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A Tool to investigate the status of engineering asset management in organizations

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Abstract
This paper presents a framework which addresses a series of activities defined in Engineering Asset Management (EAM). This framework is proposed to serve as a guideline of organizations when investigating if the status of the EAM system that they have in place is adequate to achieve the intended objectives. It also serves as a guide for researchers in EAM. The framework ensures a holistic approach to EAM in place that it explores the required asset management activities, relationships and mechanisms for achieving the organizational goals. In order to demonstrate the framework, a 'retroductive' approach in the context of case study is given this present paper which leads to a better understanding of the framework functions, i.e., the activities and relationships covered. The framework can also be used as a research tool, as well as a practical reference base in determining what activities should be in place within the asset management system for enhancing an organization's ability to capture the intended benefits.

Keywords
organizations, tool, management, asset, status, engineering, investigate

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A TOOL TO INVESTIGATE THE STATUS OF ENGINEERING ASSET MANAGEMENT IN ORGANISATION

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SUMMARY:

This paper presents a framework which addresses a series of activities defined in Engineering Asset Management (EAM). This framework is proposed to serve as a guideline of organizations when investigating if the status of the EAM system that they have in place is adequate to achieve the intended objectives. It also serves as a guide for researchers in EAM. The framework ensures a holistic approach to EAM in place that it explores the required asset management activities, relationships and mechanisms for achieving the organizational goals.

In order to demonstrate the framework, a 'retroductive' approach in the context of case study is given this present paper which leads to a better understanding of the framework functions, i.e., the activities and relationships covered. The framework can also be used as a research tool, as well as a practical reference base in determining what activities should be in place within the asset management system for enhancing an organization's ability to capture the intended benefits.

Keywords: Engineering asset management, tool, framework, system status, organization, energy pipeline industry

1 INTRODUCTION

1.1 Definition of Engineering Asset Management

Capital intensive industrial organizations deal with the management of life cycle of physical assets to achieve the intended strategy. The effective management of assets utilized by an organization, through their life cycle, for the purpose of value creation and delivery is generally termed 'Engineering Asset Management (EAM)'. Asset Management Council (2009) defines EAM as: "*The life cycle management of physical assets to achieve the stated outputs of the enterprise*". As such, EAM includes both technical and business activities of an organization. The EAM system is defined as: "*The system that plans and controls the asset-related activities and their relationships to ensure the asset performance that meets the intended competitive strategy of the organization*" (El-Akruti 2012). As a control system EAM involves a set of planning and control activities at different organizational levels. Its span of control extends from identification of the need to the disposal and liability thereafter. This definition provides an integrated view of the EAM system within the whole organization's management system.

The interdisciplinary nature of EAM stems from the fact that it is concerned with the life cycle processes at the different stages and through often temporally separated activities – for example, from the identification of the need for assets to bringing them to being, their design, construction and utilization to the problem of getting the best out of the assets by extending their productive life cycle; minimizing their life cycle cost; monitoring their condition; keeping them reliable; utilizing their full capacity; operating them safely; and to upgrading their capabilities or capacities when necessary (Dwight and El-Akruti, 2009). The overall EAM process can be set out as a succession of four stages: acquire, deploy, operate/maintain and retire (Ouertani *et al*., 2008). The success of organizations often depends on their ability to establish and utilize assets efficiently and effectively throughout these stages. Concurrently, organizations must identify the need, and make decisions, regarding the needs of new assets, their development, operation, maintenance, replacement and retirement. These require integrating EAM activities with a range of supporting activities such as procurement, engineering, development, safety, finance and accounting. In essence, assets need to be managed as part of the broader socio-technical system of the organization. This leads to the concept of asset life cycle optimization or life cycle management which is the underpinning focus of EAM. From this perspective, EAM can be treated as a relatively new discipline area.

Systems engineering principles implies that the EAM system must normally have a strong influence over the acquisition phase of any asset given that usually this provides the greatest opportunity to control the life cycle cost and life cycle performance or system effectiveness of assets(Arnold and Lawson 2004; ISO/IEC 15288 2008; Blanchard 2009). The challenge in managing the entire asset life effectively lies in integrating the fragmented activities through the various stages (Charles and Alan 2005; Luan et al. 2007). This leads to integrating the need identification, alternative analysis and project selection to the business management focus.

It is assumed that the EAM system that plans and controls asset-related activities, involves EAM activities typically distributed among most of the organization's departments and at the different organizational levels (El-Akruti *2012*). It is suspected that conformance to the enterprise competitive strategy can be achieved by an integrated decision making process that includes EAM activities. Such integration involves the alignment of all decisions taken by individual departments and at the various management levels. But the relationship between the organizational competitive strategy and strategies related to the conduct of particular activities is more complex than the simple top-down hierarchical approach. For example in studying the manufacturing strategy Kiridena (2009) concluded that this relationship is far more complex than could be described by simple hierarchical links associated with the organizational structure. Such a relationship was either defined as an integration between activities and their alignment with competitive and corporate strategies (Russel and Taylor 2006), or as information flows that extend between activities (Slack et al. 2006).

The requirement for interdisciplinary activity creates complexity raising integration challenges through the life cycle stages, between activities and along hierarchical levels within the organizational structure. For example, this is highlighted in the link between EAM and the organizational strategy making (El-Akruti 2012). An important activity following from the need for integration within an EAM system is the need to build interfaces between disparate organizational asset-related activities, along and between organizational hierarchical levels and through numerous life cycle stages. This type of multi-dimensional integration can only be maintained with management activities. The effort required, the types of activities, and the benefits gained from such activities are part of the organization management system. It is suggested that organizations have difficulty in devising these management activities and justifying the application of resources to them. Through the establishment of a framework for EAM the nature of the required activities, mechanisms and relationships can be identified.

1.2 Applicable Tools for Engineering Asset Management

The available tools that have been considered for EAM systems are generally not comprehensive. Their contribution has mostly focused on specific life stages or processes and has not considered a holistic approach that includes the interfaces between stages or processes. Charles and Alan (2005) indicated that most efforts have been directed to the primary drivers of the utilization phase. As cited in many publications, industry has primarily focused on maintenance management tools, e.g. TPM, RCM and BCM (Campbell 1995; Hoskins et al. 1997; Kelly et al. 1997; Amadi-Echendu 2004). A major disadvantage of applying these tools in isolation is that they address only a limited set of technical life cycle activities (Barringer 1997; Waeyenbergh and Pintelon 2002). The design stage is more relevant to the need identification, alternative and selection decisions. Potential benefits are consequently lost due to short-term focus on cost during the acquisition. Decisions related to asset selection, development and deployment are often not taken based on proper synthesis, analysis and evaluation process.

An available model to consider for the asset acquisition phase is the system life cycle model (Blanchard 2009) which emphasises the value of coordinating between the acquirer and supplier organization. The concept of terotechnology cited in (Bamber, Sharp et al. 2004) is similar to system engineering approach. These approaches tend to present a set of activities following the sequence of the life cycle stages and concentrating usually on one asset.

Other frameworks concentrate on the maintenance activity and its relationships to the life cycle processes (Geraerds 1992; Dwight 1999). The (Australian Asset Management Council 2007) present a 'technology model'.

It is suggested that these frameworks do not adequately represent the collaborative asset decisions that involve strategic and technical organizational asset-related activities. 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 as established previously. These decisions highlight the need for a holistic approach to EAM.

Organizations have also utilized some standards and guides. The Institute of Asset Management has produced some guidelines: (PAS 55-1&2 2008). Dependability standards including ISO/IEC 15288 (2008) are relevant to some aspects of EAM. In addition, new EAM-related standards are emerging (Kennedy 2010). Although the ISO/IEC 15288 (2008) standard and PAS 55 guidelines are relevant, they do not reasonably explain the task of linking EAM to the competitive strategy development activity of the organization. As a limitation such standards do not detail activities, methods or procedures required to meet the requirements and outcomes of a strategy. Nor do they detail documentation in terms of format, explicit content and performance measurement. They do not give directions on how to select or modify the processes in order to tailor them to the need. They do not adequately instruct the process of linking the organizational strategy to the organizational activities. The PAS 55-2 (2008) guideline indicates the link between EAM system elements and the organizational strategy without identifying how such a link is maintained. According to the typical elements of the EAM system in this guideline, the element that connects the EAM system to the organizational strategy is the EAM policy. However, this EAM policy is several 'shall' statements that do not show the EAM system's role in influencing the strategy. It states that "the EAM policy shall be derived and be consistent with the organization's strategic plan" but it does not show the activities to be taken or the control required to maintain the relationship with the organizational strategy. ISO/IEC 15288: (2008) claims to provide for the assessment and improvement of the life cycle processes. As a unique collection of system life cycle processes based on system principles and concepts, that standard provides processes for both technical and non-technical systems (Arnold and Lawson 2004). In this mode there appears to be an assumption of a static external and internal environment, however; the reality is that environments are dynamic.

Following a set policy or general static processes may not be consistent with the specific needs of the organization. There is a need to establish a conceptual framework that indicates the essential activities, relationships and mechanisms for the EAM cycle to be formulated and acted on. This approach stems from a view that the enterprise is a system; changes to that system require consideration of their effects on the system as a whole. This leads to the need of coordination to support the overall organization objective. Achieving such objective requires synergy between the management activities within the various activities of the organization system (Geraerds 1992).

The framework developed by El-Akruti and Dwight (2013) is proposed to be used as a tool to investigate the status of EAM in organizations. As a tool, it provides a methodological approach that involves reviewing and synthesising the EAM systems in particular; examining the complex relationships between the elements of an asset management system to determine whether a specific asset management system, as hypothesized by this framework, exists within a selected organization. The proposed tool ensures a holistic approach to asset management in the sense that it views the asset management system as an integral part of the broader organizational system and explores the required asset management activities, relationships and mechanisms for achieving organizational success.

2 A TOOL TO DETERMINE ENGINEERING ASSET MANAGEMENT SYSTEM STATUS

2.1 The Adopted Framework

Utilising the idea and format of the Porter's vale chain (1985), a typical representation of the main asset-related activities in an organization have been established (El-Akruti and Dwight 2013). El-Akruti and Dwight (2013) have further used the idea and developed an EAM framework as shown in Figure 1. This EAM system framework shows relationships between the asset life cycle activities and the supporting activities and incorporates coordination activities to control and maintain relationships between asset-related activities.

The EAM activities may be classified relatively to organizational hierarchical management levels. Organizational management levels can be defined according to the planning horizon as strategic, aggregate or operational (Anthony, *et al*., 1989; Anthony and Govindarajan, 1995). They proposed that in an organization, management control is facilitated by planning and control activities that can be considered to take place at these three levels: strategy formulation activities, management aggregate control activities and task control activities.

These categories of activities are consistent with the concept of EAM as presented by PAS 55-1&2 (2008) with the 'typical priorities and concerns': management of asset portfolio, management of asset systems and management of asset life cycle. (Kostic, 2003) indicates that EAM activities are considered to be envisaged under three categories. In support of this view, Sinha, *et al*. (2007), state that the enterprise EAM system forms integrated activities in management processes in a utility business.

The Asset Management Council (2007) in Australia derived an EAM model based on Plan-Do-Check-Act process (Tague, 1995; Gupta, 2006; Moen and Norman, 2011) and the control management cycle for continuous improvement (ISO 9001, 2008; Anderson, 2011).

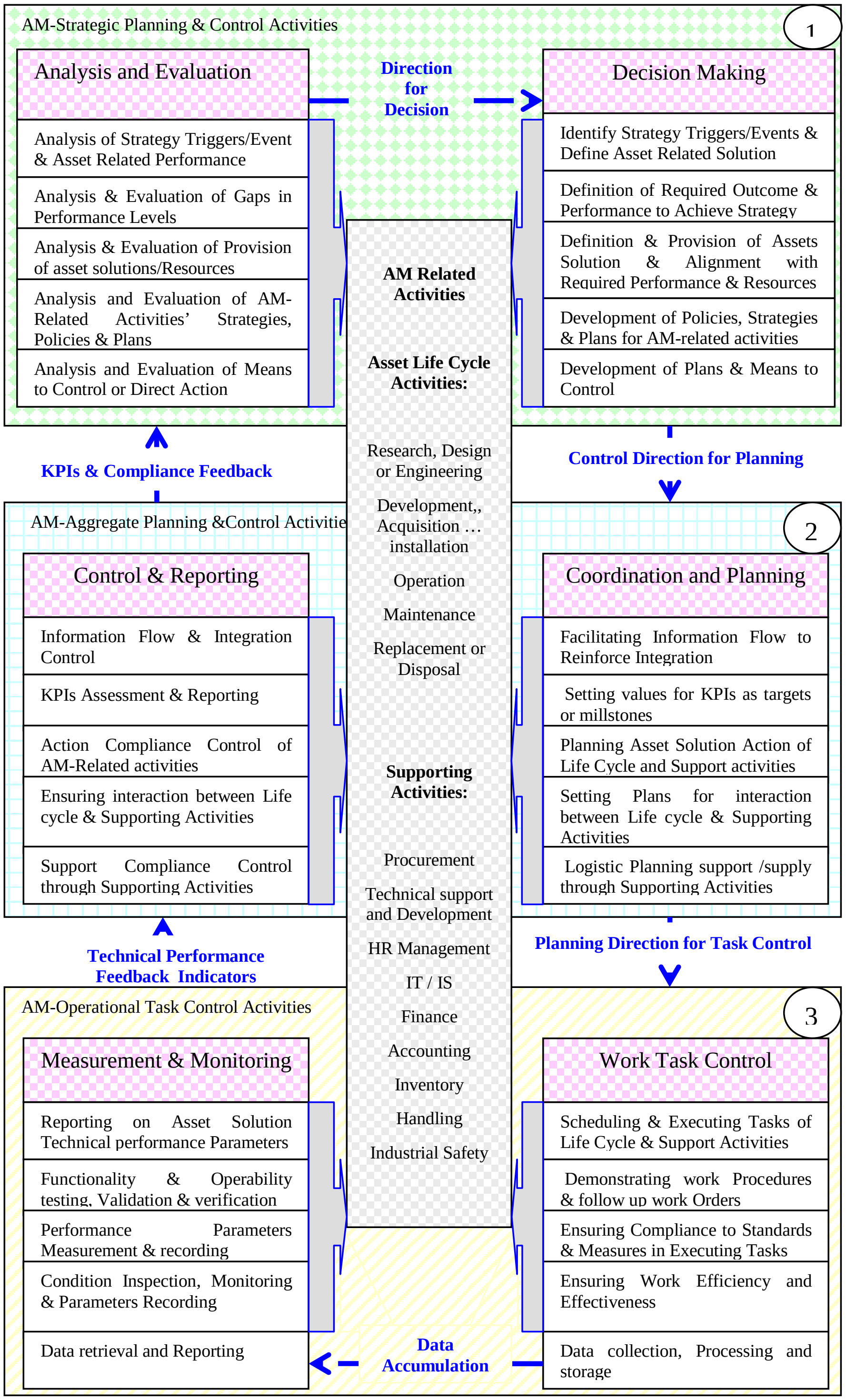

Figure 1: Framework of EAM System (El-Akruti & Dwight 2013).

The framework in Figure 1 has been derived based on the nature of the asset-related activities. The idea of the EAM control cycle is similar in these models. This framework sets out the organizational levels, activities, relationships and mechanisms of the EAM system. It implies that the management of the asset-related activities is maintained by a control process constituted by a cycle of these activities of the EAM system through the management levels. Each asset-related activity will have an iterative planning and control process acting on it. Through these activities at the three levels and with feed-forward & feedback mechanisms, the framework proposes that EAM plays a role in strategy development and implementation.

This notion of having an EAM system as a collaborative control system that exists over the organizational levels leads to an integration within the enterprise system. El-Akruti (2012, pp. 72, Figure 3.8) developed an EAM system functional model, which offers this perspective in terms of relationships between asset-related activities, control activities and the boundary between the system and its external environment. This system functional model is developed based on the widely used production model e.g. as given by Hunger (1995). However, this developed functional model includes categories of life cycle activities and supporting activities as found in the value chain framework, and the life cycle framework presented by Blanchard (2009).

2.2 The Proposed Retroductive Approach and methodological procedure

EAM is primarily concerned with the long term (longitudinal) effects of actions on the organization. In designing an approach to examine this perspective, there exists a variety of challenges, due to temporal barriers and inter-dependence between activities. As such, an appropriate procedure, should consider the influence of many contextual factors such as operating environment, market characteristics, location and local legislative requirements.

It is argued in this paper that a retroductive approach to examine a sequence of actions/events on a particular asset over a long term period can explore the complex nature of EAM and build theory that reflect what might constitute the best form of the EAM system.

The approach adopted is based on the retroductive logic and the ideas of the contextualist methodology in case study (El-Akruti and Dwight 2010). It uses a retroductive approach to explore the complicated processes in the organization (El-Akruti and Dwight 2010).The focus is on setting an appropriate procedure to establish correct operational measures of the concept being investigated, and identify relationships. In this respect and from a research viewpoint, Kiridena and Fitzgerald (2006) has argued that being as specific as warranted by the context in which the case study is carried out is an effective way to articulate the connection between the phenomena to be investigated and the findings.

The retroductive approach proposed in this paper is based on a combination of the hypothesized model and the incorporated sequence of events that may be reflected by this model supported by historical and longitudinal data to establish the causal relationships between these events. The multiple events for the purposes of EAM may follow a sequence of events: i.e. the progression from an event such as strategy change to an asset solution and eventual asset performance. The study of each event such as a strategy change and the resulting set or sequence of asset solutions constitutes one embedded case investigation. Each event or action can be analysed to determine the effects on the change in the organization's outcomes or contribution. The retroductive and contextualist approaches use the same ontological approach: a model or framework for data collection, sorting and analysis. However, they differ in their epistemological approaches in the sense that the contextualist approach seeks a descriptive account of the phenomena studied over time while the retroductive approach determines whether the underlying structure and mechanism proposed by the hypothesized model explains the phenomena El-Akruti and Dwight (2010). EAM can vastly benefit from the complementary strengths of these two approaches.

2.3 Tailoring the Retroductive Approach to EAM System Status Investigation

The approach uses the hypothesized system functional model as shown in Figure 2. In this approach, series of events are defined by identifying strategy events to which the asset-related solutions respond El-Akruti *et al.* (2013). Each EAM-related solution has to be defined and must be examined according to the sequence of the phenomena represented by elements 1-to-4 in Figure 2. This involves identifying the strategy event, defining the asset solution and its provision, determining the asset performance and outcomes related to the strategy.

As shown in Figure 2, Element 5 presents the control over the process of events. In this process, the required asset solution or solutions is established for any triggered strategy related event or change. The management behaviour related to the asset-related activities and the resulting asset performance can be assessed. This involves mapping the elements of the EAM framework against the actions undertaken in actual practice and linking the adopted EAM actions to existence or adequacy and/or absence or inadequacy of activities and relationship as proposed by the framework.

The ideas of the retroductive approach can be best illustrated considering a representation of an organization and the interfaces with EAM system elements as illustrated in Figure 2. As such, the existence (adequacy) or absence (inadequacy) of the underlying structure and mechanism of the hypothesized model can be verified by a two stages process. Stage 1 involves establishing the sequence of an observed phenomenon: the event; the asset solution choice; asset provision; and resulting asset performance – these elements are represented within the hypothesised model. Stage 2 involves drawing implications for the nature of the asset management system from the phenomenon defined in Stage 1. This stage involves analysis of the elements of the asset management system functional model. These elements (listed below) are presented as specific parts of the hypothesized model, as shown in Figure 3.

1. ***The event***: this may include events triggered by certain factors in the external or internal environment
2. ***The asset solution***: this involves the action in response to the event(s) in Element 1 which may include the change in assets or asset-related activities – 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 EAM system***: this constitutes management activities, mechanisms and relationships to plan and control actions for the provision of the solution and achievement of the desired level(s) of asset performance and business outcomes. This may include planning, decision making, feedback control and managing technical tasks.

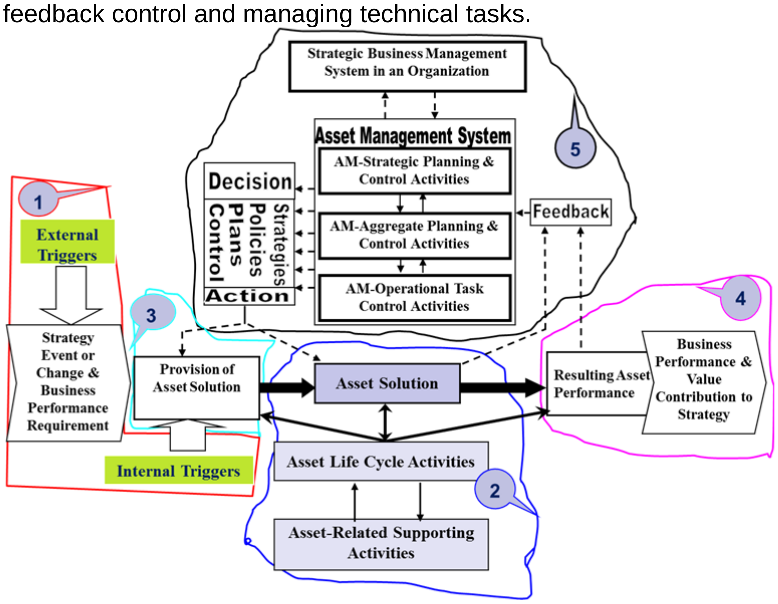

Figure 2: Elements of the 'Hypothesised System Functional Model'

Elements 1 to 4 belong to Stage 1 and follow the contextualist approach, and require a narrative descriptive account to convey the sequences of occurrence of phenomena. Element 5 belongs to Stage 2 and follows the retroductive design which focuses on the existence of these underlying activities, mechanisms and relationships of the EAM system to explain the context for specific action to take place in certain ways.

2.4 Structuring the Procedure for the Retroductive Approach

As shown in Figure 2, the procedure pertaining to conducting the retroductive case investigation is based on five structural elements that undergo a two-stage process. This two-stage process may be used to investigate a phenomenon by several cases embedded with one unit of analysis such as an organization. For example, El-Akruti *et al.* (2013) reported the use of such an approach to study the strategic role of EAM in an organization by investigating the control of the EAM system activities, relationships and mechanisms through three cases where each case involved a sequence of a strategic event, asset solution, asset performance and final outcome. Elements 1-to-4 in Figure 2 reflect the sequence of the case phenomenon studied and element 5 reflects the role of the EAM system.

The two-stage process involves ‘data collection, sorting, analysis and interpretation’ and can be structured to match with the five elements of the hypothesized model. Stage 1 involves data collection and sorting in relation to identification of the event, definition of the asset solution, provision of asset solution and establishing the outcomes. Stage 2 involves analysis and interpretation in relation to establishing and interpreting the EAM control action. These steps within the two stages comprise a case, and multiple cases are preferred for each unit of analysis for better validation. These aspects are briefly outlined below.

Stage 1: Establishing the phenomenon

This includes the first 4 steps referred to in the asset management system functional model and provides the data required in step 5 to evaluate the asset management system in place.

1. Identification of an event or change: This involves identifying an event that took place as a consequence of some external or internal triggers.

2. Definition of the asset solution: This involves identifying the particular asset solution(s) adopted in response to the event or change. Definition involves determining if the response was an asset solution and what resulted from that response. This occurrence of an asset solution in response to a triggered event or change defines the sub-case to study as proposed by the model.

3. Provision of the asset solution: This requires recording of how the asset solution was provided, and includes, for example, the details of designs, plans, testing, resources used, budgets and procedures relating to the implementation of the solution.
4. Establishing the outcomes – the resulting performance and value contribution identified in two steps, as follows:
    a. Establishing the resulting asset performance associated with the selected asset solution. This involves defining whether this resulted asset performance indicators are in compliance with the designed or targeted performance. The resulting performance is one indication of the outcome of the EAM system.

    b. Establishing whether the resulting asset performance has resulted in positive or negative value contribution. This involves indications of the value contribution or destruction as delivered by the EAM system. Positive contribution is an indication of the existence and adequacy of the EAM system and negative contribution is an indication of absence or inadequacy of the EAM system.

Stage 2: Drawing Implications from the Phenomena

This involves establishing and interpreting the EAM control action relative to a hypothesized framework utilising the data resulting from procedure followed in Stage 1.

Establishing and interpreting the EAM system in place involves verifying the existence or absence of the activities, relationships and mechanisms of the EAM system as postulated by the framework. Establishing the existence (adequacy) or absence (inadequacy) of these involves the following four steps:

a. Establishing how the organization decided that a certain event or change required an asset solution. This will provide some indication as to the existence or absence of the relationship between EAM and the organizational development process or strategy. This will indicate how the EAM system activities handle the relationship with other management systems and the interface-relationships with external environment such as supplier, contractors, outsourcers, manufacturers, regulators or environmentalists.
b. Establishing how the EAM system selected/established the possible solutions and how the particular solution adopted was selected, over other solution options, as the most suitable to achieve the objectives. This will provide a view on the status of the existence or absence of the EAM system activities, their interrelationships and control cycle and mechanism as proposed by the hypothesised model. These include analysis and evaluation of the gaps in the resulting asset performance to achieve the desired business performance under specific strategic objectives. These also include the decision activities based on the feed-forward flow from the business management and the feedback from the other lower levels of EAM system activities in the hypothesised model.

c. Establishing how the EAM system dealt with the provision of the asset solution to achieve the resulting asset performance. This will indicate the existence or absence of the EAM system activities their interrelationships and mechanisms as proposed by the hypothesised model. This includes analysis and evaluation of requirements of the asset-related activities to cope with the resulting asset performance. It also includes the strategic decision activities based on the feedback from the other lower level activities: aggregate and operational.
d. Establishing how the EAM system dealt with the implementation of the asset solution. This will give an indication to the existence or absence of the EAM system aggregate and operational activities. It also indicates the interrelationships existing between these two lower levels of EAM system activities with the EAM system strategic activities. On the one hand, these interrelationships include a feed-forward flow in a top-down direction for the solution implementation strategies of asset-related activities and their policies, plans and task control. On the other hand, they include a feedback in a bottom-up direction as basis for carrying analysis, evaluation and decision making support for selection and formulation of the asset solution for intended outcomes.

As a result of analysing a specific asset solution and a conclusion on the value contribution resulting from the asset performance can be established relative to the existence or absence of the EAM system as proposed by the model adopted. This resulting value contribution provided by the EAM system can be reflected on the customer value, as well as contribution to achieving organizational goals. Therefore, for any case of a series of events, explanation of how the structure and mechanism of the EAM system plays a role in the organizational success can be established.

Only those EAM solutions or actions that are determined as the main response to the particular event should be considered in such investigation to avoid any other influence on the resulting performance. There also may still be other reasons for the outcomes. However in this type of investigation, the EAM-related solutions or actions are examined to determine how they caused performance outcomes and indicate if other causes may have been involved.

Interpretation requires a detailed search for causes and resulting effects. For each case, the particular event or change is investigated to understand how certain triggered events were responded to by the development and implementation of an asset solution(s). The management behaviour of the asset-related-organizational activities and the resulting asset performance can be assessed. The search is for both negative and positive results while referencing the cause to absence/inadequacy or existence/adequacy of EAM system activities, relationships and mechanisms. Such existence/adequacy or absence/inadequacy may be associated with duties and responsibilities related to the asset-related activities. Negative results may be associated with missing or poorly executed EAM system activities. Positive results may be associated with appropriate EAM system activities. EAM system activities may not exist at all or may not exist to the extent that they meaningfully serve organizational objectives, or may exist in a conflicting manner resulting in an intermediate negative impact. The ultimate conclusion is to demonstrate that the achievement of outcomes is due to having an adequate EAM system in place or its poor achievement is due to an inadequate EAM system in place. However, results may also be influenced by non-EAM factors such as a particular individual's approach taken in responding to various factors within the organizational environment. In such cases these factors should be identified and their associated impact illustrated.

3 APPLICATION OF THE TOOL TO DETERMINING THE STATUS OF ENGINEERING ASSET MANAGEMENT SYSTEM

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. The following status investigation 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 reviewing the organizational structure in charge of organizational asset management. When mapping the organizational structure of the pipeline companies surveyed to the framework proposed 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 elements described in Fig. 2. In order to determine the status of the current activities, those activities evidenced by documents and explained by representatives have been mapped against the cycle of activities depicted in Fig. 1 and tabulated. For the purpose of this paper the main activities are mapped as:

1) Asset development plans and procedure;
2) Implementation plans and supervised execution process;
3) Test, measurement and record;
4) Data collection, processing, storage and reporting;
5) Assessment and control of the asset performance to comply with the standards such 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 activities in the asset management cycle were found to be allocated to specific parts of an organization.

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

1) Asset management is generally in place in industry.
2) The main concern of asset management in industries such as the energy pipeline industry is asset integrity.
3) Sophisticated inspection systems are in use and data used to determine risk level and need for further action (inspection or repair).
4) Inspection intervals are set qualitatively and are affected by practicalities – accessibility.
5) 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.
6) 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.
7) Decisions to conduct more detailed inspections are being made using various qualitative decision making processes. The quantitative decision-making techniques need to be developed.
8) Data currently available may be analyzed to improve the understanding of remaining life and/or the time needed for major repair work.
9) There is cost assessment of activities but a structured life cycle costing is not generally being used to help make long planning decisions.
10) 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.

This leads to highlighting the particular challenges or requirements for better performance:

- Establishing an integrated EAM information system for better data utilization.
- Establishing quantitative life prediction models 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.

4 Conclusions

Comprehensive tools to investigate EAM system status are lacked in the dual aspects of theoretical credibility and practical validation. Tools that provide holistic approaches need to be introduced to address these limitations. An EAM framework is proposed in this paper as a tool to investigate the status of EAM system. This framework is a reflection of the EAM system elements required to have proper actions in place for organisation’s success. It provides a more EAM-oriented, systematic and holistic approach to analyse activities, relationships and mechanisms that constitute the linkages between EAM and other organisation's functions.

In this paper, the approach and methodological procedure to utilizing this framework as a tool has been comprehensively illustrated and evidenced as applied in several organizations to investigating the status of the EAM system. The retroductive approach to case investigation of a chain of events: triggering event, asset solution and performance outcomes has been identified as suitable to determine if the EAM system activities arte adequately in place. It results in a credible approach that is considered to be capable of highlighting inadequate or missing EAM elements that can result in negative impacts on cost, integrity and safety and ultimately business outcomes.

In applying the tool in several companies in the energy pipeline industry, several inadequacies and opportunities for improvement were found and relevant solutions were suggested.

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