International Journal of Computer Science and Applications, 2008, Vol. 5, No. 3b, pp 25 - 44 

# TOWARDS AN APPROACH TO SELECT AN ASSET INFORMATION MANAGEMENT STRATEGY

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Abstract: The management of engineering assets such as facilities and equipments can be a challenging task and optimising their usage is critical. To ensure effective utilization of an asset, one has to make effective decisions regarding the asset lifecycle. Consequently, it becomes imperative to gather useful information about the asset lifecycle. The objective of this paper is then to propose an approach for decision makers to develop an effective asset information management (AIM) strategy. We focus on the management of this set of information associated with the asset throughout its lifecycle. For this purpose we propose first to identify asset information requirements for an effective management. Second, we examine different technologies and systems for information capture, storage, retrieval and use. The findings of this paper would help in selecting an AIM Strategy aimed at providing timely, accurate, complete and consistent information about location and condition of assets so as to result in better decision-making. Furthermore, in order to assist asset managers to select a strategy, we discuss the role of information quality to assess the performance of an asset information strategy.

*Keywords*: Engineering asset; asset information management (AIM); AIM strategy.

## 1. Introduction

In today's world of globalization, companies must maximize every conceivable advantage to keep pace with their competition. Industries are therefore under increasing pressure to reduce costs, meet tougher performance and production targets, comply with regulatory requirements, and maximize return on assets. Those with vision are looking for opportunities to reduce the cost of maintaining their assets, improve the performance and extend the life of those assets, speed up information and decision making, and gain competitive advantage throughout the asset life cycle. This has recently put a strong emphasis on to the area of Asset Management (AM).

The management of assets such as facilities and equipment can be a challenging task and optimizing their usage is critical. For instance, decisions such as the scheduling of maintenance events have a critical impact on the utilization and overall equipment effectiveness of assets. Hence, companies that merely regard efficient maintenance and management of assets as an unavoidable cost are neglecting one of the most important strategic opportunities available [1]. However, we should note that even though effective scheduling of maintenance has an important role to play it is really only one of the decisions in managing an asset during its lifecycle. When managing assets, decision makers such as engineers, operators, business managers etc. have to ensure that the assets perform at peak levels and, at the same time, keep capital and maintenance costs down. To ensure effective utilization of an asset, one has to make effective decisions regarding the asset lifecycle phases. Consequently, it becomes imperative to gather useful information about the assets throughout their lifecycle for efficient management and control [2]. A set of information such as design specifications, reliability data, location, usage rate, environmental conditions, is then required to make effective decisions that aim to maximize its utilization throughout the asset's life. In this paper we focus on the management (information capture, storage, retrieval and use) of this set of information associated with the asset throughout its lifecycle.

The emergence of automated identification and data capture (AIDC) technologies such as RFID and sensors could greatly improve asset lifecycle management thanks to their ability to capture and manage information regarding key events along an asset's lifecycle [3]. It has been shown that such technologies have the potential to allow manufacturers to dramatically increase their capability and capacity to offer high-quality after-sales service while, at the same time, being able to demonstrate responsibility as producers of environmental friendly and sustainable products [4]. For instance, these technologies enable greater quantities of real-time operational data to be made available to organizations. This data can then be used to monitor and control assets, as well as ongoing operations, to improve their performance. However, it is yet a great challenge for current information systems to handle the increasing amount of information generated during the asset lifecycle.

The objective of this paper is to propose an approach for asset managers to develop an effective asset information management strategy. The key information for effective asset management as will be shown in later sections, includes location as well as condition of these assets. The findings of this paper would help in selecting an AIM Strategy aimed at providing timely, accurate, complete and consistent information about location and condition of assets so as to result in better decision-making.

The remainder of this paper is structured as follows. Section 2 provides background and definitions of *asset* and *asset management* when considering the asset *lifecycle*. Section 3 focuses on asset information requirements as well as on the available technologies and systems to support AIM. Section 4 describes the proposed approach to select an effective asset information management strategy, while section 5 concludes the paper and proposes future prospects.

## 2. Background

In this section, we provide the reader with a background in asset management by reviewing existing literature. First, we shall define what we mean by an "asset", and then we shall discuss asset management in the context of this paper.

### 2.1. *Asset*

There are fundamental differences in interpretation and usage of the term "asset" depending on the domain of use. For instance, an asset is defined by Swanson and Curry [5] from a software development point of view as "… *a qualified entity that, through its reuse, improves quality, provides a competitive edge, and reduces software development and support costs*."

From an infrastructure perspective, according to the International Infrastructure Management Manual [6], an asset is defined as "… a physical component of a manufacturing, product or service facility which has value, enables services to be provided, and has an economic life of more than twelve months".

The BSI PAS 55-1 standard specifications [7] provides a more focussed definition of an asset as "… plant, machinery, property, buildings, vehicles and other items and related systems that have a distinct and quantifiable business function or service."

A general definition of an asset is given in [8] as "… anything of economic value that is owned by an organization".

References [9] and [10] distinguish between the broad range of assets an enterprise has, and classify them as:

- Intangible assets: designs, knowledge, software, intellectual property, and processes.
- Tangible assets: liquid assets (cash or inventories) and fixed assets (building and infrastructures, IT equipment, machineries, hardware, and product and service equipment.

According to the different definitions presented above, we define an asset as follows:

**Definition 1 (Asset):** *An asset is defined as any physical core, acquired* * *elements of significant value to the organisation, which provides and requests services for this organisation*".

Furthermore, this paper focuses on complex engineering assets. Complexity is a multi-dimensional, multi-disciplinary conception, and could arise, but not limited to, from:

- Physical complexity of the asset: refers to high parts count and high connectivity between parts or subassemblies.
- Information management complexity: refers to how is difficult to capture, storage, retrieval and use/analysis of asset information.
- Manufacturing operations complexity: related to the different activities performed to manufacture the asset, their costs and lead-time.
- Maintenance complexity: refers to the cost and time to maintain the asset, as well as

* By acquired we mean that the organization has either the possession or the custody of the asset.

to the maintenance responsibility. In other words, who is the responsible for providing asset maintenance services: the owner, manufacturer or provider?

- Decision making complexity: refers to the 'criticality' of the decision to be made due to managerial constraints, feasibility constraints, scheduling constraints, and so on.

Hence, we use the term "complex engineering asset" here for complex products such as aircraft, heavy load vehicles, and machine tools. A complex engineering asset is thus seen as a physical element that generates revenue, provides and requests services to/from its user throughout its lifecycle, and requires considerable effort and cost in ensuring effective utilization. In the next section, we examine the literature in order to define asset management.

### 2.2. *Asset Management*

Similar to an asset, the definition of the term "Asset management" is largely dependent on the perspective from which we are analysing the assets and the purpose of the study. Even a fairly superficial survey of uses for this term reveals some fundamental differences in interpretation and usage.

Woodhouse [11] listed six distinct yet common current uses of the term:

i. The *financial services* sector has long used the phrase to describe the management of a stock or investment portfolio.
ii. Main board (usually *financial*) *directors* and some city analysts use the term in relation to mergers and acquisitions.
iii. *Equipment maintainers* have also adopted the term in order to gain greater credibility and visibility for their activities. As 'maintenance' has for so long been treated as a necessary evil, and low in the budgeting priority list, whereas 'asset management' sounds more professional and value adding.
iv. 'Asset management' in *information systems* context is interpreted as 'asset tracking': simply the bar-code labelling of computers and peripherals, and the tracking of their location and status.
v. Finally, a few critical infrastructure or plant owners and operators have adopted the term 'asset management' to describe their core role in life, both caring for, and making best sustained use of physical plant, infrastructure and its associated facilities. This interpretation is adopted by the new British Standard PAS 55-1.

According to the BSI PAS 55-1 [7], asset management is defined as "… systematic and coordinated activities and practices through which an organisation optimally manages its assets, and their associated performance, risks and expenditures over their lifecycle for the purpose of achieving its organisational strategic plan."

The focus of this paper is on engineering asset management. An engineering asset refers to the tangible asset as defined in [9] and [10]. From this point of view, Woodhouse [11] define asset management as "the set of disciplines, methods, procedures and tools derived from business objectives aimed at optimising the whole life business impact of costs, performance and risk exposures associated with the availability, efficiency, quality, longevity and regulatory/safety/environmental compliance of an organisation's assets."

Furthermore, Koronios [10] argues that "asset management entails preserving the value function of an asset during its lifecycle and maintaining it to as designed or near original condition through maintenance, upgrade, and renewal until sustainable retirement of the asset due to end of need or technology refresh."

According to the different definitions presented above, we adopt in this paper the definition proposed by the Cooperative Research Centre for Integrated Engineering Asset Management [12], which reflects our point of view of asset management.

**Definition 2 (Asset Management)** "*Asset management is the process of organising, planning and controlling the acquisition, use, care, refurbishment, and/or disposal of physical assets to optimise their service delivery potential and to minimise the related risks and costs over their entire life through the use of intangible assets such as knowledge based decision-making applications and business processes*."

From the above, we can see that there is a common thread that binds these different definitions of engineering asset management. This is the view that an asset has to be "managed" throughout its whole lifecycle. We shall now discuss this aspect in detail.

### 2.3. *Asset Lifecycle Management*

Management of assets throughout their lifecycle is process-oriented. When one considers the complete "cradle-to-grave" life of a typical asset, its lifecycle can be divided into three interdependent processes (cf. Figure 1).

1. Beginning of Life (BOL): which involves the design and creation (manufacture) of the asset;
2. Middle-of-Life (MOL): when the asset moves into the usage stage, when it provides its intended service to its user, and requests services from the user in the form of maintenance, upgrade, etc.;
3. End-of-Life (EOL): when the asset is eventually retired from its operation.

Coordinating these processes and decisions made during these processes are vital to effective asset management, and this can be achieved through monitoring and capturing of information regarding key events throughout the asset's lifecycle. In order to facilitate the interoperability of information systems that support management of this information, an industry/government initiative has resulted in an ISO standard (ISO 10303-AP 239 Product Life Cycle Support (PLCS)) [13] for the support of complex engineering assets, such as ships and aircraft, through life. PLCS provides mechanisms for maintaining the information needed to support complex assets, and to capture feedback from their operational use related to faults, failure modes and diagnostic data.

The BSI PAS 55-1 standard [7] defines an asset lifecycle as "… the time interval that commences with the identification of the need for an asset and terminates with the decommissioning of the asset or any liabilities thereafter."

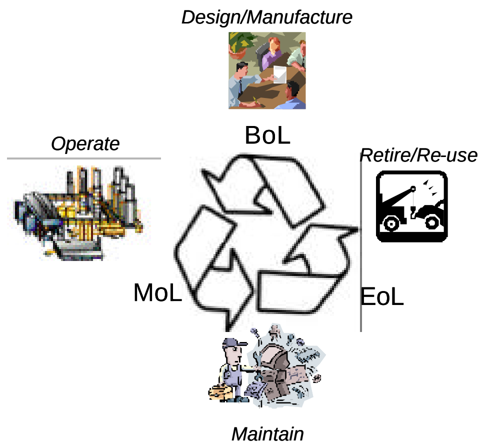


**Figure 1. "cradle-to-grave" asset lifecycle**

The above definition corresponds with our definition of an asset, which takes a user-perspective. Hence we define the asset lifecycle as the succession of five main phases (cf. Figure 2):

- **Acquire –** all activities involved in technical and financial analysis, justification, and planning for acquisition of new assets, as well as in managing the acquisition of assets.
- **Deploy**- all activities associated with the installation, testing, and commissioning of new and reapplied assets.
- **Operate/Maintain** - all activities involved in most effectively maintaining asset availability (health), longevity, and capability (quality, performance).
- **Retire** - all activities involved in managing assets that are still owned, but no longer being used, including decommissioning, protection, and disposal. These assets, or some of their components, might be re-used, re-manufactured or re-cycled.

Being the longest and most complex lifecycle stage, operate/maintain often deserves additional attention. However, we should note that even maintenance has an important role to play, it's really only one of the variables in managing assets, others include, for instance, choosing the right assets in the first place, using them appropriately, or trading short-term performance against long-term sustainability, etc.

Accordingly, we believe that the monitoring phase is crucial during the asset lifecycle. This phase not only monitors the condition of an asset use, but should also provide further decision making information for:

- Improving asset reliability through efficient prediction of asset failures
- Planning and scheduling of repairs, replacement and redeployment
- Maximizing the asset performance and throughput

Such monitoring information could be captured through an array of sensors, filed devices and/or manual inspection systems, which is then collated and analysed to see how the asset behaves over a period of time.

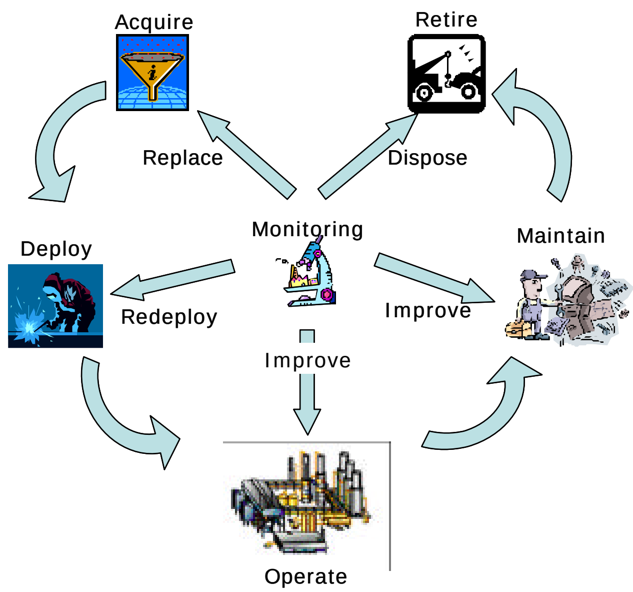


**Figure 2. Asset Lifecycle (inspired from [14])**

### 2.4. *Summary*

Based on the above discussion, we classify the different perspectives, from which an asset could be analysed, as:

- Financial perspective: the scope of analysing assets from a financial point of view is to reduce the costs, increase reliability, performance and return on investment (RoI) in order to increase customer satisfaction. Financial-perspective asset management deals with the dynamic impact of asset health, availability, reliability and performance values on each other, and focuses on the financial value of an asset.
- Engineering perspective which could be decomposed into two points of view: *information* and *decision making*. The information point of view refers to gathering and managing (real-time and dynamic) data and monitoring the asset along its lifecycle. These data are related to traceability issues and could be determined by answering basic questions such as: When, Who, Why, Where, What. The decision making point of view relates to performing intelligent diagnosis and analysis in order to support decision makers during asset maintenance, asset scheduling, asset reliability, asset reuse, etc.

The following section will discuss asset information requirements as well as the available technologies and systems to manage the required information.

## 3. Asset Information Management

Asset information is used by a diverse set of people and systems, each with their own concerns, requirements and specific needs. Bringing all of disparate information together into widespread asset-centric information is yet a key challenge facing asset users today. In order to acquire and manage the vast amount of information emerging during the asset lifecycle, an integrated asset information management strategy is required. However, lifecycle information occurring during the acquisition, deployment, usage, maintenance and disposal stages are usually hard to capture and in most cases lost. For this purpose, we propose in section 3.1. to identify the asset information management requirements for an effective decision-making. We focus primarily on asset location and asset condition monitoring. Technologies and systems to capture and manage asset information are afterwards discussed in section 3.2. The aim of this section is to examine the capabilities of different emerging technologies and systems that are important for through-life asset information management.

### 3.1. *AIM requirements (Challenges)*

Asset information is very important for organizations because it represents the collective knowledge used to manage assets as well as to produce and deliver products and services to customers. Understanding what information is needed to support decision making process and what data can be gathered as raw material for such information, is an essential starting point to build up an information management strategy. In the following, the benefits and the necessity of asset location and utilization tracking is described.

#### *3.1.1. Monitoring of asset location*

In today's world, organizations have become increasingly collaborative, with business partners and competitors sharing a wide variety of equipment and resources. In this context, assets become increasingly mobile, distributed and shared across workgroups. Moreover, on large-scale organizations, it is often difficult to manage the exact location of spares, tools and people, which causes sub-optimum performance. Knowing the location of those assets is critical to effectively managing them. Indeed, providing relevant, timely and useful location information to the people and systems responsible for managing asset-intensive business processes provides a number of significant benefits, such as making quick and informed decisions based on real-time business information, reducing costs associated with searching for misplaced or lost assets, and improving overall productivity and throughput.

Furthermore, one of the major reasons to track assets is when the cost of not knowing the location of an asset at a given time can be considerable. Sometimes the value of the asset itself is not as important as the cost of the consequence of losing track of the asset or information about its location. Hence, asset location tracking involves understanding (i) where your assets are at present; (ii) where they were last; and (iii) how many of them are in a given location. With this set of information, a company can collect, reposition, and redeploy its assets in the most effective manner; especially when employees spend significant amounts of time searching for misplaced assets and resulting in wasted labour time. For example, routine maintenance of biomedical equipment is compromised by the inability to find it, which in turn increases the risk that hospitals will fail to meet stringent Joint Commission on Accreditation of Healthcare Organizations (JCAHO) regulations requiring timely equipment maintenance. Therefore, location-enabled AM in hospitals can help biomed departments find the equipment and get it back into service as efficiently as possible. This unlocks equipment-related cost reductions and allows biomed managers to spend less time looking for equipment and more time on maintenance.

In order to manage assets, it must be possible to track them and get accurate, timely data on their locations and status. There is more than one reason to track assets, and not all are related to financial gains. The return on investment of location tracking systems can also include non-monetary elements, such as higher quality of service to customers, or correcting errors when they occur. According to a 2004 survey of 233 companies in a wide variety of industries, the Aberdeen Group[†] found that 50% have manual AM processes. By automating the process, location tracking systems can remove the error factor that is introduced by direct human involvement in asset tracking.

We shall now discuss the motivations for monitoring and tracking the condition of assets through their lifecycle.

### *3.1.2. Monitoring of asset condition*

The benefits and necessity of tracking asset condition during its lifecycle are discussed from both perspectives: an asset user perspective and an asset provider perspective. From an asset provider point view, it has become more important to understand and track how each asset is used and behaves. For example, tracking the asset utilisation conditions will enable more intelligent maintenance regimes, e.g. predictive maintenance [15]. The fundamental issues in ensuring asset reliability are capturing information during its operational stage and use them to predict asset behaviour and failure conditions. The information captured could be used to trigger appropriate and timely follow up actions.

From an asset user point of view, the reliability of manufacturing or production processes is heavily dependent upon the flawless operation of the assets utilized in the processes. An asset lifecycle starts at the time of designing the manufacturing or production system, and typically illustrates, stages such as, asset acquisition, deployment, operation, maintenance, decommissioning and replacement. Being the longest and complex lifecycle stages, operation and maintenance often deserve additional attention. The maintenance itself is an extremely complex process. Hence the challenge of overall equipment effectiveness during an asset lifecycle is a continuous level of performance as it had on day one or better. An essential requirement in this regard is the continuous availability of the condition monitoring information and its analysis in order to predict failures as soon as the asset starts deviating away from its standard operational behavior.

In order to achieve both objectives, i.e. profitable services (asset provider point view) and lean manufacturing (asset user point view), there is a need of an AIM system that enables to timely access complete and accurate asset information. In the next section, we examine technologies used for capturing data regarding location and condition, as well as approaches to manage this information.

[†] Aberdeen Group Report. http://www.aberdeen.com/

### 3.2. *Technologies and systems for asset information management*

This section examines emerging technologies and systems that are important for through-life asset information management, i.e. from acquisition to disposal. The two key stages of asset information management are (i) capture of the required information, and (ii) effective management of the captured information. Technologies and systems to achieve these are now discussed separately.

#### *3.2.1. Data capture technologies*

Information about the identity, current location and condition status of assets is assuming a pivotal role in AM. Emerging technologies in product identification, sensors and wireless telecommunication, enable improved information visibility through whole product lifecycle. For an exhaustive review on identification technologies, the reader is referred to [16, 17].

An improvement on the traditional manual system (e.g. manual paper inventory) is to affix a barcode to each asset and use a barcode reader to retrieve information contained in the barcode. While faster and less error prone than a manual process, it is still a human intensive task that takes time. Furthermore, barcodes have additional disadvantages, such as requiring line-of-sight to read them and can store limited amount of information.

Radio Frequency IDentification (RFIDs) aims to address these concerns, and in time replace barcodes altogether. A RFID system consists of a “tag” which has a small integrated circuit, memory and an antenna onboard, and a reader which can interrogate the tag through the antenna to retrieve information contained in the tag memory. The key differences between barcodes and RFIDs are the amount of information that can be stored on them, and the ways in which they can be read (no line-of-sight requirement for RFID). An RFID tag can store a lot more information as compared to a barcode, such as delivery date, or even the last maintenance action and date.

Although passive RFID tags can be used as an information carrier, their use to determine precise location is limited. However, for the purposes of asset management, RFID tags can be used to determine the logical or business location within a factory or a supply chain by strategic positioning of readers. Real-Time Location Systems (RTLS) have emerged as an alternative and cost effective method for tracking the location and status of assets within local areas. RTLS systems differ from other types of automatic identification technologies in that tagged assets are not required to be scanned or pass within close proximity of a reader in order to be detected. In contrast, RTLS tags transmit their ID’s and status information at frequent intervals via a low power radio signal to a central processor. For locating assets in transit, technologies such as GPS can also be considered.

In addition to these technologies, sensors can be used to provide information about the condition of an asset. This can be defined as a set of variable quantities, which can completely describe the system at a given point in time [18]. Sensors can be used to measure many different parameters, including temperature, humidity, acceleration, shock, pressure, or velocity. There is a plethora of sensor devices with many different characteristics. For instance, sensors can be wired or wireless, analogue or digital with a varying degree of intelligence and data storage capacity. According to [17], it needs to be pointed out that sensors are limited in what they can perceive. Their limitations arise from the following: (i) their spatial coverage (range) and measurement accuracy (resolution) is subject to physical limitations, (ii) they can measure a restricted number of state variables, and (iii) sensors might fail and are subject to noise.

To satisfy the requirements of AM, the use of a single sensor are not always enough and an integration of various sensor technologies is required (e.g. a type of sensor integration systems are wireless sensor networks (WSN)). Furthermore, in order to achieve the key requirements of AM (cf. Section 3.1), a combination of technologies, including RFID, Sensors and Wireless communication is necessary. Recent implementations of such a combination are expected to show great benefits for AM. For example, thanks to their new real-time visibility system, the Dutch KLM is expecting to save over £1m through a reduction in fleet without lowering service levels [19].

In the next section, we discuss different approaches to manage asset information captured using technologies described here.

### *3.2.2. Data management methods*

Identification technologies are only part of the solution for AIM. Consequently, there is a need for an overall framework to specify, design, and operate these technologies for asset lifecycle management. For instance, The EU-funded PROMISE project has developed an architecture for RFID enabled product lifecycle management [3]. The PROMISE initiative pointed out a key component for product information tracking which is the "Product Embedded Information Device – PEID". Where *product embedded*: implies that product lifecycle data can be tracked and traced in a real time way over the whole product lifecycle by embedding an information device to a product itself. The PEID should possess a unique identity which requires a product identification function in the PEID. *Information device*: indicates that the PEID can gather, process, and store data into itself. This strategy for managing asset information management is called peer-to-peer based information management. The information can be stored where it was created and fetched when needed or moved/copied where it is the most appropriate.

In addition to the peer-to-peer strategy, examples of different strategies for asset information management are given in Figure 3a and 3b. First, asset data can be stored on the PEID and then processed when requested. The data are stored where it is created and carried when needed or copied where it is the most appropriate. Second, asset data is stored on a networked database and linked to the product through a unique identity stored in the PEID. In this case, two possible architectures exist. First, all asset data can be managed in centralized database architecture. The asset related data, i.e. usage and location tracking, are collected into one single database for asset lifecycle management (cf. Figure 3a). For this purpose, most efficient systems integration method is obtained if all partners (asset users) use compatible communication interfaces. Second, asset data can be managed in distributed databases (cf. Figure 3b). Data about the same asset can be distributed over different system users.

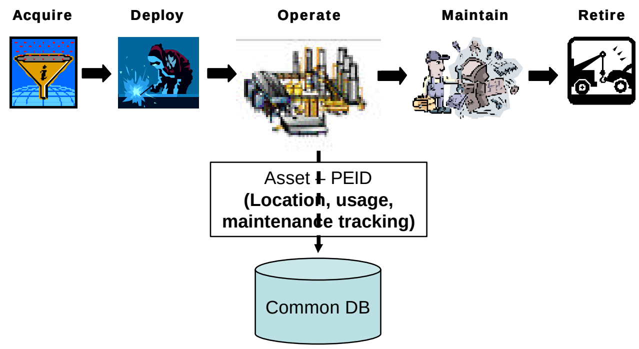


**Figure 3a. Centralized architecture for asset information management**

In several situations, asset information would have to be stored partly within the PEID, and partly on a network. This is typical of complex asset such as heavy vehicles, where critical information is stored within the asset so as to ensure its availability for on-site maintenance.

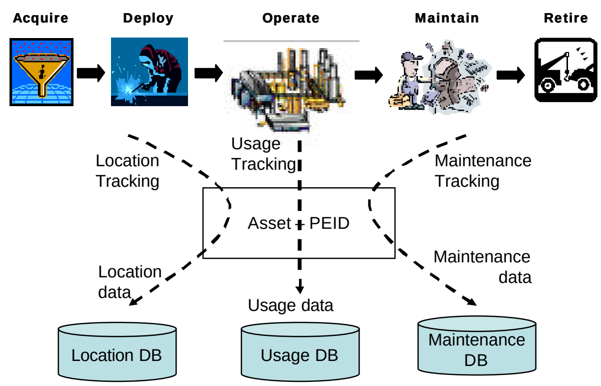


**Figure 3b. Distributed architecture for asset information management**

Figure 4 summarises the discussion in this section. We examined different data capture technologies and data management methods to monitor the asset location and condition throughout its lifecycle. Several data capture technologies are available such as barcodes, RFID or sensors and all of them present different characteristics. Depending on the end-objective of using these technologies, the choice may differ. For example, it is sufficient to use barcode or passive RFID tag to track the location of an asset. However, to monitor the condition use of an asset, a combination of RFID tag and sensors might be needed.

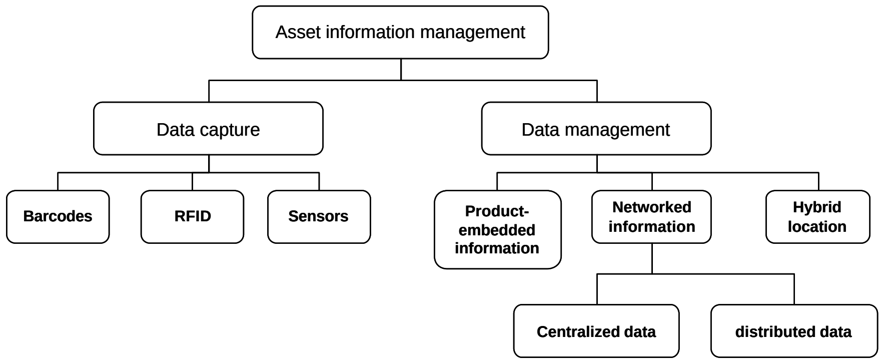


**Figure 4. Asset information management approaches**

When it becomes to manage the captured data, the different aforementioned methods proposes different characteristics and advantages. From one hand, the centralised alternative is a suitable solution because it allows: (1) keeping a 'one version of the truth' and thus high consistency of data, (2) up-to-date information, since there is no need of synchronization between databases. However, some of the disadvantages of a centralized solution are (1) the amount of gathered data which could become overwhelming, and (2) the need for network configuration and systems integration. Alternatively, the distributed solution is suitable because (1) there is no explicit need of system integration, and (2) the amount of stored data is relatively less overwhelming. However, since databases need to be synchronized, a distributed solution could suffer from data inconsistency and unavailability of up-to-date information.

In summary, we have illustrated that effective asset management requires efficient tracking and capturing of events throughout the asset lifecycle, and that there are variety of technologies and approaches that the asset manager can choose from in order to do so. Once a list of asset information management strategies is established based on the available technologies and data management systems, the next logical question is how do we choose the best alternative? In the following section we propose an approach to select an asset information management strategy based on the requirements described in section 3.1. This approach aims to take into account the capabilities of the available technologies and data management systems as described in section 3.2.

## 4. Approach to select AIM strategy

Forward-thinking managers are striving for better ways to increase the productivity of their assets, proactively maintain them, and maximize their usefulness over the asset lifecycle. An asset lifecycle typically illustrates activities such as, asset acquisition, operation, maintenance, decommissioning and replacement. Asset management is an information intensive process that consists of many sub processes to manage the asset lifecycle.

A strategy for asset information management is composed of two key stages: (1) identifying what information are required, and (2) deciding the best way to effectively manage these information. By effective information management we mean capture of the required asset information, storage of the captured information and retrieval of the stored information. Moreover, in order to make an effective use of these information, different stages such as filtering and transformation are incorporated.

Different technologies (e.g. RFID technology for data capture) and systems (Data Management systems) are available to address the requirements of asset information management. However, these technologies and systems come with different capabilities and limitations. A strategy would then to identify, depending on the data requirements, what technology and system are suitable for an effective asset management.

This section presents an approach to support decision makers to select a strategy to manage information associate with their assets. Figure 5 presents this approach to identify and select the suitable strategy to manage the asset information. The approach consists of three stages: (i) design possible strategies for asset information management; (ii) evaluate these strategies; and (iii) select the best strategy on the basis of evaluation. We shall now examine each of these stages in turn.

### 4.1. *Design strategies*

In order to identify possible strategies, asset managers need to examine two perspectives: (i) *top-down* perspective to understand the requirements posed by organizational-level business objectives; and (ii) *bottom-up* perspective where requirements are posed by the asset itself. These perspectives are described in following sections in detail.

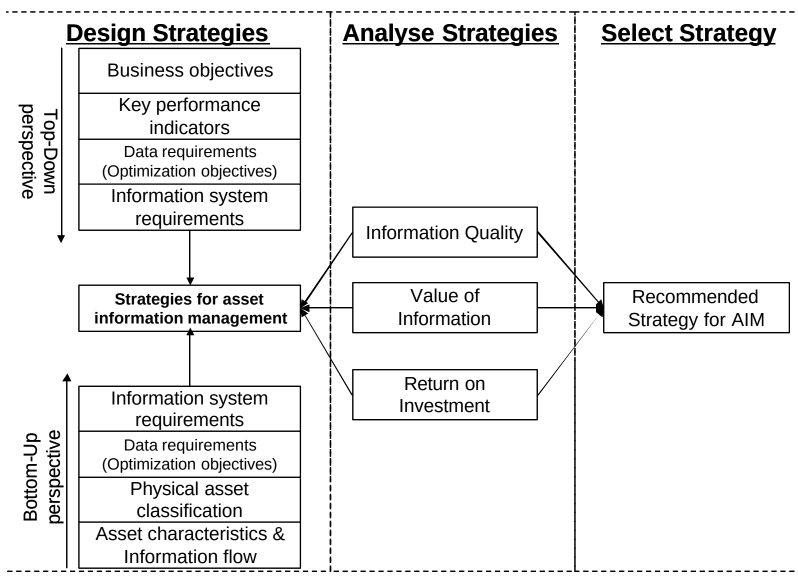


**Figure 5** Architecture for designing and analysing strategies for asset information management

*Top-down perspective*

The bottom-up perspective consists on designing strategies according to the asset characteristics. It is the asset nature which dictates the requirements for asset management. In other words, the requirements to manage a robot are different from the requirements to manage a conveyor, while both of them are assets for their owner. This leads us then to address the problematic of asset classification and understanding what are the key attributes that makes an asset different from another. Once the classification is established one can identify the different requirements for asset management. In order to illustrate this rationale, we now present a non-exhaustive classification of assets to help understanding the key requirements for asset management (cf. Table 1).

This classification is based on the mobility and the complexity of the asset to be managed. Management of moveable assets is still not appropriately supported by existing IT systems effectively. Information about location, status and usage is either lacking or inaccurate. This can cause delays in industrial operations, inefficient use or excess inventory of costly assets.

**Table 1. Asset classification**

| | **Simple** | **Complex** |
|---|---|---|
| **Fixed** | **Type I**<br>e.g. Conveyor<br>e.g. Gas bottle<br>*Reqs.: Asset condition monitoring (simple)* | **Type II**<br>e.g. oil rigs<br>e.g. machining tool<br>*Reqs.: Asset condition monitoring (regular/real-time)* |
| **Mobile** | **Type III**<br>e.g. tools<br>e.g. container<br>*Reqs.: Asset location monitoring / Asset condition monitoring (simple)* | **Type IV**<br>e.g. engine, trucks<br>*Reqs.: Asset location & condition monitoring* |

As illustrated in Table 1, the key information requirements depend on the type of the asset to be managed. For example, for a Type II (i.e. fixed and complex) asset, it is sufficient to track its condition since the location is fixed. However, for a mobile and complex asset (Type IV), tracking location and condition is necessary for effective asset management. In the case when the asset is simple (Types I and III), the requirements depend on its mobility. If the asset is fixed, asset management is typically not an issue.

Simple corrective maintenance would be more appropriate in such cases. However, if the asset is mobile tracking its location through the lifecycle would be required.

Based on this classification and the review of technologies and approaches in section 3.2, we provide some preliminary recommendations for asset information management. For instance, a simple barcode-based solution with networked information architecture to manage the captured data would suit Type I assets. For Type II assets, a solution could be sensor-based to capture asset data and hybrid information architecture to manage this data. Since the asset is fixed, a centralized data repository would be ideal for information management. An RFID-based solution with networked (distributed) information would satisfy the AM requirements for Type III assets. When assets become complex and moveable (Type IV), an RFID-based sensor integration system for data capture and a hybrid information architecture to process these data are required.

*Bottom-Up perspective*

The top-down approach consists on designing strategies to optimize business processes in order improve asset performance. It can be achieved by increasing reliability, availability, and operations and maintenance productivity. This leads us to identify the different business objectives and Key Performance Indicators (KPIs) to improve.

For asset-based industry, the most important elements in achieving success are the assets. Businesses need to adopt a holistic view of asset lifecycles to plan optimal operational and maintenance strategies that achieve commercial aims, favourable regulatory treatment and customer satisfaction. For instance, in the utilities industry, this has been most notably described in the British Asset Management Standard PAS-55 [7], where the underlying driver is that existing assets should be continually managed as their age and their condition degrades to satisfy ongoing demands for optimum financial and technical performance.

In a more general way, we can assimilate the business objectives to the strategic goals of an organisation, and they correspond to the well-known trihedral Cost-Benefit-Risk. These business objectives could then be formulated as: increasing benefit, reducing cost and reducing risk. In order to reach these objectives, operational business objectives or KPIs have to be designed, and should be quantifiable. For instance, key performance indicators include the system reliability, safety and operating requirements. Business objectives relates to the corporate values like utilisation, profit and return on investment.

To achieve these business objectives, successful AIM strategy must be based on fundamental elements – What data to collect, how to collect it, how to measure it, how to analyze it together with other data, and how to interpret and respond to the results to develop in-depth asset expertise and best practice management.

Health Indices, to provide a basis for assessing the overall health of an asset, can be developed from relevant condition information and, together with asset age and past performance, be used to derive the asset residual life. Moreover, by evaluating the probability of failure and the consequence cost for assets, risk costs can be assessed, allowing asset owner/operator to focus attention on their highest risk assets. A solution can then be established based on economical optimization of a maintenance intervention, life cycle and risk cost streams.

In summary, the objective of the *design strategies* phase with the top-down and the bottom-up perspectives is to support the asset manager in identifying a set of strategies to manage through-life asset information. These strategies are identified based on the information requirements to manage the asset. Once a list of feasible AIM strategies is established, the next phase is to analyse these strategies in order to select the most suitable one. The following section discusses our approach to analyse different strategies. Two main concepts are considered in order to evaluate different strategies: value of information and return on investment.

### 4.2. *Analyse strategies*

Two essential elements to consider when appraising the success and robustness of a given asset information strategy are the value of information generated by the adopted information technology (i.e. in terms of operating and management), and the return on investment gained from acquisition, deployment and disposal. These proxies are important to decision-makers not only because they underline gains from a specific strategy but also can guide decision-makers about the decision steps to be undertaken when dealing with complex assets and fragmented information in a lifecycle context.

Methods and tools to be used when addressing these problems should take into account risk, uncertainty, behaviour and complexity within an extended planning horizon. These techniques should be dynamic in nature and must vary according to the type of assets under study and where we are in the asset lifecycle. Hence, decisions to maximise the value of information and return of investment can be addressed and formulated as portfolio optimisation [20], dynamic programming [21], or utility maximisation problems [22].

According to Banker and Kauffman, information value arises as the difference between a decision maker's payoff in the absence of information relative to what can be obtained in its presence [23]. Existing work on the topic of "Value of Information" mostly focuses on specific quality dimensions from specific background, such as:

- Supply chain management: For example, [24] established cost models against the yield information and lead time to measure the value of information. Authors in [25] used mathematical models that consist of the costs of labour, labour-hours (regular, increase, decrease, additional), transportation, raw materials, carrying goods inventory (at manufacturing facilities, in transit, at the distribution centers) and over time.
- Risk analysis: Value of Information analysis makes explicit any potential losses from errors in decision making due to the uncertainty and it also identifies the "best" information collection strategy, which leads to the greatest net benefit to the decision maker [26]. Bayesian decision theory plus some more constraints that are relevant to information is mostly used to diagnose the overall system risk. Mussi [27] developed a methodology for building a theory-based Value of Information sequential decision support system, and a design engine to build step-by-step knowledge-base and the related inference.

Although these works presented models or/and approaches to support decision makers, none of them addressed the whole asset lifecycle. Each research work focused on a specific area and a specific stage of the asset lifecycle. However, they all recognise the need and the importance to improve information quality. Better information quality relies on better information management. Indeed, a poorly designed information management system may produce high amount of information that no one uses, while decision makers lack the information they do need. Furthermore, according to [28], without quality of information architecture that stores the enterprise's knowledge resources, information quality will be much more difficult to achieve. Consequently, concerted research has to be done to develop models and tools to comprehensively evaluate the value of information and information systems in asset management.

### 4.3. *Select strategy*

Once the different identified strategies are analysed, the asset manager is equipped with the outputs of the evaluations of each of these strategies. This evaluation revolves around the quality of information produced by the system, the value of information generated by this system and the overall returns induced from this strategy in terms of benefits and costs. This set of information enables the decision maker to choose the best strategy to be deployed.

After implementing the AIM strategy, i.e. data capture technology(ies) and data management system(s), asset manager have to monitor the overall system and evaluate its effectiveness compared to the expected performance. Consequently, the quality of information generated by the implemented system has to be re-assessed and further adjustment might be needed to achieve an effective and efficient asset information management system.

## 5. Conclusion and Future prospects

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. When managing assets, decision makers have to ensure that the assets perform at peak levels and, at the same time, keep capital and maintenance cost down. For this purpose, a set of information is required to ensure an effective utilization of an asset.

Asset information is used by a diverse set of people and systems, each with their own concerns, requirements and specific needs. Bringing all of disparate information together into widespread asset-centric information is yet a key challenge facing asset users today.

In order to acquire and manage the vast amount of information emerging during the asset lifecycle, an integrated asset information management strategy is then required. However, lifecycle information occurring during the acquisition, deployment, usage, maintenance and disposal stages are usually hard to capture and in most cases lost.

In this paper we proposed an approach to support asset managers developing an effective asset information management strategy. Key asset information management were identified and classified into asset location and asset condition monitoring according to the asset characteristics; i.e. the bottom-up perspective. However, further information could be identified according to the business objectives of the organization. The top-down perspective will support asset managers identifying asset information requirements based on the key performance indicators to be optimized.

Based on the indentified technologies and systems to manage asset information, the objective is to propose a guideline for asset managers identifying the best strategy. For this purpose, we investigated the available techniques to quantify the value of information for each strategy. The next step is then to define the information quality dimensions to be studied in order to deliver metrics to support the decision making process. Based on these metrics, a set of tools for strategy evaluation could be delivered to decision makers to support the strategy selection phase. Furthermore, the overall approach proposed in this paper needs to be tested through use cases in an industrial environment.

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