A DATA QUALITY MODEL FOR ASSET MANAGEMENT IN ENGINEERING ORGANISATIONS

(Completed Paper)

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Abstract: Data Quality (DQ) is a critical issue for effective asset management. DQ problems can result in severe negative consequences for an organisation. Several research studies have indicated that most organizations have DQ problems. This paper aims to explore DQ issues associated with the implementation of Enterprise Asset Management (EAM) systems. The study applies a DQ research framework for Asset Management (AM) in a preliminary case study of two large Australian utility organisations. The findings of the study suggest that the importance of DQ issues for the implementation of EAM systems is often overlooked; thus, there is a need for more scrutinised studies in order to raise general awareness.

Key Words: Data Quality, Data Quality Model, Asset Management, Enterprise Asset Management

INTRODUCTION

Industry has recently put a strong emphasis on to the area of asset management (AM). In order for organizations to generate revenue they need to utilize assets in an effective and efficient way. Often the success of an enterprise depends largely on its ability to utilize assets efficiently. Therefore, asset management has been regarded as an essential business process in many organizations. Furthermore, as companies today are running leaner than ever before, physical assets such as equipment, plant and facilities are being pushed to their limits, as engineering enterprises attempt to continuously drive more productivity out of their equipment, in order to improve their bottom lines. Consequently, physical asset management is moving to the forefront of contributing to an organization's financial objectives. Effective physical asset management optimizes utilization, increases output, maximizes availability, and lengthens asset lifespan, while simultaneously minimizing costs.

There is strong evidence that most organisations have far more data than they possibly use; yet, at the same time, they do not have the data they really need [26]. Modern organizations, both public and private, are continually generating large volumes of data. On a personal level, according to Gartner Research [39], each person on the planet generates an average of 250 Mbytes of data per annum, with this volume doubling each year. At the organizational level, there are incredibly large amounts of data, including structured and unstructured, enduring and temporal, content data, and an increasing amount of structural and discovery metadata. Data and information have become the lifeblood of the organization and organizations are insatiably generating more and more data. Outside the business environment, there is an increasing number of embedded systems such as condition monitoring systems in ships, aircraft, process plants and other engineering assets, all producing gargantuan amounts of data. Despite this apparent explosion in the generation of data it appears that, at the management level, executives are not confident that they have enough correct, reliable, consistent and timely data upon which to make decisions.

This lack of data visibility and control often leads to decisions being made more on the basis of judgment rather than being data driven. This can lead to less effective strategic business decisions, an inability to reengineer, mistrust between internal organizational units, increased costs, customer dissatisfaction, and loss of revenue. In some cases, it could also lead to catastrophic consequences such massive power failures, industrial or aviation disasters. Data and information are often used synonymously. In practice, managers differentiate information from data intuitively, and describe information as data that has been processed. Unless specified otherwise, this paper will use data interchangeably with information.

BACKGROUND

Numerous researchers have attempted to define data quality and to identify its dimensions [24][21][44][14][41][45][36][22]. Traditionally, data quality has been described from the perspective of accuracy. However, this description has been challenged by a number of researchers [40][11][31][42][3][29], from the point of view that data quality should be defined beyond the accuracy dimension. Although there is no universal agreement on the meaning of “quality data”, a common understanding found in the literature is that: “*quality data are data that are fit for use by the data consumer*” - Wang and Strong [45]. Orr [29] also suggests that the issue of data quality is intertwined with how users actually use the data in the system, since the users are the ultimate judges of the quality of the data produced for them. With the aim of improving data quality, Wang [43] suggests a Total Data Quality Management (TDQM) framework (define, measure, analyze and improve) for continuously managing data quality problems.

Dimensions of data quality typically include accuracy, reliability, importance, consistency, precision, timeliness, fineness, understandability, conciseness, and usefulness [41]. Wand and Wang [41] use ontological concepts to define data quality dimensions: completeness, unambiguousness, meaningfulness, and correctness. Wang and Strong [45] categorize data quality into four dimensions: intrinsic, contextual, representational, and through accessibility. Shanks and Darke [36] use semiotic theory to divide data quality into four levels: syntactic, semantic, pragmatic, and social. Recently, Kahn et al. [22] have used product and service quality theory to categorize information quality into four categories: sound, useful, dependable, and usable.

Maintaining the quality of data is often acknowledged as problematic, but is also seen as critical to effective decision-making. Examples of the many factors that can impede data quality are identified within various elements of the data quality literature. These include: inadequate management structures for ensuring complete, timely and accurate reporting of data; inadequate rules, training, and procedural guidelines for those involved in data collection; fragmentation and inconsistencies among the services associated with data collection; and the requirement for new management methods which utilize accurate and relevant data to support the dynamic management environment.

Clearly, personnel management and organizational factors, as well as effective technological mechanisms, affect the ability to maintain data quality. Wang et al. [43] clarify this relationship by drawing an analogy between manufacturing and the production of data. In this way they derive a hierarchy, adapted from international ISO 8402 product quality standards, of responsibilities for data quality, ranging from management processes down to individual procedures and mechanisms. Their framework specifies a top management role for data quality policy, i.e. overall intention and direction related to data quality, and a data quality management function to determine how that policy is to be implemented. This, in turn, should result in a data quality system for implementing data quality management, within which data quality control is enforced through operational techniques and activities. Data quality assurance then comprises all of the planned and systematic actions required to provide confidence that data meet the quality requirements.

Total Data Quality Management and information manufacturing systems

Wang [43] drew an analogy between total quality management (TQM) of manufactured physical products and total data quality management (TDQM). He argued that product manufacturing can be viewed as a processing system that acts on raw materials to produce physical products. Analogously, information manufacturing can be viewed as a processing system that acts on raw data to produce information products (IP) (as shown in Figure 1).

	Product Manufacturing	**Information Manufacturing**
Input	Raw Materials	Raw Data
Process	Assembly Line	Information System
Output	Physical Products	Information Products

Figure 1: Product vs. information manufacturing (Source: Wang [43])

Using this analogy, he proposed an information manufacturing system. He adapted W. E. Deming's method of defining, measuring, analyzing, and improving products, to apply them to the information-manufacturing environment. Figure 2 illustrates the TDQM cycle of continuous improvement and delivery of high-quality information products.

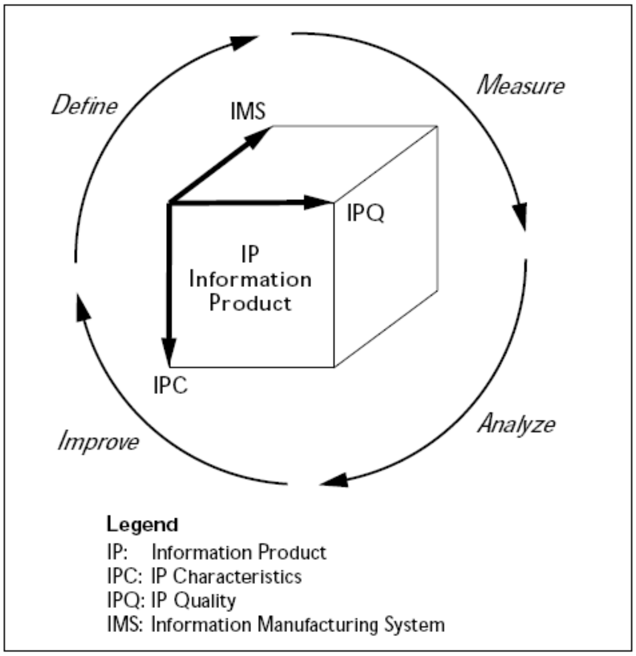

Figure 2: TDQM Cycle (Source: Wang [43])

The following DQ factors table (Figure 3) summarizes findings from the literature, in order to understand the emerging DQ issues [11][43][35][12][33].

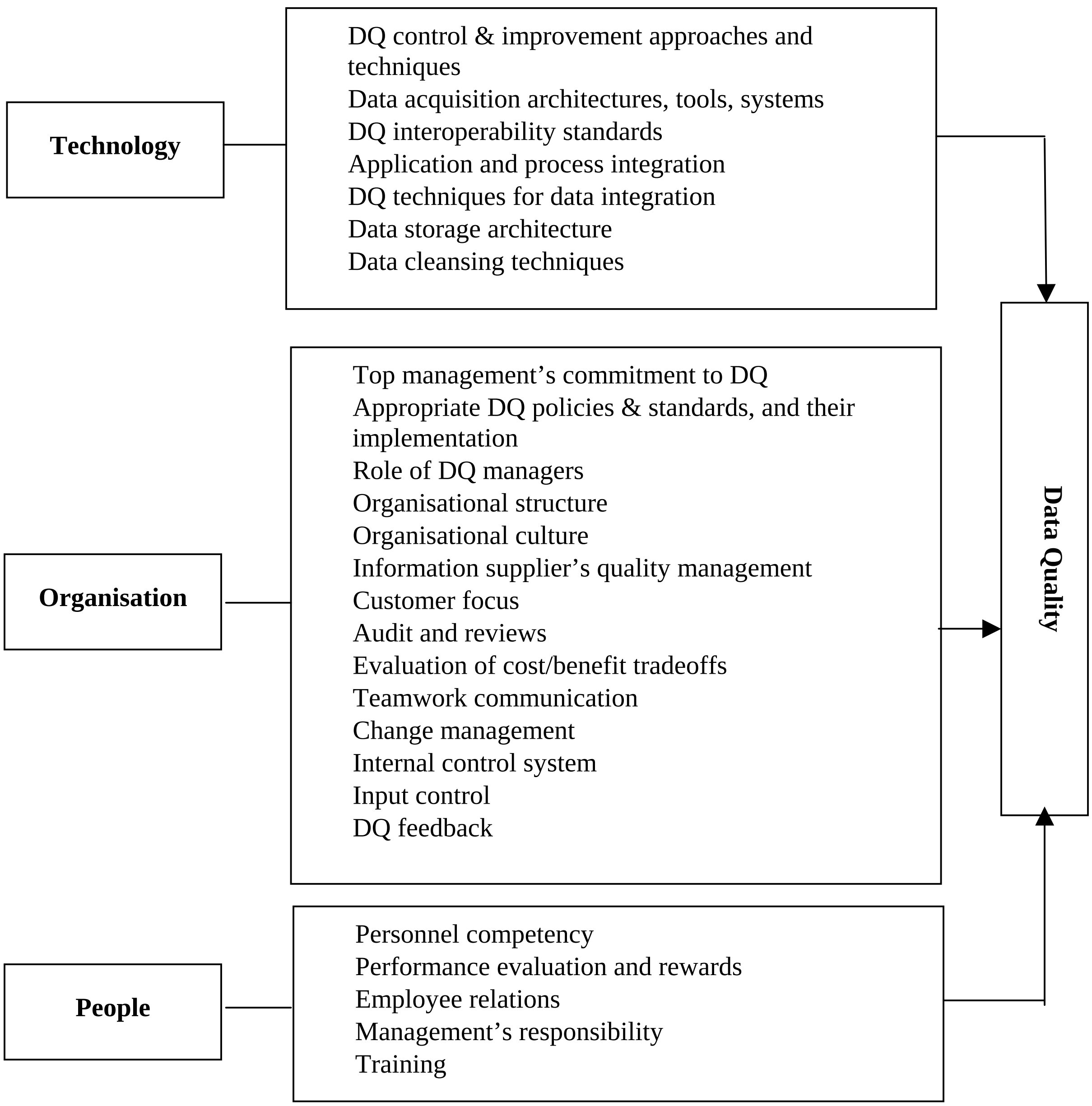

Figure 3: Summary of factors influencing data quality

(Source: [11][43][35][12][33])

ENTERPRISE ASSET MANAGEMENT

Enterprise asset management (EAM) maximizes the performance of fixed, physical or capital assets that have a direct and significant impact on achieving corporate objectives [28]. Organisations rely on vital assets to provide goods and services to their customers. This process often involves the utilization of a number of inter-dependent assets. Knox [23] further asserts that these tightly inter-dependent assets should be managed as a set of unified enterprise resources at higher levels in the organization, in order to achieve higher corporate performance (e.g. shareholder value, revenue growth, profitability or customer satisfaction). The concept of EAM suggests that companies should firstly focus on managing the interdependencies between all of the different types of assets that drive their operations (assets that have previously been viewed as functioning separately and independent from one another); and secondly recognize the need to manage assets from a strategic perspective across the entire organization, rather than purely from a maintenance perspective.

Asset management in general

Asset management essentially is the management of the plant and equipment during its whole life (i.e. from specification through manufacturing, commissioning, useful life, maintenance, and then managing the consequences from the decision to refurbish or replace the item before final decommissioning and recycling any components). At its core, the extended life cycle of a particular asset (also covering the period before the equipment/asset has been put in place for operational purposes, and the period after the asset has been deactivated) will be monitored and controlled. The consideration of this extended asset life cycle is critical when addressing the planning and historical requirements.

Steed [38] indicates that, during its lifetime, the asset is subjected to a host of external factors: environmental conditions, system events, normal and abnormal loads, even changes brought about (for whatever reason) to the dielectric balance. At several critical stages, information is required on the condition of the assets. Knowing what to measure, how to measure it, and then what to do with the information becomes very important. Sandberg [32] argues that contemporary asset management demands an elevated ability and knowledge to continuously support the asset management process, in terms of data acquisition, real-time monitoring, and computer supported categorization and recording of divergences from standard operations.

The process of asset management requires substantial information to be collected from many different parts of the organisation. This information must be maintained for many years in order to identify long-term trends. The asset management engineering and planning process uses this information to plan and schedule asset maintenance, rehabilitation, and replacement activities. The following diagrams (Figure 4 & 5) illustrate the variety of information required for asset management and also indicate the need to establish enterprise-wide asset management information systems. It is thought that these information systems will ease the processes of capturing, storing, processing and maintaining large volumes of asset-related data for effective asset management [1].

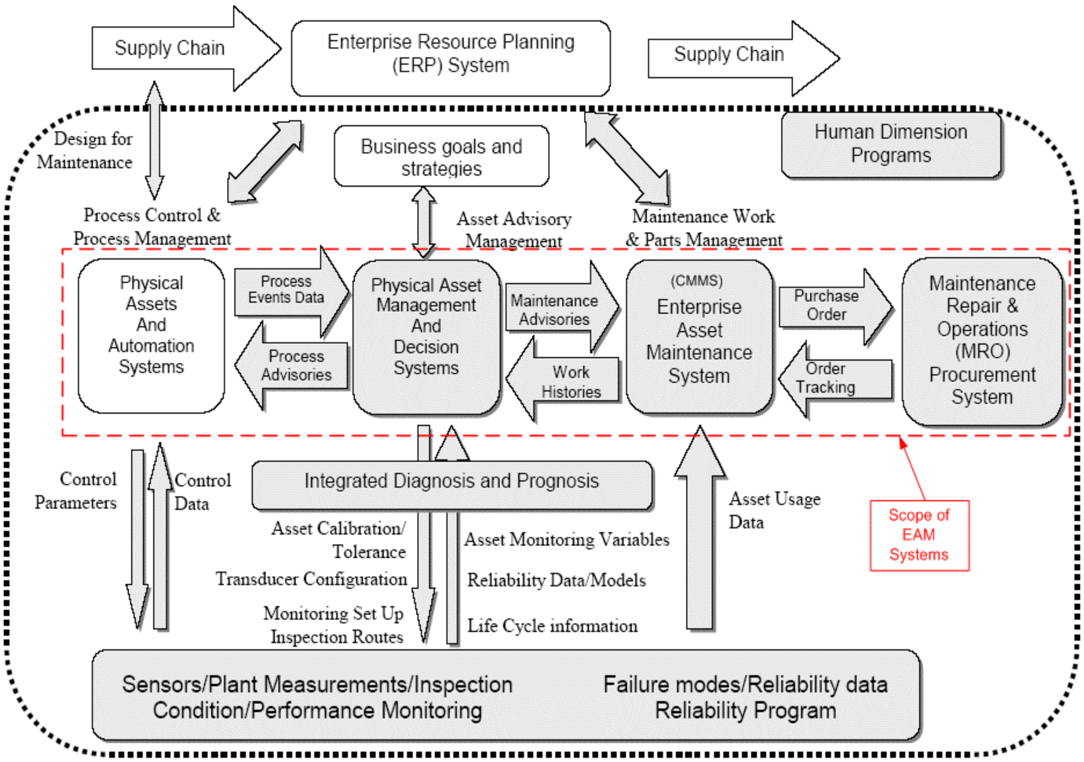

Figure 4: Information flow in asset management
(Source: CIEAM Business Plan [8], adopted and modified from Bever [4])

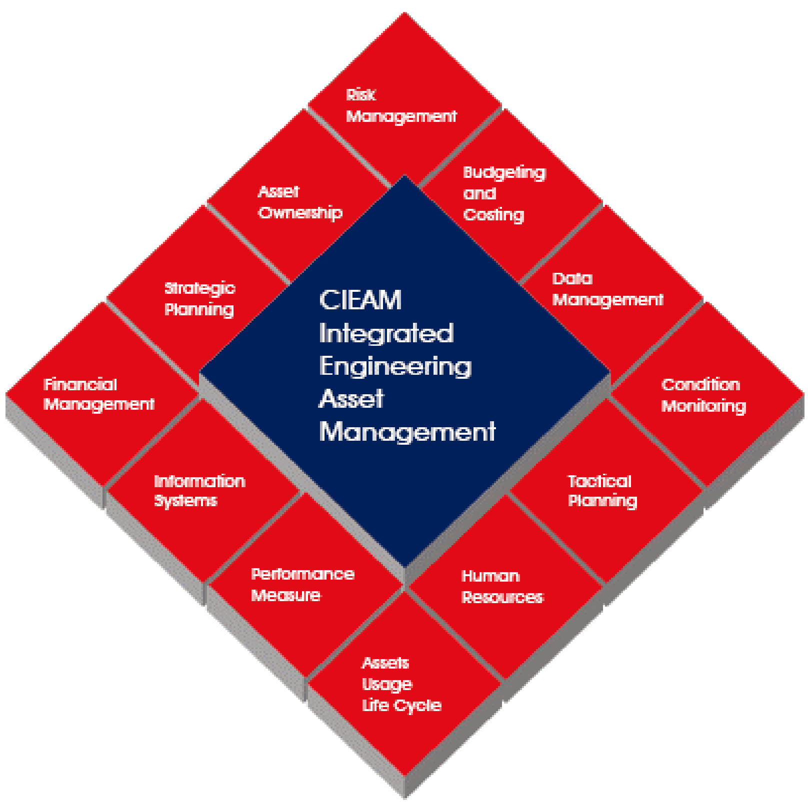

Figure 5: Integrated asset management framework (Source: CIEAM [7])

Competitive companies today utilize enterprise asset management (EAM) not only to reduce costs but also to provide more opportunities for profit. They have realized that plant downtime costs money. In fact, in some asset intensive businesses, such as utilities, losses due to significant plant downtime can mean the difference between positive and negative bottom line results for the company. The primary role of plant equipment maintenance has therefore become downtime prevention, which means that if the equipment does break down and stop, plant maintenance has failed in its main role. Fortunately, forward-looking and better performing companies have now discarded the old-fashioned view of maintenance as a necessary and often costly evil. Even the once common perception of the maintenance professional, as a person in dirty overalls with an oilcan and a wrench, is disappearing. Instead, the concept of EAM is considered as a way to ensure that plant maintenance business processes are used to contribute to bottom line performance. As such, plant maintenance is seen as an investment rather than a cost.

Due to tough market conditions, many industries today are being forced to operate at maximum efficiency and to work on a just-in-time basis. This means there is limited spare plant capacity, little tolerance on order delivery times, and few, if any, surplus resources. In addition, with many customers using the Internet to place orders and compare prices, companies must utilize their assets effectively to ensure that they retain their customer base. This is where EAM can add significant value to the business in ways that include:

- Minimizing downtime when the plant is needed for production, thus being able to respond to market and customer demand
- Ensuring that essential maintenance work is scheduled to maximize production or operational efficiency
- Preventing the delay of customer orders due to production equipment breakdowns
- Maximizing product or service quality by ensuring that the plant operates correctly.

THE NEED FOR AN AM SPECIFIC DQ MODEL

Previous studies in asset management [50][51][10][20] suggest that a common, critical concern with EAM is the lack of quality data.

The unique characteristics of asset management

Asset management is not considered as a core business activity by many businesses, which therefore depend on traditional organizational information sources to manage assets [16]. These traditional sources reflect both the tacit and implicit knowledge of engineers, and operators, as well as information contained in information systems, which have been primarily designed to increase productivity rather than to improve the efficiency of the processes involved in production.

Foundation of the Organization

Assets are the lifeblood of capital-intensive industries and Return-On-Assets (ROA) is the key measure of performance. Maximizing ROA is a key challenge facing asset owners today. The objective of asset management is to optimize the lifecycle value of the physical assets by minimizing the long-term cost of owning, operating, maintaining, and replacing the asset, while ensuring the required level of reliable and uninterrupted delivery of quality service. At its core, asset management seeks to manage the facility's asset from before it is operationally activated until long after it has been deactivated. This is because, in addition to managing the present and active asset, asset management also addresses planning and historical requirements.

Sophisticated and Long Process

The process of asset management is sophisticated. It is an engineering and planning process and covers the whole asset lifecycle that can span a long period of time. There are a variety of specialized technical, operational and administrative systems in asset management, which not only manage the operation of asset equipment but also provide maintenance support throughout the entire asset lifecycle. Asset management requires linking those systems that are currently unrelated. In addition to the requirements for specialized IT/IS supporting systems and system integration & collaboration, the process of asset management also require the involvement of assorted engineering and business stakeholders, internally and externally. Because of the diversity and high turnover of AM stakeholders, asset management outcome is also greatly associated with organizational culture, management commitment, staff competency, communication & feedback, and training.

Information Oriented Process

Asset information is a key enabler of high ROA and better management of this information is the main priority in gaining control of assets [49]. Information that is comprehensive, accurate and immediately accessible enables people to make decisions faster and more accurately, leading to higher availability and lower maintenance costs. Gaps in asset information, out of date or wrong information, or the inability to rapidly access necessary information wastes time and money and reduces ROA. Gaining control of asset information is therefore the main priority in gaining control of assets.

The effective asset-based management process has to utilize a variety of technical and business data such as inventory, condition, performance, lifecycle costs, risk, reliability, and criticality information about a system of infrastructure assets to continuously provide the required level of service while minimizing costs and risks. Consequently, significant quantities of asset data are collected, stored and used for a variety of asset management functions and analyses. This information must be maintained for many years in order to identify long-term trends. The asset management engineering and planning process uses this information to plan and schedule asset maintenance, rehabilitation, and replacement activities. The information management system that captures, maintains, and provides the needed asset information is critical in providing effective asset management.

There has always been a limited degree to which data has been obtainable, sometimes due to the lack of data acquisition standards, sometimes due to company culture, and often due to the inability of a business to discern operational from strategic data and information. Furthermore, due to the multiplicity of systems, stakeholders, and system requirements, and the level of unpredictability in asset operation within asset management, it is often difficult to tap user requirements. This further contributes to the ‘dirtiness’ of asset data. In managing physical assets through the entire asset life cycle, large amounts of data are needed for long term performance and reliability prediction, as well as informing the decision making process on when to retire an asset. Although very large amounts of data are generated from condition-monitoring systems, little thought has been given to the quality of such generated data. Thus the data obtained from such systems may suffer from severe quality limitations [34].

Asset information is itself complex to manage. Asset information is created by many organizations, in many forms, during all stages of a typical asset’s lifecycle. Information is likewise used by a diverse set of people and systems, each with their own specific needs and requirements. Bringing all of the disparate information together into one, asset-centric, source of truth that is accessible to all parties is vital. In this way, information is then available to be used by a diverse set of people and systems, each with their own specific needs and requirements. As asset information is created throughout all stages of a typical asset’s lifecycle, managing the flow and the quality of information is critical to managing the asset’s availability and reliability.

Manual and Automatic Data Capture

In practice, data are collected both automatically and manually involving sensors, field devices, field people and contractors, in a variety of formats, processed in isolation, stored in a variety of legacy systems. Data captured and processed by these systems is not comprehensive; it is process dependent, making it difficult to be reused for any other processes or process innovation [16]. In most engineering organisations the asset databases and tools as described above are islands of separate data and are dispersed throughout the organization. Access to the data by other sections within the organization is often difficult, which limits the effectiveness of the organizations knowledge base for asset management [49]. Various data integration options exist, including enterprise resource, planning applications, web-based systems that link databases and other specialized software.

In managing engineering assets, there appears to be little cognizance when adopting business systems such as financial, human resource and inventory information systems of the need to ensure compatibility with technical systems such as SCADA, CMMS, GIS, EAM, asset register systems, work order management systems and condition monitoring systems. Most users are unable to translate the vast amounts of available asset data into meaningful management information to optimize their operation and control the total asset base. This has led to the notion of 'islands of information'. Such disconnects make it extremely difficult to bring real-time information from the plant into business systems. There are disconnects between the transaction-driven, product-centric business data environment and the continuous data, process-centric open control system and manufacturing data environments. The lack of process-to-product data transformation capabilities in linking business systems and plant floor EAM applications have significant data quality consequences and thus negatively affect data-driven decision-making.

It is found that the data quality requirements can be best described by using a TOP multiple-perspectives approach. Mitroff and Linstone [27] argue that any phenomenon, subsystem or system needs to be analyzed from what they call a Multiple Perspective method – employing different ways of seeing, to seek perspectives on the problem. These different ways of seeing are demonstrated in the TOP model of Linstone [25] and Mitroff and Linstone [27]. The TOP model allows analysts to look at the problem context from either Technical or Organizational or Personal points of view:

> The technical perspective (T) sees organizations as hierarchical structures or networks of interrelationships between individuals, groups, organizations and systems
>
> The organisational perspective (O) considers an organization's performance in terms of effectiveness and efficiencies. For example, leadership is one of the concerns.
>
> The personal perspective (P) focuses on the individual's concerns. For example, the issues of job description and job security are main concerns in this perspective.

Mitroff and Linstone [27] suggest that these three perspectives can be applied as "three ways of seeing" any problems arising for or within a given phenomenon or system. Werhane [48] further notes that the dynamic exchanges of ideas which emerge from using the TOP perspectives are essential, because they take into account "the fact that each of us individually, or as groups, organizations, or systems, creates and frames the world through a series of mental models, each of which, by itself, is incomplete". In other words, a single perspective on the problem context is not sufficient to elicit an insightful appreciation of it.

RESEARCH MODEL FOR DQ IN AM

Moreover, having chosen a particular way of seeing, Linstone's TOP perspectives are still useful in practice. Firstly, by employing TOP, the problem solvers can put stakeholders' perspectives into categories. This process may help problem solvers understand the interconnections between different emerging perspectives, in order to develop a 'big picture'. For example, the "T" perspective is a synthesis of concerns from all technical people (e.g. system administrators, machine operators, etc); the "O" perspective gathers all managers' and leaders' thoughts; and the "P" perspective considers all other stakeholders' concerns. In addition, TOP could also be used to explore an individual's perspectives of the problem contexts. For example, "Do I have sufficient skills to complete the task?" is a Technical concern. "Will my task contribute to the organization's success?" is an Organisational issue. "If I complete the task, will I get a promotion?" is certainly a Personal motivation.

Therefore, drawing on both the processes of asset management (as illustrated above), and the TOP perspectives, the following research framework (Figure 6) is proposed, in order to guide the process of exploring the data quality issues emerged from the modern (EAM Information Systems facilitated) approach to asset management.

In addition to the TOP approach, this study also takes Wang [43]'s TDQM framework into consideration; however, the framework has not explicitly suggested an approach for defining/identifying specific data quality problems emerging from the business domain. Based on the previous discussion, it is felt that the process of modern asset management consists of the adoption of enterprise-wide information systems, various business processes, participants (e.g. maintenance people, managers, etc) and organizational policies (and business goals, structures, etc). It is thought that Linstone's TOP approach can be used to establish a preliminary research model for this study (as a mean of identifying emerging DQ issues from EAM).

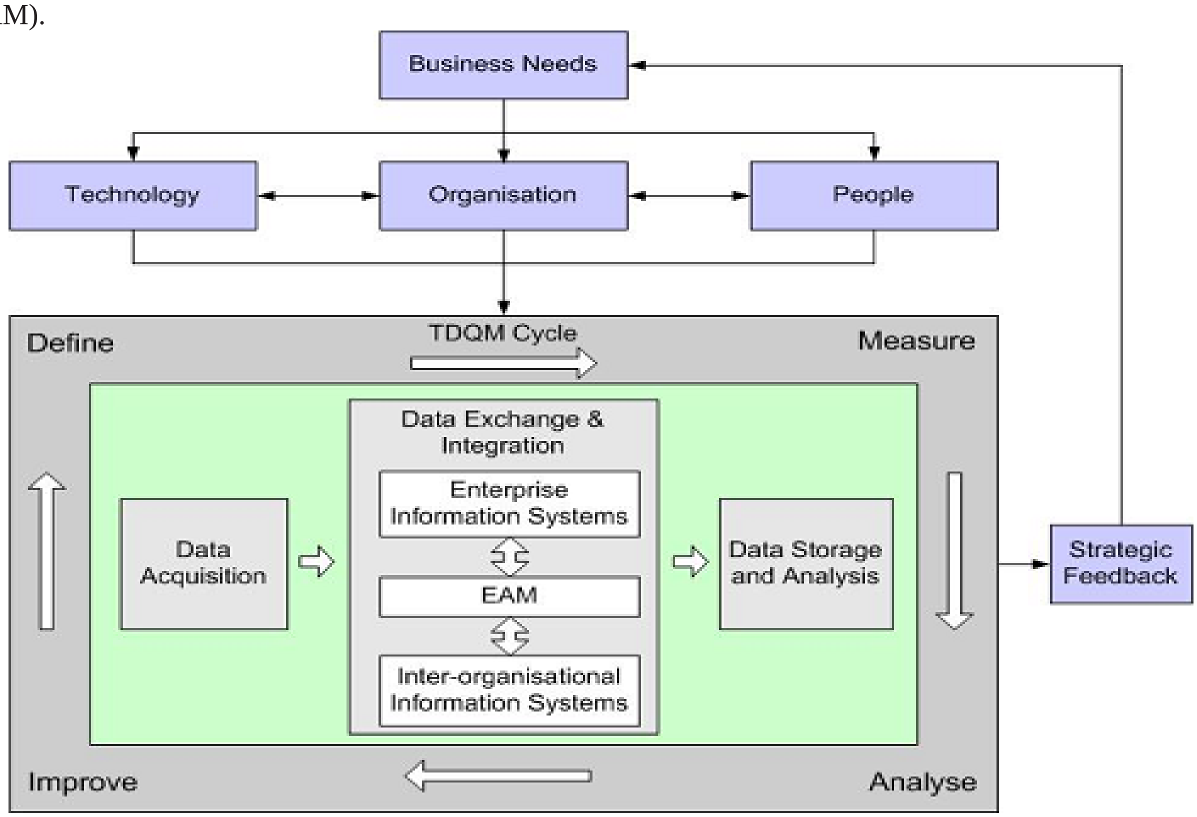

Figure 6: Generic data quality framework

(Source: Developed by the authors)

There is strong evidence that most organisations have far more data than they possibly use; yet, at the same time, they do not have the data they really need [26]. Therefore, identification of business needs is essential. The TDQM methodology [44][22] emphasized the importance of continuous improvement and delivery of high-quality information products. It demonstrated that defining requirements, measuring, analysing, and monitoring improvement are important processes within the information manufacturing system. As data is not static, it is a dynamic, fluid resource. It flows in a data collection and usage process. The DQ problems that may arise at each stage are different, and require different metrics as well as solutions [9]. Because of the continuum nature of data, DQ is not a one-time, fix-it-and-forget-it practice [13]. Building and keeping good quality corporate data takes constant vigilance and feedbacks in the context of the entire data life cycle. Feedback loop is an important DQ monitoring tool. The application of strategic feedback loop can serve to ensure business needs are up-to-date.

The framework (as shown in Figure 6) has identified three possible angles of view – the Technology, Organisation and People (TOP) perspectives to exploring data quality issues (factors) in various stages of asset management. However, asset management is a broad concept, which is difficult to apply as an overall analysis. Thus, in order to explore the DQ issues, the individual process of asset management should be considered because data will be captured, created and stored from these processes. Therefore, the collective understanding of various DQ problems emerging from individual AM processes allows researchers to obtain an insightful and overall understanding about what DQ problems are in AM and why they have emerged. Thus the following research model (Figure 7) has been created, to illustrate this approach.

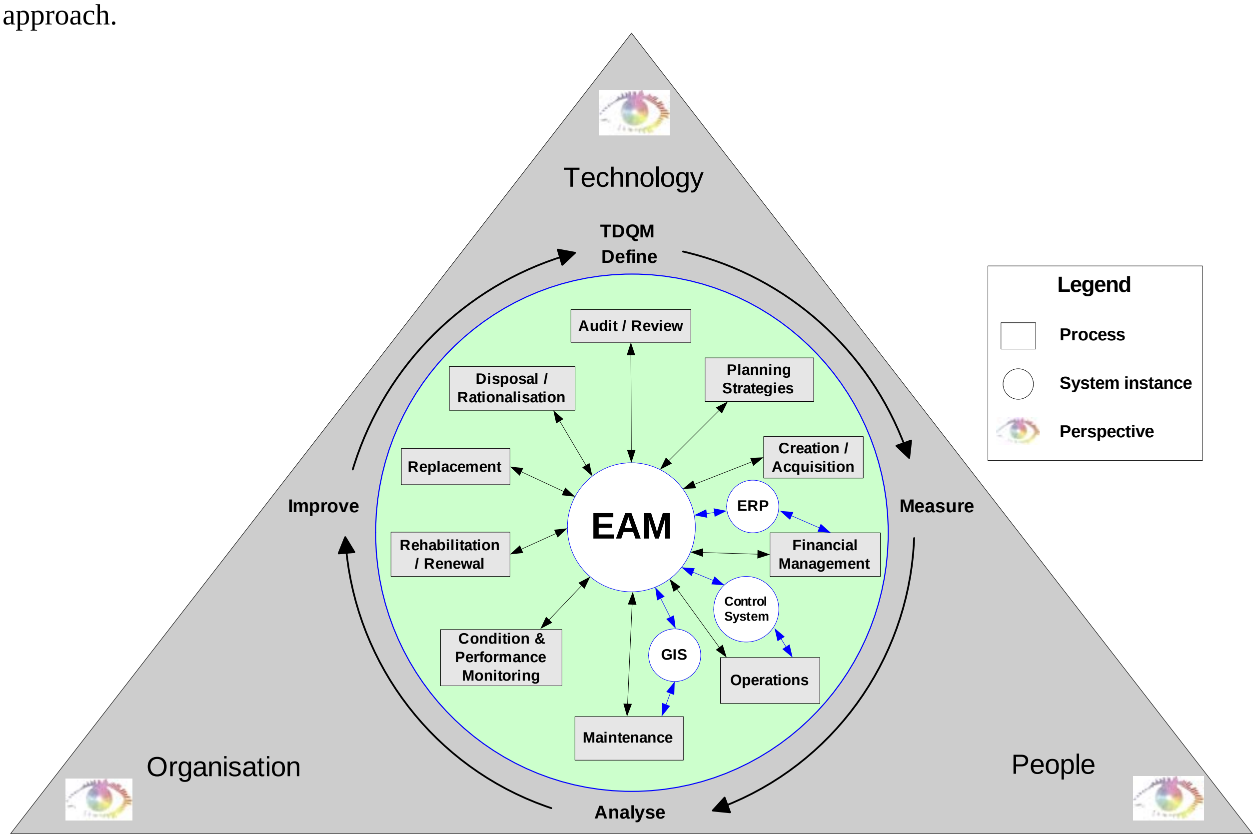

Figure 7: Data quality framework for lifecycle asset management

(Note: The lifecycle asset management processes listed by IPWEA [20] is adopted as the basis of this model.)

Manufacturing assets are complex and expensive with multi-stage lifecycles. They begin as simple concepts to address an organization's needs and rapidly become physical entities that must be acquired, installed and handed-over to operating departments for use in generating revenues. During operation they must be carefully maintained to get maximum performance and longevity. Eventually they become obsolete and must be retired. Achieving maximum return-on-assets requires use of asset information and best practices for every activity, across all of these stages. In order to provide a further in-depth explanation of the complex lifecycle asset management processes, the collaborative asset lifecycle management model [49] is adopted and illustrated in the following diagram (Figure 8).

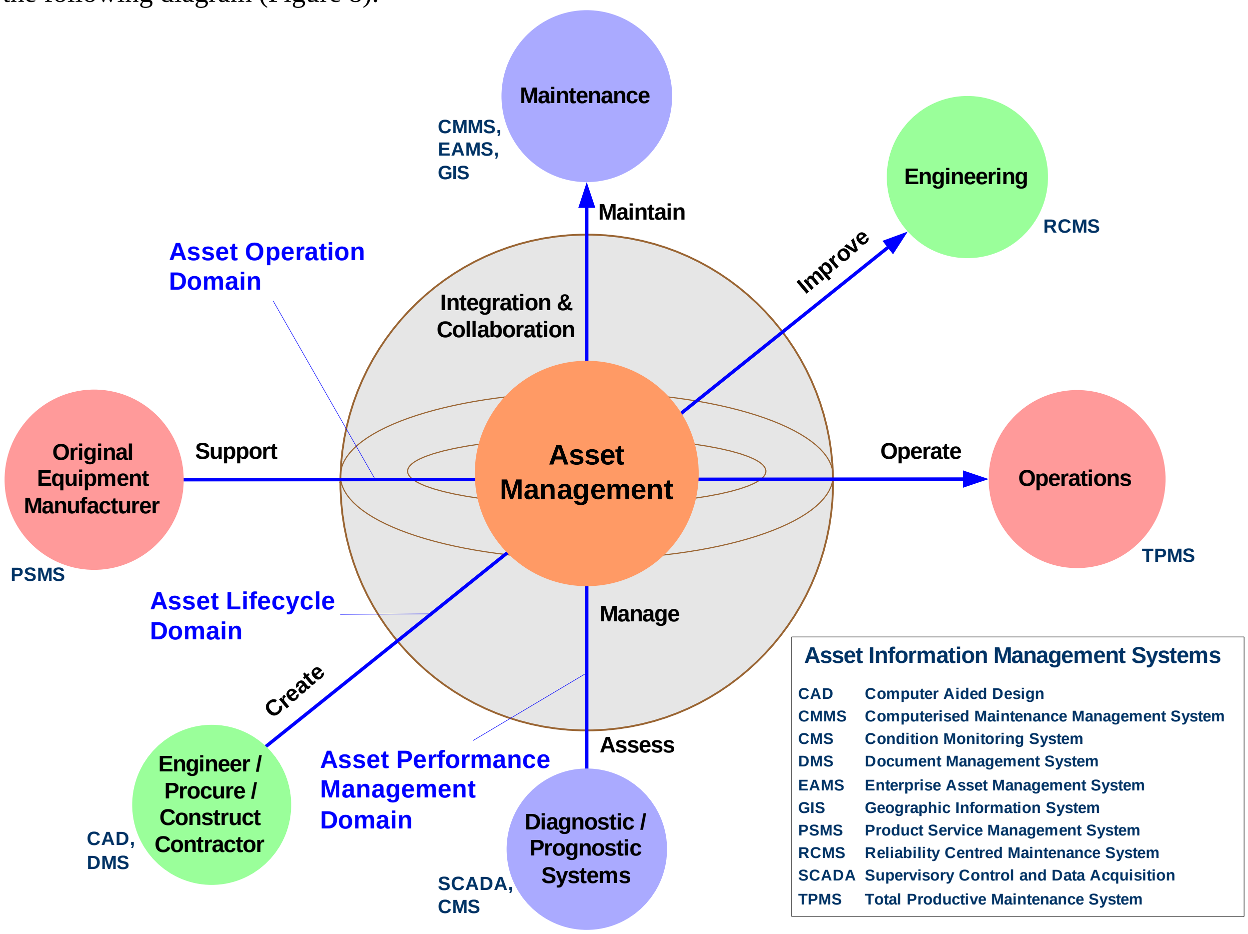

Figure 8: Collaborative asset lifecycle management and asset information management

(Source: Adopted and modified from [49])

The above model captures the complexity of lifecycle asset management [49]. There are three domains focused on the creation, use and management of the manufacturing assets in the model. The *Asset Lifecycle Domain* captures the processes related to asset creation, improvement and retirement. It includes key processes like design, manufacture, installation and decommissioning of complex facilities. The primary stakeholders in this domain are the asset owner and their Engineer, Procure and Construct (EPC) contractor. Once assets have been installed, they are operated and maintained by the respective groups in the owner/operator's organization. The *Asset Operation Domain* recognizes that operations consumes an asset's capabilities and these are restored periodically with parts and services acquired from the Original Equipment Manufacturers (OEM). The *Asset Performance Management Domain* includes those processes that occur during operation to monitor an asset's condition and manage the performance of the asset and the maintenance processes. Key players in this domain are the condition monitoring systems, Supervisory Control and Data Acquisition (SCADA) systems, the maintenance and technical staff and management. Asset management is at the heart of this model. This is a collaborative activity which includes the maintenance technicians, engineers and operators charged with the care and improvement of the manufacturing assets. And these stakeholders depend upon a reliable service network of service and parts providers.

Asset Information Management (AIM)

According to ARC Advisory Group, asset information management underlies all the business processes in each domain [49]. Based on the structure described above, the business processes in each domain have been analyzed and asset information management systems identified for each process. As asset Information is created and consumed by every process in the model, management of this information is vital to efficient and effective asset management and thus to the eventual return-on-assets of the investment. Asset information is created by a variety of stakeholders together with systems and electronic devices throughout an asset's lifecycle. Other stakeholders use that information to perform their activities in the same or subsequent lifecycle stages. Best practice solutions have been developed for various combinations of stakeholders and lifecycle stages. The model in Figure 8 also defines the roles and responsibilities of these individual solutions in achieving a complete, integrated solution.

Computer Aided Design (CAD) and Document Management Systems (DMS) are asset information management solutions for asset creation. EPCs (Engineer, Procure and Construct contractors) use CAD to create equipment designs, instrument diagrams, bills of materials, construction drawings, etc. DMS systems are then used to manage the dissemination of this information to myriad OEMs (Original Equipment Manufacturers) and contractors involved in the overall project.

Enterprise Asset Management (EAM) and Plant Asset Management (PAM) systems are the solutions for asset information management during the Operate/Maintain lifecycle stages. EAM systems maintain asset information in hierarchies that support maintenance and spare parts planning and execution for individual systems and subsystems. EAM also maintains a history of all asset maintenance to enable performance management. PAM solutions, which are often part of the automation systems, support online condition monitoring and evaluation of an asset's health.

OEMs provide the basic components in the facility and play a critical role in asset information management through their instruction books, parts lists, catalogs, etc. During operation, the ability to rapidly identify parts is critical and best solutions in this area include electronic catalogs and "active" instruction books that contain "hot spots" for ordering parts directly from drawings, etc. Product Service Management (PSM) systems also play a role in AIM for OEMs. These systems support the OEMs customers through interfaces that facilitate service requests, product information, etc. Depending upon the service agreement, these systems may also support histories of service calls, repairs, etc.

The Ideal World of AIM

The key applications in AIM are all best practices in their own domain. But, despite the grandiose visions of some suppliers, no single one will ever become a complete AIM solution. The technologies and focus of the different systems are simply too different. Integration of applications is and will always be a key requirement for a complete AIM solution. It is therefore important to establish the role for each solution.

In the ideal world, the role of individual applications is clear. EPCs would use their CAD and DMS systems to design the facility and the information would be in a form that facilitates extraction of the basic information required by the EAM system. This would include a structured asset hierarchy with all assets grouped appropriately into systems, subsystems, components, etc. and with links pre-established to all drawing trees, etc. A separate Bill of Material would likewise be extracted as the basis for managing spare parts inventories. The Bill of Material would have links to the drawings, the OEM's catalogs and the EAM asset hierarchy. OEM's would likewise be using an electronic parts catalog that fully supports all past and present products and all advanced functionality.

The EAM system would use the downloaded information for developing proper maintenance programs, planning maintenance activities, and would maintain its own record of all work done on the asset. This information would be linked back into the CAD system so that anyone looking at a drawing would have immediate access to the service history and all modifications that have occurred. OEMs could likewise have access to the service history to evaluate recurring problems and to help the asset owner improve system reliability.

The EAM system would also be connected in real-time with the PAM system. The PAM system would periodically evaluate the condition of each asset and notify the EAM system of pending problems and the need for maintenance support. Service people would then be able to access the PAM application in order to troubleshoot the problems. The status of work orders would also be continuously shared and PAM would be responsible for notifying operators and initiating specific control actions, like shutdown procedures.

Integration in the ideal world would also be extremely straightforward. All applications would use a common data model, be open and use exposed web services to support other users. Integration would happen seamlessly between all applications, based solely on hyperlinks associated with individual assets.

AIM in the Real World

The real world of asset management is certainly more challenging than the ideal. Manufacturers already have existing assets with only paper documentation that may or may not be accurate since they have been maintained for years using only manual systems. Warehouses already have spare parts, many of which may be obsolete or redundant because they have been stored under different codes for the same parts. At a minimum the parts documentation is out of date with the supplier's new numbering systems and product changes. Documentation that is already in electronic form is in a variety of incompatible formats and lacks any structured information that could be used to make it actionable. AIM applications that do exist are neither open nor easy to integrate with other applications. History cannot be changed and this is particularly true with asset management. Therefore, AIM requires effective solutions for integration and collaboration to fill the voids between the ideal and the real world. The role of the integration and collaboration solutions is to make the outside world appear ideal to EAM.

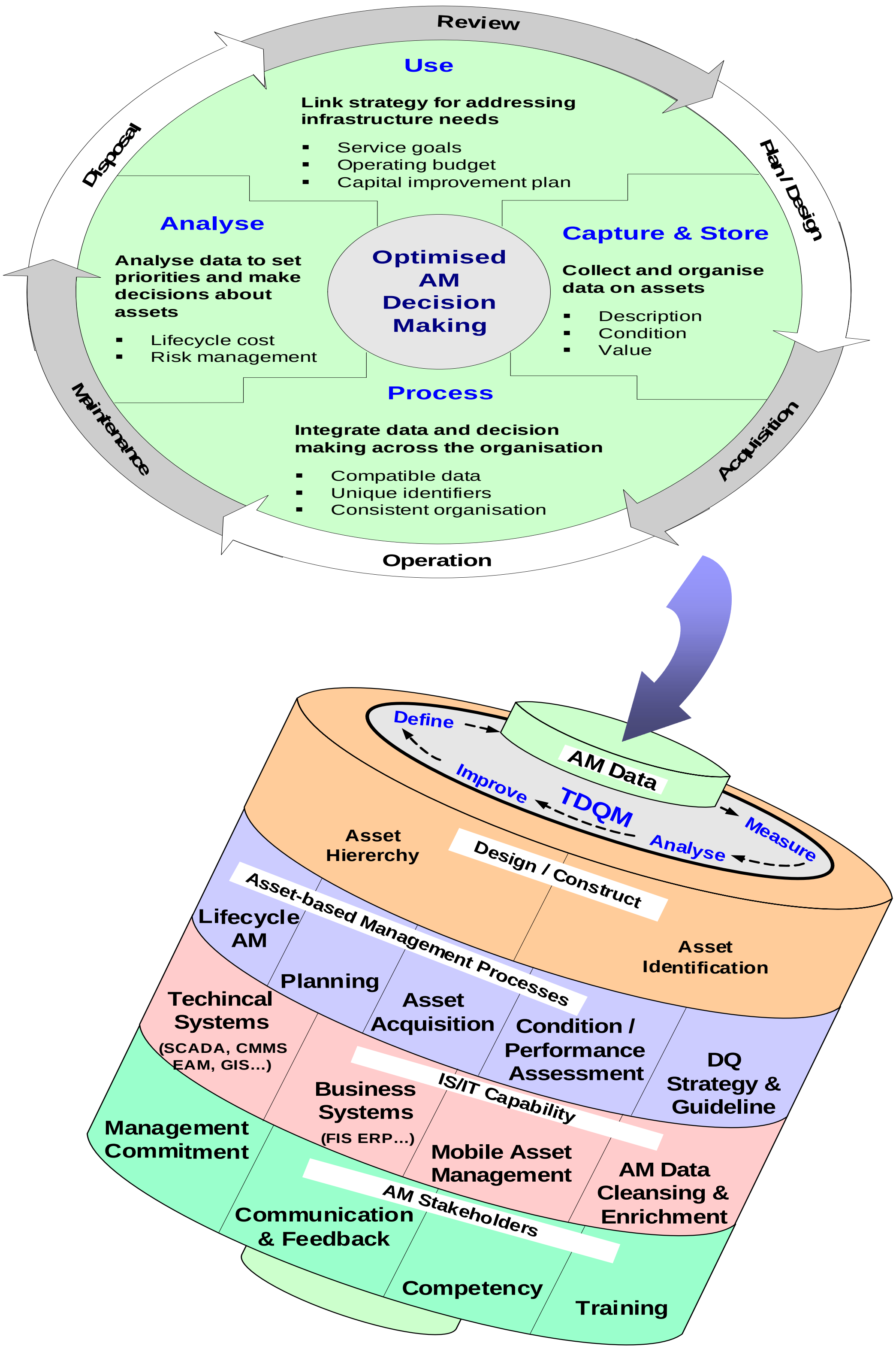

Figure 9: AM specific data quality model (Source: Developed by the authors from [54])

Based on the discussions on various data quality issues [46][15][53][52] and the unique characteristics of asset management, the AM specific DQ model was developed as shown in Figure 9. This model is useful to guide the research into data quality issues in asset management, because it highlights the three root perspectives (TOP) on data quality problems, illustrates how they emerge during the process of asset management; and outlines the basic data quality management criteria.

Physical engineering assets are the lifeblood of capital-intensive industries. The process of asset management is complicated. Asset information is a key enabler in gaining control of assets. Asset information is created, stored, processed, analyzed, and used throughout an asset's lifecycle by a variety of stakeholders together with an assortment of technical and business systems during the whole AM process. Asset information management (AIM) underlies all the asset-based management processes, and ensured DQ in AIM assist AM decision making optimization.

The objective of constructing an asset hierarchy is to provide a suitable framework for assets, which segments an asset base into appropriate classifications. The asset hierarchy can be based on asset function, asset type or a combination. The intent of the asset hierarchy is to provide the business with the framework in which data are collected, information is reported, and decisions are made. In most cases, organizations work with an informal asset hierarchy. This often leads to data being collected to inappropriate levels, either creating situations where costs escalate with minimal increases in benefits, or insufficient information is available to make informed decisions [20]. Infrastructure assets generally have a clear hierarchical relationship that breaks down from the asset type as a whole to large units (facilities), then to assets and their components. The information needs of the organization vary throughout the management structure. At the workface the key elements are operations, maintenance, and resource management, at a component level. At higher management levels this information needs to be aggregated to provide details on assets, facilities and (infrastructure) systems as a whole in terms of finance, strategic and policy. The objective of designing asset identification is to create a unique identifier for each asset group and the service areas/components/sub-components for corporate financial, economic, technical and management use. The development of the asset identification needs to be appropriate for the asset hierarchy and complement the data/information needs of the organization [20].

The asset-based management process is sophisticated. It is an engineering and planning process and covers the whole asset lifecycle that can span a long period of time. The process is associated with capital planning, asset acquisition, condition & performance assessment, and asset-related data strategy & guideline. A variety of specialized technical and business systems exist in asset management including SCADA, CMMS, EAM, GIS, ERP etc, which not only manage the operation of asset equipment but also provide maintenance support throughout the entire asset lifecycle [16]. Asset management requires linking those systems that are currently unrelated. In addition to the requirements for specialized IS/IT supporting systems and system integration & collaboration, the process of asset management also require the participation of assorted engineering and business stakeholders, internally and externally. Because of the diversity and high turnover of AM stakeholders, asset management outcome is greatly associated with organizational culture, management commitment, staff competency, communication & feedback, and training.

While the specific terminology may differ in the published manuals and handbooks on asset management practices and how to apply them, some fundamental elements of implementing asset management appear consistently in the literature.

Collecting and organizing detailed information on assets

Collecting basic information about capital assets helps managers identify their infrastructure needs and make informed decisions about the assets. An inventory of an organization's existing assets generally should include (1) descriptive information about the assets, including their age, size, construction materials, location, and installation date; (2) an assessment of the assets' condition, along with key information on operating, maintenance, and repair history, and the assets' expected and remaining useful life; and (3) information on the assets' value, including historical cost, depreciated value, and replacement cost [54].

Integrating data and decision making across the organization

Managers ensure that the information collected within an organization is consistent and organized so that it is accessible to the people who need it. Among other things, the organization's databases should be fully integrated; for instance, financial and engineering data should be compatible, and ideally each asset should have a unique identifier that is used throughout the organization [54]. Regarding decision making, all appropriate units within an organization should participate in key decisions, which ensures that all relevant information gets considered and encourages managers to take an organization-wide view when setting goals and priorities.

Analyzing data to set priorities and make better decisions about assets

Under asset management, managers apply analytical techniques to identify significant patterns or trends in the data they have collected on capital assets; help assess risks and set priorities; and optimize decisions on maintenance, repair, and replacement of the assets [54]. For example:

- ***Life-cycle cost analysis.*** Managers analyze life-cycle costs to decide which assets to buy, considering total costs over an asset's life, not just the initial purchase price. Thus, when evaluating investment alternatives, managers also consider differences in installation cost, operating efficiency, frequency of maintenance and repairs, and other factors to get a cradle-to-grave picture of asset costs.

- ***Risk/criticality assessment.*** Managers use risk assessment to determine how critical the assets are to their operations, considering both the likelihood that an asset will fail and the consequences—in terms of costs and impact on the organization's desired level of service—if the asset does fail. Based on this analysis, managers set priorities and target their resources accordingly.

Linking strategy for addressing infrastructure needs to service goals, operating budgets, and capital improvement plans

An organization's goals for its desired level of service—in terms of product quality standards, frequency of service disruptions, customer response time, or other measures—are a major consideration in the organization's strategy for managing its assets. As managers identify and rank their infrastructure needs, they determine the types and amount of investments needed to meet the service goals. Decisions on asset maintenance, rehabilitation, and replacement are, in turn, linked to the organization's short- and long-term financial needs and are reflected in the operating budget and capital improvement plan, as appropriate.

Implementing the basic elements of asset management is an iterative process that individual organizations may begin at different points. Within the water industry, for example, some utilities may start out by identifying their infrastructure needs, while other utilities may take their first step by setting goals for the level of service they want to provide. The interrelationship between the elements of asset management can alter an organization's strategy for managing its assets. For example, once an organization has completed a risk assessment, it may scale back its efforts to compile a detailed inventory of assets to focus initially on those assets determined to be critical. Similarly, as information on infrastructure needs and priorities improves, managers reexamine the level of planned investments, considering the impact on both revenue requirements and the level of service that can be achieved. According to advocates of asset management, while many organizations are implementing certain aspects of the process, such as maintaining an inventory of assets and tracking maintenance, these organizations are not realizing the full potential of comprehensive asset management unless all of the basic elements work together as an integrated management system.

RESEARCH ISSUES & METHOD

A qualitative approach was deemed appropriate to guide the focus of the first phase of this study given that there is little existing empirical research on Data Quality for Engineering Asset Management. This is inline with methodologies for this type of research [56]. A qualitative approach allowed the researchers to explore the general research question by capturing rich domain knowledge from experienced practitioners, to identify the key issues and develop an appropriate conceptual model that reflects the reality of current practice.

A case study research is an accepted research strategy in IS. Cavaye [6] suggests that the term "case research" is not a monolithic one: case study methods can be applied and used in many different ways and, as such, case research is open to a lot of variation. It is further suggested that case research can be carried out taking a positivist or an interpretivist instance, can take a deductive or an inductive approach, can use qualitative and quantitative methods, and can investigate one or multiple cases.

Based on the previous discussion about the EAM problems, an interview-based case study was designed to explore the DQ issues emerging within the chosen organizations. The organizations included two large Australian water utilities, as well as several of its subcontractors. A number of stakeholders at all levels of the organizations were interviewed, chosen on the basis of their experience in the use and management of engineering assets. The target organisations used a variety of information systems for EAM (e.g. GIS for asset location, Maximo for asset maintenance).

Approximately 30 interviews were conducted and included senior executives, asset managers, maintenance engineers, maintenance technicians, and data operators. In functional these stakeholders came from different position levels with different data roles at various office locations, including data provider, data custodian, data user, and data manager. In cases of conflicting issues, crosschecking for interviews was also conducted to validate the results.

Data collection sources also included relevant documents, such as position description, policy manuals, organizational structure charts, and training documents, as well as some published information about the social and historical background of the participating organizations. Documents can be used to corroborate and augment evidence from other sources and they play an explicit role in the data collection process in doing case studies [56].

Responses to our research questions were collated, stored, and analysed using qualitative data analysis software. This analysis allowed us to explore the raw data, identify and code the common themes, and identify relationships between themes in a rigorous manner. In analyzing the collected data, an extensive examination of the viewpoints of various stakeholders was conducted. The views and actions of various interviewees in terms of their organizational interests were also examined. Interpretive research requires sensitivity to possible differences in interpretations among the participants as are typically expressed in multiple narratives of the same sequence of events under study [55]. Klein and Myers also suggest that interpretive research requires sensitivity to possible "biases" and systematic "distortions" in the narratives collected from participants [55]. A very preliminary validation of the DQ for asset management model was achieved. While there are some limitations in the approach used, we feel that the richness of the data collected far outweighed the methodological shortcomings of such an approach.

FINDINGS

The following represent some of the preliminary findings based on using the TOP model. The integration of asset management related technical systems, as well as the integration between business systems and technical systems in AM, are particularly important.

Integration of technical systems in asset management

A variety of specialized technical systems exist and include reliability assessment systems, asset capacity forecasting systems, asset maintenance systems, electrical motor testing systems, turbo-machinery safety systems, rotating machine vibration condition monitoring systems, operational data historians, root cause analysis systems, and physical asset data warehouse systems. Such specialized systems are acquired from multiple vendors and as they are quite disparate, they often lead significant integration problems.

There appears to be little cognizance when adopting business systems such as financial, human resource and inventory information systems of the need to ensure compatibility with technical systems such as asset register systems, work order management systems and condition monitoring systems. Most users are unable to translate the vast amounts of available asset data into meaningful management information to optimize their operation and control the total asset base. This has led to the notion of 'islands of information'.

Such disconnects make it extremely difficult to bring real-time information from the plant into business systems. There are disconnects between the transaction-driven, product-centric business data environment and the continuous data, process-centric open control system and manufacturing data environments. The lack of process-to-product data transformation capabilities in linking business systems and plant floor EAM applications have significant data quality consequences and thus negatively affect data-driven decision-making.

Sensor calibration and integrity check for condition monitoring

Interviews with asset maintenance field workers indicate that data captured by intelligent sensors may not always be accurate. Data capturing devices typically used in condition monitoring are electronic sensors or transducers, which convert numerous types of mechanical behavior into proportional electronic signals, usually voltage-sensitive signals, producing analog signals which in turn are processed in a number of ways using various electronic instruments. As signals are generally very weak, a charge amplifier is connected to the sensor or transducer to minimize noise interference and prevent signal loss. The amplified analogue signal can then be sent via coaxial cables to filtering devices to remove or reduce noise, before being routed to a signal conditioner and/or Analogue-to-Digital converters for digital storage and analysis. To ensure the data received by the SCADA system conforms to the original signal data captured by sensors, integrity checks for signal transmission process and sensor calibration need to be performed and maintained. However, as the sensor calibration and integrity checks are often neglected in asset maintenance in most industries, the extent to which acquired data is correct and reliable was shown to be of concern with respondents.

Data access

As part of the asset acquisition process, all asset information required to own and operate the asset should be handed over to the user organisation at the commissioning of the asset, in a form that can be assimilated readily into the user organization's asset information systems. These asset data may include a fully-fledged technical information database with GIS maps, technical specifications, and even video clips of the equipment and its operation.

The research has found that a data gap may exist between the maker and the user of asset equipment. The user organization needs to populate the EAM with data from the manufacturer — particularly the component structure and spare parts. These capabilities exist in manufacturers' product data management (PDM) and product lifecycle management (PLM) systems. Unless arrangements or contract conditions are made, in many cases, the data is not passed on to the buyer in a usable electronic format. However, in some cases, the asset data handed over to the user organisation does not conform to the physical assets received. In other cases, updated asset data, particularly the component structure, may not always be passed on to the user organisation.

Information such as job instructions, maintenance cycles and advisory notices is also available. However, without standards and interfaces to share this information across systems, it is often held offline either as paper documents or poorly linked electronic copies of instructions.

Data standard for condition monitoring systems

Although it appears that condition monitoring equipment and systems are proliferating, an apparent lack of dialogue among vendors (as found in the target organisation) has led to incompatibilities among hardware, software and instrumentation. Data collected by current outdated equipment could become obsolete and inaccessible to new upgraded systems. To fully realize the integration of systems over the various levels of asset maintenance and management, new standards and protocols are needed. A focus on standardization of condition monitoring data modeling and exchange tools and methodologies, such as Standard for the Exchange of Product model data (STEP) is critical.

Database synchronization

The capability of EAM systems can be enhanced through a link with GIS to provide the ability to access, use, display, and manage spatial data. The ability to effectively use spatial asset data is important for utilities with geographically dispersed utility networks. However, it was found that one of the most critical activities in is to establish synchronization between the two database environments. One asset manager indicated that there has been an issue existed for overcoming the synchronization of asset register in a very common work management system with GIS in the company. Both automated and manual processes needed to be defined and implemented to maintain synchronization between the GIS and EAM databases. Database triggers and stored procedures need to be defined to automate the attribute update process maintaining synchronization between the GIS and EAM databases. Workflows and business rules must be developed for GIS and EAM data editing, to ensure synchronization from both applications.

Organisational readiness

The literature pointed to many companies which attempt to implement EAM systems running into difficulty due to lack of preparedness and planning for integration initiatives particularly when various departments and business units have conflicting objectives. This was confirmed during interviews with various stakeholders. Organizational readiness can be described as having the right people, focused on the right things, at the right time, with the right tools, performing the right work, with the right attitude, creating the right results. It is a reflection of the organization's culture. EAM implementations involve broad organisational transformation processes, with significant implications for the organisation's asset management model, organisation structure, management style and culture, and particularly, to people.

EAM implementation project within the utility organisation expected a high acceptance of the system in areas that provide just as good or better functionality than the old system. However some functions and processes did not get the full appreciation, which the legacy systems once had. This research revealed a high level of frustration by field workers with the use of maintenance information systems and consequently a loss of confidence in using such systems.

Business process reengineering

Organisational fit and adaptation are important to implementation of modern large-scale enterprise systems. Like enterprise resource planning systems, EAM systems are also built with a pre-determined business process methodology that requires a fairly rigid business structure in order for it to work successfully. They are only as effective as the processes in which they operate. Companies that place faith in EAM systems often do so without reengineering their processes to fit the system requirements. Consequently, this often results in negative impacts on the effectiveness of both the EAM system and the asset management practices. It was found that a mismatch existed between the business processes requirements of the EAM and actual practice in the organisation.

Data recording

In asset management, all of the analytical methods, prediction techniques, models, and so on, have little meaning without the proper input data. The ability to evaluate alternatives and predict in the future depends on the availability of good historical data, and the source of such stems from the type of data information feedback system. The feedback system must not only incorporate the forms for recording the right type of data, but must consider the personnel factors (skill levels, motivation, etc.) involved in the data recording process. The person who must complete the appropriate form(s) must understand the system and the purposes for which the data are being collected. If this person is not properly motivated to do a thorough job in recording events, the resulting data will of course be highly suspect.

Research in data collection has found that data quality and validation effectiveness improve, the sooner the collected data is entered and the nearer the data entry is to the asset and its work. If a data entry point is remote from the asset, then the capability for accurately confirming the data is considerably reduced and the temptation to enter something - anything that the system will accept - is great. One manager said in the interview that "I feel that most of the (data) errors over time have been because of the lag between the field data and being continued in the computer somewhere….they (field staff) might wait a week before they complete their work order (entry)". It was found that the longer the time lag between using the entered data and the time it was initially created, the less chance of cleaning up the data to make it useful.

Training

From a data quality perspective, training has not been adequately addressed in the organisation at the time that the new state-wide asset management system was first introduced. During this time, several staff members were chosen to take a brief 3-day training workshop and then were assigned to be trainers for the rest of the organisation. The choice of trainers as well as the level of training was inadequate in the opinion of many of the respondents. This lack of an effective training program resulted in significant skill issues in the use of the new system. Several respondents indicated that the training was tailored for the specific areas but the same for everyone and thus of limited use to some. Many respondents contended that what they knew about the system was in fact ‘self taught’.

A gap between current practices and capabilities seem to exist. Awareness of issues such as the cost of downtime or how the data being collected was going to be used was not existent; yet they agreed that such knowledge would increase motivation and performance by the asset operators/technicians.

Managing assets requires all aspects of training as well as appropriate documentation of the system. It was found that organisations tended to focus more on the ‘hardware’ part of the systems’ development process, putting less effort on the ‘soft’ part, that is, the training of how to operate and manage the system. The people’s skills, people’s abilities to use the system efficiently are critical to ensuring data quality in asset management systems. If people do not have the skills and knowledge to control the system, then even the perfect system will not be able to produce high quality information. Lack of training can cause serious damage and have an adverse impact on information quality. It is easy for organisations to find reasons/excuses for avoiding adequate training for the staff and management.

Communication & management feedback

Competitive asset intensive companies have reported that most of their asset improvements come from their workforce. Despite the fact that “people are our greatest asset”, evidence of the opposite is often found. People’s problems, relationships, aspirations and their personal agendas are seldom given any consideration. In the implementation and management of EAM systems it appears that this is not different and was quite evident in the responses. Respondents were quite convinced that the system implementation neglected the human dimensions and thus contributed to the partial failure of these systems.

> *“year after year they filled out field data without feedback……if we did nothing, nothing happens so why bother?”*

Implications

Understand data quality issues for EAM systems

Data quality issues are critical to the success of asset management. The framework proposed in this paper provides a useful tool for planning the establishment of an awareness of data quality issues in managing assets. The discussion in this paper has highlighted some data quality problems, which existed in the current condition monitoring systems and engineering asset management systems, such as intrinsic, accessibility and contextual data quality problems, and the key factors that impact on data quality while managing assets.

Data quality issues need to be widely understood and managed in order to ensure effective asset management. When analysis is required for making decisions to establish a data quality project regarding the management of engineering assets, the issues discussed in this paper can help practitioners to perform a cost/benefit analysis in relation to data quality issues. The identification of data quality issues within the area of asset management will serve to provide additional research opportunities for the development of tangible solutions to data quality problems in asset management.

There are certain factors that influence data quality when managing assets. Organisations should focus on those key factors as defined by the framework in this paper, including systems integration, training, management support, employee relations, and organisational culture. Understanding these key factors should lead to high-level data quality management practices, which is a key to the successful implementation of effective asset management. For example, quality communication among engineering, business, field and IT people will significantly reduce data quality problems.

Adequate training is essential

Adequate training on data quality for all personnel involved in managing engineering assets is important for ensuring and improving data quality. People’s ability to use the system is equally important to ensure a relatively high level of data quality in asset management. Sufficient training should be provided to all employees to obtain a broad understanding of the system as a whole, as well as providing particular personnel with adequate documentation and specific training to deliver the critical mode of knowledge (know-what, know-how, know-why) for their specific data roles (data collector, data custodian, data customer) in their relevant functional areas in relation to the system.

EAM system vendor’s standard training procedures normally covers the ‘what’ and ‘how’ to do things, but rarely covers the ‘why’ aspect. And it is the ’why’ aspect that concerns most individual users, affects their daily work and affects their concerns about the future. The ‘why’ aspect will in part depend upon the group culture and in this respect may be addressed by extending the training activity to include sessions on the objectives of the organisation and where asset management, maintenance and the individuals concerned fit into this plan. However, the ‘why’ aspect has also to be looked at from the individual’s viewpoint in order for the system to be able to achieve any measure of success.

CONCLUSIONS

This research is providing a better understanding of data quality issues for asset management and is assisting in identifying elements which will contribute towards the development of a data quality model specific to engineering asset management. This in turn will assist in providing useful advice for improving data quality in this area. Key data quality issues discussed and the use of the identified framework should help organisations obtain a better understanding of data quality issues throughout the process, leading to activities which will help ensure data quality. Future research will further develop this model and identify guidelines for improvement data quality in the management of engineering assets.

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