Development of techniques to manage asset condition using new tools

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Abstract

Asset Management and maintenance is an area which is undergoing rapid change due to new budgetary and environmental pressures and rapid progression in the technologies applied. At the heart of this topic are the collection, management and use of data pertaining to the condition and maintenance of key assets. In this chapter we outline some of the technologies which have recently been developed and applied to the area of asset management.

Introduction

Over recent years, the importance of maintenance, and therefore maintenance management within manufacturing organizations has grown. This is a result of increasing pressure upon manufacturing organizations to meet customer and corporate demands, and equipment availability and performance is a central issue (Gerst et al 2005). Recent trends have indicated that, in general, many manufacturing systems are not performing as intended, so far as cost effectiveness in terms of their operation and support. The majority of systems often operate at less than full capacity with low productivity and the costs of producing products are high (Muller et al 2008). Furthermore energy efficiency has become increasingly important with rising energy prices and growing awareness of carbon emissions. This means that maintaining equipment to ensure it operates at optimum efficiency is now seen as a key priority for many organisations.

It is widely acknowledged that it is necessary to support maintenance staff by supplying them with accurate and up-to-date information regarding maintenance tasks and recent history. In order to do this it is important that the necessary data is captured, stored and presented in an appropriate fashion. Asset management and condition data can be captured either manually or with sensors but this potential wealth of information must be effectively managed if it is to be of use. One method to achieve this is to identify and 'label' an asset with the correct identification using 'smart data tags' which can store maintenance data, cost to maintain and recent maintenance problems. Furthermore such data tags can also be used to provide condition based maintenance data which is vital in assisting the scheduling of maintenance tasks and in assessing the performance and suitability of maintenance procedures.

Smart tags are quickly becoming a popular method for managing assets which could be moved and utilized at different sites, utilizing wireless tag technologies. The method includes storing information relating to each asset, which is then displayed to a user of the system.

The significant aspects of an integrated maintenance management system are:

- Data gathering
- Data storage
- Data analysis
- Data presentation

These are illustrated in figure 1 below. It is our view that this relationship is cyclic, with results and analysis informing continuous development of the asset management and condition monitoring system. The successful application of these techniques will result in an extended and properly managed lifecycle for the asset in question.

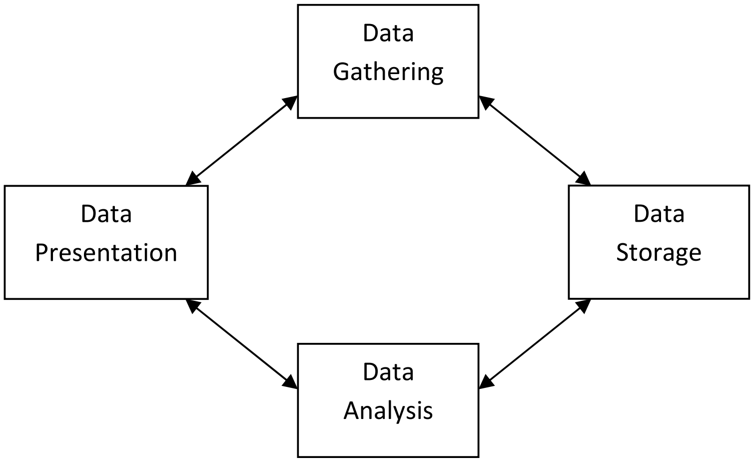


Fig. 1. **Asset management data lifecycle**

As previously mentioned data gathering is crucial for both scheduling maintenance and for assessing the performance of the maintenance regime. In order to fully optimize maintenance regimes it is necessary to collect condition data, either through manual inspection or online sensors, cost data for both maintenance and repairs following failures, usage statistics and downtime costs resulting from both maintenance and repairs. Only when all the data is available can the optimal scheme be determined. Furthermore energy consumption is becoming an ever more important factor in manufacturing organizations and poorly maintained equipment often leads to increased costs. Automatic energy monitoring can therefore be vital in the condition monitoring process as well as in optimizing processes.

The advent of automated data gathering and condition monitoring has lead to a need to manage this data efficiently. Many organizations simply store data electronically and never use it due to the intimidating volume. Furthermore data is often fragmented across different systems and without an efficient scheme it can be difficult to integrate and link to information on documentation, parts and their availability and personnel training. Many software packages exist which allow data to be stored in a database which allows efficient access to the data from many perspectives. Management staff can access high-level statistics, while personnel involved in routine maintenance activities can access the latest data and relevant documentation.

Once the data is efficiently stored it is important that it can be efficiently stored and accessed. The presentation of data to maintenance staff in particular requires consideration since it is unusual for there to be a PC terminal located in a convenient location for them to access maintenance information. Hand-held devices such as smart-phones and Personal Digital Assistants (PDAs) are increasingly capable of storing and accessing large amounts of data and documentation, as well as being capable of communicating on a wireless basis with central data repositories. Furthermore additional technologies such as Global Positioning (GPS) receivers are becoming increasingly common on affordable hand held devices.

At a management level it is important to present information in such a way as to enable decision to be made easily by presenting useful high level statistics and by automatically detecting areas where improvements are necessary through the use of intelligent algorithms and metrics. This will allow the software to direct attention towards areas where maximum improvement is possible.

In the following sections we will evaluate each stage of the data lifecycle and identify appropriate technologies, as well as describing how they can contribute to an integrated asset management system.

Tools for gathering data

Automated data collection is of crucial importance in developing maintenance systems. Many condition sensors are available ranging from simple temperature probes, vibration sensors, and pressure transponders to advanced systems such as IR spectrometers for automatically measuring the condition of lubricating oil.

In the refrigeration sector simple technologies can be applied to monitor industrial chilling apparatus, including monitoring refrigerant pressure, checking temperatures around the system and monitoring moving parts such as compressors for abnormal vibration. The successful application of these technologies can lead to additional benefits in efficiency and compliance with regulations regarding refrigerant emissions (Baglee and Knowles 2009).

In the marine environment failures can be costly and problematic if ships become stranded due to break downs. The Posseidon project (Progressive Oil Sensor System for Extended Identification ON-Line) addressed this by using sophisticated sensors to monitor the condition of lubricating oil. This provides not only a snapshot of the performance of the oil but also provides indications of other engine faults which result in contamination of the oil (Baglee and Knowles 2010a,b, Gorritaxetegi et al 2007, Mohammadi et al 2010). The sensors developed are capable of making measurements of oil properties including:

- Water content
- Soot content

- Insoluble content
- Base number
- Particulate content
- Viscosity.

The application of oil analysis is not limited to the marine environment. Similar technology is under development for application in wind turbines, supported by remote data links which reduce the need for personnel to visit remote and difficult to inspect installations (Baldwin and Lund 2010) and for use in aircraft gearboxes (Byington et al 2010) amongst others. Other important condition monitoring technologies include vibration analysis, acoustic emission analysis, thermography and mechanical stress measurement. These condition-specific techniques can be supplemented with the analysis of other general characteristics such as flow rates, temperatures and pressures. Furthermore energy consumption is increasingly finding applications as an indicator of condition.

These automated techniques can also supplement manual data collection using devices such as PDAs and hand held data collectors. We envisage that the increased memory capacity computational power of mobile phones will lead to them finding application in this area.

In addition to collecting condition data, an efficient asset management system must also manage and provide easy access to maintenance manuals and documentation and information relating to parts and materials such as their availability, price, location and ordering details. Much of this data is now available online in the form of electronic documentation and online inventory and stock control systems. In order to fully realize the potential of such systems it is crucial that such data is linked to other maintenance systems through a single, easy to use interface which allows the data to be accessed at the point of need.

Tools for storing data

Once condition data has been captured and other maintenance information has been collated it is necessary to adequately store and manage this data in a manner which makes it easily accessible and which allows the required data to be accessed efficiently when required. Databases systems offer many advantages in the field of asset management and maintenance in terms of scalability, security and data accessibility. The MIMOSA (Machinery Information Management Open Systems Alliance) is an enterprise-level maintenance open database specification which uses XML-based information standards for data exchange using the database standard SQL (Structured Query Language) and XML (eXtensible Markup Language). A MIMOSA based database system was used at the heart of the Dynamite project for connecting all services from different maintenance areas together including intelligent sensors, machine diagnostics, prognostic and decision support.

In Figure 2, the Dynamite system architecture is shown. The active RFID asset localization system is located on the left and the passive RFID for asset identification system is on the right. They are connected by a central MIMOSA maintenance database via the internet or a local network.

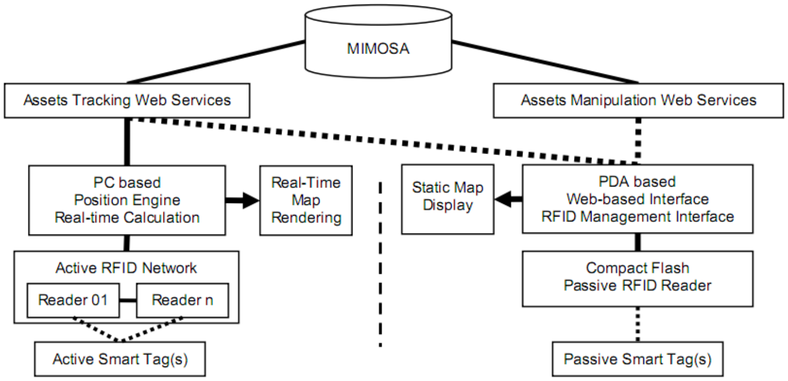


Fig. 2. Dynamite System Architecture

Although the two e-maintenance structures are located side-by-side, they are connected to a central database which forms a key part of the architecture. This means that the two systems can work together to provide PC-based and mobile-based services to users. In this case, companies do not need to replace their existing systems, which is a good reason to motivate manufacturing companies to invest. This core functionality allows significant developments to be made while building on existing systems, reducing the required outlay.

Some applications do not warrant large scale database structures such as those described above. Embedded maintenance management systems such as that developed as part of the The Progressive Oil Sensor System for Extended Identification ON-Line (Posseidon) project (Baglee and Knowles 2010a and b), are better suited to simpler systems for managing the necessary information. In terms of storing the condition monitoring limits, the messages to be passed to the operators and the sensor readings which must be stored and read, XML was selected. The use of XML in Posseidon is illustrated in figure 3.

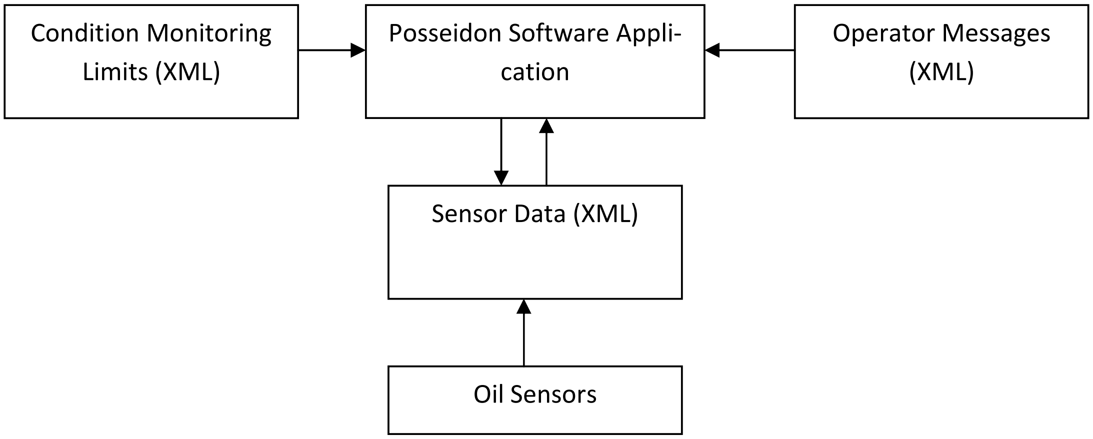


Fig. 3. Use of XML for data transfer in Posseidon application

The advantage of such a scheme is that these files can easily be opened and read by the human eye since a simple XML structure was developed. Furthermore the use of XML means the file format can be extended and altered without rendering the data unreadable to previous versions of the software. Furthermore an XML configuration file is used to provide the location of various other data files and other important parameters.

Tools for presenting data

Captured and stored data is of little use unless it can be presented efficiently and effectively to the appropriate user. Presenting data in a convenient and appropriate fashion is vital in ensuring that asset management systems are used effectively and provide a return on their investment. The success of data presentation systems is reliant on them efficiently providing the correct data to the correct personnel. Management personnel require a high level overview indicating current performance across an appropriate reporting period while shop-floor maintenance engineers require current data relating to assets which are their responsibility.

The Dynamite project developed the use of PDA technology. PDA technology supports the transfer of data between the user and a central maintenance database system. The role of the PDA is to provide a user-friendly, comfortable and powerful mobile computing device for dealing with different types of data processing and maintenance activities (Campos et al 2007). In order to manage what maintenance information should be displayed on the screen, six types of fundamental information templates were designed for machines, parts, tools facilities, locations and agents. The templates are mainly used to help categorizing and standardizing what information and what functions should be included. For example, a machine should have an information interface for specifying some basic information, an image gallery interface for displaying images, schematics and diagrams of machinery and different functional service interfaces for reporting failure of machinery, checking quantity and locations of spare parts etc.

For Machines

DYN-SUN-MIMOSA Web > RFID Identification > Machine Menu

Machine Info: 6789001100001101.9

For Parts

DYN-SUN-MIMOSA Web > RFID Identification > Part and Spare Part Menu

Parts Info: 6789001100001101.10

For Tools

DYN-SUN-MIMOSA Web > RFID Identification > Tool Menu

Tools Info: 6789001100001101.33

For Facility

DYN-SUN-MIMOSA Web > RFID Identification > Facility Menu

Facility Info: 6789001100001101.95

For Location

DYN-SUN-MIMOSA Web > RFID Identification > Location Menu

Location Info: 6789001100001101.100

For Agent

DYN-SUN-MIMOSA Web > RFID Identification > Agent Menu

Agent Info : 6789001100001101.1

Name	Value
AgentUIC	6789001100001101.1
Agent Name	Chi-Yung (Alan) Yau
User Tag Ident	cs0yyu
Agent Role Type	Dynamite: System Development and Administration

[Back to RFIDIdentification.aspx]

DYN-SUN-MIMOSA Web > RFID Identification > Asset Image Gallery

Asset Image Gallery 6789001100001101.9

○ Photo - Waukesha Cherry-Burrell Centrifugal Pump

● Schematic - Waukesha Cherry-Burrell Centrifugal Pump

Show Image

DYN-SUN-MIMOSA Web > RFID Identification > Asset Recommendation

Asset Recommendation 6789001100001101.9

Current AgentUIC (or Place Agent RFID for Query) : 6789001100001101.1

Query AgentUIC

Recommendation Type: Select one of them

- Select one of them
- Human Sensor - Sight
- Human Sensor - Hearing
- Human Sensor - Smell
- Human Sensor - Touch
- Vibration
- Thermal
- Corrosion

DYN-SUN-MIMOSA Web > RFID Identification > Model Children

Model Children (Spare Part) List 6789001100001101.9

Parent Model : 6789001100000011.111.17 - Centrifugal Pump 2065

<< 11 Child Model (Part) were found. >>

Child Model :

● Waukesha Cherry-Burrell 109260 Impeller 6-1/2 DIA 142-2153M Motor

○ Waukesha Cherry-Burrell 142-2153M Motor Frame

○ Waukesha Cherry-Burrell 143/145T Motor

○ Waukesha Cherry-Burrell 309-242 Basic Seal Kits

○ Waukesha Cherry-Burrell 309-246 Complete Seal Kits

○ Waukesha Cherry-Burrell 62-528X Shaft

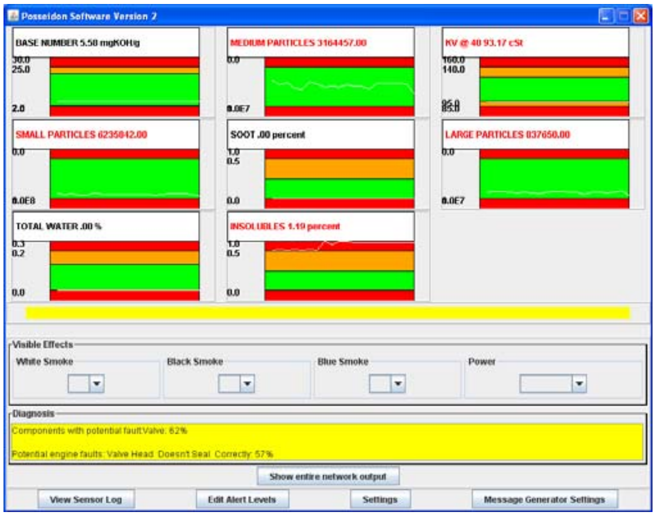
Fig. 4. Screenshots of Dynamite Software

A large and high resolution screen on a PDA is also beneficial since it allows users to read electronic materials more comfortably. Engineers can follow the on-screen instructions step-by-step to complete a maintenance task. Even in poor conditions where no network connection is available, PDAs will become more useful since a compact database can be pre-stored inside the PDA’s internal memory or memory stick.

Increasingly mobile phone technology and capability has converged with that of PDAs. So-called ‘smart-phones’ are available at relatively low cost and offer the ability to run easily-written software. Furthermore they are increasingly equipped with high level systems such as GPS receivers and broadband connectivity. Smart-phones also feature calendar and organizer systems which can be integrated with bespoke software. These features, coupled with steadily growing memory capabilities make smart-phones the likely replacement for PDAs as mobile maintenance management tools, especially in applications where remote maintenance is required due to their mobile connectivity.

Presenting higher level data to management involves creating a user interface suited to the needs of the user. In order to promote energy aware maintenance procedures, it is essential that the relevant data is provided in a convenient and easily understood fashion. Dashboard systems have been a well covered topic in many areas of decision support. These systems provide management personnel with only the most essential information required for senior managers to asses. A rare example of a dashboard system applied to energy efficiency was developed to improve the performance of street lighting and to manage routine and reactive maintenance. Simple graphical displays are used to illustrate power consumption, maintenance and condition monitoring data with click through access to greater detail and analysis as required. (http://www.streetlight-vision.com).

Optimal interface design must be based on consultation with industry experts. A user interface was developed as part of the Posseidon project. In order to generate the most suitable design for the front end of the software, a mock-up version was constructed as an html web-page. This allowed comments and feedback sought from industry experts with experience in both on-ship engineering issues and condition monitoring of lubricating oil. Based on this feedback a second prototype interfaces was produced. This second version was approved by the industry experts and formed the basis for the developed software.



BASE NUMBER 5.58 mgKOH/g

MEDIUM PARTICLES 3164457.00

KV @ 40 93.17 cSt

SMALL PARTICLES 6235842.00

SOOT .00 percent

LARGE PARTICLES 037650.00

TOTAL WATER .00 %

INSOLUBLES 1.19 percent

Components with potential fault:Valve: 62%

Potential engine faults: Valve Head Doesn't Seal Correctly: 57%

Fig. 5. Screenshot of the Posseidon Software

Analysis of Asset Management Data

In addition to capturing, storing and displaying data, an effective asset management scheme will perform some analysis to identify areas where improvements are possible or necessary. Several methodologies exist to maximize the performance of a maintenance regime based on an analysis of the performance of the assets and the existing maintenance regime. The primary methodologies are Total Productive Maintenance (TPM) and Reliability Centered Maintenance (RCM), with variations being developed to suit individual organisations. In general, there can be considerable benefits, but these are usually demonstrated in large organisations. Unfortunately, the majority of organisations are constrained by certain barriers, with the resulting loss of major benefits. These are usually the Small and Medium Sized Enterprises (SMEs). Based upon an analysis of these needs and barriers a new maintenance methodology, the Advanced Integrated Maintenance Management System (AIMMS) was developed (Baglee and Knowles 2010c). AIMMS succeeds through focusing on specific maintenance tasks that will maximise gains based upon the inherent barriers within SMEs. To enable implementation, monitoring and evaluation of AIMMS, a computerized system Maintenance Management (MainMan) was developed and implemented within several of case study companies. The results indicate that AIMMS supports strategic maintenance decisions and helps increase equipment effectiveness by prioritizing equipment criticality and focusing on specific resources that will maximise gains based upon a return on investment.

Data analysis is also important in terms of extracting meaningful information from raw sensor data using statistical techniques. The goal of any statistical analysis is to uncover facts. This can be broken down even further into three potential sub-goals:

1. Exploration
2. Description

3. Confirmation

Each of these applies in some contexts to the scenario described above. Various tools are available for data processing and analysis. The most widely used techniques are Artificial Neural Networks, Statistical Learning and Probabilistic Modeling.

Most fault detection systems function by studying the relationship between various sensor readings and using some form of model to detect abnormal behaviour (Isermann 05). The majority of sensors will be subject to some noise pickup which can influence the performance of the detection system and in many cases some noise filtering or denoising will be necessary (see for example Lewin 05).

The qualities of artificial neural networks (ANNs) which lend themselves to the target application are their ability to deal with time series data, to form generalisations and to adapt and learn. These properties match several of the desired objectives and particular network types suit particular objectives. Artificial neural networks have been applied to such situations by several authors (Hu et al 2007, Sidhu et al 1995, Benieri and D'Apuzzo 1994, Murphey et al 2006, Khomfoi and Tolbert 2007, Mohamed et al 2005, Zhang 2006, Marwala 2000).

Various statistical techniques could be applied to the sensor data. In control applications statistical models of sensor data are used to model the unknown internal state for the purposes of achieving some goal in the systems behaviour. Such approaches include Bayesian Networks, Hidden Markov Models, Particle filters, Expert systems, Principal component analysis and Kalman Filters.

Bayesian networks are seen as having considerable promise for maintenance applications. Bayesian networks allow inferences to be made about the state and condition of a system based on measurements and existing knowledge of the statistical likelihood of faults occurring and how faults can influence measurements. Lerner et al (2000) describes a Bayesian network system for fault detection and apply it in a test situation involving a dynamic system of water tanks. Furthermore a Bayesian network was developed for the Posseidon project. Based on an analysis of the likely fault modes to be found in diesel engines and the effects they have a Bayesian system was developed. This is illustrated in figure XX. It can be seen that probabilities are assigned to the likely failures and components that are likely to fail.

Conclusions

Manufacturing organisations have come under increasing pressure in recent years to improve efficiency and environmental performance. Failures in key manufacturing assets must be minimised and steps need to be taken to obtain maximum reliability improvement from maintenance expenditure. Energy consumption has become an increasingly important factor due to rising prices in recent years. Previous research has shown that Energy efficiency is influenced by maintenance and usage, and running costs are influenced by energy efficiency, energy costs, maintenance costs and downtime costs. Our hypothesis is that in order to obtain maximum efficiency improvements it is necessary to bring together data on maintenance schedules and costs, energy costs and usage patterns for integrated analysis in order to detect and highlight areas where the greatest savings are possible. Thus we expect that energy measurement will become an increasingly important aspect of asset management and maintenance scheduling systems.

In this chapter we have outlined the entire data life cycle in a stage by stage fashion. The technologies and techniques we have described are illustrated in figure 6 below in relation to their role in the data lifecycle.

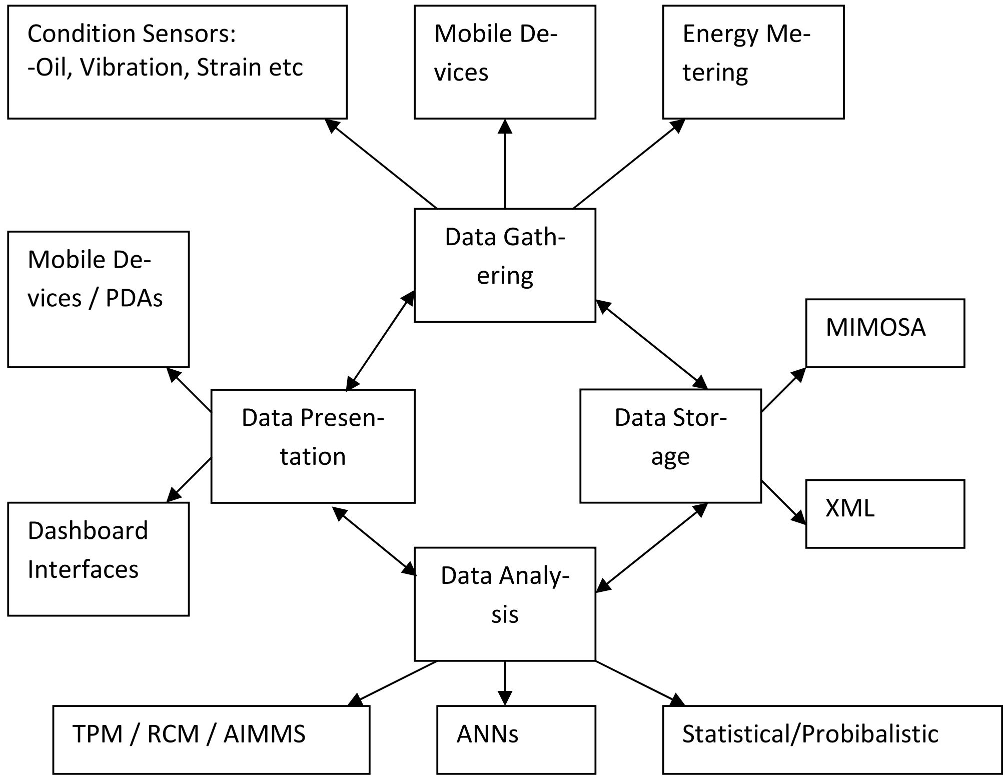


Fig. 6. Asset management tools by position in data lifecycles

When designing new asset management schemes it is important to maintain an awareness of the entire data lifecycle to ensure the developed system meets the requirements of all those who work with it. Wherever possible schemes should be built on a principle of complementarity to existing schemes to prevent barriers of cost, compatibility set up costs/problems etc becoming obstacles. For this reason it is our expectation that few schemes will be designed and implemented in their entirety.

Instead modules will be developed for integration into existing, live systems. This makes the adoption of international standards for the transfer and management of data across its entire lifecycle a crucial issue in the ongoing development of effective asset management techniques.

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