

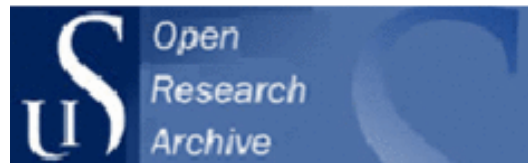


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A decision model for executing plant strategy: maintaining the technical integrity of petroleum flowlines

R.M. Chandima Ratnayake

Abstract: The ‘strategic’ management of technical integrity has become a high profile subject matter over recent years within inspection and maintenance of assets in the process industry. The assets such as production and process facilities require being optimised, prioritised and cost-effective inspection and maintenance, depending on whether they are at the beginning or end of their design life. In both cases, it is vital to ensure that sufficient condition monitoring data from all relevant sources are collated and analysed as a part in a planned scheme of inspection and maintenance. This is largely driven by certifying authority requirements, sound mechanical and corrosion engineering principles as well as inspection and maintenance approaches, indicated in a plant strategy. This manuscript suggests a model to execute plant strategy using analytic hierarchy process method. The model indicates the incorporation of requirements specified in a plant strategy for reaching optimised, prioritised and cost-effective outcome.

Keywords: strategy execution; technical integrity; analytic hierarchy process; AHP; decision model.

1 Introduction

In general, industrial organisations manage strategy in fits and starts. Basically, executives and managers formulate an excellent strategy fitting to the purpose of the industrial organisation. However, the strategy can easily fade from memory as the organisation tackles day-to-day operations issues, a practice also known as ‘fighting fires’ (Lagace, 2008; Kaplan and Norton, 2000a). However, linking the organisational strategy to operational activities creates a competitive advantage resulting in organisational principles being woven into a more effective management system. Consequently, it represents the differences between strategy and operations while integrating them in a powerful and holistic way.

The quote by Sun Tzu in *The Art of War*: “Strategy without tactics is the long road to victory; tactics without strategy is the noise before defeat” communicates the importance of integrating strategy and operations (Tzu, 2008). This is the central theme in a strategy execution system. However, without a strong visionary leadership recognising the importance of strategy and related tactics, no strategy can be executed effectively.

In most situations, responsible personnel in industrial organisations tend to focus on day-to-day operations and short-term problem solving. During their management meetings, they focus on ‘fighting fires’ and fixing problems by just allocating a little time and committing few resources to strategic issues. For instance, the KP3 report reveals that within the North Sea oil and gas (O&G) related operations, the influence of the engineering function has declined to a worrying level and the technical authorities are under pressure, often reacting to immediate operational problems rather than taking a strategic role to provide expertise and judgment on key operational engineering issues (KP3, 2009). Table 1 summarises the challenges, currently used approach/es/pitfalls, consequence/s, and suggested solutions for linking strategy with industrial operations.

The balanced scorecard (BSC) offers an opportunity to report and discuss all strategically relevant measures, along with performance-improving initiatives. “It intensifies the focus on the strategy and identifies the management and organisational actions required to get performance back on track” (Kaplan and Norton, 2000a). Moreover, the BSC identifies five principles for strategy management in the book *Strategy-Focused Organization*: ‘mobilise, translate, align, motivate, and govern’ (Kaplan and Norton, 2000b).

In the book *The Execution Premium*, the above principles are discussed in depth (Kaplan and Norton, 2008). Moreover, the book *Strategy Maps*, which focused on the second principle – translate, described and illustrated how strategy maps and scorecards could be customised to many different strategies (Kaplan and Norton, 2004). The third principle – align, i.e., how to create and capture corporate synergies through vertical and horizontal alignment of business and support units, is discussed in the book *Alignment* (see Kaplan and Norton, 2006; Ratnayake and Markeset, 2010a). The same book also contained material on the fourth principle – motivate (and align) employees for strategy execution in their business or support units. Double-loop management: Making strategy a continuous process provides a discussion about the fifth principle – govern, to make strategy a continual process (Kaplan and Norton, 2000a). However, the first challenge in strategy execution is to be sure that all of the ‘sub goals’ and ‘departmental action plans’ are themselves aligned with the larger strategy (Ratnayake and Markeset, 2010a). Kaplan and Norton (2004) discuss this challenge in the strategy mapping process. In that process, a hierarchical list of strategy drivers is mapped onto the company strategy. At that point, it is relatively straightforward to develop targets and action plans for each driver. The mapping process, however, is not as formalised as the analytic hierarchy process (AHP) methodology (Saaty, 1980, 1990). Also, neither strategy maps nor BSC have paid sufficient attention to integrating enterprise risk management (ERM) as well as how to evaluate the priorities in relation to the organisational strategy.

Table 1 Challenges of linking the strategy with industrial operations

<i>Challenge</i>	<i>Currently used approach/es/pitfalls</i>	<i>Consequence/s</i>	<i>Suggested solution</i>
1 Align the operational improvement activities to strategic priorities.	<ul style="list-style-type: none"> Total quality management, Six Sigma, or other continuous improvement activities. 	<ul style="list-style-type: none"> Done across the organisation with no sense of priorities or impact from process improvements. Much effort wasted without showing tangible results. Quality and improvement activities are like teaching people how to swim without a swimming pool. 	<ul style="list-style-type: none"> Implement a formal process for using strategic objectives to set priorities for where operational improvements can have the largest impact on strategy execution.
2 Budgeting and financial planning.	<ul style="list-style-type: none"> Done separately from strategic planning. 	<ul style="list-style-type: none"> Operational plans either provide too little or too much capacity for the strategic plan. 	<ul style="list-style-type: none"> Drive the operational plan and budget from the revenue targets in the strategic plan. Use a time-driven activity-based cost model that provides the previously missing link between the revenue growth targets in a strategic plan.
3 Management meetings.	<ul style="list-style-type: none"> Discussions about short-term operational and tactical issues. 	<ul style="list-style-type: none"> Industrial originations err when they devote all their time together for fire-fighting and coping with near-term issues. 	<ul style="list-style-type: none"> Meet to discuss and solve operational problems. Schedule strategy review meetings at a different time from operational review meetings focusing on frequency, agenda, information system, and participation, satisfying the goals of the meeting.

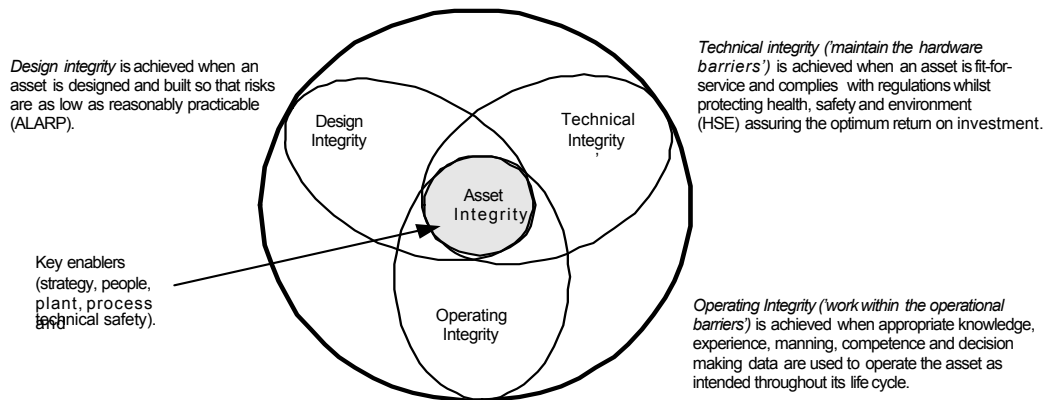
On the contrary, the strategy execution process is carried out by human beings who tend to work on an exception basis. They do not, and often cannot, deal with the entire strategy at once. The vastness of most strategy execution problems is generally beyond a human being's mental capacity (Kennedy, 1998; Ratnayake and Markeset, 2010a; Saaty, 1980). Thus, it is desirable for the strategy execution process to deal with most of the strategy execution related challenge modelling and to involve the human being at critical points where needed. It is desirable to provide a strategy execution application that not only models intelligently, but also cooperates intelligently and coordinates the efforts with human strategy executors. At present, all the information about the strategy execution process, including what is truly feasible, and the information about the plan goals, the real definition of optimal, are rarely or not at all fully modelled in a measurable way within the strategy execution approaches.

This paper suggests a formal model and a framework to execute plant strategy in order to optimise the number of inspections that should be carried out visually. The model is derived using a multi-criteria decision-making approach: the AHP. The model is developed based on literature, industrial practices, and experiences to satisfy the inspection demands of aging offshore O&G installations located on the Norwegian Continental Shelf.

2 Technical integrity

The management and assurance of the technical integrity (TI) of offshore O&G production and process facilities is vital on the Norwegian Continental Shelf, as they are facing aging problems since many of the installations have either reached or are about to reach end of the designed lifetime. TI in this context is defined as an item's fitness-for-service and compliance with regulations for health, safety and environmental (HSE) protection whilst assuring the optimum return on investment. Figure 1 illustrates the place of TI [as well as design integrity (DI) and operating integrity (OI)] within the context of asset integrity. The asset integrity can be considered as a hub where the axle connects. For example, the axle holds the organisation, which runs smoothly when all three spokes (DI, TI and OI) are equally balanced round the hub within the traction surface.

Figure 1 Design, technical and operating integrity



Technological advancement made it possible to extend the oil/gas reservoirs which were previously thought to be unprofitable. However, with the global economic crisis, substantial investments on available and new installations are not justified for extended production (life time). At the same time, aging, overloading, and various stresses degrade the systems and components (Valdez Flores and Feldman, 1989). Degradation particularly may take place in the form of corrosion, erosion or stress generation. Any of these factors or their combination can become a cause of failure. Therefore, O&G production and process facilities are under the constant threat of leaks and failures which might lead to catastrophic consequences. Figure 2 illustrates the failure rate vs. the age of an asset.

Figure 2 Failure rate vs. age of an asset

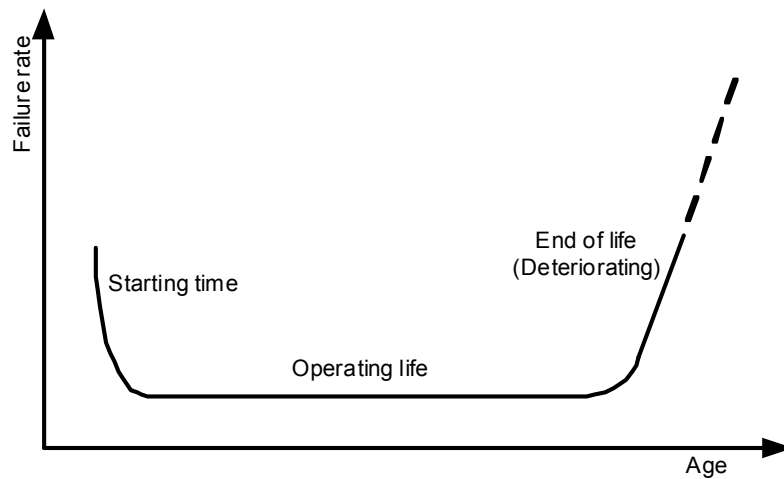
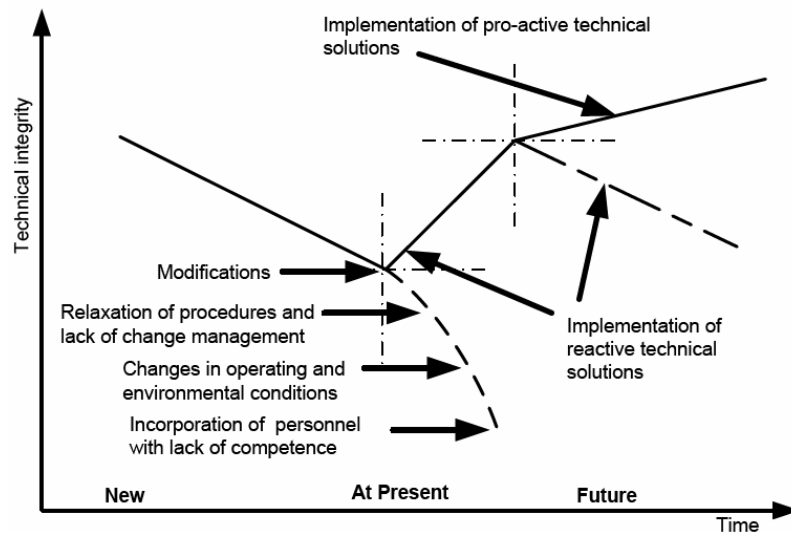


Figure 3 Technical Integrity vs. time



During the end of life, TI tends to decline at a fast rate. However, as illustrated in Figure 3, it is possible to improve the TI continuously by implementing pro-active solutions (Ratnayake et al., 2011).

For instance, to avoid incidents, inspection, repair, and replacement activities are carried out according to the stringent HSE norms. In complex plants and process industries, there is a constant need to maintain a desired safety level or to improve upon the present safety level in order to safeguard lives, property, investments and the environment (Bjorge and Bratseth, 1996; Khan and Amyotte, 2002; Mearns and Flin, 1995; Rundmo et al., 1998; Vanderperre and Makhanov, 2002). The harsh marine environmental conditions result in adverse operational challenges, due to degradation in the form of corrosion, erosion or stress generation of a production and process facility's infrastructure. Therefore, it is customary for installations to experience the constant threat of leaks and failures which might lead to catastrophic consequences. Wear, corrosion, erosion, fatigue and crack generation are major contributors to system/component degradation (Clifton, 1974). The challenge is to manage TI while optimising the cost without compromising on risk and safety issues. Therefore, a cost-effective approach for maintaining the TI through optimum maintenance and up-gradation of the existing production and process facilities' infrastructure is an economically sound alternative in the current scenario.

One of the major facets in TI management is to plan adequate inspections based on focused areas as specified by the plant strategy of the operator company, degradation mechanisms that can be anticipated and historical data about the equipment status. For example, in the case of petroleum flowline inspections, the wall thickness of the components will speak for the status. Petroleum flowlines are the topside piping systems on a production and process facility delivering well stream from the wellhead (from the Christmas tree) to the production manifold. Inspection in the operational phase is a maintenance activity carried out at predetermined time intervals in order to reduce the probability of failure (or the performance degradation) of the system/component (Bahrami-Ghasrchami et al., 1998). The inspection cost increases when the inspection interval is shortened (or the inspection frequency is increased), as inspection is one of the cost elements (Jardine and Tsang, 2006). However, the probability of loss caused by failure will increase when the inspection interval is lengthened (Rajasankar et al., 2003). Therefore, an appropriate setting of inspection schedules is also important for optimising expenses.

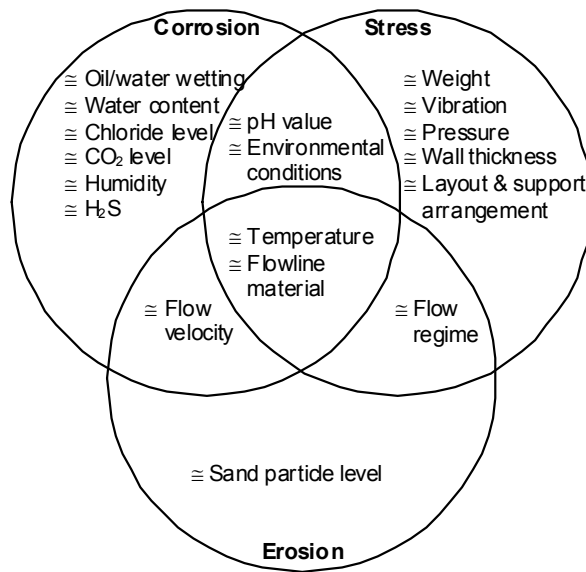
Generally, the petroleum pipelines are designed in such a way that safety provisions are created to provide a theoretical minimum failure rate for their lifetime and they are considered to be the most energy efficient, safe, environmentally friendly and economic way to deliver hydrocarbons (gas, crude oil, and finished products) (Dey et al., 2004). Various techniques are regularly used to monitor the status of pipelines. For instance, pipelines for hydrocarbons, kill-mud, blow-down, etc. are inspected with different priorities based on the impact to the main production stream.

The flowlines on an O&G production and process facility are one of most critical piping components which demand a major share of inspection time to assure their reliability as they carry water, oil, gas and sand particles along with different combinations of other chemical compounds. Furthermore, they are mainly made of carbon steel (except in modern production facilities), in the field where this study has been carried out. Consequently, there is a higher vulnerability to suffer from the prevalence of 'time-dependent' type threats, including internal corrosion (pitting, impingement, erosion, corrosion, etc.), hydrogen blistering, hydrogen embrittlement, sulphide stress corrosion cracking and hydrogen assisted corrosion fatigue (Olorunniwo and Imasogie, 2005).

3 Factors influencing flowline degradation

The degradation rate of a flowline can be affected by a number of factors as summarised in Figure 4 (Ratnayake and Markeset, 2010c; Ayazi et al., 2006). Under the continuous influence of these factors, different types of degradation can be observed in a flowline. Khan and Howard (2007) have classified the flowline degradation into uniform and non-uniform/localised degradation. A uniform corrosion is an example of the uniform degradation process. In uniform degradation, the life of different components is defined as the time taken for the wall thickness to reach the optimum acceptance criteria depending on the financial situation of the facility owner, HSE requirements, etc. On the contrary, pitting, crevice corrosion and stress corrosion cracking are the best known examples of non-uniform degradation.

Figure 4 Flowline degradation factors



Adverse climatic conditions corrode the petroleum flowlines externally, whereas undesirable contents flowing in the flowlines corrode them internally. The potential for flowline failure, caused either directly or indirectly by corrosion, is perhaps the most familiar hazard associated with steel pipelines (Muhlbauer, 1996). Corrosion is an electrochemical process. It is a time-dependent mechanism and depends on the local environment within or adjacent to a pipeline (Cosham et al., 2007). The flowline material plays an important role in withstanding the degrading conditions, both internally and externally. Flowline degradation takes place mainly due to stress generation, corrosion or erosion. A higher sand particle level can accelerate the erosion rate of the internal surface of the flowline. Erosion is the accelerated mechanical removal of surface material as a result of relative movement between, or impact from solids, liquids, vapour or any combination thereof. Erosion-corrosion is a description of the damage that occurs when corrosion contributes to erosion by removing protective films or scales, or by exposing the metal surface to further corrosion under the combined action of erosion and corrosion (API RP 571, 2003).

4 Strategy for maintaining piping components' TI: virtual failure state

In order to assure TI (i.e., basically to prevent leakages), it is vital to maintain the wall thickness of piping components which has been designed based on the operating factors (i.e., T_3). However, when it comes to steel piping, it is required to have corrosion (and/or erosion) allowance (CA) over the expected lifetime of a particular sub-system and/or a production and process facility. However, once the CA is added to the design thickness based on the operating factors, the corresponding piping component with the resultant thickness might not be available in the product catalogue. Moreover, it is customary to select the next highest thickness available in a product catalogue. The final thickness is designated as nominal thickness (T_n). For TI management purposes, companies use their own notations to represent different degradation levels of piping components in terms of wall thickness. For instance, ($T_n - \text{corrosion allowance}$) is designated as T_1 . Alternatively, the wall thickness of a piping component before starting its intended function is designated as nominal thickness level (T_n).

T_3 Minimum wall thickness of piping components as specified by ASME B31.3 (2006)

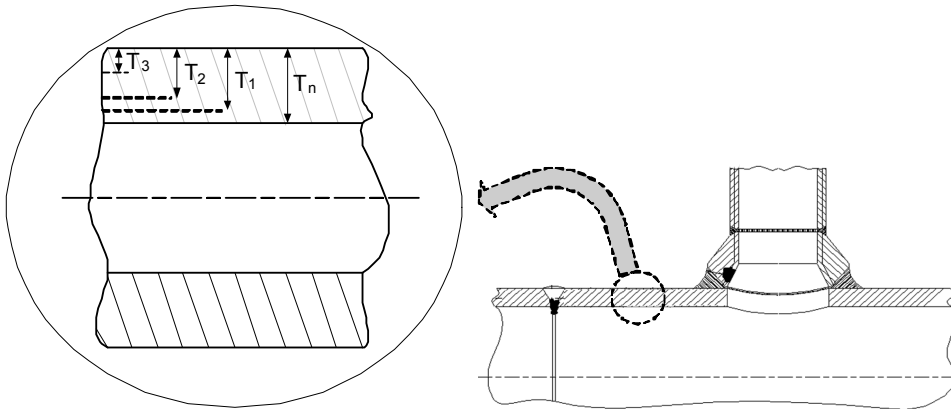
T_n The wall thickness according to diameter and flowline-class [the next highest dimension from $T_3 + \text{corrosion allowance}$]

$$T_1 = (T_n - CA)$$

$$T_2 = (T_3 + CA)$$

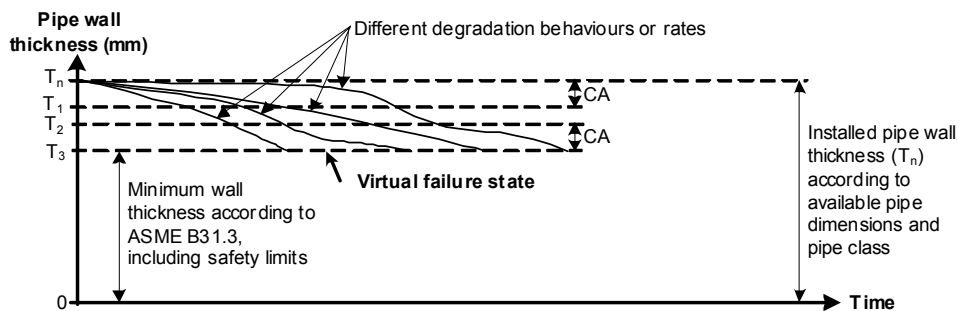
Figure 5 illustrates the different thickness designations.

Figure 5 Thickness designations in relation to a piping component's wall thickness



The nominal wall thickness starts to decrease over time as a result of degradation (corrosion, erosion, chemical attack, etc.). When it reaches the safety limit specified in relation to a universally accepted standard (e.g., ASME B31.3, 2006), it is referred to as 'virtual failure state' (see Figure 6, Ratnayake and Markeset, 2010c). If a component's wall thickness level has passed all the other levels and reached the virtual failure state [i.e., technical condition (TC) has reached 0%], it is considered to have failed and some maintenance and/or modification action in the form of replacement, repair, etc. needs to be taken.

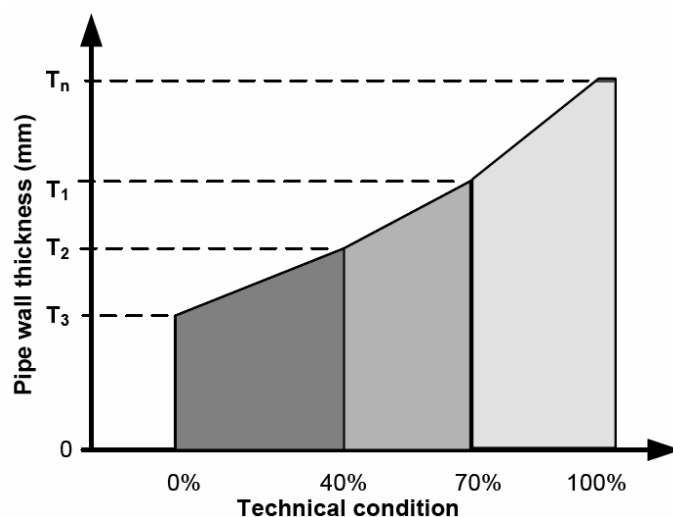
Figure 6 Degradation in flowline components in the form of wall thickness reduction



Also, the piping components undergo different failure rates (see Figure 6) where some components (or component groups) indicate failure rates higher than the others. This can happen due to special causes such as a sudden increase in the sand particle level, change in turbulence pattern, etc. These components can only be recognised by doing a random check of certain locations in a sub-system (e.g., petroleum flowline, closed drainage system, etc.), based on the amount of time elapsed without inspecting. They are observed through the historical data of an equipment group under inspection. Some components are replaced before they reach the virtual failure state, due to a campaign/bulk replacement policy being followed by various companies on their production and process assets. A justification for such an action may be based on the estimation that these components will enter the virtual failure state before the next block replacement is performed. A component may also be considered normally critical based on its location, thus leading to its early replacement. These places are mentioned in the plant strategy document of a particular production and process facility.

The safety limit is derived to avoid serious and unacceptable damage due to failure in the form of leaks or cracks. Serious and unacceptable damage may result, for instance: the loss of human life, damage to the marine environment, production loss, loss of physical assets, etc. Therefore, periodic inspections are performed in order to assure that replacement and repair actions are carried out well in advance of the actual failure state being reached. However, to carry out inspections means to invest significant finance. For instance, when the inspection interval is increased (or frequency decreased) more piping components may come closer to the virtual failure state and consequently actual failure state. Hence, the companies estimate the TC of piping components based on the wall thickness reduction (see Figure 7). For instance, if there is zero degradation then the TC of the component is said to be 100%. The inspections are carried out based on the frequency specified by the plant strategy, until a component reaches T_1 . When the thickness level passes T_1 , the inspections are carried out more frequently and then the TC is said to be in the range of 40% to 70%.

Figure 7 Wall thickness vs. TC

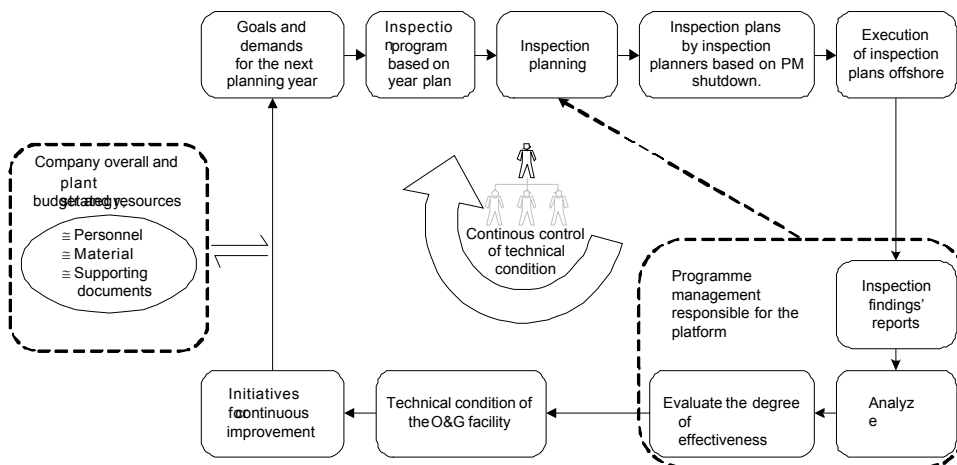


The TC designations are utilised for inspection management purposes. For instance, when inspection planning is carried out focusing on upcoming preventive maintenance (PM) shutdown, it is required to assign the number of inspections for a certain subsystem. Hence, in order to place special attention on the different levels of degradations on piping components, TC categorisation is utilised. In general, the frequency of inspection is decided by inspection managers with the help of a plant inspection strategy and the TC of a subsystem on a specific production and process facility. The plant inspection strategy replicates inspection planners' past experience about similar locations, data available, intuitions, intentions and the perception of HSE consequences.

5 Framing the inspection planning process

The inspection planning process is based on the continuous improvement initiatives (indicated in the plant inspection planning strategy), personnel, material and supporting documents. For each production and process facility, a manager is assigned (called the programme manager) to guide the inspection planner/s through the follow-up recommendations. The follow-up points are the locations where degradation is already recognised based on previous inspection/s results. Hence, based on findings' reports, past data, experience in similar locations, etc., the programme manager provides recommendations for maintaining the TI of an installation. Then, based on recommendations received by the inspection programme manager, and incorporating his/her own experience, data, intuitions and the intentions, the planner arranges an inspection programme. Once the inspection programme is ready, it is sent to the offshore production and process facility, then inspectors start to execute inspection activities and update the piping inspection database (Ratnayake and Markeset, 2010c). The whole process can be framed as shown in Figure 8.

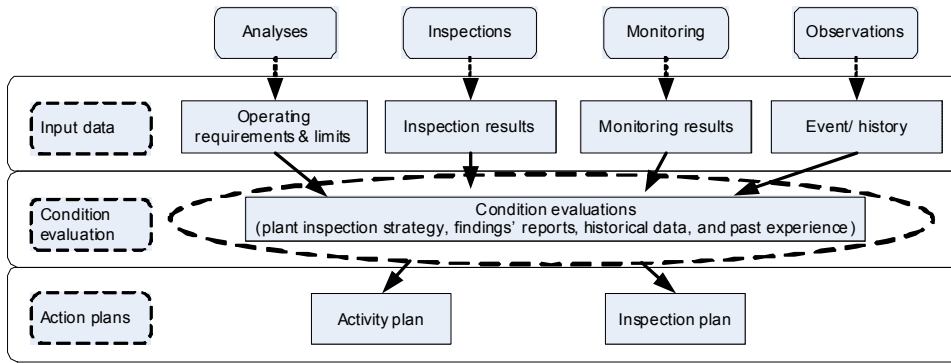
Figure 8 A framework for carrying out inspection planning to maintain the TI of a production and process facility



Source: Adapted from NPD (1998)

The programme management is responsible for the installation, and the inspection planner utilises reports, data, etc. from different sources. This again is a kind of iterative process and illustrated in Figure 9.

Figure 9 Inspection planning: an iterative process



The iterative process can be further cascaded down to activity level, as illustrated in Figure 10 (Ratnayake and Markeset, 2010c). It also illustrates interrelationships between different sources that are used to obtain the status of TC and how improvement suggestions (inputs or improvements) are used to improve the plant inspection strategy and as inputs to PM projects.

The data and information are transferred through several data handling tools along with governance documents. Figures 11(a) and 11(b) illustrate the strategy execution and improvement, respectively, used in the inspection planning process.

Through analysis, the evaluation of future consequences and trends of the TC of the installation is determined. This information is used as input to next year's inspection programme, the development of follow-up points, suggestions for PM projects, etc.

Figure 10 A map of inspection planning aids used to maintain the TI of a production and process facility

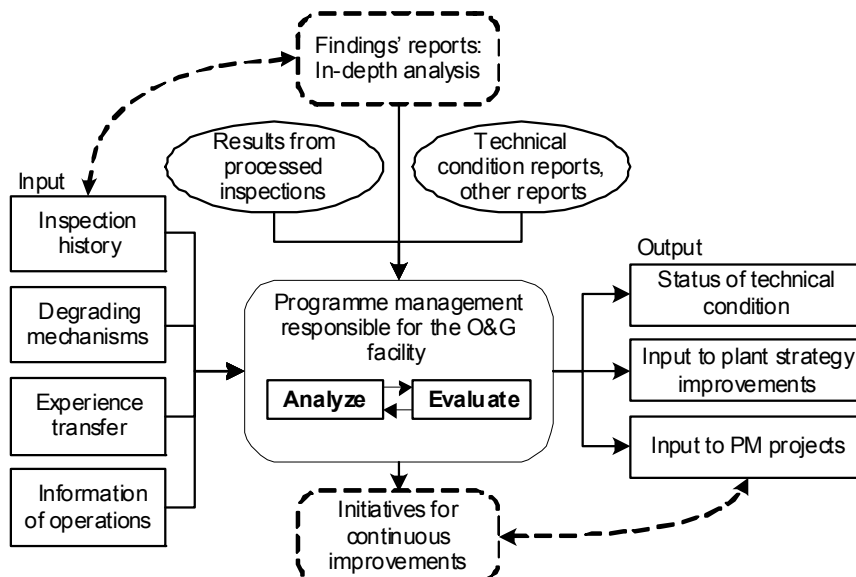
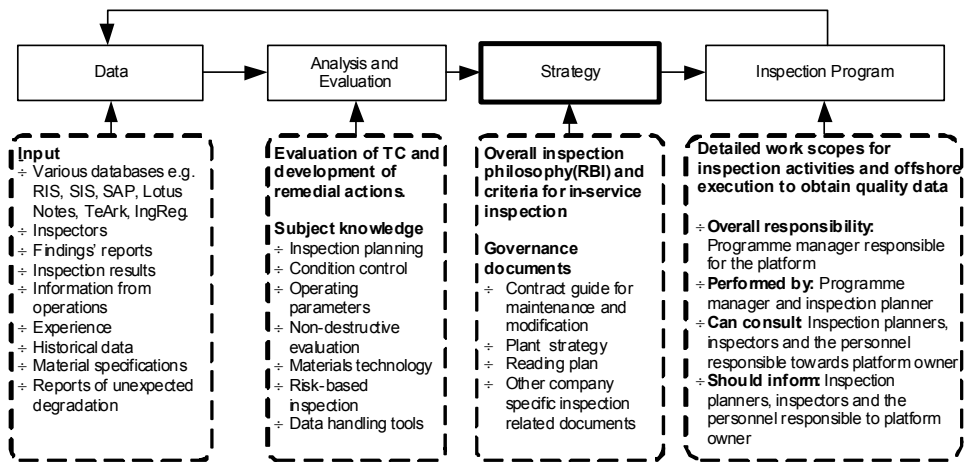
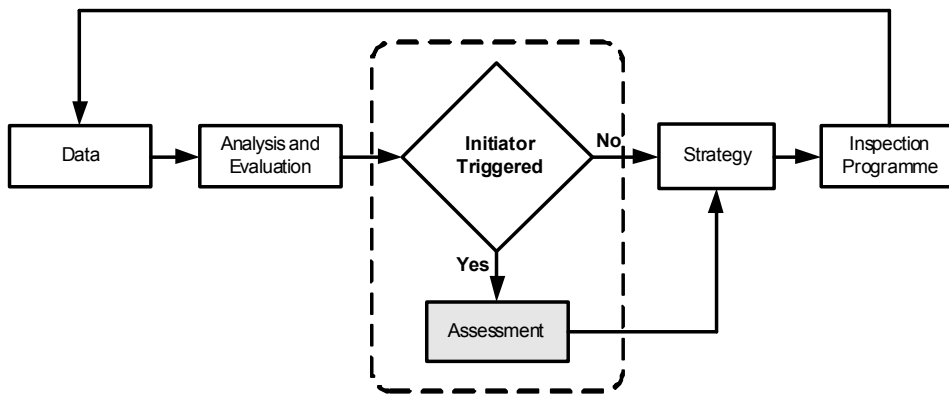


Figure 11 Roles, resources, conditions and tools used to control the TC of a production and process facility



(a)

Figure 11 Roles, resources, conditions and tools used to control the TC of a production and process facility (continued)



(b)

6 Challenges in executing company and plant strategy: an industrial case

Flange inspection is mainly carried out by close visual inspections. The visual inspection is considered as the most reliable method of inspection as long as the inspector has access to the location. Visual inspections are comprised of two approaches: general visual inspections and close visual inspections. In this manuscript, the authors consider close visual inspection of flanges where the flange should physically be opened. In order to open the flange, the complete spool should be taken out when it is not a blind flange. This process consumes fairly considerable time and resources depending on the physical orientation of a spool and to what extent the surrounding area permits without a congestion. Hence, the limited period of PM shutdown, financial constraints, and time and resource availability restrict the number of close visual inspections. In addition to that, within a certain inspection programme, it is customary to have more openings than can be inspected. For instance, in a certain PM shutdown, the approximate number of openings goes up from ten to 15. Thus, a multi-criteria decision-making approach has to be utilised by the programme manager responsible for the production and process facility as well as by the inspection planner to prioritise them based on the conditions imposed by the plant inspection strategy and historical data analysis. The model should be able to eliminate already recommended openings to reach an acceptable level of openings while maintaining the TI of the production facility, as dictated in the plant strategy.

TC reports are developed based on the discoveries made from past offshore inspection findings on piping components and/or degradation trends. The developed TC reports recommend the number of locations (or piping components) that should be inspected on petroleum flowlines in a certain year, using non-destructive evaluation methods such as: visual inspection, ultrasonic testing, radiographic testing, etc. In general, the TC report suggests ten to 15 visual inspections focusing on a PM shutdown. However, it is customary to suggest several close visual inspections in the final inspection programme that cannot be carried out during a PM shutdown because of resource limitations (e.g., number of man hours, equipment, shutdown period, etc.).

The main reason is that for an average inspection planner, it is not possible to simultaneously take into consideration all the criteria specified in the plant inspection strategy such as: data received from findings' reports, historical trends, and special focus points from piping inspection data, as well as various other recommendations. The optimisation of such points is currently done on an ad hoc basis. The final outcome of ad hoc or unstructured decisions does not guarantee that the TI of a production and process facility is assured. This is due to the fact that the least requirement; where, the criteria in plant inspection strategy is not executed as supposed to.

7 Mathematical modelling: plant strategy execution and AHP approach

AHP is a problem-solving framework and a systematic procedure for representing the elements of any problem (Saaty, 1983). The AHP framework provides a flexible and easily understood way of analysing complicated problems (Saaty, 1980). The framework itself provides a multiple criteria decision-making technique that allows subjective as well as objective factors to be considered in the decision-making process. The AHP is a theory of measurement for dealing with quantifiable and intangible criteria that have been applied to numerous areas, such as decision theory and conflict resolution (Vargas, 1990). The active participation of decision-makers in reaching agreement whilst giving managers a rational basis on which to make decisions is the main role of the AHP approach, which is based on the following three principles: decomposition, comparative judgment and synthesis of priorities.

Dyer and Forman (1992) describe the advantages of AHP in a group setting as follows:

- 1 both tangibles and intangibles, individual values and shared values can be included in an AHP-based group decision process
- 2 the discussion in a group can be focused on objectives rather than alternatives
- 3 the discussion can be structured so that every factor relevant to the discussion is considered in turn
- 4 in a structured analysis, the discussion continues until all relevant information from each individual member in a group has been considered and a consensus choice of the decision alternative is achieved.

A detailed discussion on conducting AHP-based group decision-making sessions (including suggestions for assembling the group, constructing the hierarchy, getting the group to agree, inequalities of power, concealed or distorted preferences and implementing the results) can be found in Saaty (1990) and Golden et al. (1989). For problems with using AHP in group decision-making, see Islei et al. (1991).

Researchers use AHP in various industrial applications. Partovi et al. (1990) used it for operations management decision-making. Dey et al. (1994) used it in managing the risk of projects. Eyrich (1991), Korpela and Tuominen (1996) and Dey (2002) have also effectively used AHP for benchmarking various business functions. Mian and Christine (1999) used AHP for the evaluation and selection of a private sector project. Meredith and Mantel (2000) described AHP as an effective tool for project selection. Dey and Gupta (1999) used AHP for cross-country petroleum pipeline route selection.

In this research study, a simultaneous analysis of conditions coming from plant strategy, criticality aspects of flowlines and historical data is modelled using AHP. The following are the rationale for using AHP for inspection planning:

- The factors that lead to inspection planning are both objective and subjective.
- They are also conflicting in nature, where achievement of one factor may result in sacrificing others.
- There is a need for a subjective approach to the selection of inspection points that can incorporate objectivity.
- AHP provides a flexible and easily understood way to analyse each factor that is coming under the inspection planning. It allows subjective as well as objective factors to be considered.
- AHP calls for the active participation of decision-makers in reaching agreement and gives managers a rational basis on which to make decisions.

8 An industrial case to illustrate the proposed mathematical modelling approach

Basically, 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 data collection
- 3 the computation of normalised weights
- 4 the determination of a synthesis-finding solution to the problem (Saaty, 1990).

8.1 Structuring the decision problem

The model for executing the plant strategy (this can also be referred to as inspection planning strategy) is established using the AHP approach by conducting a few brainstorming sessions and studying the company inspection planning strategy. In this case study, we have selected one critical case related to optimisation of close visual inspections. Hence, it is indicated at level 0 in Figure 12.

In a plant inspection strategy, the focused areas are specified based on the criticality of the location of the flowline. For instance, hook-up spool, material specification changes (e.g., carbon steel to duplex stainless steel), the spool just after the chick-valve, etc., are highly vulnerable to degradation. However, if a certain flange is not inspected for a considerable time (within the period of time specified by the regulatory authorities, standards, etc.), then, there is high likelihood of a leak in the near future. Hence, the ‘criticality of the flowline’, ‘focused areas specified by the plant strategy’ and ‘historical data’ are at the same level of the developed AHP hierarchical model (see Figure 12).

Figure 12 Optimisation objective and incorporating a company plant inspection strategy

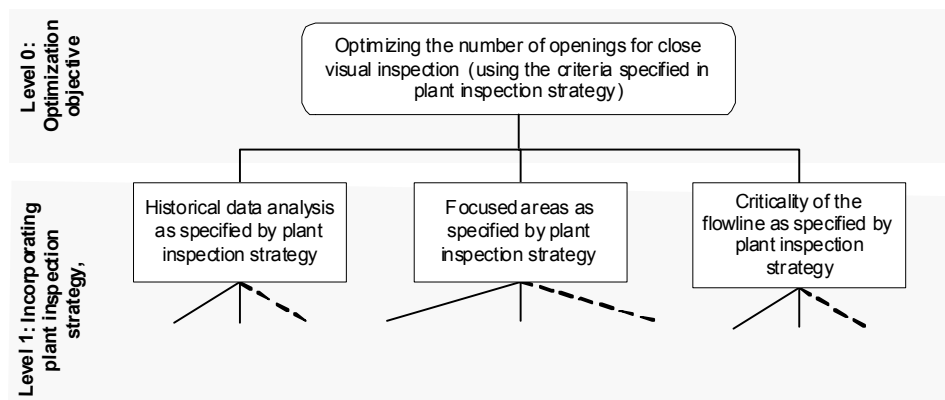
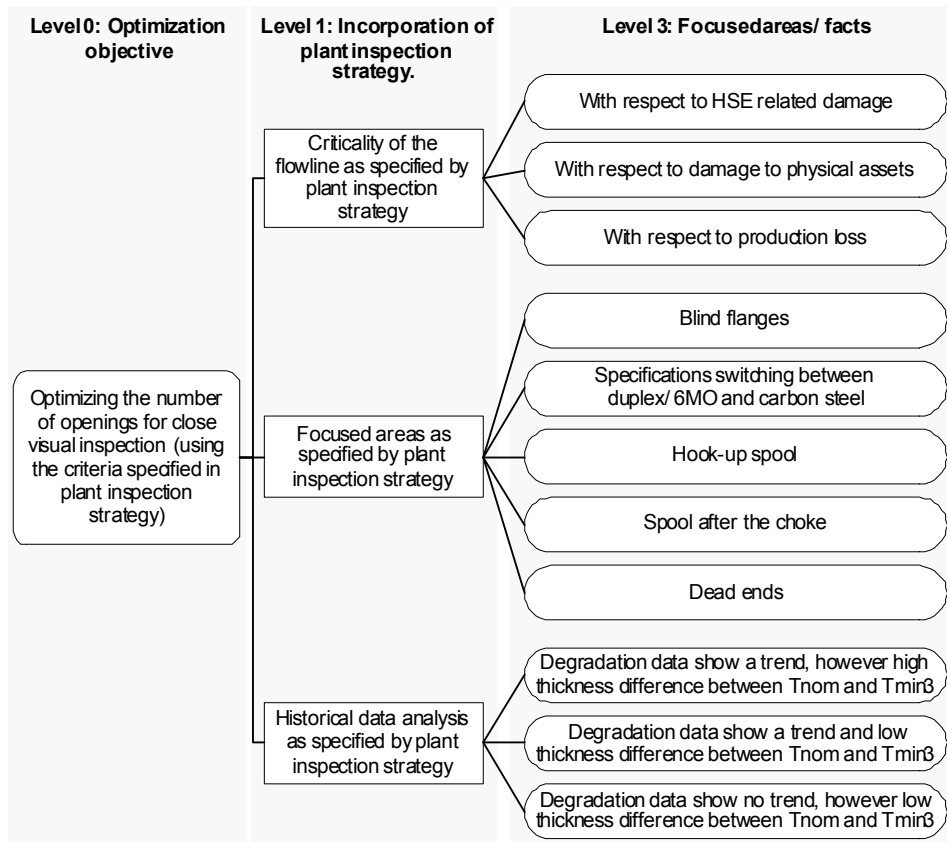


Figure 13 Incorporation of a company plant inspection strategy: criticality, focused areas and historical data analysis



Then, each of them is further cascaded down into level 2, based on the company plant inspection strategy (Ratnayake and Markeset, 2010c). For instance, criticality of the flowline is taken into consideration with respect to HSE related damage, damage to physical assets, and production loss. It is recommended that the possible incidents are maintained at as low as reasonably possible (ALARP) (Ratnayake and Liyanage, 2009). On the other hand, the ERM concerns and results can be integrated at this node (see Figure 13). Moreover, the focused areas specified by the plant strategy typically address the concerns that are available in a company plant strategy and they should be at level 2. Also, the observations made with the help of ‘historical data’ analysis should be at level 2 (see Figure 13).

At level 3, the total number of visual inspection recommendations should be included (i.e., the number of locations to be optimised) and should be independently evaluated with respect to each fact at level 2 (see Figure 14). They represent plant inspection strategy as well as historical data analysis.

Figure 14 A model to optimise the recommended inspection points based on company plant inspection strategy: criticality, focused areas and historical data analysis

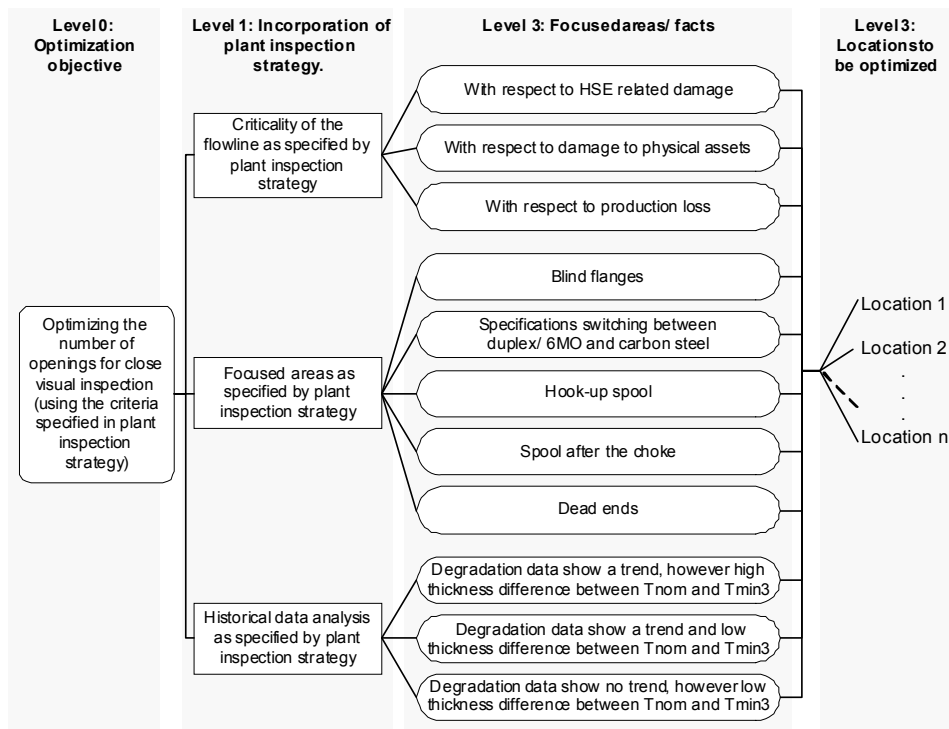


Figure 14 maps the contents defined by the company plant inspection strategy and human judgment and historical data analysis into a single decision model. This model helps to replace current ad hoc decision making approach/es while providing a structured mechanism to execute company plant inspection strategy along with quantitative results.

8.2 Conducting data collection: design of a questionnaire

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 four experts/evaluators. Therefore, the number of experts or evaluators necessary to execute the company plant inspection strategy should be decided based on the significance of the application.

Table 2 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 pairwise fashion.

Table 2 Nine-point rating scale to implement model

<i>Intensity of importance</i> ¹	<i>Definition</i>	<i>Explanations</i>
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over other	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring 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: ¹If 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.

Source: Saaty (1980, 1990)

Sample questions for acquiring information from the experts or evaluators during the interviewing exercises are proposed in Table 3 (Ratnayake and Markeset, 2010b).

The questions' building process should be continued until all comparison judgment matrices corresponding to the decision criteria and alternatives used are obtained, as illustrated in Table 3. 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 3 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)		
	<i>Increasing importance</i>	<i>Increasing importance</i>
	←	→
A	What is the relative importance of the 'criticality of the flowline' and other decision criteria in the right column in the table below when you compare with 'optimising number of openings for close visual inspection'?	
Criticality of the flowline	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Focused areas specified by plant strategy
Criticality of the flowline	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Historical data
B	What is the relative importance of the 'focused areas specified by plant strategy' and other decision criteria in the right column in the table below when you compare with 'optimising number of openings for close visual inspection'?	
Focused areas specified by plant strategy	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Criticality of the flow line
Focused areas specified by plant strategy	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Historical data

8.3 *Computation of normalised weights*

Phase 3 focuses on the determination of the normalised weights of decision criteria, sub-criteria and alternatives. The pairwise comparison judgment matrices obtained in Phase 2 translate into an Eigen-value problem. With the aid of a software tool, the normalised and unique priority vectors of weights can be calculated for the individual decision criteria, sub-criteria and alternatives (see Ratnayake and Markeset, 2010a, 2010b). The geometric mean approach is recommended to combine the pairwise comparison judgment matrices obtained from individual evaluators (Saaty, 1980).

8.4 *Determination of a synthesis-finding solution to the problem*

In Phase 4, the global priority weights in each hierarchy level are calculated by multiplying the normalised priority weights in the preceding levels. The summation of the global priority weight in each level is equal to one. The results of the global composite weights (i.e., the global priority weights at the lowest alternative level) help to determine the relative priority for inspecting locations in relation to focused areas/factors. Furthermore, in the framework, all the factors at each level would be comprised of relevant weights which would be a reflection of the extent to which the strategy related factors as well as quantitative analysis have been used to arrive at a final conclusion about optimisation of openings for carrying out close visual inspections. In this process, not only strategy related factors are taken into account, but the relative contribution of each factor to the final outcome can be assessed. These results alternatively send feedback signals to the management to improve lagging areas of concern.

The former mapping is done through common consensus among the expert(s) – those who have had experience in inspection planning and relevant documentation. However, if disagreements occur in this kind of modelling process, they are resolved by reasoning and by collecting more information. The model is built to include a company plant inspection strategy along with qualitative results based on a production and process facility which, in turn, would support the selection of the optimum number of points for carrying out close visual inspections. This gives opportunity to the approving authority to understand the whole process and the basis of selection.

In this process of modelling, the factors imposed in a company plant inspection strategy as well as experiences, data, intuitions and intentions of managers responsible for inspection programmes and inspection planners are formally merged into a single mathematical model using pairwise comparison matrices (see Saaty, 1980) described in the AHP approach. Then, using software or manual calculations, the pairwise comparison matrices are analysed as suggested in the AHP approach. At the end of the analysis, each inspection point would receive a number. Based on the numbers, corresponding points can be arranged in descending order of magnitude. Using the descending sequence, the points (i.e., those having the highest priority number) are recognised. Care must be taken to include no more than nine items under each node of the hierarchy (see also Haj Shirmohammadi and Wedley, 2004). Hence, when there are more than nine points to be optimised ($n > 9$), the analysis can be carried out several times. The points with the highest priority number from each group can finally be included into the inspection programme depending on the total number of openings allowed in the inspection programme for a PM shutdown. Ratnayake and Markeset (2010a) illustrate the application of a suggested kind of model in a different scenario (i.e., measuring organisational alignment in a manufacturing organisation).

9 Conclusions

The hierarchical decision model generated by the AHP method represents an interesting and alternative analysis tool which is useful to execute the conditions specified by a company plant inspection strategy, trends revealed by historical data analysis as well as the criticality of the flowline in relation to HSE, financial and damage to the physical assets. In this process of analysis, the risk perception can also be taken into account when making pairwise comparisons. This addresses ERM incorporation within the strategy execution process. Apart from that, an excellent compromise between the hierarchical model readability and its visualisation capacity has been obtained with the help of the AHP approach. The outcome of the analysis makes it possible to recognise the most important locations in a hierarchy among the recommendations to carry out close visual inspections in relation to the projected TC of the production and process facility. Hence, by proper execution of a company plant inspection strategy, the assets (e.g., flowlines, processed gas supply lines, closed drainages, fire-water systems, etc.) can be subjected to appropriate monitoring or protection action maintaining the risk of an incident at ALARP. Consequently, this improves the TI by reducing the risk of leakages.

For adaptation of the strategy execution model proposed in this manuscript to suit the specific requirements of a production and process facility, a detailed knowledge about the company plant inspection strategy is required. In particular, the right knowledge about tools that are used for inspection planning, focused areas specified by plant strategy, etc., reinforces the ability of implementing the suggested strategy execution model. Also, an understanding of the physical configuration of the asset (e.g., flowline) and critical parameters is essential. Such information can be obtained from detailed drawings such as PM-drawings, P&ID, etc., as well as from the offshore inspectors (i.e., those who carry out physical inspections on offshore production and process facilities based on the recommendations made by inspection planners) and the design office staff.

It is also vital to have an overview of the production and process facility. Hence, an inspection tour of the production and process facility and having discussions with the personnel responsible for operations are recommended. Information obtained from these sources will be beneficial to get the real essence of strategy related factors for making pairwise comparisons. When making pairwise comparisons, the range of values or numerical values of the physical parameters which are appropriate to the assets (e.g., petroleum flowlines) or process, a consideration of the legal requirements, moral obligation and financial requirements should be borne in mind. The beauty of the approach is that strategy related factors as well as analysed data, experiences, intentions and intuitions are incorporated in a logical and methodical way in a single mathematical model to explore an optimum result. Further research should be carried out to investigate how analytic network process (ANP) can be used if/when there are dependencies among factors at each level.

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