within the organizational hierarchy. At the same time the decision-making process has to consider multiple criteria, since both economic and non-economic factors are involved (Al-Najjar and Kans, 2006; Blanchard and Fabrycky, 1998). This has led to the development of innovative performance measurement frameworks such as the balanced scorecard (Kaplan and Norton, 1992), the EFQM Excellence Model (European Foundation for Quality Management, 2003), etc. Those frameworks viewed business performance through more than one perspective to mitigate the weaknesses of traditional measurement systems which are uni-dimensional and backward-looking in nature (see Andersson et al., 1989; Eccles, 1991; and Kaplan and Norton, 1992).

However, these frameworks do not provide a formal mechanism to analyze the performance and are often vague as they lack mechanisms to carry out measurements. Kaplan and Norton (2004 and 2006), for example, address the challenge of having strategic alignment through the strategy mapping process. In that process, a hierarchical list of strategy drivers is mapped onto the company strategy and it is relatively straightforward to develop targets and action plans for each driver. The mapping process, however, is often not formalized to enable a complete analysis mechanism as done in an AHP framework. Therefore, an AHP framework is proposed for measuring the performance for managing TI. Figure 4 illustrates the basic TI measurement framework. The basic idea behind this process is to synchronize TIM directional clarity and tools, and organizational and behavioral factors in a hierarchical structure. The next step is then to synthesize industrial data, as well as experiences, intentions, and intuitions in a logical and thorough way.

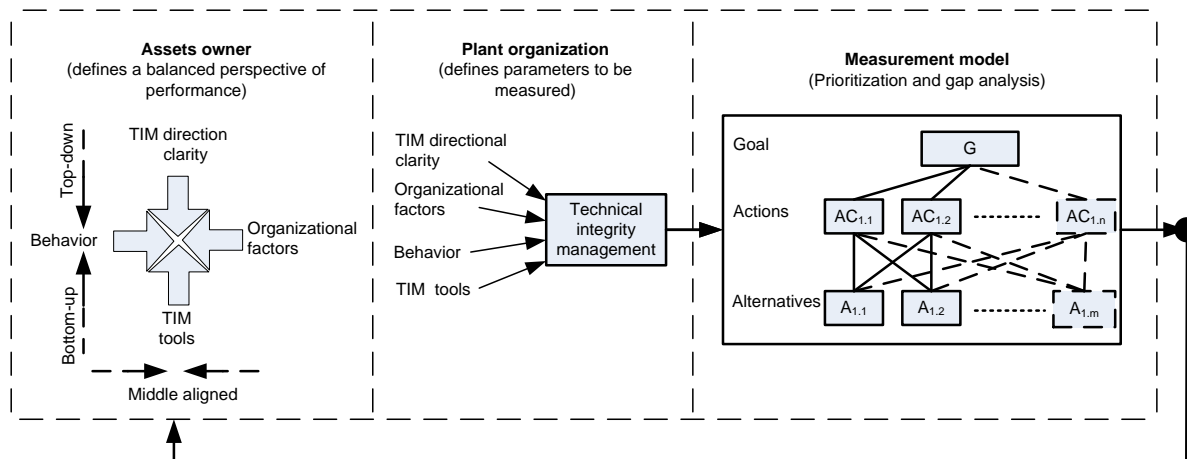


Figure 4: A framework for managing TI

In the following section, the utilization of the framework is described with the help of a case study. The particular case proposes a model for measuring experts' and key personnel's awareness of the company's financial interests and HSE concerns when they are in the process of selecting a maintenance strategy. The objective of such a measurement would be to distinguish the extent to which the experts' decisions are deviated from a defined balanced perspective defined through the stakeholder demands.

Basis for modeling with AHP

As mentioned previously, equipment maintenance management has a close resemblance to TIM. Furthermore, TIM can be considered as a broader perspective of equipment maintenance management. When building the model, the following HSE factors are identified as shown in Figure 5:

- reduce leakages,
- reduce the risk of injury to the people (personnel safety),
- improve company goodwill,
- reduce consequential damage to the O&G installation (process safety),
- reduce harm to the environment.

The Baker Report after the Texas City accident states that it was caused by: "Leadership not setting the process safety "tone at the top", nor providing effective leadership or cascading expectations or core values to make effective process safety happen" (Baker III, 2007). However, the model proposed in this study helps to assess how an organization responds to personnel safety versus process safety through the evaluation of experts' judgments. For example, an organization should take all precautions to achieve success in personnel safety by providing necessary safety equipment and procedures through personnel involvement in safety training programs, etc. to reduce personnel injury. Another organization should succeed in process safety measures to avoid unexpected releases of toxic, reactive, or flammable liquids and gases in the processes involving highly hazardous substances. The Texas City accident provides a real case of the consequences when the process and personnel safety considerations are not treated with equal priority, and how these can cause damage to personnel, installation, or both (Baker III, 2007).

The damages to the O&G installation are divided into direct and indirect: the direct damage deals with the tangible effects of the failure on the machine, the indirect damage takes into account the possible influences (i.e. reduction) of the failure on the working life of the plant

as a consequence of a “domino effect” on other facilities and instruments. Finally, the harm to the environment is divided into internal and external to the plant.

With respect to the policy economy factor (cost), four sub-criteria have been considered for the successive hierarchy level:

1. Increase saving in the stock of spare parts.
2. Reduce cost of assurance (i.e. possible decreases in insurance premiums that can be obtained by adopting a particular maintenance policy).
3. Reduce costs due to the production loss which is linked to facility downtime derived from a failure (time required for detection, repair or replacement and re-starting) and divided into MTBF and MTTR in a successive hierarchy level.
4. Reduce costs required for the policy implementation (i.e. the maintenance costs are divided into hardware (i.e. sensors), software and personnel (i.e. training costs).

Some of the possible maintenance strategies suggested in the model include corrective maintenance; time-based preventive maintenance; condition-based predictive maintenance; opportunistic maintenance, etc. Briefly, they are as follows.

Corrective maintenance: The main feature of corrective maintenance is that actions are only performed when there is a machine breakdown. This maintenance strategy is sometimes referred to as: run-to-failure, fire-fighting maintenance, failure-based maintenance or breakdown maintenance.

Time-based preventive maintenance: This maintenance strategy is based on the reliability characteristics of equipment. Maintenance is planned and performed periodically to reduce frequent and sudden failures. Basically the preventive maintenance policy tries to determine a series of checks, replacements and/or component revisions with a frequency related to the failure rate.

Opportunistic maintenance: The opportunistic maintenance strategy is often used together with preventive maintenance strategy. If the plant, equipment, subsystem, etc., needs to be shut down for preventive maintenance or is shut down for other causes, one can use the opportunity to perform maintenance which normally is planned to be performed later. The possibility of using opportunistic maintenance is determined by the nearness or concurrence of control or substitution times for different components on the same equipment, subsystem or plant. This type of maintenance can lead to the whole plant or subsystem being shut down at set times to perform all relevant maintenance interventions at the same time. For example, when scaffolding is required to be built to enable equipment inspections during maintenance shutdown, the surrounding equipment should also be put into the same inspection plan to take the fullest advantage of the expenditure on constructing the scaffolding.

Condition-based predictive maintenance: In this strategy the maintenance decision is made depending on measured data from a condition monitoring system. A number of monitoring techniques are already available, such as vibration monitoring, oil analysis, radiography, ultrasonic testing, etc.

The proposed hierarchy is designed in relation to the requirements of an O&G installation located on the NCS. The same kind of hierarchical structure can be adopted for other specific applications through brainstorming sessions together with relevant experts’ group/s. Besides, it is possible to note how some possible dependencies among the attributes have not been

treated. However, the structure simplification choices derive from the necessity to obtain a good trade-off between a suitable level of detail and a manageable complexity of the hierarchy structure for day-to-day real-time TIM-related applications.

Here optimization is supposed to be achieved through the equipment (static and dynamic) in the moderate risk region. In the low risk region mostly corrective maintenance will be performed. In the high risk region mostly preventive or predictive maintenance will be performed. Hence, trade-off can only be analyzed in the medium risk region. However, the optimization is not possible individually, although optimization is supposed to be carried out within moderate risk regions. This is mainly because, in an ordinary O&G installation, there are numerous items of equipment within the suggested region. To avoid making decisions on individual items of equipment, they can group them, based on the following criteria.

- Group 1: A failure of group 1 machines can lead to serious consequences in terms of workers' safety, plant and environmental damage, production losses, etc. Significant savings can be obtained by reducing the failure frequency and the downtime length.
- Group 2. The damage derived from a failure can be serious but, in general, it does not affect the external environment. A medium cost reduction can be obtained with an effective but expensive maintenance. Then an appropriate cost/benefit analysis must be conducted to limit the maintenance investments (i.e. inspection, diagnostic, etc.).
- Group 3. The failures are no serious consequences. Spare parts are not expensive and, as a consequence, low levels of savings can be obtained through a reduction of spare stocks and failure frequencies. With a tight budget the maintenance investments for these types of facilities should be reduced, also because the added-value derived from a maintenance plan is negligible.

Developing a TIM model

The analytical hierarchy process (AHP) methodology, as devised by Saaty (1980), is a powerful management tool in structuring fuzzy and complex problems (Saaty, 1980; 1990). The measuring of HSE awareness while addressing value added and financial exceptions in TIM decision making is a typical multicriteria decision-making problem with reasonable fuzziness involved. The problem becomes more complicated and elusive as the number of decision criteria increases (Tummala and Wan, 1994). The AHP methodology involves the decomposition of a complex problem into a multi-level hierarchical structure of characteristics and criteria with the last hierarchical level constituting the decision alternatives. These alternatives are compared so as to determine the objectives of the problem (Saaty, 1980). AHP can accommodate both objective and subjective judgments of the evaluators involved in order to make a trade-off and to determine priorities among them for making sharp decisions. The process has four main phases, involving:

1. the structuring of a decision problem;
2. the conduct of measurement and data collection;
3. the computation of normalized weights; and
4. the determination of a synthesis-finding solution to the problem (Saaty, 1990).

Phase 1 included decomposing the identified critical decision factors in relation to HSE into a series of hierarchies where each level represents a set of meaningful and relevant factors leading to balanced decisions, i.e. making a return on investments without harming the personnel, improving societal safety, safeguarding the physical assets without degrading the environment (soil, water and air). Considering various decision criteria and benefits, the

decision problem of adopting HSE in TIM decision making was structured into a hierarchy decision model as illustrated in Figure 5. The model has five levels, which are composed of:

1. a goal (i.e. level 0);
2. the decision criteria (i.e. level 1);
3. the sub-criteria (i.e. levels 2 & 3);
4. alternatives (i.e. level 4).

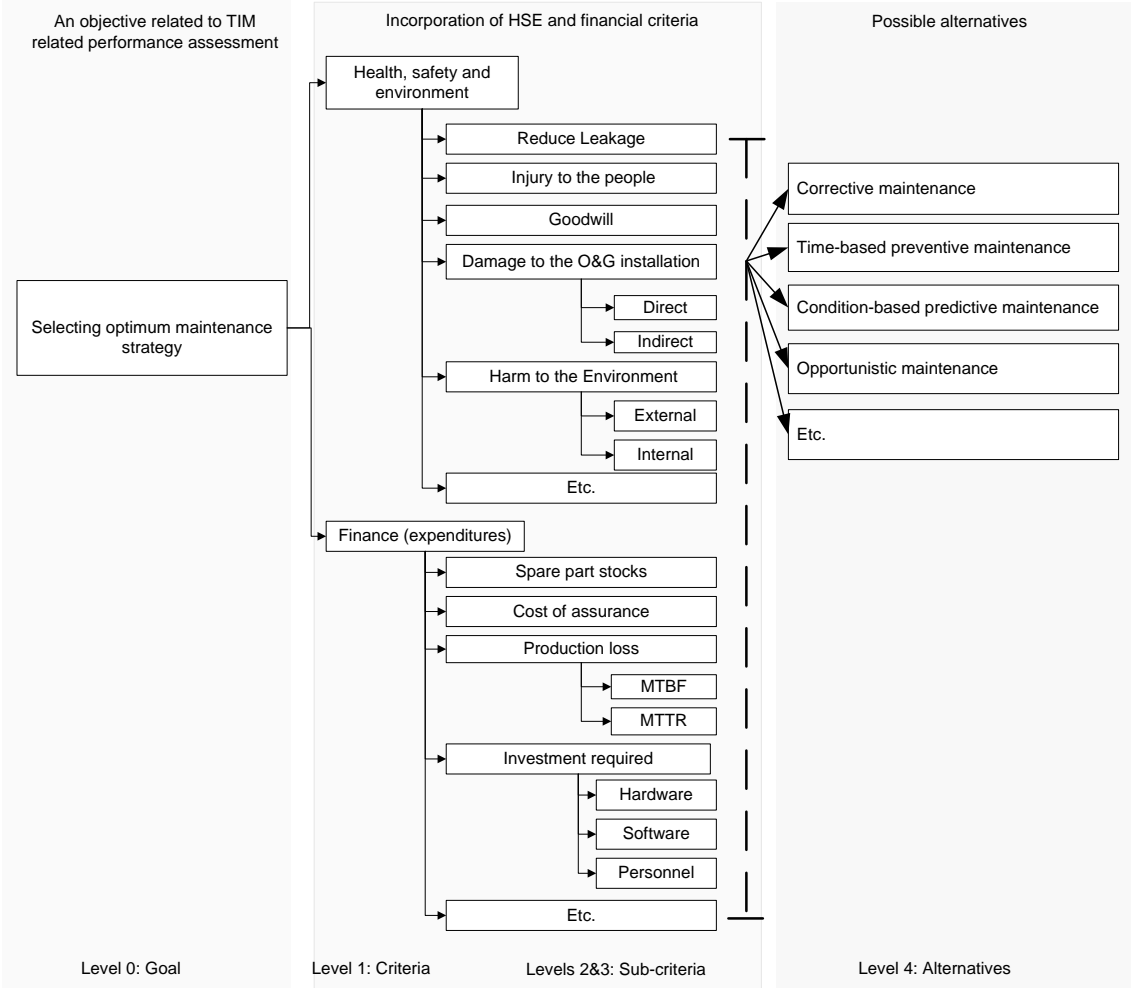


Figure 5: Model for measuring HSE performance whilst giving equal priority for financial consciousness in TI-related decision making

However, depending on the objective in relation to TIM-related performance assessment, the number of levels can be changed. In this work, the authors have chosen to assess the extent to which the experts are giving priority to HSE factors and financial factors when selecting an optimum maintenance strategy. Optimum maintenance strategy selection is an ordinary dilemma. For instance, Wang et al. (2006) proposed a fuzzy AHP model to select optimum maintenance strategies in a power plant, Bevilacqua and Barglia (2000) proposed an AHP model for selecting the best maintenance strategy for an Italian oil refinery and Bertolini and Bevilacqua (2006) proposed a combined goal programming-AHP approach to the maintenance selection problem.

The goal of the proposed model is to measure the awareness of HSE policies among the decision makers and the degree to which they are taking these factors into consideration in TIM decision making whilst giving equal consideration to return on investments. Similar kinds of models can be constructed for different scenarios within a TIM context. However,

since the 1900s economic factors have dominated, encouraging short-termism (Kaplan and Norton, 1987) in decision making. Kaplan and Norton (1992), Liyanage and Kumar (2000), and Liyanage (2003) argue the importance of having a balanced view. Ratnayake and Liyanage (2007) discussed the importance of translating sustainability concerns to plant level operations whilst striking a balance between financial and HSE factors. Thus, the factors pertaining to finance and HSE were included in the proposed model. Each hierarchy level in the model has several decision elements, which were decomposed into another set of sub-elements in the next hierarchy level. These decision criteria and elements were relevant to the situations of companies upon which the evaluators made their expert judgments on determining the adoption of HSE considerations, along with other factors, to reach a balanced decision.

Implementation of the model

Phase 2 involves the collection of data and the determination of the relative importance of criteria and sub-criteria in the AHP model. Various researchers reported differing numbers of experts/evaluators helping to assess the AHP model in relation to their application. In the case of Chiang and Lai (2002), this was 12 experts/evaluators, for Qureshi and Harrison (2003) the number was 13, Pun and Hui (2001) reported six experts/evaluators, Law et al. (2006) eight and Sinuany-Stern et al. (2006) reported 4 experts/evaluators. Therefore, the number of experts or evaluators necessary to measure the HSE performance in TIM should be decided based on the significance of the application.

Table 1 depicts a nine-point scale that is used to assign the relative scales and priority weights of the decision criteria and sub-criteria. Individual evaluators are asked to evaluate carefully the criteria of each hierarchy level by assigning relative scales in a pair-wise fashion.

Table 1: Nine-point rating scale to implement model (Saaty, 1980, 1990)

| Intensity of importance ¹ | Definition | Explanations |
|--------------------------------------|--|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 3 | Weak importance of one over other | Experience and judgment slightly favor one activity over another |
| 5 | Essential or strong importance | Experience and judgment favor one activity over another |
| 7 | Demonstrated importance | An activity is strongly favored and its dominance is demonstrated in practice |
| 9 | Absolute importance | The evidence favoring one activity over another is of the highest possible order of affirmation |
| 2, 4, 6, 8 | Intermediate values between the two adjacent judgments | When compromise is needed |

Note: If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i

Some sample questions for acquiring information from the experts or evaluators during the interviewing exercises are proposed in Table 2. The process should be continued until all comparison judgment matrices corresponding to the decision criteria and alternatives used are obtained. Experience has confirmed that the scaling mechanism reflects the degree to which one could distinguish the intensity of relationships among decision criteria and elements (Saaty 1980, 1990).

Table 2: Proposed sample questions for implementing AHP model

| | | |
|---|-----------------------|-----------------------|
| Please compare the decision criteria and circle your answer using the scale below: 1 = Equal; 3 = Moderate; 5 = Strong; 7 = Very Strong; 9 = Extreme (see Table 2) | | |
| A. What is the relative importance of the "Finance (expenditures)" and other decision criteria at the right column in the table below when you compare with "optimum maintenance strategy"? | | |
| | Increasing Importance | Increasing Importance |

HSE goals and financial interests are implemented in the process of selecting a maintenance strategy for an O&G production installation via AHP methodology. The notion that “experts’ perception provides a direct reflection of organization’s performance” is used as the measuring criteria. The proposed model hierarchal scheme described in Figure 5 should be developed using a brainstorming process. In fact, it should involve maintenance personnel who perform criticality analyses, develop maintenance improvement procedures, perform the maintenance on-site, etc. Off-site maintenance experts who manage the maintenance operations should also be included where appropriate.

TI management is about making decisions under uncertainty and multiple conflicting criteria. This article has attempted to provide a case model for measuring the HSE awareness of the expert personnel working with TIM-related decision making. The example case used in the paper illustrates how this can be integrated in a TI-related decision-making process. By utilizing the Expert Choice software (see also Lo et al., 2000) along with a questionnaire (see sample questions in Table 2), the weights can be obtained for each factor. Then the managers responsible for the TI of an O&G installation can decide whether the awareness of experts is satisfactory with respect to their financial and HSE perception. This will provide opportunities for managers to recognize the standpoint of an organization and hence to improve lagging areas.

In general, the criteria for overall optimum such as HSE and cost factors cannot be measured by the same metrics and combined in the same objective function. However, this paper illustrates how such criteria can be achieved through AHP. The beauty of this approach is seen when it is integrated with a pre-analysis of the facility criticality. The technique can then provide a valid support for recognizing overall priorities through data, experiences, intentions and intuitions of experts. The hierarchical structure of the proposed AHP combines many features which are important for the selection of the maintenance strategy (e.g. economics, safety, health, environmental, etc.).

However, in this paper, a methodology is proposed for measuring HSE awareness in TI-related decision-making processes. The approach can enhance and improve the understanding of the dynamics of a similar kind of complex problem related to TI management and represents an effective approach to arrive at decisions and then evaluate how those decisions are made. Based on the findings of this study, it may be tentatively concluded that evaluators or experts from different organizations can follow the AHP method as a practical management guide. The proposed AHP model also provides an effective means to help them determine the priorities among decision criteria and benefits and assess the extent of HSE adoption in their organizations. In order to have a competitive leverage, it is strongly recommended that organizations exploit HSE expertise, to gain the enormous power in transforming business from compliance to competitiveness. Nevertheless, effective adoption and implementation of HSE must acquire organization-wide support, contributions and commitment.

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