1-1-2016

Exploring structure and role of engineering asset management system in production organizations

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

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

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

Exploring structure and role of engineering asset management system in production organizations

Abstract

Little has been done in literature on the structure of Engineering Asset Management System (EAMS) and its relationship to production and organizational strategy. In this paper, the position of an EAMS within an organizational structure and its strategic role within a production organizations strategy has been explored. It is argued that the structure and mechanism of EAMS play a key role in directing the production process and linking to the organizational strategy: the absence or inadequacies of asset-related activities cause insufficient production performance that negatively impacts the strategic achievement. Production Actions are mapped with reference to the activities of the hypothesized framework to stipulate the structure and role of engineering asset management system in a production organization. Production organizations can use the developed framework to check the required adequacy of their activities of the EAMS for success.

Keywords

exploring, system, management, asset, engineering, organizations, role, production, structure

Disciplines

Engineering | Science and Technology Studies

Publication Details

El-Akruti, K., Dwight, R. & Zhang, T. (2016). Exploring structure and role of engineering asset management system in production organizations. International Journal of Strategic Engineering Asset Management, 3 (1), 1-22.

Exploring structure and role of engineering asset management system in production organisations

Khaled El-Akruti*, Richard Dwight and Tieling Zhang

School of Mechanical, Materials and Mechatronic Engineering,
Faculty of Engineering and Information Sciences,
University of Wollongong,
Wollongong, NSW 2522, Australia
Email: khaled@uow.edu.au
Email: radwight@uow.edu.au
Email: tieling@uow.edu.au
*Corresponding author

Abstract: Little has been done in literature on the structure of engineering asset management system (EAMS) and its relationship to production and organisational strategy. In this paper, the position of an EAMS within an organisational structure and its strategic role within a production organisation's strategy has been explored. It is argued that the structure and mechanism of EAMS play a key role in directing the production process and linking to the organisational strategy: the absence or inadequacies of asset-related activities cause insufficient production performance that negatively impacts on the strategic achievement. Production actions are mapped with reference to the activities of the hypothesised framework to stipulate the structure and role of engineering asset management system in a production organisation. Production organisations can use the developed framework to check the required adequacy of their activities of the EAMS for success.

Keywords: engineering asset management; EAM; production assets; asset life cycle; system activity; organisation performance.

Reference to this paper should be made as follows: El-Akruti, K., Dwight, R. and Zhang, T. (xxxx) 'Exploring structure and role of engineering asset management system in production organisations', *Int. J. Strategic Engineering Asset Management*, Vol. X, No. Y, pp.xxx–xxx.

Biographical notes: Khaled El-Akruti received his PhD from University of Wollongong in 2012. He is currently working on two funded energy pipeline projects with EPCRC, teaching several subjects in the engineering asset management master program and involved in supervision of MSc and PhD students. He has published about 20 articles, numerous research reports for production industry and over 12 years experience in teaching in international universities. He has over 13 years of experience in steel industry and has worked on a number of industrial and infrastructure projects. His research interests include engineering asset management, maintenance management, systems engineering, life cycle cost analysis, performance measurement, and production and quality systems.

Richard Dwight directs the engineering asset management and rolling stock engineering programmes at the University of Wollongong, Australia. He leads major Australian federal government funded research programmes on asset management on behalf of energy pipeline CRC, and similar projects for the CRC for rail innovation. He has published over 40 papers related to asset management and rail research in addition to his work in other areas and produced numerous reports for industry. He is a research team leader in asset management and Education Manager for the EPCRC programmes at the University of Wollongong. His research interests include reliability and maintenance engineering, engineering asset management, and noise and vibration control for railway.

Tieling Zhang received his PhD from Tokyo University of Mercantile Marine, Japan, in 2001. He has extensive industrial and academic experience in reliability and maintenance engineering, health prognostics, and system optimisation. He has completed many research projects and published around 70 research articles in peer-reviewed journals and international conference proceedings. He holds five patents and several others pending for grant. He serves as an invited referee for over 20 international journals. His research interests include data processing and modelling, fault diagnostics and prognostics, system reliability and maintainability, energy storage system and smart grid management.

1 Introduction

The Asset Management Council (2009) defines engineering asset management (EAM) as: "The life cycle management of physical assets to achieve the stated outputs of the enterprise". This EAM definition, addresses the management of life cycle activities relative to an organisation's success. Asset management plays potentially a significant role in production industry by controlling the asset life cycle from concept to disposal. EAM itself embodies technical and business activities; for example, Tam and Price (2008) address the relationship between these business decision dimensions within a generic asset management framework. The nature of engineering asset management system (EAMS) activities requires interdisciplinary or collaborative involvement within an organisation. From this perspective, the EAMS has been defined as: a management system that plans and controls asset-related activities and their relationships directed at ensuring the achievement of the asset performance that meets the requirement of the intended competitive strategy of the organisation (El-Akruti, 2012).

Charles and Alan (2005) explain that the EAMS has not been considered with the involvement of all relevant activities such as production and business activities. Most reported research on EAM focuses on discrete life cycle activities: e.g., Pinjala et al. (2006) investigated the relationship between business and maintenance strategy. Generally, the relation between EAM and business activities is rarely enclosed. Frolov et al. (2009) indicate that EAM has been historically considered as a technical activity e.g. reliability and maintainability of assets. Ouertani et al. (2008) suggest the importance of considering all life cycle activities and their relations to business activities in an EAMS.

There has emerged a shift in EAM toward a business related engineering discipline which has been reported in literature (e.g., Dornan, 2002; Lo Porto and Udo, 2003; Mohseni, 2003; Amadi-Echendu, 2004; Charles and Alan, 2005; Narman et al., 2006; Stapelberg, 2006; Haffejee and Brent, 2008; Asset Management Council, 2009).

Recently, asset management has become the focus of industry groups, professional societies and research organisations (e.g., IPWEA, 2011; Asset Management Council, 2009). In general, the role of EAMS in production organisations have not been analysed and investigated to determine its usefulness for success. It is observed that collaboration between organisations and academic researchers to extend the body of knowledge in this area is under way (Frolov et al., 2009).

The asset-related activities and relationships between activities for success in production organisations are usually unrevealed. Despite their impact, literature indicates a lack of studies on the role of the EAMS in the success of production process (Alsyouf, 2006; Bamber et al., 2004). It has long been recognised that organisations experience significant shortfalls in their asset performance. Miles and Snow (1978) have shown that failure is a result of inadequacy in the activities required to manage the new assets, systems or technology. Project management is an asset-related activity as some studies have shown (Morris, 2004; Srivannaboon and Milosevic, 2005). Some studies showed inconsistency between the intended and the delivered system, as a result of inadequate feasibility studies and other system engineering activities (Donovan, 2002). It has been observed in production industry that life cycle cost analysis is required to achieve the optimal replacement intervals (Mathew and Kennedy, 2003; El-Akruti, 1999).

It is contended that the nature of the EAMS activities and relationships in the production industry have not been adequately defined in literature. The proposition is that production organisations are not sufficiently in control of the required EAMS activities and relationships between activities to properly prioritise their establishment and appropriate resourcing. It is suspected that the EAMS activities are inseparable parts of the various activities and relationships within the organisation system as a whole.

It is hypothesised that certain EAMS activities and relationships need to exist within a production organisation for success.

2 Asset management system framework

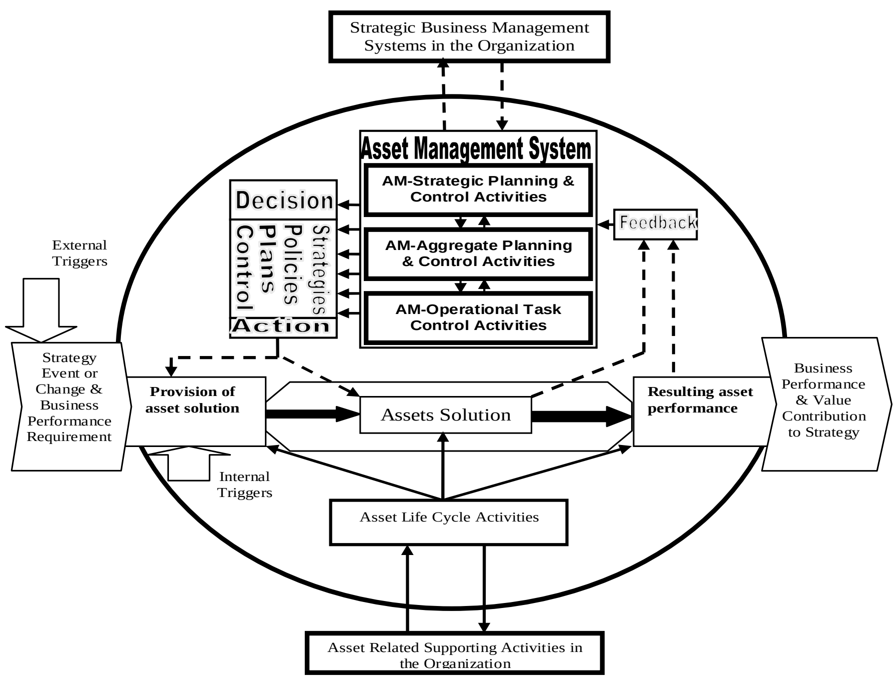
The main asset-related activities as El-Akruti (2012) has defined in an organisation are related to the idea and format of the Porter's (1985) value chain. The EAMS incorporates coordination activities to control and maintain relationships between asset-related activities. These EAMS activities may be classified relative to organisational hierarchical management levels. Organisational management levels can be defined according to the planning horizon as being strategic, aggregate or operational (Anthony et al., 1989; Anthony and Govindarajan, 1995).

This notion of having an EAMS as a collaborative control system existing over the organisational levels leads to synthesising its integration within the enterprise system. Figure 1 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 building on the widely used production model (Hunger, 1995; Al Marsomi, 1997). However, this model developed in Figure 2 includes categories of life cycle activities and supporting activities as found in Porter's (1985) value chain, and the life cycle framework presented by Blanchard (2009). This model proposes that in an organisation, management control is facilitated by planning and control activities that can be considered to take place at three levels as shown in Figure 1. Al Marsomi (1997) similarly suggested three control levels. In PAS 55-1&2 (2008), the existing categories of activities are consistent with this concept of EAMS activities. Kostic (2003) indicated that EAMS activities are considered to be envisaged under three categories. In support of this view, Sinha et al. (2007), stated that the enterprise EAMS forms integrated activities in management processes in a utility business.

Based on this nature of the asset-related activities, a framework in Figure 2 has been derived by El-Akruti (2012). The Asset Management Council 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).

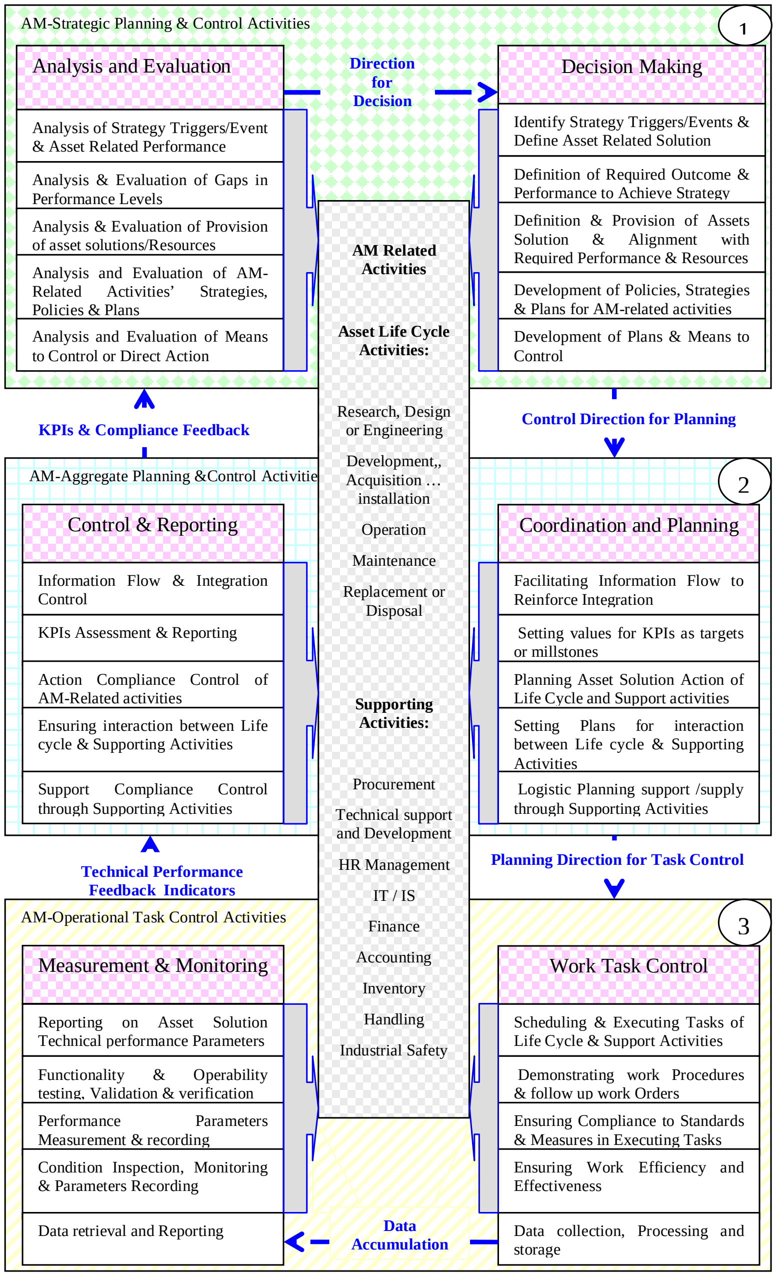
The idea of the EAMS control cycle in Figure 2 is similar and proposed to be applied in this field. This framework implies that the management of the asset-related activities is maintained by a control process constituted by a cycle of these activities of the EAMS through the management levels. Each asset-related activity will have an iterative planning and control process acting on it.

Figure 1 EAMS functional model: integration of EAMS in the enterprise



Source: El-Akruti (2012)

Figure 2 Framework of EAMS activities, relationships and mechanism (see online version for colours)



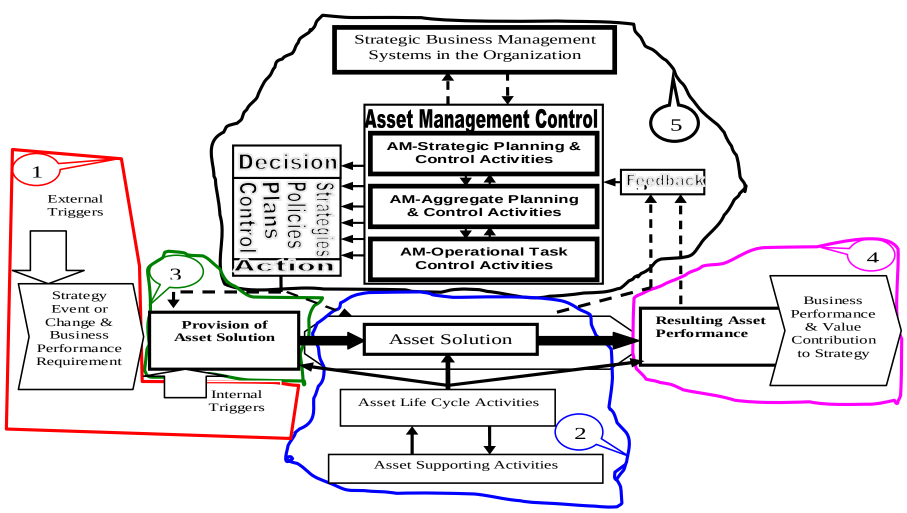
Source: El-Akruti (2012)

3 Research methodology and approach

The requirement to study the integration of activities within a holistic EAMS is argued to be a central issue. Case studies are argued to provide a suitable approach to EAM research (El-Akruti and Dwight, 2010). Case studies can allow exploring interdisciplinary relationships in EAM. In this perspective, Iravani and Duenyas (2002) argued that the common practice of making maintenance and production decisions separately can be costly and that there are significant benefits in making these decisions in an integrated manner. In this respect, the performance is related to the overall effectiveness of equipment (Muchiri and Pintelon, 2008). Muchiri and Pintelon (2010) analysed the influence of the manufacturing environment and maintenance objectives on key performance indicator choice and their role in decision support and improvement. Garg and Deshmukh (2006) argued that integration of activities such as maintenance, operation and procurement by information systems can be a major factor for improvement. Jonsson (1999) stated that the integration of the maintenance activity with others produces better results relative to quality improvement and manufacturing capabilities.

The research design and procedure is set out by El-Akruti (2012). He uses a hypothesised system functional model comprising five distinct elements as depicted in Figure 3. El-Akruti and Dwight (2010) argue that the retroductive research logic in utilising case studies method is an effective approach for EAM research. This approach is based on using models in order to explore complex processes, facilitating theory building (Ragin and Becker, 1992; El-Akruti and Dwight, 2010). This model allows for establishing the phenomenon represented by elements 1 to 4 and element 5 presenting the implications for the EAMS activities. These EAMS activities and mechanism are elaborated as depicted by the framework in Figure 3.

Figure 3 Five elements of hypothesised system functional model (see online version for colours)



Source: El-Akruti (2012)

This methodology involves identifying the event that triggers the change, defining the asset solution, its provision and determining the asset performance and outcomes. For any case, the particular event or change can be investigated to understand how certain triggers required asset solutions. Through this methodology, the management behaviour related to particular asset-related activities and the resulting asset performance can be assessed. The search is for both negative and positive results while referencing the cause to the absence or existence of EAMS activities, relationships and control mechanisms and to the adequacy with which these are performed. The ultimate objective is to determine the extent to which the organisation's performance is dependent on having an adequate EAMS in place.

4 Case studies analysis and interpretation stage 1 – establishing the phenomenon

4.1 Case studies identification

A review of records of two case studies of an un-named production company was done. The production company comprises a large number of manufacturing plants and a large working capital. Over the preceding years, the company instigated improvements in quality management. Events or changes that reflect overcoming process deficiencies are studied as cases in this production company. In the studying cases, the phenomenon associated with each particular case is defined in terms of the first four elements of Figure 1: the event; the asset solution choice; the asset provision; and, the resulting asset performance. The event together with the asset solution choice defines each case.

In order to identify suitable cases, employees from the company were interviewed and various documents were reviewed. A member of the chief executive's committee stated that: "Our company lacked a formal procedure relative to asset related development projects". The company's quality manual was analysed and revealed that the aims of the company included improving quality, optimising cost and expanding product mix for entering international markets.

The engineering manager indicated that decisions depended on three major factors: product quality, product price or cost and customers or demand in the market. Many managers mentioned that the company had initiated many projects and actions in response to market events. These included modifying asset solutions for the production of new products allowing entry to international market. The phenomena selected for this study involve particular events and their EAM responses. The specific events are related to the demand increase in local market for certain products triggering responses in terms of two consecutive projects in the production facilities: resulting in two asset-related solutions that are considered as two case studies as defined in Table 1.

Table 1 Case studies

Cases	*Definition of case studies*
Case 1	The local demand increase for certain products triggering a modification of the production facility to slit-technology.
Case 2	The further increase in local demand for these products triggering a subsequent introduction of a new but similar facility three years later.

Although more cases are required for replication and drawing generalisation from them as presented in El-Akruti and Dwight (2010); this paper focuses on these two cases to explore the nature, structure and role of the EAMS.

4.2 Establishing the asset solution as a response to an event

Addressing these cases, the company's reaction to the increase in local demand took the form of two successive asset solutions implemented four years apart. The first asset solution is identified as a modification of 'slit-technology' and the second as an introduction of a 'new facility'. The objective of the company related to the first asset solution was to satisfy the local market without affecting existing export capacity. A dramatic increase in production rate was required in a very short time. A review of the annual production planning reports indicates that the production lines were operating at full capacity indicating a production capacity limitation. Production planning as presented in these reports was based on batch production to fulfil the requirement for each order. According to the marketing manager the situation was "whatever is produced can be sold". That the company documented quality manual aims at "achieving quality leadership in the region by emphasising customer satisfaction". Independent publications, sales records and interviews confirm that the company maintained good quality products and customers' relations.

All of the interviewees indicated that the company had to find a way to increase its production capacity to cope with the increase in demand while maintaining the same quality level and customers' relations. The company initially undertook an in-house slit-technology modification aimed at doubling production rate.

Meanwhile it was reported that the market demand continued to increase to levels beyond the capacity of the modified facility resulting in the subsequent asset solution of a new facility. In turn the capacity of the second solution was surpassed by market demand. This resulted in further plans for increased production capacity and interim measures to import the shortfall. The demand increase in the market is a great opportunity for the organisation but it failed to develop its assets to capture this opportunity by coping with the demand. The event and asset solutions can be summarised as shown in Table 2.

Table 2 Event and asset solutions

(1) Event	*(2) Asset solution selected*
Year 1: An asset solution was required to cope with the increase in the demand of the local market. The trigger of the event is identified as the new developments in the country.	In-house modification of the existing single production facility to slit-technology for doubling throughput
Year 4: An asset solution was required to cope with the increase in the demand of the local market. The trigger of the event is identified as the new developments in the country.	Introducing a new production facility to double the capacity

4.3 Establishment and interpretation of provision actions

In the process of investigating the asset solution provision, operating department managers stated that the in-house modification as an asset solution aimed at low acquisition cost and fast implementation: "… The project was based on low investment...

only minimum requirement of equipment to be changed were acquired for obtaining (slit-technology) modifications in a very short time...".

Figure 4 Performance indicators of original facility vs. modified facility trial operation (see online version for colours)

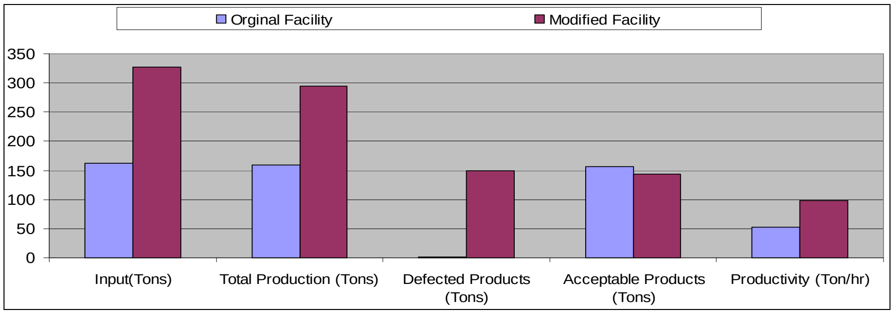


Figure 5 Loss indicators of original facility vs. modified facility operation trial (see online version for colours)

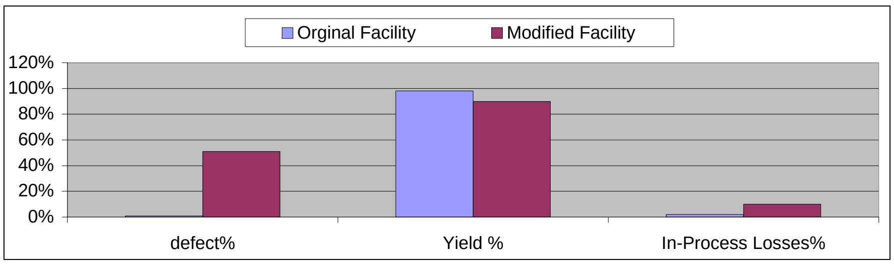


Table 3 Resulting asset solution provision indicators for the two cases

Asset solution	*Indications of provision actions and their results*
Modification to slit-technology	• Selection and provision involved determining the required capacity increase; selection and design of modification; determining requirements for equipment acquisition; installation, operation and maintenance. • Achieved through in-house modification, so low capital investment. • Expected doubling of capacity but also resulted in 10% process losses and more than 50% defect production
New production facility	• Selection and provision involved determining the required capacity increase; selection of supplier; establishing and managing the project. • Achieved through outsourced supply; delivering on time; successful commissioning. • Doubled capacity without significant process losses or defect production.

According to records, the performance during the operating trials indicated poor performance of the modified facility. Performance of the trial operation has been compared with the original facility in Figures 4 and 5. While productivity and production rate increased by 100%, defective product reached over 50% of the total production and yield also dropped. One of the managers involved in the provision of the asset solution in particular, recounted that: "Efforts in terms of further modification and control were applied to gradually lower the defects percentage". Comparison of the results achieved from the initial modification solution with the subsequent introduction of the new facility is presented in Table 3.

4.4 Establishing indicators of performance, outcome and contribution

Relevant performance indicators are demonstrated in Figures 4 and 5, by comparing the achievement and loss parameters after the adoption of the 1st-asset solution 'modification' to those before the adoption. Indications of performance are summarised in Table 4 and the indication of outcomes and value contribution are summarised in Table 5.

As indicated by most interviewed managers, despite all the efforts to improve performance, the targets were not fully achieved. The plant manager stated that: "...We were not able to really reduce irregularity defect rate to a very low level but the severity was controlled to a level ... [where] we were able to sell products ... after reducing their price". Performance indicators obtained from the production and quality control records are presented in Figures 4 and 5. It is observed that the increased annual production evidenced by Figure 6 is associated with a high percentage of rejects and a large part of it was downgraded as evident from Figure 7.

Figure 6 Performance achievement indicators for modified and original mill (see online version for colours)

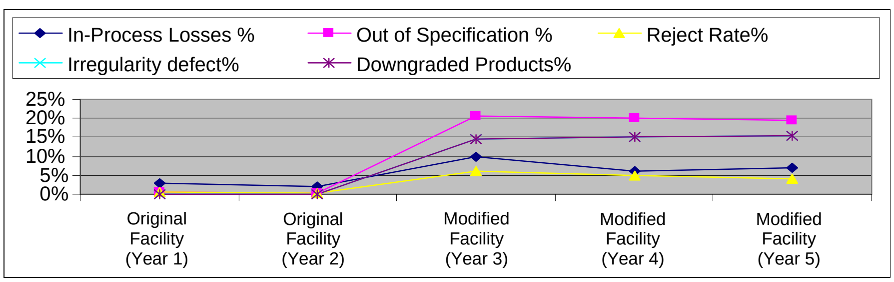
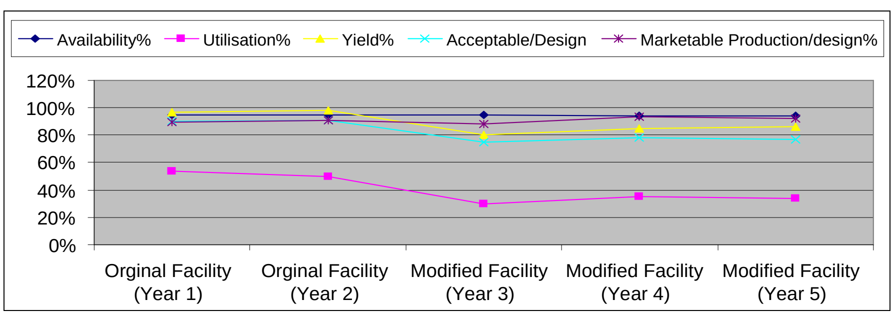


Figure 7 Performance losses indicators for modified and original mill (see online version for colours)



Figures 6 and 7 also show high losses and low utilisation of the modified facility. This reflects a lack of control over the process associated with the modified facility. The managers indicated the performance resulted from a lack of control of the modified facility which was addressed progressively: "Gradually the process was controlled to some extent but could not continue to handle the increasing demand". Many design enhancements were implemented and operation control actions were introduced to minimise the severity of the main defect. The utilisation of the modified facility had to be reduced and the achieved production rate fell short of what was expected. More control on the process was applied for better result but the percentage of defects and breakdown maintenance disturbed the operation and planning process. According to production and quality data, the annual production amount of quality products delivered was similar to the original facility. The increased product unit cost was indicated to have led to a decision to revert back to the original facility 'single rolling': the major problem was the irregularity defect.

Two years later, the 2nd asset solution was implemented 'a new production facility' and the company started operation with it. The asset performance for the two asset solutions is summarised in Table 4.

Table 4 Asset performance indications

Asset solution	*Indications of asset performance*
1st asset solution: modification to slit-technology	• The intended asset performance was to increase the annual production. • Production targets were not achieved. • The asset performance production indicators included high increase in production speed but a sharp decrease in utilisation and reliability, high rate of defect products, new product quality defects, more quality inspection, high quality losses. • The key asset performance quality indicator was the new defect (irregularity) which was the main cause of quality losses such as (rejected, scrapped, returned, downgraded and quality stoppages or delays) • The asset performance financial indicators included: high quality cost, high production stoppages, more breakdown maintenance, high maintenance cost, production delays, and some minor injuries during operation and dispatching.
2nd asset solution: new production facility	• The intended asset performance was to increasing the annual production. • The resulting asset performance included achieving high availability and utilisation rate, low stoppages and delays, high productivity and reliability. • The asset design capacity was less than required.

As shown in Figures 6 and 7 and summarised in Table 4, the 1st-solution 'modified facility' resulted in poor performance that resulted in inadequate operation and maintenance performance reflecting negative financial or business results.

Table 4 also shows indication of insufficient design capacities to cope with the continuous increase in demand for the products of the 2nd-solution 'new facility'.

Table 5 Resulting business outcome and value contribution.

Asset solution	*Business outcome indicators*	*Value contribution indicators*
Modification to slit-technology	• Did not cover demand because the targeted increase in production was not achieved • Quality and financial losses • Customer dissatisfaction • Increased safety risks • Delivery delays • Transporting delay penalties • Loss of some international customers • Loss of opportunity to gain more share in the market	• The intended contribution was to cover the increase in demand in time at competitive quality and unit cost. • The resulting contribution included some short term benefit but overall negative contribution and the objective was not achieved. • An increase in production was achieved but associated with high losses and cost. • It resulted in undesirable business performance parameters that led to negative contribution.
New production facility	• For few years it covered the local demand and the rest is exported. • High quality products • Financial gains; all produced is sold • Loss of share in the market due to the shortage in capacity	• The intended contribution was to cover the increase in demand in time at competitive quality and unit cost. • The results included positive performance but contribution was short of covering long term demand. • In few years after it started to operate the company had to import to cover the local increase in demand up to almost equal to the production capacity

The resulting asset performance has impacted on the outcome and consequently the business targets and value contributions as evidenced in Table 5. As a common indication in interviews, the factors that led to such results were quality, maintenance and safety related. The maintenance factors were related to many repetitive short period stoppages. These disturbed process stability and increased down time despite the increase in production rate.

The operation disturbance was associated with an alerting reactive maintenance action. This can also be gleaned from the indicators plotted in Figures 4 to 7. As indicated in these interviews transcripts, the introduction of new defects in products (in particular irregularity) led to many losses, increase in cost and impact on customer satisfaction. According to performance and quality records, these included change in appraisal practice resulting in more appraisals cost (more inspectors, tied sampling, more inspection, re-inspection, downgrading or replacement of sales orders and etc.) and disturbance in dispatching leading to mistakes and delays that resulted in delivery delays and defected products that did not reach the customers but were downgraded or scraped. The marketing manager indicated that many complaints were registered and several penalties were encountered with shipments loading delays. As can be seen from Figures 4 to 7, this led to less utilisation and therefore higher losses and cost. The general manager of maintenance also indicated that, this resulted in scheduling disturbance leading to shorter roll replacement times that led to not fully utilising the rolls therefore increasing their replacement cost. Also, records showed that in process losses and dispatching and handling accidents had occurred that increased cost and the risk of human injury. Interviews held with production director, manager of operation and maintenance departments, indicated inadequate contribution by the two asset solutions. The plant manager indicated that a large capacity facility should have been introduced as the first solution rather than these two solutions. Overall, the outcomes of this case as business performance and/or value contribution resulted in negative impact on the organisation outcomes.

5 Case studies analysis and interpretation stage 2 – drawing implications from the phenomena

5.1 Focus of analysis

The interpretation and analysis involve linking the adopted EAM actions to existence or adequacy and/or absence or inadequacy of activities relationships as proposed by the framework. They also involve defining how it was decided that a response to an event required an asset solution and how a solution was established, adopted and implemented.

Mapping the elements of the EAMS framework against the actions undertaken in actual practice for these cases is presented in Tables 6 to 9. The data for these tables was extracted from interviews with the relevant managers and investigation of company documents.

5.2 Mapping and interpretation of the asset-related activities

It is evident from Table 6 that the fact that the organisation had to resort to forming an ad hoc team is an indication of the absence of some of the EAMS activities implied by the framework. The analysis and evaluation activities and decision making activities were not formally in existence. There were no departments charged with the responsibility to undertake research analysis, engineering and design, as some of the EAMS supporting activities identified within the framework.

Due to the poor results from the two asset solutions the company later introduced a technical support and development department and an industrial research department. The role played by these departments in the recent development projects studied as part of the overall research was evident. For example, according to an interview held in these departments, analysis has shown that any further expansion in the rolling facilities requires development and expansion in the upstream facilities and supporting facilities. It is concluded that the introduction of these reflects the recognition of their need in order to achieve better results of asset development projects for the organisation.

Records show that these departments played a role in developing a master plan for later expansion, e.g., the introduction of a new high speed slit-technology was based on analysis and initiative made by these departments. The implementation of the master plan appears capable of satisfying the continued growth in demand. In contrast, when the decision was taken for slit-technology modification the company had no means but to allocate the responsibility to handle the analysis and evaluation for EAM decisions to an ad hoc team. The team members lacked some of the specific knowledge and skill relative to this analysis. For example, the team overlooked the expected long run increase in market demand and did not request a study into it. Due to lack of experience in analysis, the resulting performance did not meet what was expected.

Table 6 Mapping the asset-related activities to facts from the case phenomenon details

Element of framework (Figure 2)	*Status*	*Indication of action and/or resulting outcome*
Research, engineering and design	Absent	• Departments responsible for activities are missing. • Ad hoc team work for the slit-technology project but the new facility introduction project design was outsourced. • Ten years later such departments were established.
Acquisition, deployment and installation	Absent	• Responsible departments were missing and slit-technology modification managed by ad hoc teams. • New facility contract supervised by ad hoc team. • Ten years later such departments were established.
Operation (utilisation/use)	Existed	• Operation management adequately existed. • Operation managers were part of the ad hoc team to handle the modification of the old facility.
Maintenance (care/service)	Existed	• Maintenance management adequately existed. • Maintenance managers were part of the ad hoc team to handle the modification of the old facility.
Replacement and disposal	Absent	• No formal responsibility of this activity found. • It is found to be part of maintenance.
Technical support and development	Absent	• No designated department to analyses development proposals existed at the time. • Technical support and development department established six years later.
Procurement	Existed	• Existed across several departments with lack of coordination between them with respect to EAM.
Human resources	Existed	• Existed as a central activity through several departments with indication of some good coordination between the life cycle activities, e.g., training for the need.
Safety, finance and accounting control, IT/IS, quality	Existed	• Existed through several departments • Indication of good coordination between activities but mostly manually handled and lacked advanced IT. • Lack of coordination between these activities and the cost accounting control department.

With reference to asset-related activities undertaking at aggregate and operational levels of activities, Table 6 shows adequacy of existence. In reviewing the operation and the maintenance practices in these case studies, it is found that the company has responsible entities in place for asset-related activities such as central planning and control department and quality control department to coordinate between activities.

5.3 Mapping and interpretation of the EAMS planning and control activities

Table 7 implies that missing or inadequate analysis and evaluation led to improper decision making in this case. Consequently, this resulted in inadequate selection and provision and less than the required asset performance. The lack of experience of the design team in doing the proper analysis and evaluation resulted in deficiencies in the definition and provision of this asset modification solution. As a consequence, no accommodation was made for the operation and maintenance requirements. The operation manager indicated that the modification resulted in a ‘trial and error’ process that comprised a continuous process of operation, failure, analysis and redesign. The final operation and maintenance requirements were far from what was set in the original modification design. The operational stoppages were very high as a result of quality problems and equipment failures. An unexpected number of additional and often successively modified spares had to be manufactured. This caused delays in spares provision. The overall result was a noticeable impact on business outcomes.

As previously identified, it is also evident that the team focused on minimising the upfront capital cost and overlooked the effects on the remaining life cycle cost elements. This minimisation included the use of internal resources. The team prepared the design based on redesign of some existing equipment and reprogramming the computer control system. In support of the new equipment, some minor mechanical spare parts were designed and planned to be manufactured in the company’s mechanical workshop. The modification was done in-house with only minor overtime cost only essential items were acquired to lower the initial capital cost.

Table 7 Mapping the EAMS planning and control activities

Elements of framework (Figure 2)	*Status*	*Indication of action and/or resulting outcome*
Analysis and evaluation	Absent/ inadequate	• No real analysis or evaluation to define increase in demand. • As a result, the slit-technology modification resulted to losses. • The capacity for both the slit-rolling and new facility could not satisfy the demand in the long run. • Inadequate analysis and evaluation of life cycle requirement resulted in overlooking quality, operation and maintenance requirement for slit-technology. • Indications of possible negative impacts on quality by slit- technology partly ignored. • No action to mitigate risk to the customer satisfaction or product unit cost.
Decision making	Inadequate	• Decisions not taken based on current and expected conditions. • Decisions based on managers’ opinions and debates. • Lack of experience of ad hoc team members led to poor decisions.

Table 7 Mapping the EAMS planning and control activities (continued)

Elements of framework (Figure 2)	*Status*	*Indication of action and/or resulting outcome*
Coordination and planning	Existed	• Existed at the aggregate level between departments or teams. • The slit-technology modification implemented as planned. • Records shows coordination and planning between departments were handled well. • The production planning & control department and maintenance planning and control department handled coordination between activities for EAM purposes through plans and performance reports. • Planning activities adequate but manual or semi manual form.
Work task control	Existed/ inadequate	• Operational work task control adequately existed, e.g. operation and maintenance departments were well managed for executing operational tasks. • For slit-technology modification, poor design resulted from the lack of experience of team members & absence of a design activity. • Work task control followed aggregate plans. • Data recording was mostly manual or semi manual.
Measurement and monitoring	Existed	• Data gathered in shift reports and then in weekly reports • Many measured parameters but mostly lagging indicators. • Condition monitoring limited to visual checks.
Control and reporting	Existed	• Performance reports (monthly, quarterly and annual) produced indicating compliance to plans: i.e. lagging indicators. • Used to prompt possible solutions: new facility for example.

In mapping the aggregate planning and control and operational task control level activities, Table 7 summarises evidence that the required activities were undertaken. However records showed lacked integration between activities such as maintenance and procurement activities due to inadequate information system. Table 7 also indicates that coordination between departments and performance reporting, and feedback to the strategic planning and control activity existed but mainly manual. This requires automation.

In mapping the framework activities and links between operational, aggregate and strategic levels, there is evidence that implies the interdependence and integration of responsibility to the asset-related activities at these levels. The inadequacy of one EAMS planning or control activity may cause other EAMS activities to be inadequate. The poor slit-technology design indicated in Table 7 reflects inadequate operational work task control activities. However, Table 7 indicates that the absence of activities responsible for analysis and evaluation forced the company to form an ad hoc team to handle these activities.

5.4 Mapping and interpretation of the EAMS feed-forward and feedback control links

A review of these feed-forward and feedback mechanisms reflected by the cases, are set out in Table 8. It is evident that the performance indicators employed by the company as part of their feedback mechanism were in the form of lagging indicators. The decision to increase the production capacity was based on lagging indicators highlighting the increasing backlog in customer orders for the specific product of interest. This reflects a reactive response mechanism and poor integration between strategic EAM activities and business management activities. A better approach would have included early analysis of market demand as feed-forward information providing a leading indicator for decision making on production capacity changes.

Table 8 Mapping the feed-forward and feedback control links.

Elements of framework (Figure 2)	*Status*	*Indication of action and/or resulting outcome*
KPIs and compliance feedback	Existed	• Feedback on KPIs existed as manual performance reports • Information hardly used for analysis and evaluation
Results as direction for strategic decision	Absent/ inadequate	• Feed-forward as direction or basis for strategic decision making absent or inadequate because of the absence of appropriate analysis and evaluation.
Control direction for planning	Existed	• This feed-forward link existed in terms of targets set by the business planning such as the sales plans or budgeting. • These targets are translated into aggregate plans.
Direction for task control	Existed	• This feed-forward link existed in terms of these aggregate plans that are converted into schedules, work procedures, control measures for example.
Data accumulation	Existed	• This feedback link existed in terms of data collected in those shift reports.
TPPs and CPs feedback	Existed	• This feedback link existed as weekly reports presenting indicators of technical performance parameters measured based on data accumulated from shift reports.

However, the feedback indicators alerted the company to customer satisfaction and profitability shortfalls. According to the team members, realisation of possible damage was clear. Combining the lagging performance indicator with the expected demand leading indicator provided a leading view on what the EAM solution should be. For example, the production manager indicated that marketing feedback led to realising that further performance improvement will not cover the expected increase in demand of the following year.

5.5 *Mapping and interpretation of the EAMS strategic relationships*

Working through the framework and mapping its strategic planning and control activities, as set out in Table 9, it is evident that the link between organisational strategy and EAM is important to an organisation's success. The strategic relationship is a result of feedback and feed-forward between the levels in the EAMS. For example, in the two case studies asset solutions, feedback from production and sales and feed-forward provided as annual sales forecast triggered the need to increase production capacity. As a result, three alternatives were reported to have been considered by the team members:

1. expansion by installing another production facility while importing the shortfall with requiring a relatively large investment
2. increasing production of the high demand products by reducing production of other products
3. modification by installing the slit-technology equipment with requiring a relatively low investment.

Team members stated that at that time the decision ~~to select~~ the slit-technology modification as a quick solution seemed logical. However, the impact on several performance aspects and life cycle requirement such as operation and maintenance were not so obvious and were not properly considered. The maintenance manager indicated that there was a concern raised about the possibility of an increase in quality defects but not much attention was given to further investigate the concern because the impact was not expected to be a major one. The low investment capital required was encouraging and the chief executive was prepared to take the decision. These management actions as elaborated in Table 9 indicate that there was a link/interaction between the asset managers and the strategic decision makers as proposed by the framework but it was inadequately managed.

Table 9 Mapping EAMS strategic relationships

Elements of framework (Figure 2)	*Status*	*Indication of action and/or resulting outcome*
Identification of strategy triggers and definition of strategy event/change	Inadequate	• Lack of interaction and inadequate relationship between EAMS and business management; No studies or research to define expected increase in demand • Lack of market research/studies due to missing or inadequate strategic analysis and evaluation activities. • Adequate internal identification of change triggers; internal indication of demand increase through production planning and control reports and increase shown in customer orders.

Table 9 Mapping EAMS strategic relationships (continued)

Elements of framework (Figure 2)	*Status*	*Indication of action and/or resulting outcome*
Definition of the required outcome and performance to achieve strategy	Inadequate	• Lack in definition of expected demand increase required business outcome to cope with the demand increase. • Inadequate definition of production capacity and output requirements or asset performance to cope with the long run business outcome. • Lack of definition of required asset solution and its performance to cope with the required production output. • Inadequate slit-technology performance resulted in negative impacts on quality, operation and maintenance. • The resulting performance was not as targeted or designed. • Performance contributed to increasing production but did not cover increase in demand and failed to achieve strategy. • Performance indicators: high quality defects and losses, high cost, delivery delays, low customer satisfaction, low competitiveness and risk to quality leadership achievement.
Definition and provision of assets solution and alignment with required performance and resources	Inadequate	• Decision to select slit-technology was not taken based on sound analysis and failed to achieve targets. • Decision on design capacity of new facility was inadequate for the increase in demand. • The decision to undertake in-house modification for slit-technology was inappropriate and design overlooked the life cycle requirement: operation and maintenance.
Setting strategies, policies, annual business targets and aggregate planning	Existed/ inadequate	• Strategies and policies for asset-related activities were set but no check of contribution to EAM strategic objectives. • Targets existed to provide direction to implement strategy. • Approval maintained for sales, production and maintenance plans but there is indication of non-compliance to plans.

The EAM actions studied in these cases indicate inadequacies in the definition and provision of the solution that resulted in less than the required performance, outcome and contribution to the organisation. The actions were meant to cover the increase in demand by increasing the production rate; however they resulted in lowering the product quality, the assets utilisation and reliability, increasing the maintenance cost and damaging the organisation's reputation. The asset solution adopted did not meet the operational requirement. It is concluded either that the strategic planning and control mechanism proposed by the hypothesised framework in respect of the relationship between EAM and organisational strategy making was not in place or activities did not appropriately exist.

6 Conclusions

The structure and role of the EAMS are established as a set of planning and control activities that maintain cyclic mechanism to control of the production asset-related activities. The paper confirms these with reference to those activities and relationships in the proposed framework. It concludes that the adequate existence of EAMS activities and relationships as proposed by the framework is an essential requirement for success in production organisation. It further highlights that inadequacies in one activity represented in the framework can result in other EAMS activities being inadequate for success.

The case studies' findings support the proposition that adequate existence of EAMS activities and relationships as proposed by the framework is an essential requirement for success. In particular, the case studies explain how the EAMS activities manage the relationships and accounts for the interdependence between the production asset-related activities and lead toward success. The case studies highlight that the effect of inadequate or missing activities of the EAMS system can result in negative impacts on productivity and quality and ultimately business outcomes.

References

Al Marsomi, M. (1997) *Industrial System Analysis and Design*, Higher Institute of Industry, Misrata, Libya.

Alsyouf, I. (2006) 'Measuring maintenance performance using a balanced scorecard approach', *Journal of Quality in Maintenance Engineering*, Vol. 12, No. 2, pp.133–149.

Amadi-Echendu, J.E. (2004) 'Managing physical assets is a paradigm shift from maintenance', *IEEE International Engineering Management Conference*, Institute of Electrical and Electronics Engineers Inc., Singapore, Vol. 3, pp.1156–1160.

Anderson, C. (2011) 'How are PDCA cycles used', *Bizmanualz*, 7 June.

Anthony, R.N. and Govindarajan, V. (1995) *Management Control Systems*, Harvard Business School Publishing Division, Boston, MA 02163.

Anthony, R.N., Dearden, J. and Bedford, N.M. (1989) *Management Control Systems*, IRWIN, Homewood.

Asset Management Council (2009) 'Asset management', *Asset Management Council and MESA Newsletter*, April–May, p.4.

Bamber, C.J., Sharp, J.M. and Castka, P. (2004) 'Third party assessment: the role of the maintenance function in an integrated management system', *Journal of Quality in Maintenance Engineering*, Vol. 10, No. 1, p.26.

Blanchard, B.S. (2009) *Systems Engineering and Analysis*, Englewood Cliffs, N.J., Prentice Hall.

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 and Production Management*, Vol. 25, No. 6, pp.566–579.

Donovan, A. (2002) *The Use of System Engineering for the Procurement of Significant Assets*, Master of Engineering Practice, 131p, Faculty of Engineering, Wollongong, University of Wollongong.

Dornan, D.L. (2002) 'Asset management: remedy for addressing the fiscal challenges facing highway infrastructure', *International Journal of Transport Management*, Vol. 1, No. 1, pp.41–54.

El-Akruti, K. (1999) *Replacement Optimization Modelling Of Electric Arc Furnaces' Refractory Lining*, Master of Technology in Industrial Engineering, p.206, Industrial Engineering, Misurata, Libya, Higher Institute of Industry.

El-Akruti, K. (2012) *The Strategic Role of Engineering Asset Management in Capital Intensive Organisations*, Doctorate of Philosophy, p.247, Mechanical Engineering, Wollongong, University of Wollongong.

El-Akruti, K. and Dwight, R. (2010) 'Research Methodologies for Engineering Asset Management', *ACSPRI Social Science Methodology Conference 2010*, Sydney, Australia, ACSPRI.

Frolov, V., Megel, D., Bandara, W., Sun, Y. and Ma, L. (2009) 'Building an ontology and process architecture for engineering asset management', *Proceeding of the 4th World Congress on Engineering Asset Management*, Marriott Athens Ledra Hotel, Athens [online] http://eprints.qut.edu.au/27909/ (accessed 26 August 2012).

Garg, A. and Deshmukh, S.G. (2006) 'Maintenance management: literature review and directions', *Journal of Quality in Maintenance Engineering*, Vol. 12, No. 3, pp.205–238.

Gupta, P. (2006) 'Beyond PDCA – a new process management model', *Quality Progress*, Vol. 39, No. 7, p.45, ProQuest Central.

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*, Vol. 34, No. 2, pp.285–290.

Hunger, J.W. (1995) *Engineering the System Solution: A Practical Guide to Developing Systems*, Prentice Hall PTR, Englewood Cliffs, New Jersey.

IPWEA (2011) *International Infrastructure Management Manual (2011 Version)*, Institute of Public Works, Engineering Australia, Sydney NSW Australia.

Iravani, S.M.R. and Duenyas, I. (2002) 'Integrated maintenance and production control of a deteriorating production system', *IIE Transactions*, Vol. 34, No. 5, pp.423–35.

ISO 9001 (2008) *Quality Management Systems – Requirements*, ISO vi.

Jonsson, P. (1999) 'Company wide integration of strategic maintenance: an empirical analysis', *International Journal of Production Economics*, Vol. 60–61, pp.155–64.

Kostic, T. (2003) *Asset Management in Electrical Utilities: How Many Facets It Actually Has*, Institute of Electrical and Electronics Engineers Inc., Toronto, Ont., Canada.

Lo Porto, J. and Udo, V. (2003) *Using Knowledge Management to Enable Enterprise Asset Management at Conectiv*, Institute of Electrical and Electronics Engineers Inc., Dallas, TX, USA.

Mathew, S. and Kennedy, D. (2003) 'A strategy for optimal equipment replacement', *Production Planning & Control*, Vol. 14, No. 6, pp.571–577.

Miles, R.E. and Snow, C.C. (1978) *Organizational Strategy, Structure and Process*, McGraw-Hill, New York.

Moen, M. and Norman, C. (2011) *Evolution of the PDCA Cycle* [online] http://pkpinc.com/files/NA01MoenNorma (accessed 26 August 2012).

Mohseni, M. (2003) *What does Asset Management Mean to You?*, Institute of Electrical and Electronics Engineers Inc., Dallas, TX, USA.

Morris, P. (2004) *Translating Corporate Strategy into Project Strategy*, Project management Institute, Inc., Four Campus Boulavard, Pennsylvania.

Muchiri, P. and Pintelon, L. (2008) 'Performance measurement using overall equipment effectiveness (OEE): literature review and practical application discussion', *International Journal of Production Research*, Vol. 46, No. 13, pp.3517–3535.

Muchiri, P.N. and Pintelon, L. (2010) 'Empirical analysis of maintenance performance measurement in Belgian industries', *International Journal of Production Research*, Vol. 48, No. 20, pp.5905–5924.

Narman, P., Gammelgard, M. and Nordstrom, L. (2006) *A Functional Reference Model for Asset Management Applications Based on IEC 61968-1*, Department of Industrial Information and Control Systems, Royal Institute of Technology, KTH 2006.

Ouertani, M.Z., Parlikad, A.K. and McFarlane, D. (2008) 'Asset information management: research challenges', *Proceedings of the 2nd International Conference on Research Challenges in Information Science*, Marrakech, Morocco, pp.361–70.

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.

Pinjala, S.K., Pintelon, L. and Vereecke, A. (2006) 'An empirical investigation on the relationship between business and maintenance strategies', *International Journal of Production Economics*, Vol. 104, No. 1, pp.214–229.

Porter, M.E. (1985) *Competitive Advantage: Creating and Sustaining Superior Performance*, Division of Macmillan, Inc., New York.

Ragin, C. and Becker, H.S. (Eds.) (1992) *What is a Case?: Exploring the Foundation of Social Inquiry*, Cambridge University Press, New York, NY, USA.

Sinha, A., Lahiri, R.N., Chwdhury, S. and Song, Y.H. (2007) *Complete IT Solution for Enterprise Asset Management (EAM) in Indian power Utility Business*, Brighton, Technological Educational Institute, UK.

Srivannaboon, S. and Milosevic, D.Z. (2005) *The Make-up of Project Management Elements as Influenced by Business Strategy: A Case Study Approach*, IEEE Xplore, Department of Engineering and Technology Management, Portland State University, Portland, OR, USA.

Stapelberg, R.F. (2006) *Risk Based Decision Making (RBDM) in Integrated Asset Management*, CIEAM Cooperative Research Centre for Integrated Engineering Asset Management, Brisbane, Australia.

Tague, N. (1995) *The Quality Toolbox*, ASQ Quality Press, Milwaukee.

Tam, A.S.B. and Price, J.W.H. (2008) 'A generic asset management framework for optimising maintenance investment decision', *Production Planning & Control: the Management of Operations*, Vol. 19, No. 4, pp.287–300.