ICT BASED ASSET MANAGEMENT FRAMEWORK

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Abstract: Manufacturing and production environment is subjected to radical change. Impetus to this change has been fuelled by intensely competitive liberalised markets; with technological advances promising enhanced services and improved asset infrastructure and plant performance. This emergent re-organisation has a direct influence on economic incentives associated with the design and management of asset equipment and infrastructures, for continuous availability of these assets is crucial to profitability and efficiency of the business. As a consequence, engineering enterprises are faced with new challenges of safeguarding the technical integrity of these assets, and the coordination of support mechanisms required to keep these assets in running condition. At present, there is insufficient understanding of optimised technology exploitation for realisation of these processes; and theory and model development is required to gain understanding that is a prerequisite to influencing and controlling asset operation to the best advantage of the business. This paper aims to make a fundamental contribution to the development and application of ICTs for asset management, by investigating the interrelations between changing asset design, production demand and supply management, maintenance demands, asset operation and process control structures, technological innovations, and the support processes governing asset operation in manufacturing, production and service industries. It takes lifecycle perspective of asset management by addressing economic and performance tradeoffs, decision support, information flows, and process re-engineering needs of superior asset design, operation, maintenance, decommissioning, and renewal.

1 INTRODUCTION

Management of plant and equipment assets to maintain peak performance is vital for productivity and profitability of a manufacturing business. That is why businesses strive for developing best practices, advanced software applications, hardware, cutting edge management practices to manage and keep these vital assets in operating conditions. Several concepts, strategies and methodologies have been developed to address the continuously changing and increasingly complex manufacturing and production paradigms. However recent research shows that manufacturing systems, which are getting increasingly complex due to technological advances; do not provide an elevated level of customer satisfaction in terms of performance and effectiveness as their operation and support is also getting extremely costly (Blanchard 1997).

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. 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 (Sandberg 1994; Albino et al 1998). For example, a typical water pump station in Australia is located away from major infrastructure and immediate transportation and labour is generally limited, equipment on the station are specialised and the demand for water supply is continuous for twenty four hours a day, seven days a week. This requires continuous monitoring of asset operation in order to sense asset

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failures as soon as possible. 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 these production irregularities and disturbances is necessary for JIT (Just in Time) 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 asset maintenance is considered as a support function, non-productive and a non core process that adds little value to the business. Jonsson (1999) argues that this is largely due to lack of acknowledgement of the direct connection between maintenance and profitability. Al-Najjar (1996) goes a step further and claims that most businesses do not have a significant control of costs incurred by planned or unplanned stoppages and quality problems. However, not only that asset management and for that matter maintenance has a direct link and impact on business direction and strategy, at the same time management needs to have a lifecycle perspective of asset utilisation to make rational decisions to reduce the chances of errors in investment and production management. 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. In addition, asset operation, behaviour, and maintenance knowledge gained is not used for decision support for future investments, projects, and asset management initiatives. In effect, asset management strategies have little provision for sustainability of long term strategic business direction; consequently businesses are,

a. Unable to forecast and monitor the usage of their assets effectively
b. Unaware of resource capabilities and its impact on other areas of business.
c. Not able to mange resources properly due to duplication and underutilisation
d. Unaware of the cost effective maintenance strategies that best suit the business
e. Not able to fully utilise information captured to ensure smooth asset operation
f. Not able to plan an effective "exit strategy" for obsolete assets; through technology refresh or through end of need.
g. Not able to 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.

This research paper investigates how ICTs (Information and Communication Technologies) provide for an integrated approach to asset management. The resulting business model encompasses cost effective asset operation and maintenance with improved performance levels. It takes lifecycle perspective of asset management by addressing economic and performance tradeoffs, decision support, information flows, and process re-engineering needs of superior asset design, operation, maintenance, decommissioning, and renewal.

2 ASSET MANAGEMENT

There are different views about asset management, which are, however, largely dependent upon the nature of the industry that the business operates in and what that the business considers as an 'asset'. An asset lifecycle starts at the time of designing the manufacturing or production system, and typically illustrates, stages such as, asset commissioning, operation, maintenance, decommissioning and replacement (figure 1).

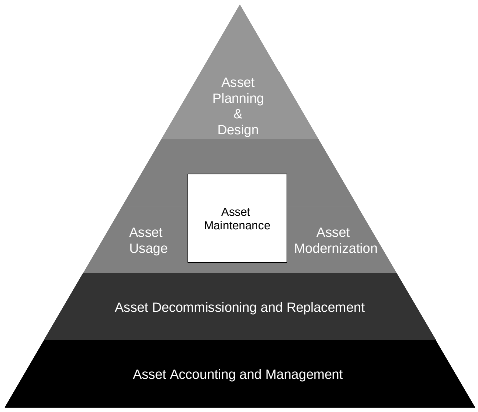


Figure 1: Asset Lifecycle Perspective
Source Grobholz (1988: p. 55)

Table 1 below further breaks down these stages and presents a description of the activities associated with each stage of an asset lifecycle management.

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

	Functions	Description
1	**Functional specifications**	Decide what each asset must do to make the production and manufacturing processes value added
2	**Design specifications**	Decide what the configuration of the asset must be in order to meet functional specifications
3	**Acquisition and 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 of the assets when they can no longer fulfil the required functions or when they are no longer needed
7	**Compliance**	Monitor and ensure compliance with laws and regulations governing the use of the assets

2.1 Asset

Assets can be mobile as well as fixed. Mobile assets may change their location geographically as, whereas fixed assets remain static, such as manufacturing plants, railway engines and carriages, aircrafts, water pumps, and oil and gas rigs. Nevertheless, the following definition guides this paper.

“A 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).

2.2 Asset

In consonance with the above definition of assets, asset management is

“the 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 company’s physical assets”. (Woodhouse 2001)

2.3 Asset Management is a Strategic Process

Asset management is a strategic process, as informed and proactive view on asset performance and associated costs provides for the necessary underpinnings for effective enterprise wide resource planning and management. Market demand and supply dynamics derive product and services design, and this product and services design derives production. Production specifies the types and design of assets to be used in production along with the operational workload of how much to produce. Operational workload and asset design specify the maintenance demands to keep the assets in running condition, whereas, maintenance determines the future production capacity of the assets. Therefore, asset management ought to be derived from the business goals and objectives; though it is itself dependent on methodical evaluation of manufacturing systems performance, workload, and associated costs. Fundamental aim of asset management processes is the continuous availability of service, production and manufacturing provisions of assets. The asset management process is policy driven, information intensive, and is aimed at achieving cost effective peak asset performance.

3 CHANGING FACES OF MANUFACTURING PARADIGM

Manufacturing and production of products and services is subjected to intense changes in technology and intensely varying market demands (Matson and McFarlane 1999; Beach et al 2000). The resulting effect on industries is one of intense competition that dictates a shift towards renewal of products and services at regular intervals, which consequently is forcing businesses to innovate and update their offerings with added value and features. Shortened product lifecycles and continuous updating of products demands increased and enhanced asset operation capacity, which means assets also have to be upgraded continuously. Therefore, this continuous renewal on one hand impacts corporate and management strategies; and on the other demands equally innovative manufacturing and production paradigms, production philosophies, and processes. According to Taskinen and Smeds (1999), technological advances are fast disappearing stock to production business models. Supply and demand mechanisms are changing so fast that, it is becoming critical for manufacturing strategies embrace just in time types of philosophies. Automotive and electronic products like cars, mobiles and computers are some examples of this variation in supply and demand. In these circumstances, it’s the ability of manufacturing businesses to adapt quickly to changing circumstances that will differentiate the leaders from the also rans (Forsythe 1997).

Koc and Lee (2003) summarise these changes in manufacturing paradigm and predicts that the emergent paradigm is ‘e-intelligent’ (Figure 2). The authors argue that the so called e-intelligent paradigm is the one in which there is 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 means a shift that is not just outwardly innovative, as in terms of product innovation, but is also inwardly creative, that is to use the same technologies for process re-engineering and innovation. Lee (2003) terms this shift as the “5Ps,” namely predictability, producibility, productivity, pollution prevention, and performance. These characteristics establish the properties of the future e-enabled integrated asset management paradigm. In essence, the emergent e-intelligent paradigm demands an elevated level of expertise and technology that could allow for realisation of distributed processes which contribute towards value creation for the business.

In such manufacturing and production environments that are riddled with continuous change, stability in manufacturing and quality processes needs to be materialised as soon as possible (Warnecke and Hueser 1994). In businesses like utilities, where demand for products or a service is continuous for twenty four hours day, disruptions and interruptions have a devastating effect on revenues as well as customer relationship (Almgren 1999). Therefore businesses not only need to keep their vital assets that are utilised to produce goods and services in operating condition, but at the same time need to have reliable and efficient support processes. This, however, is a daunting task, for managing these vital assets is much more than just automation of existing processes or compilation of existing information. A comprehensive asset management strategy entails changes in ways the business is conducted, decision are made, data is collected and processed, and information is communicated within the organisation and with the business partners. Effective asset management therefore, requires strong technological and informational base that realises quality business processes and communication channels within the business, as well as with external stakeholders such as business partners, customers, governmental watchdogs and others.

	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 2: Evolution in Product Innovation and Manufacturing
Source (Koc and Lee 2003)

4 ROLE OF ASSET MAINTENANCE IN ASSET MANUFACTURING

In the asset lifecycle, asset design is influenced by the types of products or services that the business provides; the speed and quality with which these products and services are produced; and the financial, legislative, and environmental constraints that the business operates in. Asset operation, however, is influenced by number of actors such as sales forecasting, production workload, decisions on resource allocation, and the physical operating environment. Asset maintenance runs simultaneously with asset operation, and is aimed at ensuring the continuous and reliable availability of operational assets. While, maintenance activities have been carried out ever since advent of manufacturing; modelling of an all inclusive and efficient maintenance system has yet to come to fruition (Duffuaa and Al-Sultan 1997; Yamashina and Otani 2001). This is mainly due to continuously changing and increasing complexity of asset equipment, and the stochastic nature or the unpredictability of the environment in which assets operate, along with the difficulty to quantify the output of the maintenance process itself (Duffuaa et al 1999).

Asset maintenance is the most complex sub process of asset management, as it engages a number of different actions and tasks. The aim of maintenance however, is to maintain the operational reliability of assets. Maintenance strategies and methodologies vary according to the types of assets used by different industries. These strategies include condition-based maintenance, failure-based maintenance, preventive maintenance, predictive maintenance, reactive maintenance and corrective maintenance (i.e. Horner et al., 1997; Moubray, 1997; Nakajima, 1989). These strategies represent four different maintenance philosophies. Table 2 presents the scope, objectives, and application modes of these viewpoints. It is evident from table 2 that these ideologies represent two main approaches to maintenance, i.e. proactive and reactive. This factor represents the most important determinant of the way a business views asset management, for these approaches illustrate whether the business views asset maintenance as an 'investment' or a 'cost' that is required to keep the assets in operating conditions. Businesses that view maintenance as an investment, manage their assets proactively and their decision making corresponds to a preventative or predictive stance. They prefer to invest in time based periodic maintenance and aim for fixing a failure condition as it develops, thereby aiming to sustain and improve production efficiency. On the other hand those businesses that view maintenance as a cost believe in corrective approaches and operate their assets to failure. This view is further presented in the survey conduct by Intentia (2004) (Table 3).

Table 2: Reliability Paradigms
Source (Honkanen 2004)

	RCM	TPM	Reliability Engineering	Control Engineering
Scope	Machine functionality	Machine efficiency	Machine durability	Machine controllability
Maintenance objective according to paradigm	Keeping the machine functionality at the required level	Maximising the machine capacity by equipment efficiency	Enhancing the machine life-time and reliability	Maintaining the production process state
Failure or failed state	Inability to fulfil user-required functional capability	Loss or reduction of a capability with regard to optimal performance	Loss of a function	Statistically abnormal process state
Life-cycle phase being applied	At machine design and operation phase	At the machine operation phase	At the machine design phase	At the machine operation phase
Context	Single machines, users, and plant	Single machines, users, and plant	Multiple machines, users, and plants	Single production process
Applicable methods	Proactive maintenance by preventing failures before they first occur	Personnel participation in continuous improvement for preventing sudden and chronic failures	Design-out failures with enhanced component design and materials	Control of process states and compensation of disturbances by mathematical algorithms.

The survey reveals that 49.8% of all survey respondents indicated that they were of the view that maintenance was an investment. On the whole, large organizations (over 1000 employees) were the most likely to view maintenance as an investment, with 56.4% holding that view. A similar percentage of organizations with 501-1000 employees were of the same opinion (56.4%). Small organizations (under 250 employees) were the most likely to view maintenance as a cost (41.8%). The high percentage of small organizations viewing maintenance as a cost indicates that smaller organizations are more likely to work in breakdown mode rather than in a preventive or predictive mode. Another important indicator revealed in this survey is that large sized businesses follow a proactive approach to asset management; since they have the financial luxury to invest in support technological infrastructure that enables them to be proactive. On the other hand, small to medium sized business opt for reactive or corrective maintenance, for they do not have the necessary resources. Nevertheless, important point to note is that these two divergent view points have different expectations of support processes and have different information needs for asset lifecycle decision support. Nevertheless, maintenance strategy is dependent upon the types of assets and nature of industry, for example, for assets in airline industry, or bridges and other infrastructures preventive maintenance suits better, and for operational military assets corrective maintenance is more useful. This, however, is also dependent upon the availability of maintenance expertise, financial constraints, availability of spares, and the cost benefit analysis and tradeoffs between asset maintenance and asset renewal or upgrade.

Table 3: Maintenance is an Investment or a Cost
Source (Intentia 2004)

Organisation Size	Strongly Agree Cost	Generally Agree Cost	In-different	Generally Agree Investment	Strongly Agree Investment
1 – 250	12.1%	29.7%	12.6%	27.6%	17.6%
251 – 500	7.0%	25.2%	14.8%	31.3%	21.%
501 – 1000	7.9%	27.0%	9.5%	39.7%	15.9%
1000+	14.5%	23.6%	5.5%	38.2%	18.2%
Total	10.6%	27.5%	11.9%	31.4%	18.4%

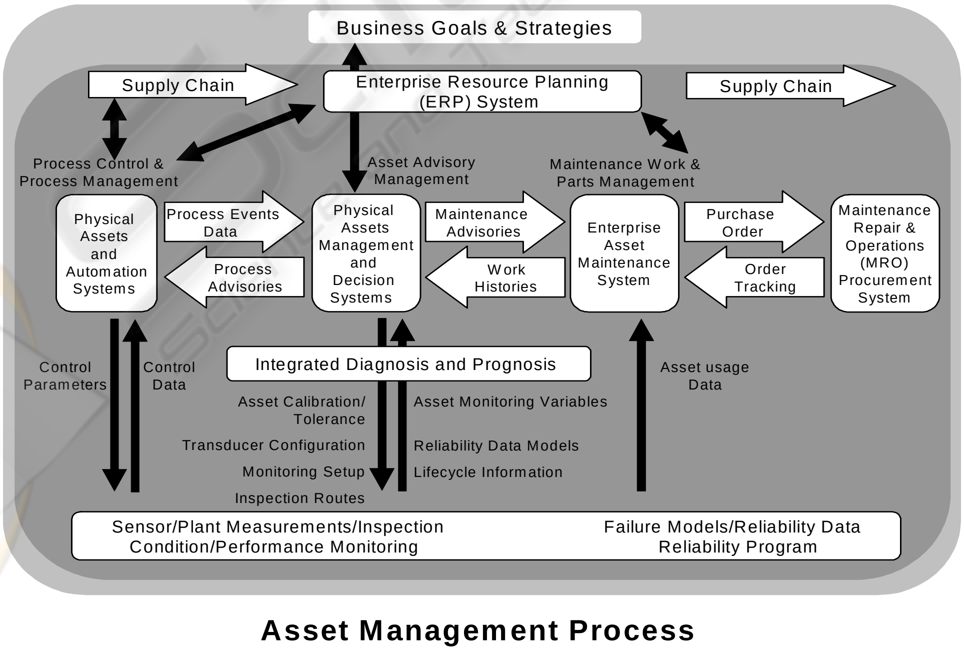


Figure 3: Source (Adopted and Modified from Bever 2000)

5 NATURE OF EMERGING ASSET MANAGEMENT SYSTEMS

Bever (2000) points out some of the intricacies of asset management and its interrelationships with other processes and systems (Figure 3). He argues that maintenance strategies that once were run-to-failure are now fast changing to being condition based. There is a need to integrate asset management systems and computerized maintenance management systems (CMMS) to support maintenance scheduling, maintenance workflow management, inventory management, and purchasing; and to integrate these functions with production scheduling, and manufacturing. At the same time, businesses are looking for ways to provide direct connections from their asset management systems to Maintenance, Repair, and Overhaul/Operations (MRO) procurement systems, which may allow for paperless purchasing of parts and offer considerable time and cost savings compared with traditional purchasing methods.

Sandberg (1994) argues that contemporary paradigm demands an elevated ability and knowledge to incessantly support asset management processes, with support in terms of data acquisition, real-time monitoring, and computer supported categorization and recording of divergences from standard operations. However, to support these objectives, smart ICT based applications are needed to allow for proactive asset management approaches, such as performance degradation measurement, fault or failure discovery, self maintenance, and remote diagnostics. These features allow manufacturing and process industries to guarantee an elevated asset and process performance and ultimately eliminate unnecessary system breakdowns (Lee 2003); thereby stressing businesses to be more responsiveness and agile in their quest for asset management. In the emergent paradigm, businesses need to focus on two areas; first, they need to manage assets from a strategic perspective and treat them as business enablers rather than managing them from a maintenance perspective, and second, they need to have a focused approach on the inter-relations of asset management processes with other business processes. This requires integration and synchronization of management practices and policies from specification of functional specifications if an asset to asset decommissioning. However, in order to achieve this businesses require,

a. Complete, current, and accurate information on each asset, including its current configuration, location, workload, health status and history, and the physical environment that it operates in.
b. A certain level of intelligence embedded with the asset, such that it itself reports any malfunctioning in its operating environment or in its own behaviour.
c. An integrated approach to economic and performance tradeoffs and lifecycle decisions, through
   (i) Organization of information relating to asset condition and performance for condition assessment and trend analysis;
   (ii) Analytic models that predict future changes in asset condition, as well as the variations in support mechanisms to forecast and plan for resources.
   (iii) Cost benefit decision support for asset repair, maintenance, renewal, and decommissioning.
d. Legacy systems and applications for support processes such as spares supply chain management, maintenance workflow management, customer relationship management, and enterprise resource planning.

6 AN ICT BASED ASSET MANAGEMENT MODEL

From the above discussion it is evident that businesses need to view assets as mission enablers, which support and contribute towards attaining organisational goals, realising business processes, and adding value to productivity. An attempt to resolve the issues at hand with a focus on only technological aspects will not yield required results, and it is therefore important to develop an understanding of cultural, economic, and process implications of asset operation; for each of these factors impact the realisation of the others. At the same time it is important to take a systems view of the whole production paradigm, where asset management acts a sub system within the whole system of the business. This allows for understanding the interrelations of the asset management with other organisational systems and also provides the foundations of assets as business enablers. The figure 4 below presents a systems view of the production paradigm that highlights the interrelationships of asset usage and management. It consists of three major areas, i.e. production, asset design and asset maintenance. The figure describes production acting on information inputs from sales forecast and production schedules, or on

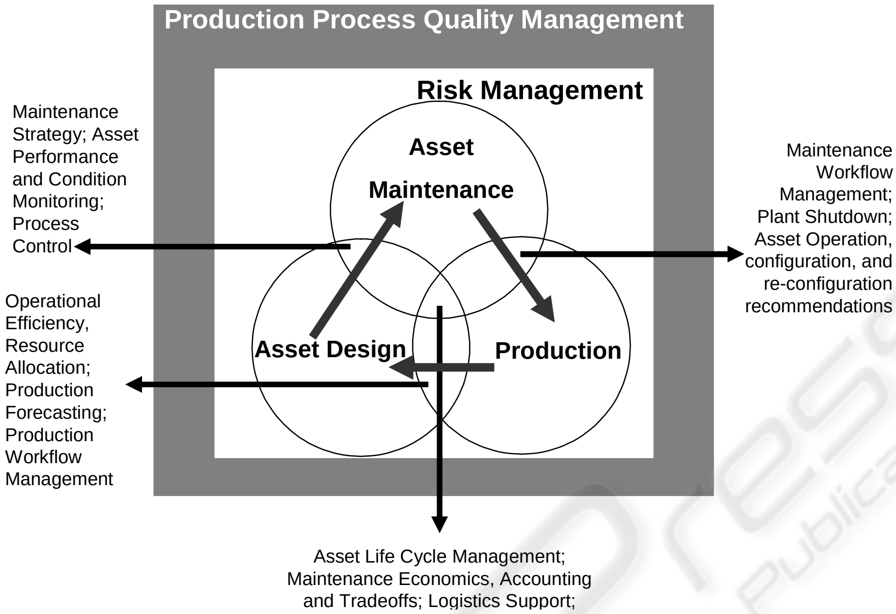
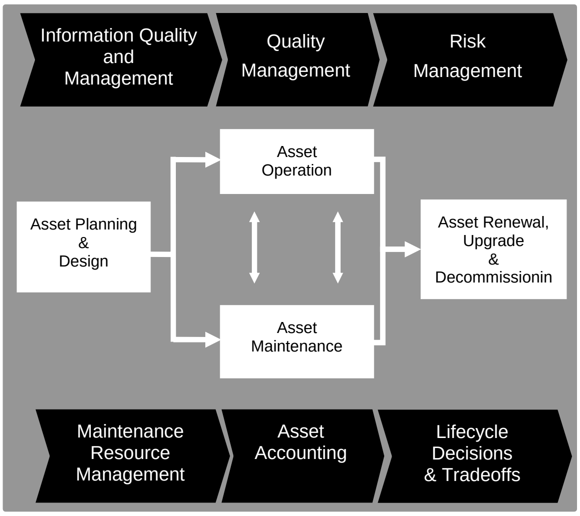


Figure 4: Systems View of Asset Management

recommendations from research and development on the launch of new products and services.

These forecasts recommendations have their roots in other business activities such as marketing, business strategy and direction. Nevertheless, these indications from sales and R&D provide indicators for the design of asset configuration and specify the workload on assets to fulfil the requests of sales forecasting. An important driver of asset design, along with others, is cost or budgetary constraints. Assets operate in changing physical environment and with varying workload, which also impacts the reliable and continuous operation of assets over a period of time. Assets are mechanical, electrical or constructed systems and have a finite life and as they go through the process of deterioration. This deterioration process is dependent upon production system design parameters, workload, material used in putting the assets together, and the environment that they operate in. These parameters derive the maintenance of assets; however, maintenance itself is motivated by different cost and efficiency assumptions, such as corrective maintenance, periodic maintenance, proactive maintenance etc. Maintenance in return recommends asset shutdown schedules, changes to asset configuration, remnant lifecycle of assets, asset decommissioning and renewal, etc., which obviously impact the future production, manufacturing and service provision possibilities. The shaded areas in the above figure describe the logical outputs from the interaction of two sub systems, while the shaded area common between all the three areas indicates the interrelation of asset management process with other business processes, such as supply chain management, enterprise resource planning, and customer relationship management.

Having a systems view facilitates a solution focus rather than application focus of the issues at hand in this paper. This solution focus provides a lifecycle perspective of asset management rather than focusing on a particular aspect of asset management, such as asset maintenance. Asset management therefore requires a systematic step by step approach that not only addresses each stage of asset lifecycle management, but at the same time contributes towards the organisational goals and objectives. Figure 5 presents an attempt to map the demands of asset management process onto technology. In the figure the left hand side illustrates the essential elements of an asset lifecycle, whereas, the right hand side provides the building blocks to address the demands of the left hand side.



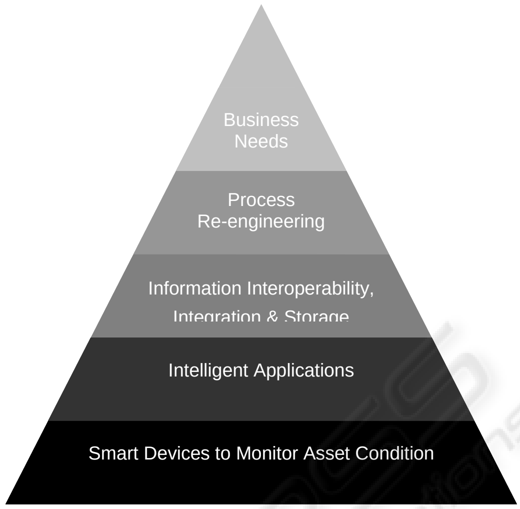


Figure 5: Technological Approach to Asset Management

This approach demands certain level of intelligence to be introduced at the asset level, such that the asset predicts and determines its own maintenance demands and triggers associated support processes. As a matter of fact, the emerging paradigm demands the assets to maintain their health and operational capacity just like the human do to safeguard against disease and loss of productivity. However, humans could be considered as active machines since they can process information, whereas assets are passive and are unable to process information at their own. Therefore, innovative mechanisms are needed to be embedded with the assets that do not interrupt or hamper asset performance in any way, but provide the asset with an ability to 'think for themselves', for example mounting devices on the assets that are microprocessor equipped and are able to capture information from asset condition monitoring sensors and processing it. Such introduction of intelligence will provide important information on operating environment, and will also allow for monitor the behaviour of asset operation; which could be used by intelligent software applications to analyse trends and performance behaviours. These trends and analysis will lead to detection of a failure conditions that constitute vital foundation for decision support for asset life cycle management as well as for initiation of asset support processes.

This framework has strategic orientations and provides for standardisation of technology and practice for business integration and process innovation. It stresses standardization at the base level, which allows for information integration, exchange and interoperability within and between systems at the processing level. This information could then be used for the process innovation and optimization. Mapping this framework on to asset management paradigm advocates standardisation of information and information acquisition systems at the asset operation level. With this foundation, when information moves to higher levels in the framework it serves as facilitator for mission enabling asset management. A detailed asset management model is presented in the figure 6 below. This model presents asset management as a core business activity and describes an integrated asset management view with other processes such as enterprise planning, enterprise decision support, production, logistics and customer relationship. This model integrates asset management activities with operational and administrative activities in the enterprise and highlights the impacts of asset operation on enterprise decision support and planning at each stage in asset life cycle. It is quantitative and information driven that describes asset management in terms of the objectives of the corporate strategy. This model has an ERP system at its core, as contemporary ERP systems such as SAP R/3 incorporate asset management modules and thus facilitate in the lifecycle management of assets

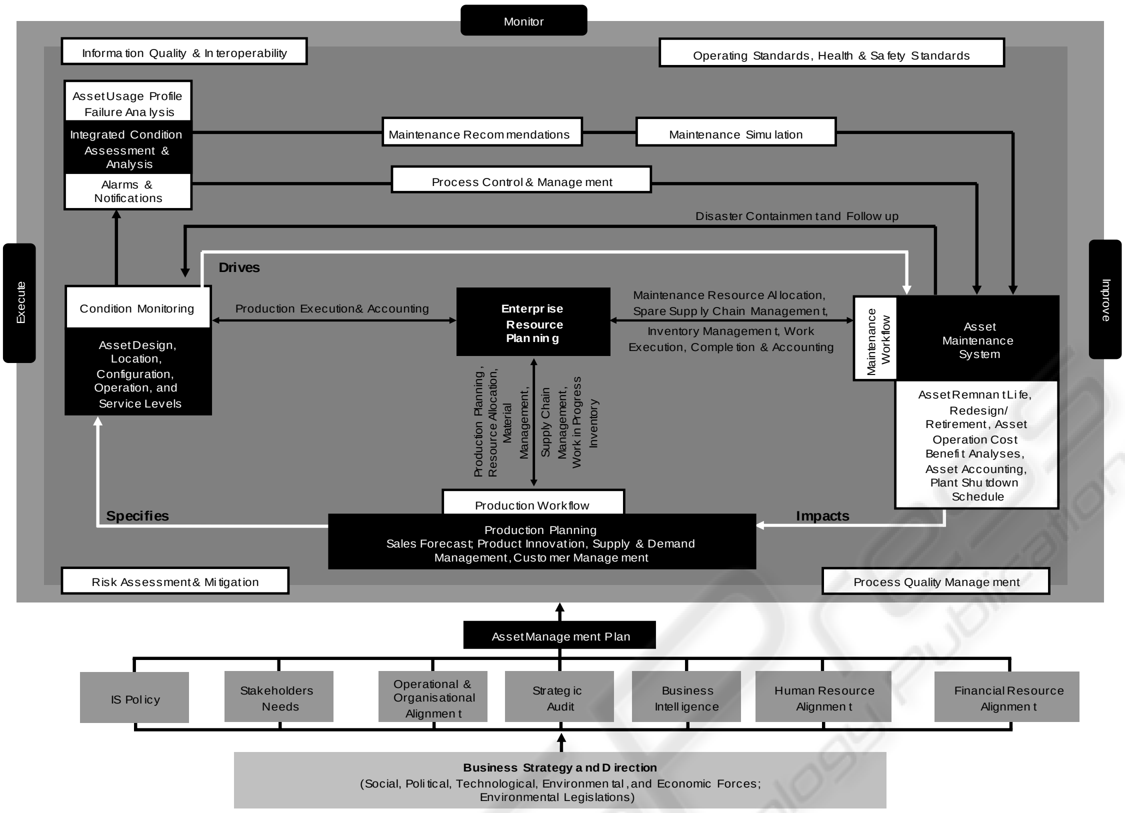


Figure 6: ICT Enabled Asset Management Model

The model highlights the importance of comprehensive information regarding the condition of an asset as the necessary foundation of an efficient asset management strategy. This information provides the basis for asset operation profiling that not only warns of an eminent failure condition developing, but also helps in determining the maintenance demands and future utilisation of the asset. Maintenance information along with the asset usage patterns and trend analyses aids in enterprise decision support encompassing asset renewal, up-gradation, asset depreciation, replenishment and retirement. These indicators also provide for planning of plant shutdown and changes required in the design or configuration of an asset. The model provides a strategic perspective to asset management provides business mangers with vital foundations for decision support such as what asset to service and at what time; how will the asset performance affect work management; what are the financial implications of asset operation; and how to reuse asset operation and maintenance knowledge for future projects.

7 CONCLUSION

This paper illustrates that any attempt to managing assets needs to have a systems perspective of the entire business. This perspective aids business managers in drawing an asset management strategy that provides a life cycle perspective of assets as mission enablers. It illustrates the ICT enabled business blocks through out the asset lifecycle. The model provides essential underpinnings for systems development by indicating a road map for the asset management process and the critical variables required for efficient asset management.

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REFERENCES

Albino, V., Garavelli, A. C., and Okogbaa, O.G. (1998). “Vulnerability of production systems with multi-supplier network: a case study.” *International Journal of Production Research*, 36(11), pp.3055-3066.

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.

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.

Beach, R., Muhlemann, A. P., and Price, D.H.R., (2000). “Manufacturing operations and strategic flexibility: survey and cases.” *International Journal of Operations & Production Management*, 20(1), pp.7-30.

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

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.

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. 207-19.

Duffuaa, S.O., Cambel, J.D., and Raouf, A., (1999), “*Planning and Control of Maintenance Systems: Modelling and Analysis*”, John Wiley & Sons, New York.

Grobholz, H. R., (1988), “*Managementaufgabe Instandhaltung”*, 2 Auflage

Honkanen, T., (2004), “Modelling Industrial Maintenance Systems and the Effects of Automatic Condition Monitoring”, Phd Thesis, *Helsinki University of Technology*, Information and Computer Systems in Automation

Horner, R., El-Haram, M., and Munns, A., (1997), “Building maintenance strategy: a new management approach”, *Journal of Quality in Maintenance Engineering*, 3(4), pp. 273-280.

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

Intentia, (2004), “Enterprise Asset Management Benchmark Survey: How do you measure your maintenance performance?”, *The Maintenance Journal*. February, pp.52 -70.

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

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, 2004.

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, 2004.

Matson, J., and McFarlane, D., (1998), “Tools for Assessing the Responsiveness of Existing Production Operations”, *IEE Workshop on Responsiveness in Manufacturing*, London, UK, February.

Moubray, J., (1991), “*Reliability-centred Maintenance*”, Oxford, Butterworth-Heinemann Ltd.

Moubray, J., (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, 2004.

Nakajima, S., (Eds). (1989), “*TPM Development Program: Implementing Total Productive Maintenance*”, Cambridge, Productivity Press, Inc.

Sandberg, U., (1994), “The Coupling Between Process and Product Quality – The interplay Between Maintenance and Quality in Manufacturing”, *Euromaintenance ´94*, Amsterdam.

Taskinen, T., and Smeds R., (1999), “Measuring change project management in manufacturing.” *International Journal of Operations & Production Management*, 19(11), pp. 168-1187.

Warnecke, H. J., and Hueser, M., (1994), “Technologies of Advanced Manufacturing”, *Organization and Management of Advanced Manufacturing*, W. Karwowski and G. Salvendy (Eds), New York, John Wiley & Sons INC:.

Woodhouse, J., (2001), “Asset Management”, *The Woodhouse Partnership Ltd*, online accessed on May 10, 2004 at http://www.plant-maintenance.com/articles/AMbasicintro.pdf

Yamashina, H., and Otani, S., (2001), “Optimal Preventive Maintenance Planning For Multiple Elevators”, *Journal of Quality in Maintenance Engineering*, 7(2), pp. 128-50.