PERFORMANCE EVALUATION FRAMEWORK FOR IT/IS BASED ASSET MANAGEMENT

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Abstract: Engineering assets managing businesses use a variety of information and communication technologies for process efficiency, control, and management. Nevertheless, key to all these is the effective measurement of the IT/IS utilisation for existing process such that the underperforming areas are highlighted, and corrective actions are taken to achieve optimal use of IS/IT. There are a variety of performance measurement mechanisms available that stimulate improvement efforts, in so doing helping businesses to translate perceived business strategy into action. However, these approaches are mostly aimed at high level evaluation of an organisation's performance; whereas the stochastic nature and ever expanding scope of asset management processes demands asset managers to have a comprehensive view of asset lifecycle and the interacting business areas. This paper proposes an evaluation framework for IT/IS based asset management in an engineering enterprise. The paper firstly seeks to present a critique of the asset management paradigm. It then discusses available performance measurement mechanisms and develops a case for the constituents of an effective asset management measurement framework that provides detailed indicators for controls actions required to achieve optimal process efficiency through the use of IT/IS. The paper, then, presents an integrated asset performance measurement framework that not only is derived from business strategy, but informs strategy formulation through a closed loop learning encompassing entire asset management lifecycle.

1 INTRODUCTION

Business and engineering disciplines are facing continuous change, facilitated by factors such as advancements in technology, deregulation, and environmental concerns. Amidst these adjustments in the operating environment, it has become imperative for business to have some sort performance measurement system in place to measure the growth and progress of the business, so as to rationalize investments and to measure if their existing technological, process, and procedural initiatives conform to business strategy. This has particular relevance for the high risk and capital intensive businesses, such as engineering enterprises (see for example Liyanage and Kumar 2000). More than ever these businesses are concerned about the usefulness of the business infrastructure that they put in place to produce products and services, and at its heart lies the measurement of the effectiveness of their production or manufacturing 'assets'. This concern is not just limited to the businesses operating and owning these assets, but is also shared by the regulatory authorities (such as, environmental protection agencies). Asset is the physical component of a manufacturing, production or service facility, which has value, enables services to be provided, and has an economic life of greater than twelve months (IIM 2003), such as manufacturing plants, railway engines and carriages, aircrafts, water pumps, and oil and gas rigs. Accordingly, management of these assets represents a set of disciplines, methods, procedures and tools to optimise the whole life business impact of costs, performance and risk exposures associated with the availability, efficiency, quality, longevity and regulatory/safety/environmental compliance of a

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company's assets (Woodhouse 2001). However, trends like convergence of technologies is making assets easier to operate on one hand, and on the other are making their management versatile due to the multifaceted maintenance demands of various technologies used in the assets. Nonetheless, traditionally manufacturing/production assets have not been given requisite attention on the strategic agenda of manufacturing or production businesses; with more emphasis been given to factors like what to produce and how much to produce. Consequently, the available performance measurement systems either tend to overlook assets altogether, or when they do allow provisions for assets performance measurement, it provides a unilateral view mainly concerned with their throughput rather than providing a multilateral view that covers their output as well as the impact of their operation on other business areas and their design, maintenance, and retirement and reinvestment demands. Furthermore, classical measurement systems generally have a financial measurement orientation (Kaplan and Norton 1996; Sveiby 1997), and do not give enough consideration to other important factors like technological maturity, skill base, and process efficiency.

This research paper investigates the role of information technologies, particularly information systems in enabling asset management processes. It takes an asset lifecycle perspective and proposes a performance measurement framework for asset management, which assists engineering enterprises to evaluate the effectiveness of their assets in operation as well as the impact of their operation on related business areas and overall business direction. The paper suggests a seven perspectives framework, which has IT/IS at its core, such that it ties asset management processes together to create a chain of value added perspectives that translate into business competitiveness.

2 IT AND ASSET MANAGEMENT

The past decade has seen significant activity in business enabling technologies, which among others also spans manufacturing and production systems, production philosophies, and processes. Impact of these technologies has intensified competition, mainly because technology provides businesses with the opportunities of competing on even grounds, regardless of their size. However, at the same time technology has also facilitated a shift towards continuous renewal of products and services at regular intervals, which consequently is forcing businesses to innovate and update their offerings with added value and features regularly. This shortening of product lifecycles and continuous updating of products demands enhanced asset operation capacity, which means assets also have to be upgraded continuously. Nevertheless, if engineering enterprises are to take optimum advantage of manufacturing technologies, their implementation should also consider the resources, structures and processes that may be impacted by technology adoption. These four areas are operational processes, operational structures, information systems, and human resources. Information systems, in particular, have the most significant bearing factor on operational performance. It is mainly due to the fact that engineering enterprises mature technologically along the continuum of standalone technologies to integrated systems, and in so doing aid the maturity of processes, skills, and business intelligence. Information, however, is the fuel of this maturity process and its magnitude and quality demand also increases along the same scale of maturity. Information technologies, which in themselves are an important constituent of manufacturing technologies, and information systems, hold the key to continuous improvement and competitiveness of manufacturing businesses (Lawrence 1999).

Koc and Lee (2003) summarise the changes in manufacturing paradigm over the last two decades and suggest that it is fast moving towards a wireless environment, or an 'e-intelligent' environment (Figure 1). The authors argue that the manufacturing paradigm is fast moving towards an environment of continuous and seamless flow of information, aimed at real time access to all the stakeholders of a business process to increase the overall business efficiency, responsiveness, and agility. This, however, means a shift that is not just outwardly innovative, as in terms of product innovation, but is also inwardly creative and aimed at process re-engineering and innovation in asset design, operation and support. Lee (2003) terms this shift as the "5Ps," namely predictability, producibility, productivity, pollution prevention, and performance. Focus of these 5Ps is on the effectiveness of assets on the manufacturing floor in terms of continuous availability, efficiency, and output, as well as on the expectations of stakeholders in terms of compliance with regulatory and environmental legislations. In manufacturing and production environments that are riddled with continuous change, stability in manufacturing and quality processes has long been advocated (see for example, Warnecke and Hueser 1994), as disruptions and disturbances in production

	1980	1990	2000	2010
Product Focus	3Cs (Chips, Computers, Communications) & Intelligent Mechatronics		Products that think & link	Products that Learn, Grow, Reconfigure, & Sustain
Manufacturing Focus	Factory Automation (Flexibility)		Business Automation (Agility)	e-factory & e-Automation
Innovation	Microelectronics & Computing		Embedded Intelligence & Smart Netware	E-intelligence Systems

Figure 1: Evolution in Product Innovation and Manufacturing Source (Koc and Lee 2003).

Table 1: Asset Lifecycle Management Perspective Source (Moubray 2003).

	Functions	Description
1	**Functional specifications**	Decide what each asset must do to make the manufacturing processes value added
2	**Design specifications**	Decide the configuration of the asset in order to meet functional specifications
3	**Acquisition & Deployment**	Acquire and deploy the assets
4	**Maintenance**	Sustain and where necessary replenish the assets in such a way that they continue to make the required contribution to the value-adding process
5	**Scorekeeping**	Identify key performance indicators that show how well the assets are making their required contribution to the value adding process
6	**Disposal**	Dispose off assets when they do not fulfil the required functions or are not needed
7	**Compliance**	Monitor and ensure compliance with regulations governing the use of the assets

or manufacturing have a devastating effect on revenues as well as customer relationship (Almgren 1999). Engineering enterprises, therefore, need to take stock of the effectiveness of their assets and manufacturing process, such that it highlights the underperforming areas and provides them with a roadmap for implementation of information systems in ways that complement business strategy. This scorekeeping, however, requires a comprehensive approach that takes a holistic view of the way asset are operated; their lifecycle demands are addressed and resources are allocated to keep them in running condition; their lifecycle decisions are made; and information is collected, processed, and communicated within the organisation and with the business partners.

3 IT AND ASSET MANAGEMENT

Asset management entails design and commissioning of assets, operation and simultaneous addressing of maintenance needs arising from the operations of assets, and consequent decision support for asset renewal or decommissioning. Table 1 below further breaks down these stages and presents a description of the activities associated with each stage of an asset lifecycle management.

Increased business automation along with the continuously changing operating conditions makes asset management increasingly intricate and multifarious as it increases their vulnerability by exposing them to disruptions and interruptions of various kinds. For example, a typical water pump station in Australia is located away from major infrastructure and has considerable length of pipe line that brings water from the source to the destination. In this situation, assets are deployed over an area of various kilometres; however, the demand for water supply is continuous for twenty four hours a day, seven days a week. Although, the station may have some kind of a early warning or process control and condition monitoring system installed, such as Supervisory Control and Data Acquisition (SCADA), maintenance labour at the water stations and along the pipeline is generally limited and spares inventory is generally not held at each station. Therefore, it is imperative to continuously monitor asset operation (which in this case constitutes equipment on the water station as well as the pipeline) in order to sense asset failures as soon as possible and preferably in their development stage. However, early fault detection is not of much use if it is not backed up with the ready availability of spares and maintenance expertise. Therefore, the expectations placed on water station by its stakeholders are not just of continuous availability of operational assets, but also of the efficiency and reliability of support processes. Elimination and control of production irregularities and disturbances is, therefore, necessary for production and service provision, agile manufacturing, and customer satisfaction. However, as businesses are beginning to recognise the importance of these turbulences, weaknesses of traditional approaches to asset equipment are coming to forefront (Lawrence 1999).

Bamber et al (1999) posit that traditionally asset management processes, such as maintenance have been considered as support functions, and are termed as non-productive and a non core processes that add little value to the business. This is largely due to lack of acknowledgement of the direct connection between maintenance and profitability (Jonsson 1999). Most organisations adopt a traditional technology-centred approach to design and implementation of new assets, where technical aspects command most resources and are considered first in the planning and design stage. Human and organisational factors are only considered relatively late in the process, and sometimes only after the system is operational (Konradt et al 1998). Al-Najjar (1996) suggests that most businesses do not have a significant control of costs incurred by planned or unplanned stoppages and quality problems. Generally tactical and operational decision made by managers have a short term focus, for example, asset procurement decisions are based on acquisition cost only and maintenance requirements are totally ignored, whereas, a significant amount of the annual operational costs are attributed to maintenance costs. Consequently engineering enterprises struggle to, utilise their assets effectively and profile its lifecycle demands; implement cost effective maintenance strategies that best suit the business; develop lifecycle management competencies; plan an effective exit strategy for assets rendered obsolete through technology refresh or through end of need; and provide a credible charge-back system to allocate maintenance costs to the business lines and thus ensure that everyone is involved in avoiding redundancy and wastage of efforts (Haider and Koronios 2005). This highlights the need for a comprehensive performance measurement system that not only provides insights into the effectiveness of the asset operation, but also quantifies impact of its operation on other business areas so as to provide a lifecycle perspective of asset utilisation to asset managers. Such a performance measurement system entails that performance measurement should have a multifaceted but integrated focus. It should include all the facets of an asset lifecycle as well as critical factors such as, technology, process efficiency, risk assessment, competencies, and organisational learning; and how these factors contribute to overall business strategy.

4 PERFORMANCE AUDIT

There have been numerous business improvement methodologies developed and implemented by businesses of all sorts. These methodologies represent a blend theory and practice, which each having its own way of performance measurement that is largely dependent upon the focus of the methodology. Some of the leading initiatives in this regard include organisational learning, Benchmarking, total quality management, learning organisation, Six Sigma, European Foundation for Quality Management Business Excellence Model (EFQM), business process re-engineering, knowledge management, and balanced scorecard. These methodologies constitute the basis of the most of performance measurement and management initiatives tailored by businesses to meet their needs. Consequently, engineering enterprises have adopted these methodologies in a variety of ways and aimed at different business areas and processes, such as for manufacturing planning and control (Kochhar et al. 1996), product development process (O'Donnel and Duffy, 2002), human resources development (Kelly and Gennard 2001; Gibb 2002) service or facility management (Wilson 2000).

Businesses have particularly been interested in measuring the performance of their information systems, in order to rationalise investment and to find triggers for further improvement. An interesting aspect of these methodologies is the fact that they are either high level performance measurements or are aiming at the functional level. Remenyi et al (2000) summarise the methodologies developed for assessing the performance of Information systems, and suggest that their focus has been on strategic match analysis and evaluation; value chain assessment (organisation and industry); relative competitive performance; proportion of management vision achieved; work-study assessment; economic assessment - I/O analysis; financial cost benefit analysis; user attitudes; user utility assessment; value added analysis; return on management, and multi-objective, multi-criteria methods.

Although research has paved the way for major developments in the filed of business improvement, yet it is interesting to note that asset performance measurement has been largely limited to physical inspection of plant and equipment for its health assessment. However, existing research provides the essential stepping stones for further research into performance measurement for asset management. From the discussion so far seven characterises of a performance measurement mechanism are formulated and are validated by the research on performance measurement systems. These characteristics entail that an appropriate performance measurement system for asset management should:

a. Focus on business processes as well as the structures that deliver value (Neely and Adams, 2001);
b. Integrate different aspects of asset management, such that they constitute a chain for business competitiveness (Suwignjo et al. 2000; Neely et al. 1996);
c. balance the needs of various stakeholders, such as business partners or third party service providers, customers, employees, regulatory agencies, and society at large (Kaplan and Norton 1996; Neely and Adams 2001);
d. information driven such that it provides inputs to strategy re-calibration rather than being steered by the business strategy (Bititci 2000; Bititci et al 2005; Neely and Adams 2001);
e. Conform to business objectives (Kaplan and Norton 2000; Bititci 2000);
f. Aim at competency development and business intelligence infrastructure development to create and sustain value for asset management processes (Kaplan and Norton 2000; Neely and Adams 2001); and
g. Provide financial (Kaplan and Norton 2000) as well as non financial assessments (Neely and Adams 2001).

5 IS/IT BASED ASSET MANAGEMENT EVALUATION

From the discussion above, two characteristics stand out. First, there has to be a strategic fit between the structure of asset management processes and the supporting infrastructure, and second, the technology should provide for the functional integration between various asset management processes. Table 2, below, provides the theoretical underpinnings for a seven perspectives framework that were identified from the literature review. IT/IS are seen here as the focal point around which asset management and support processes are organised. It provides two fundamental purposes, first it provides the strategic fit between business structure and infrastructure, and second it provides for the functional integration. This way, IT/IS facilitate a closed loop asset lifecycle management framework (see figure 2).

Table 2: Asset Management Performance Measurement Perspectives.

Perspective	Description	References
Design and Planning	Planning, design, and improvements of assets and manufacturing processes according to stakeholders' expectations and products and services demand.	Feigenbaum (1991); Flynn et al. (1994); Yamashina (2000); Zhang et al. (2000); IIM (2002); Jonsson and Mattsson (2003); Raouf (2004); Fernando and de Carvalho (2005);
Productivity	Ensuring smooth asset performance, including mitigation of risks posed to assets; their operating environment	Suzuki (1994); Bever (2000), Woodhouse (2001), IIM (2002); Raouf (2004); Mathew (2004); Seth and Tripathi (2005)
Support	Financial and non financial resources support for asset lifecycle support including maintenance management, spare supply chain management, and related processes.	Blanchard (1997); Yamashina (2000); Raouf (2004); IIM (2002); Moubray (2000); Moubray (2003); Zutshi and Sohal (2005); Oke (2005)
Stakeholders	Ensuring stakeholders collaboration and integration to achieve higher levels of asset management through enhanced work design, process efficiency, and compliance to regulatory and environmental regulations.	Crosby (1979); Liyanage and Kumar (2000); Tsang and Chan; (2000); Santos (2000); Raouf (2004); Zutshi and Sohal (2005); Bititci et al (2005); Seth and Tripathi (2005)
Organisational Learning	Profiling asset management and managing lifecycle knowledge for better understanding of improvements in asset design, operation, maintenance, reinvestment, and compliance.	Ramamurthy (1995); Hipkin (2001); IIM (2002); Marquez et al (2004); Johansen and Riis (2005)
Competitiveness	Strategic directions to strengthen business performance and competitive position with effective asset management.	Yamashina (2000); Dangayach and Deshmukh (2001); Rudberg (2002); IIM (2002); Schroeder et al (1995); Raouf (2004); Zutshi and Sohal (2005)
Information Systems/Information Technology	Appropriateness of information systems/ information technology to provide value added support to asset management	Al-Najjar (1996); Blanchard (1997); Bever (2000); Moubray (2000);Duffuaa et al (2001); Cassady et al (2001); IIM 2002); Mathew (2004); Fernando and de Carvalho (2005)

Each perspective and the rationale behind it are explained below, along with their impact on other perspectives.

Competitiveness Perspective

In engineering enterprises strategy is often built around two principles competitive concerns and decision concerns. Competitive concerns set the gaols of manufacturing, whereas decision concerns deal with the way these goals are to be met (Rudberg 2002). This perspective deals with both these principles. As shown in figure 2, this perceptive provides strategic underpinnings to asset management in anti-clock direction thereby setting gaols, and as the end point of the anti-clock cycle gets feedback from the asset management processes for better decision support and asset lifecycle management. These decisions entail the choice of assets, their demand management, and business arrangements to ensure smooth manufacturing or service provision. Business arrangement illustrates the optimum ways of doing business, such as the choice of business partners, outsourcing of asset management functions, capacity scheduling, and service provision to third parties (Dangayach and Deshmukh 2001).

Design Perspective

A usual manufacturing cycle starts with specification of the products and services that the business aspires to offer its customers in conformance with its business strategy. This specification illustrates the types of assets and processes that the business needs to put in place to produce services and products. It is also known as the demands specification of assets. This is of vital importance in a manufacturing cycle as well as in the asset management lifecycle. It is, therefore, critical to have an integrated understanding of factors such as, the characteristics of the environment that the business operates in; design, configuration management, and workload of each asset; maintenance demands of each asset; availability of asset maintenance support; and the business process that enable manufacturing as well as asset management. Any mismatch between what the market demands, manufacturing process design, and planning has a detrimental effect on the overall performance of the business (Schroeder et al 1995). For example, consider two different types of assets, one operates on fixed number of hours over a period of time, and the other operates on as needed basis that can be many times over the same time. In order to keep both these assets in running condition, both assets have some maintenance demands that entail to have a stock of spares. Usually there are two methods used in businesses, re-order point and material requirements planning, where both deal with how much and when to place an order for a specific item. However, re-order point requires an even demand that suits assets that operate in stable conditions, whereas material requirements planning better suits complex and demand dependent environments with erratic demand. Similar differences can be identified for capacity planning and other manufacturing floor control methods (see for example, Vollmann et al 1997). Planning choices at this stage drives asset behaviour, therefore it is important to assess if right choices have been made to ensure availability. Furthermore, this assessment also explains variations in output levels, and possible causes of manufacturing, production, or service provision disturbances.

Productivity Perspective

Productivity of an asset is directly related to the minimising of production or service provision disturbances. A production or service provision disturbance is an unplanned or undesirable function or failure of an asset (Kuivanen, 1996). It can be classified as asset downtime, speed or operation, and quality losses. It is important to note that disturbances do not only occur due to a mechanical or electrical fault, they can also occur due to some process and procedural issues. Disturbances occur in one of the three ways, as suggested by El-Haram (1995):

a. When an asset become inoperable suddenly, and can no longer perform its required operations;
b. When an asset cannot fulfil some or all of its operations at the same performance standard as originally specified; or
c. When an asset gradually deteriorates to an unsatisfactory level of performance or condition, and its continued operation is unsafe, uneconomical or aesthetically unacceptable.

Businesses use different methods to assess the reliability of their assets operation, just like there are many ways that can impact asset productivity and case disturbances. According to one study, more than one third of the production disturbances were caused by design errors (Jarvinen et. al. 1996). In complex manufacturing environments where there is range of assets employed, production or service disturbances in one asset can cause detrimental issues for other assets. For example, due to a mechanical fault the output of an asset is feeding substandard input to the next asset, idleness of an asset as it runs out of raw material, or hazard to other assets due to total asset failure such as nuclear radiations, and fire. Here, productivity assessment of an asset entails deviating away the convention practice of just condition monitoring of an asset and process control through the use of sensors and process control systems. Its scope is extended to include operational requirements compliance, asset operation in the planned environment, as well as the mechanical behaviour of the asset. Matson and McFarlane (1999) propose the concept of production responsiveness with refers to achieving goals of asset operation in wake of supplier, internal and customer disturbances. Therefore, support processes like asset maintenance need to take a holistic approach by taking care resource availability for myriad of factors that cause production or service provision disturbances.

Support Perspective

Operational support for assets means failure detection as well as support for maintenance execution. This support is not just limited to availability of resources, such as spares, equipment, and human resources, but it also includes factors such as employee training and skills development. Failure root cause detection is itself is a daunting task, as explained earlier a failure condition can have its foundations in different process, procedural, and mechanical reasons. Maintenance approaches differ form industry to industry, depending upon the type of assets that the business utilises. However, there are three major approaches to maintenance (Niebel 1996):

a. Failure-driven maintenance;
b. Time-based maintenance;
c. Condition-based maintenance.

Though the crux of maintenance approaches is the same as the ones described above, however different industries utilise different techniques to select the cost effective strategies that best suit their operations and nature of assets. In this quest oil, defence and aviation industries have been the forerunners, as they have introduced strategies such as reliability centred maintenance (RCM), failure modes and effects analysis (FMEA), availability, reliability and maintainability analysis (ARM), level of repair analysis (LORA), and whole life costing (WLC) (Blanchard et al. 1995). These approaches fall under the umbrella of integrated logistics support (ILS) that deals with the delivering outputs at an affordable cost throughout a project life cycle (Jones 1995). ILS is an engineering and management tool, which ensures that the project economically meets performance requirements such as reliability, durability, quality, maintainability, and availability throughout its life cycle (Green 1991).

Maintenance, however, influences many areas of the business, such as asset availability in supporting just in time principles (Nakajima 1988), relationship between technology and operations (Willmott 1997), product quality (Moubray 2000), and achieving and sustaining a safe workplace and environment (Zutshi and Sohal (2005). This perspective is the most powerful perspective of asset lifecycle management, as it not only assesses risks posed due to asset operation, but also quantifies these risks by providing indications on spending for asset lifecycle support. These assessments also provide lifecycle support decision support, such as tradeoffs between asset maintenance and renewal, changes to asset design, level of employee expertise in operating assets.

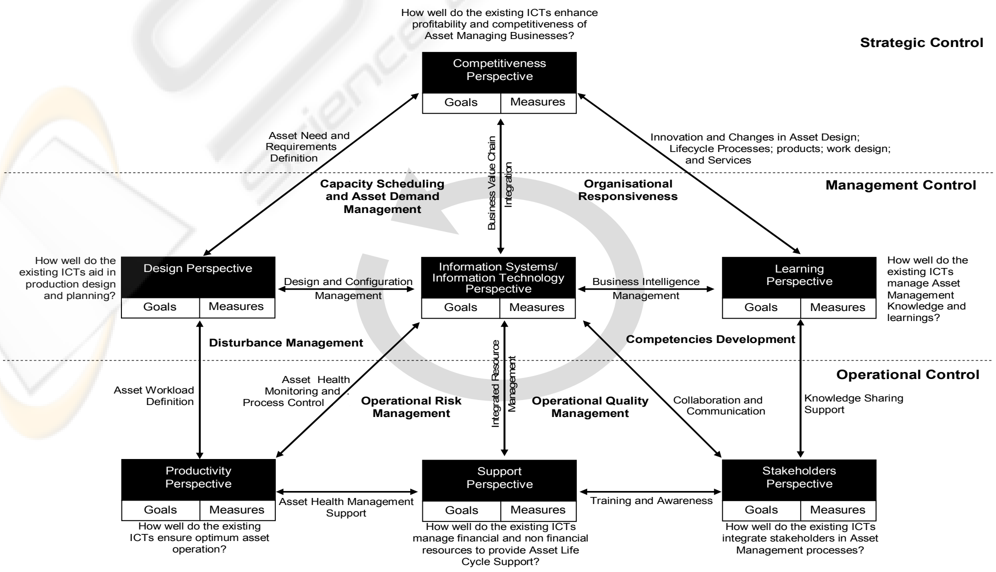

Figure 2: IS/IT based Asset Management Evaluation Framework.

Stakeholders Perspective

Asset performance, among other factors discussed above, also depends on the skills and expertise of asset operators and knowledge of asset operation, asset failure trends, and procedures (Ramamurthy 1995). A common tend among engineering enterprises is the outsourcing of core activities such as maintenance. This trend is quite common among for complex assets, such as aircrafts, and oil and gas rigs. In these circumstances neither the asset owning business, and nor the asset maintaining business has a complete understanding of asset behaviour, which obviously impacts asset lifecycle decision support. This perspective assesses the level of integration between the business stakeholders, such as employees, business partners, customers, and regulatory agencies like environmental and government organisations. The idea here is to share knowledge in order to enhance the efficiency and competencies of the overall business, which subsequently provide quality of operations.

Learning Perspective

Contemporary engineering enterprises take an adaptive learning view. Senge (1990) argues that, for continuous improvement adaptive learning generative learning (Argyris 1977) as opposed to adaptive learning should be adopted. Adaptive learning has a short term focus and aims at solving the immediate problems faced by the business; whereas generative learning has a long term focus and instead of looking at immediate issues it looks at long terms strategic issues. Here, the learning perspective illustrates assessing the way engineering business preserve the knowledge that it creates in previous perspectives, and using the same for providing triggers for change to recalibrate its competitive strategy in terms asset lifecycle management. These triggers are aimed at changing asset design, processes, and business architecture and infrastructure, whereby the objective is to induce flexibility in over all business execution and creativity in the processes of asset lifecycle management.

Appendix 1 provides the details of the asset management processes that should be assessed under each perspective. It examines the purpose of each process, i.e. primary or secondary, and assigns it to the appropriate dimension of asset performance criteria of efficiency, effectiveness, availability, compliance, and reliability as suggested by Woodhouse (2001) and IIM (2002). Information systems consist of hardware components, software applications, communications networks and facilities, and information that is captured, exchanged, processed, and stored to enable business operations. Therefore, in order to assess the effectiveness of IS/IT for each process four dimensions, namely, people, information, applications, and technology are selected, to be measured on a scale of 1 to 5. This information could be collected though surveys and with the help of Analytic Hierarchy Process (AHP) (Saaty 1990) and Multi-Attribute Utility Theory (MAUT) (Goicoechea et al. 1982) it could be aggregated to provide performance measurements, thereby providing an overall IT/IS performance measurement for asset lifecycle management.

6 CONCLUSION

This research provides the basis for further research into comparative analysis of IT/IS based asset management for industrial and infrastructure assets to be conducted through the Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM). This paper has proposed and theocratically demonstrated an approach for linking asset management to strategic competitiveness of a manufacturing business through processes measurement and control. It has particularly emphasised the use of IT/IS for integration between competitive environment and resource capabilities, competencies, and capabilities. It has also shown how asset managing businesses could benefit by taking a lifecycle perspective of asset management, such that assets are treated as business enablers rather than just production or service provision enablers.

REFERENCES

Almgren, H., (1999). “Towards a framework for analyzing efficiency during start-up: An empirical investigation of a Swedish auto Manufacturer.” *International Journal of Production Economics*, 60(61), pp.79-86.

Al-Najjar, B., (1996), Total quality maintenance An approach for continuous reduction in cost of quality products, *Journal of Quality in Maintenance Engineering*, 2(3), pp. 4-23.

Argyris, C., (1977), Double Loop Learning in Organizations, *Harvard Business Review*. 55, September-October, pp.115-125.

Bamber, C. J., Sharp, J. M., and Hides, M.T., (1999), Factors affecting successful implementation of total productive maintenance, *Journal of Quality in Maintenance Engineering,* 5(3), pp.162-181.

Bever, K., (2000), Understanding Plant Asset Management Systems, *Maintenance Technology*, July/August, pp. 20-25

Bititci, U.S., (2000), Dynamics of performance measurement systems, *International Journal of Operations & Production Management*, 20(6), 692-704.

Bititci, U.S., Mendibil, K., Martinez, V., and Albores, P., (2005), Measuring and managing performance in extended enterprises, *International Journal of Operations & Production Management*, 25(4), pp. 333-353.

Blanchard, B. S., (1997), An enhanced approach for implementing total productive maintenance in the manufacturing environment, *Journal of Quality in Maintenance Engineering*, 3(2), pp. 69-80.

Blanchard, B., Verma, D., and Peterson, E., (1995), Maintainability: A Key to Effective Serviceability and Maintenance Management, John Wiley & Sons, New York, NY.

Cassady, C., Pohl, E., and Murdock, W., (2001), Selective Maintenance Modelling For Industrial Systems, *Journal of Quality in Maintenance Engineering*, 7(2), pp. 104-117.

Duffuaa, S., Ben-Daya, M., Al-Sultan, K., and Andijani, A., (2001), A Generic Conceptual Simulation Model For Maintenance Systems, *Journal of Quality in Maintenance Engineering*, 7(3), pp. 207-219.

El-Haram, M., (1995), *Integration approach to condition-based reliability assessment and maintenance planning*, Ph D. Thesis, University of Exeter.

Feigenbaum, A.V., (1991), Total Quality Control, 3rd ed., International edition, McGraw-Hill, New York, NY.

Fernando, J. B. L., and de Carvalho, M. M., (2005), Changing product development process through information technology: a Brazilian case, *Journal of Manufacturing Technology Management*, 16(3), pp. 312-327.

Flynn, B.B., Schroeder, R.G., Sakakibara, S., (1994), A framework for quality management research and an associated measurement instrument, *Journal of Operations Management*, 11, pp.339-66.

Gibb, S., (2002), Learning and Development: Process, Practices and Perspectives at Work, Palgrave, London.

Goicoechea, A., Hansen, D. and Duckstein, L., (1982), “Multi-objective decision analysis with engineering and business applications”, *Wiley*, NewYork.

Green, L.L., (1991), *Logistics Engineering*, John Wiley & Sons, Inc, New York.

Haider, A, and Koronios, A., (2005), “ICT Based Asset Management Framework”, *International Conference on Enterprise Information Systems (ICEIS)*, 3, pp. 312-322.

Hipkin, I., (2001), Knowledge and IS implementation: case studies in physical asset management, International Journal of Operations & Production Management, 21(10), pp. 1358-1380.

http://www.plant-maintenance.com/articles/AMbasicintro.pdf

IIM, (2002), International Infrastructure Manual, National Asset Management Steering Group, Australia New Zealand Edition, Thames, ISBN 0-473-09137-2

Jarvinen, J., Vannas, V., Mattila, M., Karwowski, W., (1996), Causes and safety effects of production disturbances in FMS installations: a comparison of field survey studies in the USA and Finland, The International Journal of Human Factors in Manufacturing, 6, pp.57-72.

Johansen, J., and Riis, J. O., (2005), The interactive firm - towards a new paradigm: A framework for the strategic positioning of the industrial company of the future, *International Journal of Operations & Production Management*, 25(2), pp. 202-216.

Jones, J.V., (1995), *Integrated Logistic Support Handbook*, 2nd edn, McGraw-Hill, Inc., New York.

Jonsson, P., (1999), The Impact of Maintenance on the Production Process - Achieving High Performance, Doctoral thesis, *Division of Production Management, Lund University*. Lund, Sweden.

Jonsson, P., and Mattsson, S., (2003), The implications of fit between planning environments and manufacturing planning and control methods, *International Journal of Operations & Production Management*, 23(8), pp. 872-900.

Kaplan, R.S., Norton, D.P., (1996), The Balanced Scorecard: Translating Strategy into Action, Harvard Business School Press, Boston, MA.

Kaplan, R.S., Norton, D.P., 2000b, The Strategy Focused Organisation: How Balanced Scorecard Companies thrive in the New business Environment - Measures that Drive Performance, Harvard Business School Press, Boston, MA.

Kelly, J., Gennard, J., (2001), Power and Influence in the Boardroom, Routledge, London.

Koc, M., Lee, J., (2003), “A System Framework for Next-Generation E- Maintenance Systems”, IMS: Centre for Intelligent Maintenance Systems, Milwaukee, accessed online at http://www.uwm.edu/CEAS/ims/pdffiles/E-Maintenance.PDF, on June 27, 2005.

Konradt, U., Zimolong, B., and Majonica, B. (1998), User-Centred Software Development: Methodology and Usability Issues, *The Occupational Ergonomics Handbook*, Karwowski, W., and Marras, W.S., (eds). USA, CRC Press.

Kuivanen, R., 1996, Disturbance control in flexible manufacturing, *The International Journal of Human Factors in Manufacturing*, 6(1), pp.41-56.

Lawrence, J. L., (1999), “Use mathematical modeling to give your TPM implementation effort an extra boost.” *Journal of Quality in Maintenance Engineering*, 5(1), pp. 62-69.

Lee, J., (2003), “E-Intelligence Strategies for Product Manufacturing Innovation”, *IMS: Centre for Intelligent Maintenance Systems*, Milwaukee, accessed online at http://www.uwm.edu/CEAS/ims/pdffiles/EIntelligence Strategies.PDF,on June 27, 2005.

Liyanage, J.P., Kumar, U., (2000), Utility of maintenance performance indicators in consolidating technical and operational health beyond the regulatory compliance, Doerr, W.W., Safety Engineering and Risk Analysis: The International Mechanical Engineering Congress and Exposition-2000, pp.153-160.

Marquez, A. C., and Herguedas, A. S., (2004), Learning about failure root causes through maintenance records analysis, *Journal of Quality in Maintenance Engineering*, 10(4), pp. 254-262.

Mathew, S., (2004), Optimal inspection frequency: A tool for maintenance planning/forecasting, *International Journal of Quality & Reliability Management*, 21(7), pp. 763-771.

Matson, J.B., McFarlane, D.C., (1999), Assessing the responsiveness of existing production operations, *International Journal of Operations & Production Management*, 19(8), pp. 765-784.

Moubray, J. M., (2003), 21st Century Maintenance Organization Part I: The Asset Management Model, Maintenance Technology, accessed online at http://www.mt-online.com/articles/0203_asset_mgmtt.cfm, on July 12, 2005.

Moubray, J.M., (2000), Reliability-centred Maintenance, Butterworth-Heinemann, Oxford.

Nakajima, S., (1988), Introduction to Total Productive Maintenance, Productivity Press, Cambridge, MA.

Neely, A., Adams, C., (2001), The performance prism perspective, *Journal of Cost Management*, 15(1), pp.7-15.

Niebel, B.W., (1996), *Engineering Maintenance Management*, 2nd ed., Marcel Dekker, New York.

O'Donnel, F., Duffy, A.H.B., (2002), Modelling design development performance, *International Journal of Operations & Production Management*, 22(11), pp.1198-1221.

Oke, S. A., (2005), An analytical model for the optimisation of maintenance profitability, *International Journal of Productivity and Performance Management*, 54(2), pp. 113-136.

Ramamurthy, K., (1995), Moderating influences of organizational attitude and compatibility on implementation success from computer-integrated manufacturing technology, *International Journal of Production Research*, 32(10), pp. 2251-2273.

Raouf, A. S. I., (2004), Productivity enhancement using safety and maintenance integration: An overview, *The International Journal of Systems & Cybernetics*, 33(7), pp. 1116-1126.

Remenyi, D., Money, A., Sherwood-Smith, M., Irani, Z., (2000), The effective measurement and management of IT costs and benefits, 2nd Edition, Butterworth Heinemann, Woburn, MA.

Rudberg, M., 2002, Manufacturing strategy: linking competitive priorities, decision categories and manufacturing networks, PROFIL 17, Linkoping Institute of Technology, Linkoping.

Saaty, T.L., (1990), "How to make a decision: the analytic hierarchy process". *European Journal of Operational Research,* 48, pp. 9-26.

Santos, F., C., A., (2000), Integration of human resource management and competitive priorities of manufacturing strategy, *International Journal of Operations & Production Management*, 20(5), pp. 610- 628.

Schroeder, D.M., Congden, S.W., Gopinath, C., (1995), Linking competitive strategy and manufacturing process technology, *Journal of Management Studies*, 32(2), pp. 163-189.

Senge, P.N., (1990), The leaders new work: building learning organisations, *Sloan Management Review*, 32(1), pp. 7-23.

Seth, D., and Tripathi, D., (2005), Relationship between TQM and TPM implementation factors and business performance of manufacturing industry in Indian context, *International Journal of Quality & Reliability Management*, 22(3), pp. 256-277.

Suwignjo, P., Bititci, U.S., Carrie, A.S., (2000), Quantitative models for performance measurement systems, *International Journal of Production Economics*, 64, pp.231-241.

Suzuki, T., (1994), TPM in Process Industries, Productivity Press, Cambridge, MA.

Sveiby, K.E., 1997, The intangible asset monitor, *Journal of Human Resource Costing and Accounting*, 2(1), pp.73-97.

Tsang, A.H.C., Chan, P.K., (2000), TPM implementation in China: a case study, International Journal of Quality & Reliability Management, 17, 2, 144-57.

Vollmann, T., Berry, W., Whybark, C., (1997), Manufacturing Planning and Control Systems, Irwin/McGraw-Hill, New York, NY.

Warnecke, H. J., and Hueser, M., (1994), "Technologies of Advanced Manufacturing", *Organization and Management of Advanced Manufacturing*, W. Karwowski and G. Salvendy (Eds), NY, John Wiley.

Willmott, P.,(1997), Total Productive Maintenance: the Western Way, Butterworth-Heinemann, Oxford.

Woodhouse, J., (2001), "Asset Management", *The Woodhouse Partnership Ltd*, online accessed on September 10, 2005 at http://www.plant-maintenance.com/articles/AMbasicintro.pdf

Yamashina, H., (2000), Challenge to world class manufacturing, *International Journal of Quality & Reliability Management*, 17(2), pp. 132-143.

Zhang, Z., Waszink, A., Wijngaard, J., (2000), An instrument for measuring TQM implementation for Chinese manufacturing companies, *International Journal of Quality & Reliability Management*, 17(7), pp. 730-755.

Zutshi, A., and Sohal, A. S., (2005), Integrated management system: The experiences of three Australian organisations, *Journal of Manufacturing Technology Management*, 16(2), pp. 211-232.

APPENDIX 1

Processes	Asset Performance Criteria						IS/IT Resources			
	Efficiency	Effectiveness	Availability	Compliance	Reliability		Skills	Applications	Hardware	Information
Planning and Design Perspective										
Asset Operation/Service Standards Definition										
Asset Design and Configuration Management										
Production Scheduling										
Performance Perspective										
Operational Requirements Compliance										
Asset Performance Monitoring										
Asset Condition Monitoring										
Hazard Identification										
Asset Depreciation and Deterioration Trending										
Support Perspective										
Asset Failure Prediction and Maintenance Planning										
Asset Failure Root Cause Analysis										
Asset Maintenance Workflow Execution										
Asset Lifecycle Support Resources Management										
Asset Lifecycle Budgeting and Cost Benefit Analysis										
Operational Risk Assessment										
Asset Treatment Options and Tradeoffs										
Materials Management										
Stakeholders Perspective										
Third Party Services Management										
Asset Operator Training and Education										
Environmental and OH&S Compliance										
Stakeholder Advise, Assistance, and Collaboration										
Contract Management										
Organisational Learning Perspective										
Lifecycle Evaluation and Recommendations										
Asset Lifecycle Cost Planning and Expenditure										
Asset Lifecycle Knowledge Management										
Asset Register Management										
Project Management										
Asset Performance Reporting										
Competitiveness Perspective										
Strategic Asset Management Planning										
Strategic Business Audit										
Business Partner Integration										
Technology Perspective										
Strategic IT/IS Planning										
Information Acquisition, Integration and Storage										
Technology Direction Assessment										
Appropriateness of Technology to AM Processes										