2013

Asset management in the energy pipeline industry in Australia

Richard Dwight
University of Wollongong, radwight@uow.edu.au

Tieling Zhang
University of Wollongong, tieling@uow.edu.au

Khaled O. El-Akruti
University of Wollongong, khaled@uow.edu.au

Publication Details

Dwight, R., Zhang, T. & El-Akruti, K. O. (2013). Asset management in the energy pipeline industry in Australia. World Trends in Maintenance Engineering (M-Tech 2013) (pp. 1-10).

Asset management in the energy pipeline industry in Australia

Abstract

A review of asset management systems within the context of energy pipelines has been conducted. It covers available methodologies, current asset management systems, opportunities for improvement and research challenges. A particular point of interest is the degree to which consideration of remaining life and the influence of maintenance activities are used to drive the asset management strategy. Asset management within the energy pipeline industry is mostly concerned with integrity assurance. Irrespective of this overriding goal, cost of delivery is also of concern. At any point of the service life the remaining life of the pipeline at an acceptable level of integrity is of central interest. When dealing with remaining service life, specific attention must be given to deterioration evaluation of pipelines due to corrosion and other defects. At different life stages there are many factors that affect the remaining service life of pipelines which make its estimation problematic in some situations. Pipeline life prediction is integral with determining optimal inspection intervals and selecting repair or protection actions. Research challenges in asset management of energy pipelines include: incorporating all practically available data into an integrated decision support system; developing asset management support decision models to enhance trade off among the alternative options; establishing a systematic way for maintenance program development; and, incorporating life-cycle cost and risk assessment techniques informed by predicted performance into the overall asset management system of organisations.

Keywords

industry, pipeline, management, asset, australia, energy

Disciplines

Engineering | Science and Technology Studies

Publication Details

Dwight, R., Zhang, T. & El-Akruti, K. O. (2013). Asset management in the energy pipeline industry in Australia. World Trends in Maintenance Engineering (M-Tech 2013) (pp. 1-10).

ASSET MANAGEMENT IN THE ENERGY PIPELINE INDUSTRY IN AUSTRALIA

Richard Dwight, Tieling Zhang and Khaled El-Akruti

University of Wollongong
radwight@uow.edu.au, tieling@uow.edu.au, khaled@uow.edu.au

ABSTRACT

A review of asset management systems within the context of energy pipelines has been conducted. It covers available methodologies, current asset management systems, opportunities for improvement and research challenges. A particular point of interest is the degree to which consideration of remaining life and the influence of maintenance activities are used to drive the asset management strategy.

Asset management within the energy pipeline industry is mostly concerned with integrity assurance. Irrespective of this overriding goal, cost of delivery is also of concern. At any point of the service life the remaining life of the pipeline at an acceptable level of integrity is of central interest. When dealing with remaining service life, specific attention must be given to deterioration evaluation of pipelines due to corrosion and other defects. At different life stages there are many factors that affect the remaining service life of pipelines which make its estimation problematic in some situations. Pipeline life prediction is integral with determining optimal inspection intervals and selecting repair or protection actions.

Research challenges in asset management of energy pipelines include: incorporating all practically available data into an integrated decision support system; developing asset management support decision models to enhance trade off among the alternative options; establishing a systematic way for maintenance program development; and, incorporating life-cycle cost and risk assessment techniques informed by predicted performance into the overall asset management system of organisations.

1. Introduction

The energy pipeline asset in Australia renders an enormerous asset value. Australia's gas transmission network covers over 20,000 kilometres. The construction of new pipelines and the expansion of existing facilities in the past decade have created an interconnected pipeline network across the country. Gas transmission pipeline investment was over $6.7 billion since 2000 (Australian Energy Regulator, 2009). The total length of gas distribution networks in eastern Australia is around 74,000 kilometres with a combined asset value of almost $8 billion (Australian Energy Regulator, 2012).

Gas transmission investment typically involves large intensive capital projects to expand existing pipelines (through compression, looping or extension) or to construct new pipelines. Significant investment in the regulated and unregulated transmission sector has occurred since 2010. Additionally, a number of major projects are under construction or have been announced for development. Investment to augment and expand distribution networks in eastern Australia is forecast at around $2.6 billion in the current periods of typically five years. The underlying drivers include a rising number of connections, replacement of ageing networks, and the maintenance of capacity to meet customer demand (Australian Energy Regulator, 2012).

Clearly the energy pipeline industry is capital intensive and in Australia has expanded in recent years. Even a small improvement in asset manament can bring the industry significant benefit by possibly reducing the original expenditure through better planning and targetted design as well as reducing life cycle costs through designing for overall cost and better managing the inspection, maintenance and refurbishment of existing infrastrature to extend its economic life.

The energy pipeline industry in Australia has put significant effort into research so that its enviable record in maintaining pipeline integrity can be maintained. Funding from the Australian government, Australian industry and several Australian universities for a Cooperative Research Centre for Energy Pipelines has led to a significant increase in the volume of research being conducted. Within this program, an important research aspect is the energy pipeline asset management because asset managemenmt is concerned with all the activities in the asset life cycle including design, construction, installation, utilization and disposal. Although asset management covers all activities in the entire asset life cycle, the majority of these activities has been focusing on reliability and maintainability of the asset.

The aim of this paper is to give a generic overview of asset management status in the energy pipeline industry in Australia. The methodology applied involves a review of published knowledge on the asset management system and its models and frameworks. Using a typical framework as a guideline, a review of the asset management activities with decisions whose attributes may suit coating defects and external corrosion on energy pipelines has been conducted. This work is partially built on the work done for the rail industry. A brief report on general activities and findings of more general relevance to asset management is reported here, noting that these range far wider than the pipeline industry, either in Australia or elsewhere, and are not specific to that industry or to any particular organisation within it.

2. Context

2.1 A View on Asset Management System

Asset management involves all the activities in asset life cycle but measurement, monitoring, analysis, and evaluation activities during the utilization phase are crucial for decision making. Furthermore, the life cycles of some assets impact on the life cycles of others. This leads to the need to consider inter-dependence in life cycle management of the total system associated with a business outcome. For example, measuring and monitoring the performance and condition serves operations, maintenance, and capital replacement decisions, and should inform feasibility studies, design and construction, and deployment of new assets. The objective is to provide information and a basis for future activities including: a) improving asset reliability through efficient prediction of asset failures; b) planning and scheduling of repairs, replacement, development, and redeployment; c) maximizing asset performance and throughput; d) improving asset selection, design and construction, and deployment and e) indicating opportunity for improvement.

However, information must be managed and put into the right form for decision making in order to have a better understanding of how asset management may deal with the needs for continuous measurement or monitoring, analysis and evaluation throughout all stages of an asset's life.

The concept and possible benefits of a holistic system approach to asset management has been identified but still not fully developed (e.g., Hipkin 1998; Dornan 2002; Mohseni 2003; Charles and Alan 2005; CIEAM 2008; Haffejee and Brent 2008; Asset Management Council 2009). Several frameworks and models have been proposed. Geraerds's model (1992) 'The EUT Maintenance Model' and the Asset Management Council's Technologies Model (2007) are particular examples. These are published by individuals or organisations according to their needs. The available asset management frameworks do not cover all of the relevant aspects in a manner suitable for application. Some, for example, UK tero-technology framework cited in Bamber et al. (2004); and the system engineering or life cycle framework (Blanchard and Fabrycky, 1990; 2010) tend to present asset management related activities as following the sequential life cycle stages of an asset rather than all of the activities required to manage a portfolio of assets in an organization.

On the other hand, there is not an accepted standard currently available for setting out the requirements for an asset management system although the draft ISO/DIS 55000 suite of standards seeks to do this. Some organizations have utilized part of the standards or guides (ISO/IEC 15288; PAS 55-1&2) to enhance their asset management system. The specific needs of industries such as the pipeline industry require specific consideration.

In summary, a holistic approach to asset management is to be achieved by having an integrated asset management system within an organization. This system must account for all of the life cycle stages and activities. Reliable life estimation tools utilized within an integrated asset management system model with site-specific information will allow accurate life determination and the testing of strategies for life extension.

In view of the above, an attempt to develop an engineering asset management system to account for the interrelationships and influence of the asset management activities in an organization has resulted in a framework established as shown in Fig. 1 (El-Akruti et al., 2013). The model has a number of key elements:

1) The event: this may include events triggered by external or internal environment.

2) The asset solution: this involves the action in response to this event which may include the change in assets or asset-related activities such as life cycle activities, supporting activities or the relationship between these activities.

3) Provision of the asset solution: this involves the provision of the requirements of assets, their life cycle activities or supporting activities.

4) The resulting asset performance: this involves the results which may include the resulting technical performance relative to assets or their asset-related activities and the resulting business performance.

5) The AM system: this constitutes management activities, mechanisms and relationships to plan and control actions for the provision of the solution and achievement of the asset performance and business outcomes. This may include planning, feedback control, decision making and managing technical tasks.

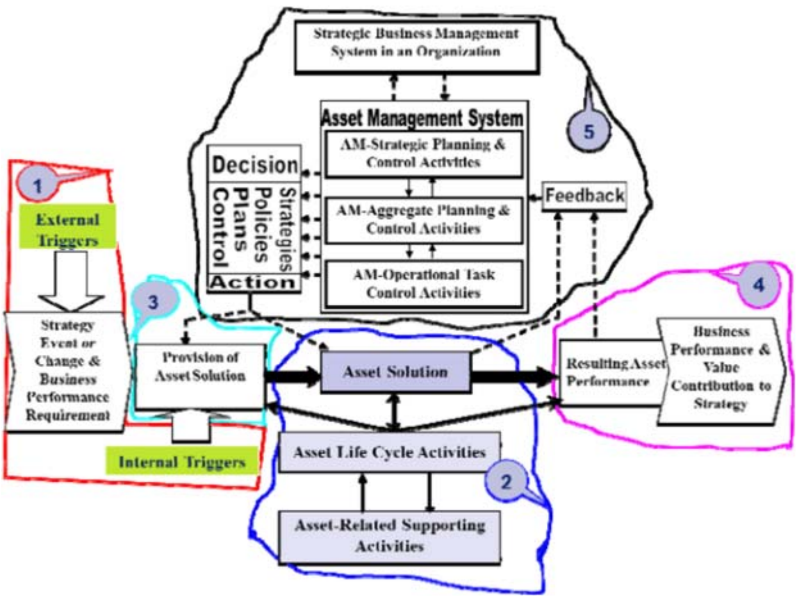

Figure 1 A framework for engineering asset management system emphasising the control aspect in asset life cycle (El-Akruti et al., 2013)

2.2 Key Aspects of Pipeline Asset Management

While the relationships and control mechanism set out in the framework as shown in Fig. 1 hold as general guidelines for the asset management system, asset management associated with energy pipelines has distinctive features. One of them is vitally concerned with the integrity of the pipeline with risk associated with leakage and explosion kept as low as possible. The importance of asset performance in terms of a capability to transport a flow-rate of gas may be less of a management issue than ensuring the integrity of the pipeline.

Business performance is arguably most affected by actions to ensure integrity. These assets are typically retained in a state that achieves a very high level of integrity. A useful depiction of the asset management process highlighting the role of asset life prediction and an integrated decision process is set out in Figure 2.

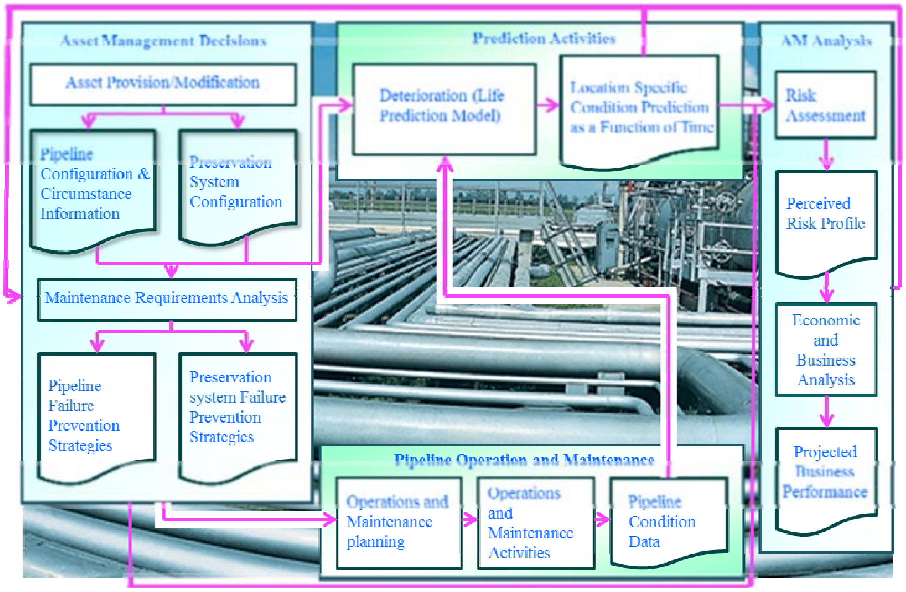

Figure 2 Asset management process highlighting the role of asset life prediction and an integrated decision process (Dwight et al, 2011)

Figure 2 highlights the asset management activities for energy pipeline assets. These activities with the asset management system are shown to be focused on integrity, risk, safety, environmental and change management. The activities shown in Fig. 2 are depicted in a closed loop interactions with the management related activities. The main point to draw out is the integration required between asset management decisions including asset configuration and development of maintenance strategies. The assurance of integrity results from the management of changes. Changes to the assets, changes to life-cycle activities, or changes in the environment of the pipeline can all lead to reduced integrity. The asset management system must also be integrated within the Meta-system of the whole organization and interacting with other business or operations activities and social systems.

Setting out the existing activities of an organization against such a process model will assist in finding gaps or areas where change may facilitate accurate prediction of pipeline conditions in order to maintain or extend a reliable pipeline service life.

3. Status of Asset Management in the Energy Pipeline Industry in Australia

3.1 Methodology

As indicated in Section 2 the asset management system activities proposed in the asset management framework can be used to examine whether an appropriate asset management system is in place. For this purpose the framework illustrated in Fig. 1 is used. In order to establish a practical process to review the current asset management status in the energy pipeline industry in Australia, a list of interview questions based on this framework has been worked out and sent to the related energy pipeline companies. Interviews with asset managers and specialists have been conducted. The objective is to develop an understanding of the existing asset management system and activities in an organization.

A comprehensive list of questions submitted to major companies in the pipeline industry allows an initial view to be formed. The questions are designed to verify the status of the asset management system in the industry referencing relevant frameworks and standards defined from literature. The verification of the asset management system involves checking the existence of the relevant organizational structure and the required activities, decision mechanisms and procedures based on relevant frameworks and standards. This involves all pipeline lifecycle activities including design, construction, operation, maintenance and replacement using Fig. 2 as a guideline. The investigation focuses on the organization records related to these activities and procedures that contain condition data related to external coating and corrosion for life estimation and its ramifications.

A first stage investigation was conducted to examine the status of current asset management systems. The investigation and analysis is based on the data obtained from interviews with representatives from typical companies in the pipeline industry and the archival records collected from these companies' websites or documents that were provided. The resulting information gained is mapped against those elements presented in the framework. This includes organizational structure, responsibilities, activities and associated mechanisms in place.

3.2 Status of Asset Management System and Asset Management Activities

This section gives a mapping analysis of the status of asset management system and asset management activities in the energy pipeline industry in Australia corresponding to the framework and the asset management activities as shown in Figs. 1 and 2. Please note that the following status report is not only specific to the pipeline industry but serves as a general indication of where asset management is up to within asset intensive industry dealing with commodities that have the potential to significantly impact their community.

The first step is to review the organizational structure in charge of organizational asset management. When mapping the organizational structure of the pipeline companies surveyed to the framework presented in Section 2 it is found that these companies have direct and supportive groups covering the levels indicated by the framework: strategic, managerial and operational.

Significant aspects of this typical structure include the inclusion of asset management as a separate department within the organization apparently at the same level as operations with direct reporting to the managing director. Presumably risk management related to integrity of pipelines is encompassed within asset management. The link between the strategic group and asset management is not so clear.

The second step is to review the asset management activities based on the asset management process described in Fig. 2. In order to determine the status of the current activities, those evidenced by documents and explained by representatives have been mapped against the cycle of activities depicted in Fig. 2 including the followings:

1) Asset development plans and procedure;
2) Implementation plans and supervised execution process;
3) Test, measurement and record;
4) Data collection, processing, store and reporting;
5) Assessment and control of the asset performance to comply with the standards such as AS 2885, AS2832 Part 1 for Pipeline License Conditions and Procedures;
6) Analysis and evaluation (covering technical or engineering assessment of pipeline materials, coatings, design parameters, defects assessment, risk and consequence assessment, risk control, pipeline future condition prediction etc.)
7) Decision-making, strategic analysis and approval;
8) Review and recommendation for asset management system change.

The main asset management system activity allocations are indicated at this stage to help follow their relationships within the decision process at a later stage. The reviewed documents indicated some of the allocations and responsibilities. These are highlighted in the review process. The 8 elements in the asset management cycle were found to be allocated to specific parts of an organization.

In summary, what have been found from the industry are as follows:

1) Asset management is generally in place in industry.
2) Sophisticated inspection systems are in use and data used to determine risk level and need for further action (inspection or repair).

3) Inspection intervals are set qualitatively and are affected by practicalities - accessibility.
4) Major improvements in inspection technology reduce the management problem for a majority of the pipelines but leave critical parts still difficult to manage. Inspection technologies are also proliferating but leave the challenges of how to integrate the huge amount of asset condition data into asset management.
5) Trade-offs are being made between increased protection and total replacement of parts of the assets. Decision makers in general do not have sophisticated decision tools available to them, relative to the available range of data.
6) Decisions to conduct more detailed inspections are being made using various qualitative decision making processes. The quantitative decision-making techniques need to be developed.
7) Data currently available may be analyzed to improve the understanding of remaining life and/or the time needed for major repair work.
8) There is cost assessment of activities but a structured life cycle costing is not generally being used to help make long planning decisions.
9) There is an opportunity to make better use of inspection data together with a broad range of other asset-related data to enhance the asset management decisions.

4. Meeting the Challenges of Improving Asset Management

4.1 Degradation modelling

Typically organisations keep numerous records that hold some information about the remaining life of their assets. Construction records, maintenance records and records of purposeful inspections are some of the most relevant information. In the case of pipelines, sophisticated in-line inspection tools promise to greatly improve the available information to the pipeline owner. Other industries also have an increasingly sophisticated array of inspection systems available to them. We seek to utilise artificial neural networks, ANNs, as a way of integrating all of this data so that the best prediction of asset condition and the remaining useful life can be obtained. This information, fed into the system set out in Figure 2, can be used to predict the results of asset management decisions and adjust those decisions to achieve the best decisions for the business. A typical ANN architecture that has been used for similar applications in the aircraft industry is shown in Fig. 3 as an illustration. This neural network model is developed by Cavanagh et al. (2010) for predicting corrosion related parameters (such as pit depth distribution) on the surface of an aircraft aluminum alloy as a function of the environment factors such as temperature (T), pH value, time of exposure (t), etc. The output parameters are shape parameter, □, and scale parameter, □, of a Weibull distribution which represents the pit depth distribution. The maximum pit depth or diameter is represented here as d_{max}.

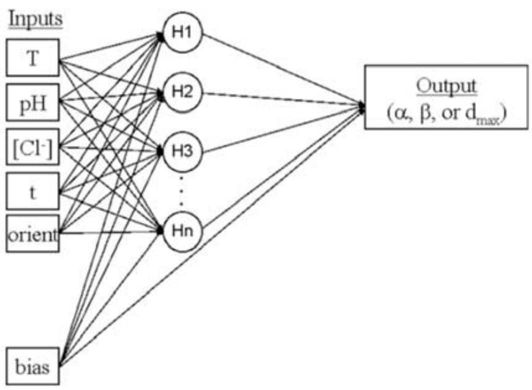

Figure 3 Corrosion related parameters predicted by a Feedforward Neural Network (Cavanaugh et al., 2010)

Corrosion is the most common and one of the critical failure modes of energy pipelines. The approaches for modeling corrosion may be categorized as Stochastic, Empirical, Probabilistic, Deterministic, and Mechanistic one. From large scope and in general, the corrosion models may be categorized as Empirical, Deterministic and Mechanistic model. The stochastic models are attributed to Empirical while the Probabilistic models are included in Deterministic one. For example, within the empirical class, there are functional models, in which (discrete) data are represented by continuous mathematical functions; statistical models; and artificial neural networks, *etc*. Within the broad class of 'deterministic' models, there exist 'definite' models that yield a single output for a given set of input values; and probabilistic models, in which the inputs are distributed resulting in a distributed output from which the probability of an event occurring can be estimated (Macdonald and Engelhardt, 2010). As mentioned above, we are seeking to utilize the Neural Network models for prediction of pipeline health condition as the Neural Network models can account for all potential impact factors on corrosion, including environmental factors, condition inspection data as well as operational and maintenance data. The approach by Neural Networks is required to infer an asset health condition or life given that an accurate model cannot be found, or the real failure mechanism is not clear or cannot be clearly described.

4.2 Improving maintenance program development

Apart from considering the asset management system as a whole and also the development of better degradation prediction techniques, we have been working for some years to improve maintenance requirements analysis processes. Figure 4 sets out a general process that is useful in understanding the relationship between key activities within a maintenance requirements analysis process. The order and nature of the analyses undertaken depend on the situation at hand.

Rather than focusing only on the pipeline industry, such approaches to maintenance requirements analysis are considered to be generally applicable and of benefit to a wide range of industries which traditionally have struggled with getting benefit from significant analysis effort put into maintenance requirements analysis (Dwight et al., 2011). The need for better consideration of these processes is born out by various comments received from practioners such as "the maintenance requirements analysis (MRA), particularly the reliability centred maintenance (RCM) process is tedious" and "we would like more focused application based on the value contribution". There is a requirement for MRA but not specifically to use RCM, however the terms are used synonymously. It has also been noticed that RCM may only superficially be applied if mandated for situations that may not benefit from its blanket use.

In order to address these issues, a possible solution has been proposed (see aslo, Dwight et al., 2011) as follows:

a) Prescribe different levels for MRA dependent on the intent and circumstances of the analysis
b) Use events in the asset life to trigger a review of MRA rather than simply a time based trigger
c) Triggers should include: asset modification; end-of-warranty; change in support arrangements including the decision to outsource maintenance; the emergence of new data; changed resource availability for maintenance; downgrading of required performance; asset re-deployment; imminent asset retirement
d) Organisations need to design these triggers and incorporate them into their management system. Large organisations are recommended to rely on written procedures and time based review.

Further a protocol for assessing whether a maintenance requirements analysis, MRA, is required has been proposed. This may follow a decision process as illustrated in Fig. 4 (Dwight et al., 2011).

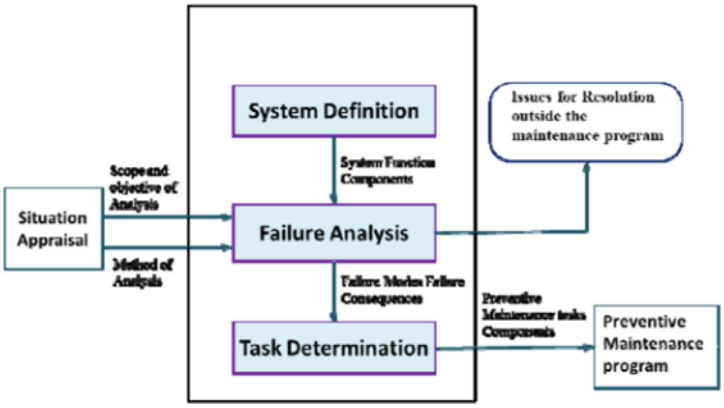

Figure 4 A maintenance requirements analysis process (Dwight et al, 2011)

4.3 **Focus on a holistic approach to Asset Management**

Ouertani et al. (2008) suggest that maintenance is complex and deserves additional attention. Conversely it is only one of the activities involved in managing the life of assets. Others include choosing the right assets, using them appropriately, and balancing short-term performance against long-term sustainability. Thus, asset management activities need to build on a life cycle cost focus. All asset-related organizational activities interrelated through all life cycle stages, require coordination. For example, the decisions about the disposal of an asset, as well as decisions about the introduction of new assets are interrelated and require contributions by many organizational entities and levels through different life cycle stages. Pinjala et al. (2006), discuss the relationship between business and some of the asset-related activities such as maintenance. A strategic approach to maintenance as an asset-related activity has been recognized especially in capital-intensive industries (Tsang 2002; Pinjala et al. 2006; Muchiri et al., 2010).

Asset management decisions may involve the issues such as:

- Establishing the remaining costs (given the asset is in the use phase), which raises the issue about replacement cost as a function of behavior of the current system.
- Repair/replacement decision logic which may give rise to economic or optimum repair frequency and replacement period.
- Prediction and estimation decisions may require Condition Based Maintenance breadth and depth for visibility.
- Projection decisions involve investment, system operation and support costs. These are based on the projected activities throughout the operational use and support phase and are usually the most difficult to estimate.
- Trade-off decisions may involve capital vs. running costs, labor and materials versus reduced services and reduced safety.

Models that organisations can adopt to allow these outcomes to be achieved must include appropriate use of data.

5. Conclusions and Research Challenges

In conclusion:

- Asset management activities are in place in industry.
- Sophisticated inspection systems are in use and data are used to determine risk level and the need for further actions (inspection or repair).
- The main concern of asset management in industries such as the energy pipeline industry is asset integrity.

- Inspection intervals are set using expert judgement rather than referencing decision models or based on regulations and the standard.

This leads to particular research challenges:
- Better life prediction using all practically available data;
- Establishing a systematic way for maintenance program development; and
- Integration of life-cycle cost and risk assessment techniques informed by predicted performance into the decision support systems for the asset management system of organisations.

6. REFERENCES

[1] AS2885 (2008). Australian Standard: Pipelines-Gas and Liquid Petroleum.

[2] AS2832.1 (2004). Australian Standard: Cathodic Protection of Metals - Pipes and Cables.

[3] Asset Management Council (2007). Asset management technologies model. Asset Management Council and MESA Newsletter, 2007.

[4] Asset Management Council (2009). Asset management. Asset Management Council and MESA Newsletter, April-May 2009.

[5] Australian Energy Regulator (2009). State of the energy market 2009 - Chapter 9 Gas transmission. http://www.aer.gov.au/node/6313.

[6] Australian Energy Regulator (2012). State of the energy market 2012 - Chapter 4 Gas pipelines. http://www.aer.gov.au/node/18990.

[7] Bamber, C.J., Sharp, J.M., et al. (2004). Third party assessment: the role of the maintenance function in an integrated management system. Journal of Quality in Maintenance Engineering 10(1): 26.

[8] Blanchard, B.S., Fabrycky, W.J. (1990). Systems engineering and analysis. Englewood Cliffs, N.J. :, Prentice Hall, USA.

[9] Blanchard, B.S., Fabrycky, W.J. (2010). Systems engineering and analysis: international Edition (5e). Englewood Cliffs, N.J. :, Prentice Hall, USA.

[10] Cavanaugh, M.K., Buchheit, R.G., Birbilis, N. (2010). Modeling the environmental dependence of pit growth using neural network approaches. Corrosion Science 52: 3070-3077.

[11] Charles, A.S. and Alan, C.B. (2005). Asset life cycle management: towards improving physical asset performance in the process industry. International Journal of Operations & Production Management 25(5/6): 566.

[12] CIEAM. (2008). Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM). http://www.cieam.com/.

[13] Dornan, D.L. (2002). Asset management: remedy for addressing the fiscal challenges facing highway infrastructure. International Journal of Transport Management 1: 41-54.

[14] Dwight, R., Gordon, P., Scarf, P.A. (2011). Dynamic maintenance requirements analysis in asset management. Advances in Safety, Reliability and Risk Management (ESREL 2011). Edited by Guedes Soares, C., CRC Press 2011, p. 847-852.

[15] El-Akruti, K., Dwight, R., Zhang, T. (2013). The strategic role of engineering asset management. International Journal of Production Economics. http://dx.doi.org/10.1016/j.ijpe.2013.07.002.

[16] Geraerds, W.M.J. (1992). The EUT maintenance model. International Journal of Production Economics 24(3): 209-216.

[17] Haffejee, M. and Brent, A. C. (2008). Evaluation of an integrated asset life-cycle management (ALCM) model and assessment of practices in the water utility sector. Water SA 34(2): 285-290.

[18] Hipkin, I. B. (1998). A new look at world class physical asset management strategies. South African Journal of Business Management 29: 158-163.

[19] International Organization for Standardization (2012). ISO/DIS 55000: Asset management Overview, principles and terminology.

[20] ISO/IEC 15288: (2008). Systems engineering - System life cycle processes. Standards Australia Internationa Ltd.
[21] Macdonald, D.D., Engelhardt, G.R. (2010). Predictive Modeling of Corrosion. Shreir's Corrosion, Chapter 2.39, P. 1630-1679.
[22] Mohseni, M. (2003). What does Asset Management Mean to You?, Dallas, TX, United states, Institute of Electrical and Electronics Engineers Inc.
[23] Muchiri, P.N., Pintelon, L., Martin, H., De Meyer, A.M. (2010). Empirical analysis of maintenance performance measurement in Belgian industries. International Journal of Production Research 48(20): 5905-5924.
[24] Ouertani, M.Z., Parlikad, A.K., et al. (2008). Asset information management: Research challenges, Marrakech, Morocco, Inst. of Elec. and Elec. Eng. Computer Society.
[25] PAS 55-1&2 (2008). Asset Management: Guidelines for the application of PAS 55-1 & PAS-55-2. P. A. Specification, The Institute of Asset Management.
[26] Pinjala, S.K., Pintelon, L., Vereecke, A. (2006). An empirical investigation on the relationship between business and maintenance strategies. International Journal of Production Economics 104: 214-229.
[27] Tsang, A.H.C. (2002). Strategic dimensions of maintenance management. Journal of Quality in Maintenance Engineering 8(1): 7-39.