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## Validating a Data Quality Framework in Engineering Asset Management

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### Abstract

*Data Quality (DQ) has been an acknowledged issue for a long time. Several researchers have indicated that maintaining the quality of data is often acknowledged as problematic, but is also seen as critical to effective decision-making in engineering asset management (AM). The study presents an AM specific DQ framework, which aims to provide a comprehensive structure for understanding, identifying AM DQ problems in an organised way. The framework was examined in a preliminary case study of two large Australian engineering organisations. The empirical findings from the research were used to validate the proposed AM DQ framework. As AM data and informational needs are very different to a typical business environment, a gap exists in the availability of DQ solutions for engineering asset management. Thus there is a need for the development of DQ solutions for engineering asset management.*

**Keywords:** Data Quality, Data Quality Framework, Engineering Asset Management

### INTRODUCTION

Industry has recently put a strong emphasis on 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, engineering asset management has been regarded as an essential business process in many organizations, and is moving to the forefront of contributing to an organization's financial objectives.

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 (Levitan et al. 1998). Modern organizations, both public and private, are continually generating large volumes of data. More data, however, does not necessarily mean better information, or more informed business decisions. In fact, many are finding it difficult to use the 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. Many say that they are drowning in data and are starved of information.

The lack of quality data often leads to decisions being made more on the basis of personal judgment rather than being data driven (Koronios et al. 2005). This can lead to less effective strategic business decisions, such as 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 as massive power failures, industrial or aviation disasters. Without good data, organisations are running blind and make any decision a gamble (ARC 2004). 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.

### DATA QUALITY AND ASSET MANAGEMENT

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 an asset well before it is operationally activated and 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.

The process of asset management is sophisticated and involves many interdependent stages within the whole asset lifecycle. Coordinating these processes is vital to effective asset management. One fundamental AM issue is that

asset management is not considered as a core business activity by many businesses, which therefore depend on traditional organizational information sources to manage assets. 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 (CIEAM 2005).

There are different types 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 (Koronios et al. 2003). The use of information technologies and process automation in asset management means increased dependency on quality AM information for quality output.

However, information has been far from being facilitative in engineering asset management systems. Imperfect, delayed, incomplete, and deficient information are the most important issues confronted by organisations (English 1999). In practice, data is captured both electronically and manually, in a variety of formats, shared among an assortment of off the shelf and customized operational and administrative systems, communicated through a range of sources and to an array of business partners and sub contractors. What is more, more often than not these assets operate in unstable environments and consequently generate maintenance demands hitherto unseen. In such circumstances, incomplete and historic information hampers the ability of a plant manager to make far-reaching decisions on asset operation; maintenance scheduling, planning and execution; and asset disposal. Therefore, there is a growing need to address the issue of data quality in engineering asset management systems, by analysing the existing practices and developing frameworks and models to assist engineering enterprises to capture, process and deliver quality data and information (CIEAM 2005).

Data quality has been the focus of many researchers worldwide (Kriebel 1979, Ives et al. 1983, Wang et al. 1993, Fox et al. 1994, Wand et al. 1996, Wang et al. 1996, Shanks et al. 1998, Kahn et al. 2002, Ballou et al. 1998). 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.

As discussed, engineering assets have a unique set of characteristics as well as a sophisticated long process with different lifecycle stages. The process itself requires substantial information to be collected, processed, stored, analysed and further used throughout all stages of a typical asset's lifecycle. Because of the distinctive differences with regard to information systems and data requirements between the general business environment and engineering asset management environment as discussed from previous research (Lin et al. 2006), it appears that there is a need for an AM specific DQ framework to help obtain an insightful and overall understanding about what DQ issues are in AM, where the DQ problems are, why they have emerged, and where improvements can be made.

### **TOP Perspective**

As discussed before, asset management consists of a number of processes across the entire organisation. At each stage of the processes, all the resources required for the effective management of the processes such as people, technology, procedures etc need to be well considered. Thus, it is appropriate to use Mitroff and Linstone (1993)'s TOP model to establish a building block for the required AM DQ framework. Mitroff & Linstone (1993)'s TOP model allows analysts to look at the problem context from either Technical or Organisational or Personal points of view:

- The technical perspective (T) sees organisations as hierarchical structures or networks of interrelationships between individuals, groups, organisations and systems;
- The organisational perspective (O) considers an organisation'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.

The aggregation of these perspectives can present a comprehensive understanding of the specific AM DQ requirements in an organised manner.

## THE AM DQ FRAMEWORK

Based on Mitroff & Linstone (1993)'s TOP model and the discussions on various data quality issues (Wang et al. 1995, Gelle et al. 2003, Xu et al. 2002, Xu et al. 2003, US GAO 2004), the AM DQ framework (Figure 1) was developed and proposed from the previous phase of this research.

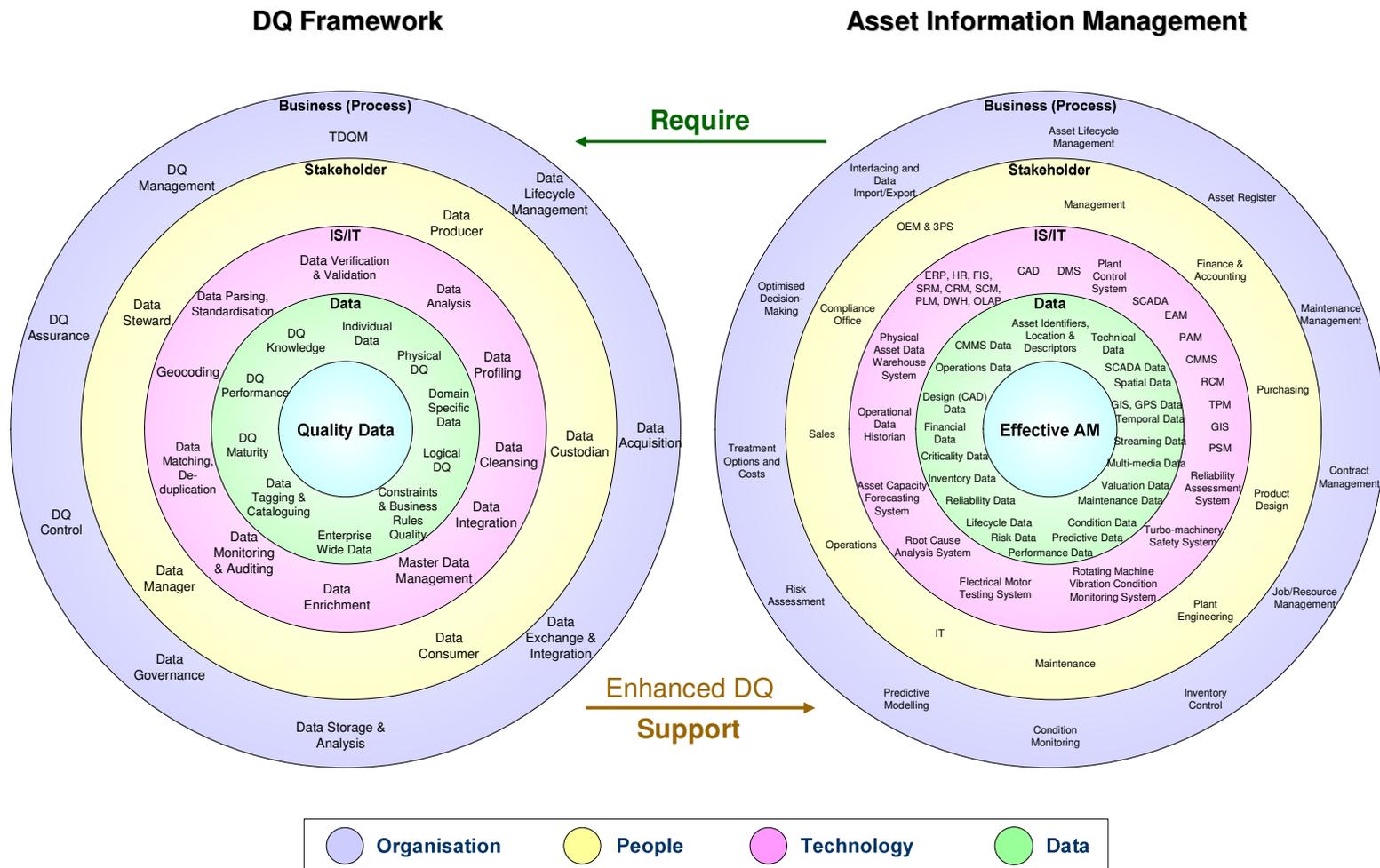


Figure 1: The AM DQ Framework (Source: Developed by the authors)

As shown in the diagram above, asset data is the key enabler in gaining control of assets. These asset data is created, processed, stored, 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. The quality asset data in turn provides foundation for effective asset management. As asset information management underlies all the asset-based management processes, the ensured DQ for asset information management assists the optimization of AM decision-making.

Because these asset data are quite different to typical business data, in order to ensure the quality of these asset data, AM DQ also has its own process, which also involve multiple DQ stakeholders such as data collector, data custodian, and require specialised supports of DQ technology and systems. The AM data will need to go through the DQ process, by a variety of DQ stakeholders and various DQ technology & systems, in order to ensure its quality. The asset data of enhanced DQ can then provide the foundation for effective asset management.

It is thought that this framework provides a comprehensive structure for understanding and identifying AM DQ issues in an organised way. It highlights the root perspectives on data quality problems, illustrates how they emerge during the process of asset management; and outlines the basic data quality management criteria.

## RESEARCH DESIGN

Based on the previous discussions, an interview-based case study was designed as the methodology to further validate the proposed AM DQ framework and obtain in-depth understanding. The objective to use case study is to investigate key stakeholders' perceptions of key factors of data quality in asset management and to determine the empirical validity of the proposed DQ framework, leading to the identification of key factors for data quality in asset management. The evidence from multiple cases is often considered more compelling and the overall study is therefore regarded as being more robust (Herriott et al., 1983). A case study research is an accepted research strategy in IS. Cavaye (1996) 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.

The organizations included two large Australian water utilities, as well as several of their 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 AM (e.g. GIS for asset location, Maximo for asset maintenance). Thirty interviews were conducted involving senior executives, asset managers, maintenance engineers, technicians, and data operators. 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 organizations e.g. annual reports. 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 (Yin, 1994). After analyzing the results, discussions with the industry partners were conducted to ensure their objectives were met.

Responses from the interviewees 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 analysing 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. A very preliminary validation for the AM DQ framework was achieved. While there may be 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 followings represent some of the empirical findings which are useful for the validation of the proposed AM DQ framework. The integration of asset management related technical systems, as well as the integration between business systems and AM technical systems, appears to be 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. This 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 use 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 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 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 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 (IPWEA 2002). 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.

### **Education and 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 appears 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 and 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. It was also found that field people within the organisation often generate the view that “year after year they filled out field data without feedback and a lot of them worked out that if they did nothing, nothing happens so why bother?”.

## **IMPLICATIONS AND CONCLUSIONS**

### **Understanding AM DQ issues is essential**

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.

### **AM specific DQ tools are needed**

Much of the DQ literature is concerned with transaction processing data in databases where the data can be controlled. Much like the data issues associated with a data warehouse (Wixom et al. 2001), the data associated with asset management must be integrated with data from other systems. However, 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. Unlike financial transaction processing systems, much of the data in asset management systems is textual and unverifiable by the current automated processes. For example, asset location data is usually started with a short-form of asset location name, followed by an asset id. It could be perfectly valid according to the existing data cleansing tools, but is meaningless because the short-form of asset location is wrong. In addition, no DQ tools were found to be able to verify if the acquisition date is correct in an asset management system. Nor can it verify that the field technicians have entered the correct maintenance records when they finally returned to the office to catch up on paperwork. From the differences shown, as well as the issues delineated in the previous sections, a comprehensive analysis of the major vendors and their DQ related products attests that the issues posed to data quality in asset management are quite unique in nature and cannot be resolved through the existing commercial off the shelf DQ tools.

The study by CIEAM (2005) as part of an Australian government funded project for the Center for Integrated Engineering Asset Management has reviewed several DQ products and evaluated them in terms of functionality and features. By following the DQ improvement cycle from data parsing to data monitoring, a comprehensive analysis of the major vendors and their DQ related products has been undertaken. Comparative analysis of the product data quality features is also given. The review of the current data quality tools indicates that the DQ tools have not changed significantly since the Neely (1998) study, and the existing DQ tools are not effective for assessing the quality of the data in an asset management system (Neely et al. 2006, CIEAM 2005).

There is a large number of data discovery, cleansing, enrichment, standardisation and prevention tools available in the current market. All data quality solutions examined during the exhaustive review focus very much on customer data bases and CRM systems. Their features and capabilities reflect this bias. As asset management data and informational needs are very different to a typical business environment, a gap exists in the availability

of data quality solutions for engineering asset management. Thus, there is a need for the development of data quality solutions for engineering asset management.

Several researchers have indicated that maintaining the quality of data is often acknowledged as problematic, but is also seen as critical to effective decision-making in engineering asset management. Managing data quality is essential to any asset management programme. This research develops an AM DQ framework in order to help organisations and practitioners understand DQ problems, identify causes, and develop solutions in the realms of engineering asset management. The framework proposed in this paper provides a useful tool for planning the establishment of an awareness of DQ issues in managing assets. With the adoption of the DQ framework, researchers can obtain an insightful and overall understanding about what DQ issues are in engineering asset management, where the DQ problems are, why they have emerged, and where improvements can be made. Future research will further develop the framework and identify DQ toolkit (e.g. guidelines, functional requirements for asset data cleansing software) for the improvement of data quality associated with engineering asset management.

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