How can SMEs adopt a new method to advanced maintenance strategies? A Case study approach

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ABSTRACT

Maintenance is crucial to manufacturing operations. In many organisations, the production equipment represents the majority of invested capital, and deterioration of these facilities and equipment increases production costs, reduces product quality. Over recent years the importance of maintenance, and therefore maintenance management, within manufacturing organisations has grown. The maintenance function has become an increasingly important and complex activity, particularly as automation increases. The opportunity exists for many organisations to benefit substantially through improvements to their competitiveness and profitability by adopting a new approach to maintenance management. Several tools and technologies including Condition Based Maintenance (CBM), Reliability Centred Maintenance (RCM) and more recently e-maintenance have developed under the heading of Advanced Maintenance Strategies. However, the adoption of advanced maintenance strategies and their potential benefits are usually demonstrated in large organisations. Unfortunately, the majority of organisations are constrained by the lack of knowledge and understanding on the requirements, which need to be in place before adopting an advanced maintenance strategy. These are usually classified as Small and Medium Sized Enterprises (SMEs).

The research strategy is based on 'empirical iterations' using survey secondary data, experts' interviews information and multiple case studies. The results show that there is a set of recommendations, which strongly influence the implementation of an Advanced Maintenance Strategy (AMS) with a Small to Medium Enterprise (SME). Organisations require a structured and integrative approach in order to take advantage of a new approach to maintenance management. This paper will propose recommendations for integrating an AMS into the organisation and provide evidence of a successful implementation.

Keywords: Condition Based Maintenance (CBM), Strategy Development

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1. INTRODUCTION

Today, Europe's manufacturing industry directly contributes around 22 per cent of EU GDP [9]. As a result, many analysts believe that if Europe is to become the world's most competitive knowledge-based economy by 2020, the presence of a strong and competitive manufacturing sector is indispensable. In addition, the global economic environment requires manufacturers to adapt to a volatile climate and find new ways to maintain stability and drive competitive advantage. One such way is to develop and implement a maintenance strategy, which is appropriate, cost effective, and energy efficient. Therefore, benefits from a sustainable resource management strategy would see a reduction in manufacturing costs and a reduction in energy usage and wastage, thus allowing manufacturers to make better use of resources to achieve greater cost savings and to prepare for an increasingly regulated environmental landscape. Sadly, relatively few companies either see, or take, this opportunity. Why?

Part of the answer lies in ignorance – especially in the small company sector. Many SMEs simply are not aware of how to do maintenance better – or if they are, they think that it will cost them too much to do so.

This perception flies in the face of the facts. There are many, many examples of companies (including small companies) reaping generous rewards from doing maintenance better – reduced costs, improved availability and reliability, better quality, and more profit. Return on Investment can, and should, be a major factor in making changes to maintenance practices, but this is not apparent to most companies who seem to be afraid of making the investment necessary to reap the rewards.

Over recent years, the importance of maintenance, and therefore maintenance management within European manufacturing organisations has grown. In addition, companies are under pressure to respond to rising energy costs and the need to protect the environment. Growth in energy consumption has a direct impact on the deterioration of the environment and on climate change. Air quality is a major environmental concern for the EU. The Commission is currently elaborating the EU Clean Air Programme (CAFE), where the harmful effects of ozone and especially particulates are revealed for human health and ecosystems.

European manufacturers have introduced a variety of innovative technologies, new business processes and enlightened management techniques to encourage greater efficiency in the industrial use of energy. However, equipment maintenance has been overlooked and falls short with regard to the development of innovate and new technologies to monitor energy and support the development of maintenance strategies. The most important barrier to increased energy efficiency is a lack of information (on costs and availability of new technology; lack of information on costs of own energy consumption; lack of training of technicians on proper maintenance and the lack of information and training on the latest technologies and their economic and financial impact on the rate of return from investment). Investments in cost-effective energy efficiency improvement will almost always have a positive impact on manufacturing costs, energy consumption, energy costs, skill development and the environment by reducing the amount of energy consumed and wasted through poor and inadequate bad maintenance practices. Table 1 provides an overview of costs associated with lost production in one year attributed to unplanned downtime.

Manufacturing Sector or Activity	**Average Cost of One Day's Lost Production or Unplanned Downtime**
Automated Production Line	100,000 €
Automotive Engine Production Line	288,000 €
Chemical Production Facility	100,000 €
Paper or Pulp Plant	200,000 €
Power Plant	100,000 €
Cargo Ship	10,000 €

Table 1 – examples of costs of lost production or unplanned downtime [1].

Research [1,2,3] have stated that a methodology for maintenance strategy development needs to incorporate an appropriate mix of maintenance practices and technology relevant to manufacturing taking into account the development of energy efficient maintenance practices. This will allow the company to focus on developing a sustainable methodology utilising modern maintenance strategies, which are multi-dimensional, such as Total Productive Maintenance, Reliability Centred Maintenance and Condition Based Maintenance to allow management to develop and implement a modern maintenance methodology which suit their often perceived constraints such as a lack of financial support, a lack of skilled operators and a lack of time to develop and implement alternative strategies.

In addition, a structured implementation process needs to be mapped to the corporate strategy to suit the company requirements. This will require the development and validation of pilot models enabling the implementation of the models and demonstrate the benefits resulting from the developed appropriate maintenance strategies. The sustainable models will incorporate managerial and technological advances for identifying, developing and implementing a complete asset management system based upon a Return on Investment (ROI).

Maintenance of plant assets has acquired an importance that it never had. In the current economic downturn worldwide, plant asset maintenance has become equally important as the production itself. Money saved with optimum maintenance is money earned. Industries no more see expenditure on maintenance as wasteful. Maintenance costs have now become investments that yield good results. There is a cost associated with diagnostic actions. An increased inspection frequency results in higher incurred cost for the industry. Therefore, optimization of diagnostics schedule is an issue that needs careful attention. Deciding optimal condition monitoring intervals is another issue needed to be addressed. The condition-based maintenance of large assets of an industry should be carried out with seamless integration of data and in-formation with other activities (such as production/inventory planning) that are influenced by maintenance actions so that optimum utilization of plant assets is effected with minimum overall cost. Intelligent Maintenance Management Systems (IMMS) have emerged as the solution to address these complex requirements.

It helps the maintenance managers to achieve highest levels of plant asset performance by shifting from a reactive "fix when failed" approach to a more proactive "predict and prevent" approach. This requires them to synchronize maintenance activities with production schedules through the use of in-formation technology i.e. wireless, web, etc. [6]. This requires heavy reliance on acquiring and transforming machine condition data to useful information for improved productivity and asset utilization [8]. The use of e-technologies increases the possibilities of utilizing data of multiple origin and type, processing larger volumes of data and to make more advanced reasoning and decision-making, and implementing cooperative (or collaborative) activities (Marquez, 2007). This section will make an effort to highlight the current state of Maintenance Management Systems, e-maintenance and its advantages and describes the need to have ontology as knowledge repository.

2. CURRENT MAINTENANCE MANAGEMENT SYSTEMS

Most manufacturing industries today have realised the importance of going beyond the conventional maintenance management techniques to computerised maintenance management. The increase in processing powers of computers, coupled with a sharp decrease in the cost of acquiring them has led to a surge in use of computers in the field of maintenance management as well. Computer Maintenance Management Systems are being used with limited success in many industries today. Most of these management systems are limited in their capabilities where they help generate work orders and job sheets, assign maintenance personnel to their tasks, manage inventory to a certain extent and produce maintenance schedules based on set rules. But there has been a tremendous increase in the complexity of the manufacturing operations, which in turn demands a lot more from the investments being made in the maintenance management systems. These systems do not have the capability of knowledge storage and retrieval, prognosis or diagnosis. Some Maintenance Management Systems have moved ahead in this sense by having certain 'plug and play' Condition based Maintenance modules being supplied by different vendors. CBM modules are available which enable a CMMS to use condition monitoring alarm levels to trigger maintenance activities.

Incoming condition-based data for assets is compared to predefined thresholds and when the threshold is exceeded an alarm is raised to highlight the event. [5] (2006) have highlighted another improvement in the current Maintenance Management Systems. Some of these have criticality assessment capability in them. This capability helps in assessing the parts of the manufacturing system that are most critical to the operation. This is arrived at by evaluating the past data and collective knowledge of the operators. This in turn leads to formulation of maintenance strategy with these critical assets as the focus of attention. These improvements have led to different set of problems arising. [4] (2005) observed that with the numerous asset management systems offered by different vendors, the process of integration can be problematic as many systems have their unique data exchange interfaces. This is a common problem being faced by many plants and factories. It often so happens that the customisation of the needs of a plant requires more than one system and more often than not, from different vendor. Purchasing systems from a single vendor leads towards system compatibility, however suppliers may not provide a total asset management solution, and the reliance on one vendor can prove risky. This leads to a conflict due to differences in data exchange interface. Custom bridges are available to integrate various systems being supplied by various vendors but that means additional expense. Also, these custom bridges need updating as and when the vendor brings out a newer version of his asset management system. Another option is to use an industry-standard bridge, which allows businesses to mix different systems with reduced integration costs. However, there may be performance loss compared to a custom solution and vendors must be willing to support the standard.

A set of ISO standards deals precisely with addressing the problems of integration of modules of different vendors. ISO 16100 aims to provide a method to represent the capability of manufacturing application software relative to its role throughout the life cycle of a manufacturing application, independent of a particular system architecture or implementation platform. This can lead to reduced production and information management costs to users and vendors/suppliers of manufacturing applications. The reasons for developing ISO 16100, as given in www.iso.org are as given below.

- a growing base of vendor-specific solutions;
- user difficulties in applying standards;
- the need to move to modular sets of system integration tools;
- the recognition that application software and the expertise to apply that software are assets of the enterprise.

ISO 15926 is an International Standard for the representation of process industries facility life-cycle information. This representation is specified by a generic, conceptual data model that is suitable as the basis for implementation in a shared database or data warehouse. The International Standard (ISO 15745) defines an application integration framework - a set of elements and rules for describing integration models and application interoperability profiles; e.g. generic elements and rules for describing integration models and application interoperability profiles, their component profiles - process profiles, information exchange profiles, and resource profiles. ISO 18435 provides a framework for harmonized use of industry and international standards in order to integrate control, diagnostics, prognostics, capability assessment, and maintenance applications. By using an ISO 15745 application integration modelling approach, key interoperability interfaces can be identified and concisely documented in terms of profiles. ISO 18435 also provides the elements and the rules to describe the integration requirements of an automation application. The elements include the key aspects when integrating an automation application with other applications and the relationships of these key aspects.

3. CONDITION BASED MAINTENANCE

CBM is a predictive maintenance strategy that focuses on monitoring the critical parameters of an asset to determine its current health level and predict future problems to avoid them beforehand by scheduling maintenance at the optimal moment. It is worth noting that implementing a CBM system is a continuous process more than a single step plan.

To be able to implement this maintenance strategy, it is necessary to do an initial study about the asset that is going to be monitored to decide whether it is cost effective or not. However, it is possible that not every asset is suitable for a CBM system. Usually, CBM is used for safety critical components where an unexpected failure could cause a risky situation or could result in costly losses.

After the initial cost analysis, an equipment audit needs to be carried out, to choose which parameters generate the most meaningful information. Once this is analysed and the parameters decided, a suitable set of transducers is chosen to monitor said parameters. The gathered data are consequently manipulated to extract the significant descriptors that help diagnose the current health level of the asset. These descriptors are then compared with the historical data and, with the assistance of mathematical and physical models of the system, it is possible to predict how the asset is going to behave in the future. The models for prognostics can be classified into two main groups: data-driven prognostics and model based prognostics. The data-driven prognostics are based on pattern recognition from previously collected data, and while it could be appropriate for very complex systems, obtaining initial run-to-fail data could be time costly. On the other hand, the model based ones create a physical model of the system based on mathematics and physical interactions. Nonetheless, this approach balances between the coverage and the accuracy of the model. Typically, the designed prognostics system is a hybrid between both approaches.

The key concept in a CBM system is the recommended maintenance action. Once the system predicts the future behaviour of the asset, it should create an action report containing important information to link it with the CMMS.. This action reports could include instructions on disassembling the component, the tools needed or the priority of the repair. This way, if it is known when a component is going to fail, it is possible to schedule the pertinent maintenance actions so that it causes the least downtime possible, increasing the availability of the asset and consequently the Overall Equipment Efficiency (OEE). It could make automatic orders for new components so that by the time the technician gets to the destination, the spare part is already there.

All the process can be done remotely and in real-time if the system is implemented in a cloud service. The users can access the information from any device with an internet connection, making the system very versatile. Microsoft Azure, Google Cloud or Oracle offer this type of service.

4. BACKGROUND TO CASE STUDY

This case study provides an overview of the development and implementation of a maintenance concept within company A. who are a subsea cable manufacturer in Europe. Senior management at Company A are aware that maintenance contributes significantly to the total cost of production, and that an effective maintenance system is an efficient way of enhancing a company's capability to handle production losses due to unplanned downtime. However, the introduction of an improved maintenance system would require changes, and these changes, especially changes to the corporate culture, always meet resistance and generate conflict.

Therefore, the management at Company A, required a maintenance concept tailored to their particular organisation, one which would help to identify the barriers and obstacles such as lack of resources, lack of skills and cultural change, which may impede the integration of a new maintenance concept. However, in order to be effective the concept would need to have a supporting structure/model around which a detailed maintenance plan could be developed. To implement the framework or model successfully, certain change factors, identified through research undertaken, at the University of Sunderland, would need to be addressed. The factors are:

- create support for change from top management
- formulate a clear policy or strategy form improved maintenance activities
- explain the meaning and extent of the new initiative to everybody involved with maintenance
- provide a strong organisational responsibility for supporting the implementation
- promote the new initiatives through group activity

The framework, developed in partnership with the management at Company A was designed by identifying which elements were essential to allow the asset manager to develop a maintenance strategy which: (1) Records data relevant to the cost of failure and the cause and effect of the failure. (2) Records the estimated cost of the current maintenance system (3) provides a detailed list of tasks ranging from basic inspection to fault diagnosis allowing the user to determine which tasks to select based upon equipment needs and the resources available. (4) Provides an estimate of the cost to implement the sub elements selected.(5) Provides a ROI analysis to determine if the new approach is feasible.

The model, **A**dvanced **I**ntegrated **M**aintenance **M**anagement **S**ystem (AIMMS) is structured in a way that allows the management to follow a 'path' or 'road map' to the implementation of an appropriate maintenance initiative. The model, which can be viewed in figure 1 offers Company A management a fundamental paradigm shift from traditional activities, to the adoption of a tailored system that incorporates acceptable and effective elements of modern maintenance practices such as Total productive Maintenance (TPM) and Reliability Centred Maintenance (RCM).It should be noted that that this model is a **'management tool'** and is designed to complement a Microsoft Access database.

5. MODEL DEVELOPMENT BASED UPON THE KEY ELEMENTS IDENTIFIED AT CASE STUDY COMPANY

The model contains a decision support module aimed to increase the effectiveness of the maintenance function. However, in order to utilise this module and develop an improved maintenance strategy the maintenance management needs a powerful tool, information. Information is readily available, and raw data is collected, analysed and processed. After this process it becomes significant for maintenance planning and decision-making. The collection and analysis of data helps the management formulate a strategy, which is based upon real and accurate data. The model allows the data to be stored and used within different scenarios, therefore providing an alternative approach, if required.

A new concept is not always clear or understood, and hence it was thought that the maintenance engineers would not utilise the system and stick with their own way of doing things. Therefore, in order to be successful the maintenance department would need to be consulted about the different approach to maintenance and how the model would work in conjunction with the Database already developed. Meetings were held with maintenance engineers and management and the problems and possible solutions were discussed. The use and requirements of the model were discussed with management, comments were used to re-design and improve the model.

6. MODEL EVALUATION

Certain difficulties were identified, the management stressed that a precondition for change would have to be an immediate increase in OEE and an increase in operator maintenance. The increase in OEE was evident within 4 weeks, although the increase in operator maintenance was not. The argument from the maintenance department was that the model allowed the operator to input a suggestion for maintenance but did not take into account the fact that operator maintenance initially requires extra support from maintenance staff, providing help with the extra workload of the initial phase. Therefore, without a push for change on behalf of the maintenance engineers, success if any would be limited, and if the maintenance department were busy the operators would have to wait or seek alternative help.

The model had the capability to be linked to the Database produced by Assynt and the University. The database includes PowerPoint slides to develop single point instructions and training exercises, the model allows the staff to develop a maintenance strategy, and if this strategy is successful the new approach could be translated into PowerPoint slides or other training devices, thereby increasing the capacity for training.

The analysis of the equipment data has identified that the first stage evaluation was:

- useful and helped to develop an alternative maintenance strategy and is reasonably easy to use and understand
- flexible enough to be used on different equipment from within the different bottling lines
- able to identify alternative maintenance approaches
- provides a progressive approach to implementation
- can be used to educate and train the workforce
- provides an identification of the cost of maintenance

The model, after the first stage evaluation would appear to be capable achieving its intended aims.

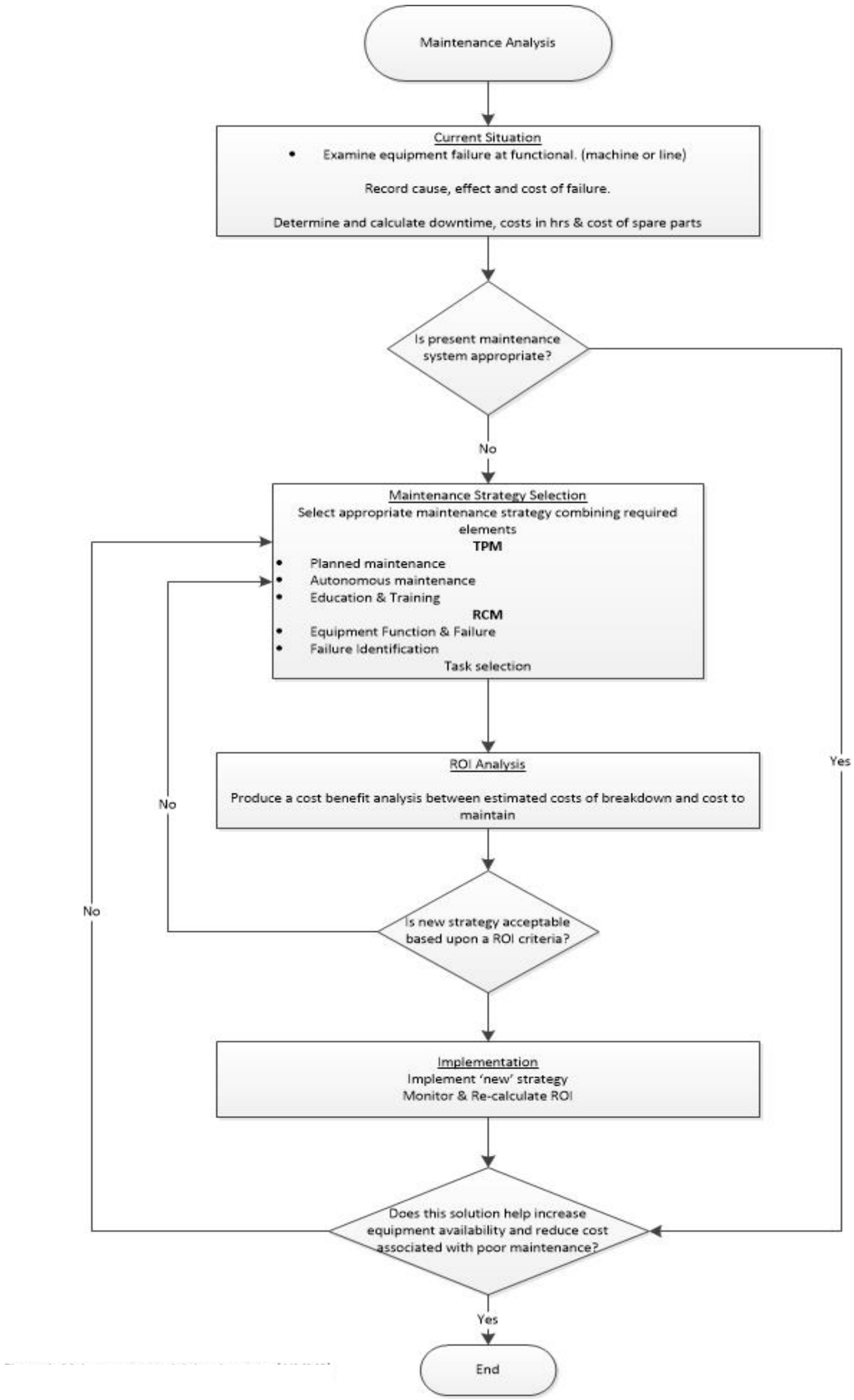

Figure 1 Maintenance model development (AIMMS)

7. DISCUSSION

In some cases, the equipment is complex, yet it should be too difficult to analyse with a view to generating continuous improvement. The database, developed in partnership with Assynt and the University, and the model developed in partnership with Company A and the University

Operators were sceptical about the possibility of extra work and the maintenance engineers believed they would not have enough say, and a new method to hopefully improve maintenance may indicate that the maintenance and operators were not doing their job properly. However, the model was not used to identify the failures or shortcoming of staff but to aid the **management** to perform machinery analysis of losses on a detailed level. The model was also developed with the aim of promoting technical changes to the production system, by promoting operator maintenance though condition monitoring. Finally, the model managed to achieve, albeit on a small scale, a balance between an identification of the technical complexity, the identification of the competence of the operator and an increase in the amount of access the operators had to the maintenance engineers.

8. CONCLUSION

As a result, companies' performance and responsiveness will be substantially increased, and both management and workforce knowledge/skills will be consistently and continuously developed. The project will also contribute to the reduction in the release of harmful gases and toxins by developing systems which allow for the analysis of energy consumption i.e. water, electricity, and raw materials. In addition, Maintain-IT will benefit small local industry by developing a "network of excellence" between academia and industry to create a forum for debate to encourage innovative thinking and develop new methods for maintenance and manufacturing.

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