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Maintenance strategy development within SMEs: the development of an integrated approach*

by

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Abstract: Maintenance can play a key role in the long-term profitability of a company in the manufacturing sector, where it can have major impact on delivery, quality and cost. The importance of maintenance has increased, as high productivity and quality can be achieved by means of well-developed and organized maintenance strategies. However, this assumes that maintenance is controlled in such a way that equipment is stopped for maintenance via a systematic schedule. With the recent advances in technology many methodologies, tools, techniques and strategies have been developed and tested. The primary methodologies are Total Productive Maintenance (TPM) and Reliability Centred 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). The paper identifies the barriers to the implementation of TPM within SMEs. Based upon our analysis a new maintenance methodology, the Advanced Integrated Maintenance Management System (AIMMS) is developed. 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 paper examines the implementation process in one of these 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.

Keywords: maintenance, TPM.

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1. Introduction

Over recent years, the importance of maintenance, and therefore maintenance management, within UK manufacturing organisations has grown. This is a result of increasing pressure upon manufacturing organisations to meet customer and corporate demands, and equipment availability and performance is central to achieving these. The "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 (Chan et al., 2005). The majority often operates at less than full capacity, with low productivity, and the costs of producing products are high". A number of modern maintenance practices, of which Total Productive Maintenance (TPM) is one example, have been developed to allow organisations to strategically direct their resources to the maintenance tasks that are considered critical to the effective and efficient running of their equipment. A number of organisations have claimed improvements in equipment availability, reliability and a reduction on maintenance costs when implementing TPM (Blanchard, 1997; Cooke, 2000). The benefits of TPM are often quoted as increase in product quality, equipment availability, and a reduction in operating costs (Cholasuke, Bhardwa and Jiju, 2004; Bohoris et al., 1995; Al-Najjar, 1996). Nakajima (1988) believes TPM is predominantly used because it integrates production and maintenance functions, but, more importantly, redefines the roles of the operators and maintainers.

Nakajima, often regarded as the originator of TPM, states that the goal of TPM is to enhance equipment effectiveness and maximise equipment output. It seeks to achieve this by striving to attain and maintain optimal equipment conditions in order to prevent unexpected breakdowns, speed losses, and quality defects in process (Bamber, Sharp and Hides, 1999). Through TPM, it should also be possible to increase employee morale and job satisfaction by allowing the workers to be involved with every aspect of TPM. Most of the universally accepted definitions of TPM, by Barnes (2002), Baglee, Trimble and MacIntyre (2003), Hansson and Backlund (2002), and Kardon and Fredendall (2002), build upon the basic five pillars outlined by Nakajima:

1. Improve Overall Equipment Effectiveness (OEE) - OEE is a metric used to help target the major losses associated with poor maintenance practices. The OEE figure is derived from individual measurements relating to availability, performance and quality.

2. Autonomous maintenance by operators - requires equipment operators perform some of the routine maintenance tasks, which may be presently carried out by maintenance engineers. These tasks include daily cleaning, inspection, basic upkeep, and lubricating that the equipment requires. Since the operators are more familiar with their equipment than anyone else, they are able to notice quickly any anomalies.

3. Planned Maintenance - The aim is to allow equipment operators and maintenance engineers to analyse the cause of equipment failures and develop a planned maintenance system to repair or modify the equipment to improve maintainability. According to Cooke (2000), planned maintenance is responsible for supporting autonomous maintenance to improve OEE. Planned maintenance typically involves the work conducted by skilled maintenance engineers, but the aim is to transfer the tasks to the equipment.

4. Train to improve operator and maintenance skills - The skills of the operators and maintenance personnel must be improved if autonomous maintenance and maintainability improvements, the basic method of TPM, are to be successful (Nakajima 1988). Firstly, the manufacturing and maintenance staff and their management are educated in the concepts of TPM and the benefits of autonomous maintenance. Secondly, maintenance staff educates equipment operators on how to properly clean and lubricate the equipment, and thirdly, special safety awareness training is provided to address the new tasks performed by the equipment operators.

5. Early equipment management - This pillar is aimed at avoiding future maintenance problems by considering maintenance during the equipment design phase. If maintenance issues are considered early enough in the design cycle, this can result in easier equipment maintenance. In addition, the equipment supplier may be able to provide data on their components that will help to determine the required frequency of inspections and planned maintenance.

In essence, TPM is an approach which seeks to develop maintenance practices through a combination of measurement (pillar 1), planning (pillar 2), training (pillar 4), and the active involvement of a broader range of employees in addition to maintenance personnel in maintenance related activities (pillars 2 and 5). The academic literature regularly reports on the success of TPM within large organisations, see Percy and Kobbacy (1997), Wiklund and Wiklund (1999). However, SMEs, who according to Sherwin (2000) account for 99% of companies in the UK, would appear to be less likely to have TPM implemented. This factor is largely assumed due to the absence of case studies within the academic literature, concerning TPM implementation within SMEs and this position is supported by Barnes (2002), Lambert, Drolet and Abdul-Nour (1999) and Hall (2002), who agree that research into the maintenance strategies and practices of SMEs is inadequate.

Previous research provides some suggestions as to why this may be the case. Cooke (2003) has indicated that the majority of SMEs typically adopt a run-to-failure maintenance strategy, as this largely requires limited knowledge on why and how the equipment failed. In addition, senior management within SMEs rarely view maintenance as a strategic issue that will translate to a significant contribution to the company profit margins. Cooke (2003) and Finlow-Bates and Visser (2000) have further suggested that SMEs may lack the necessary skilled workforce and time to examine and adopt proactive maintenance strategies such as TPM and, instead, focus on operational aspects, primarily geared towards day-to-day survival. There would appear to be a gap in the literature regarding SME managements' attitudes towards TPM as a maintenance philosophy and its applicability to their particular context. With this issue in mind, this paper sets out our work in three specific areas:

1. Through interviews with SME, owners/senior managers, the barriers that impede TPM implementation within this type of organization are identified.

2. The development of a new maintenance methodology for SMEs: Advanced Integrated Maintenance Management System (AIMMS), based upon the selective integration of TPM and RCM elements, to help overcome the identified barriers is outlined. In addition, a software enabler (MainMan) to aid its implementation within this specific organizational context is also introduced.

3. The implementation of AIMMS within one of our case study companies is described and the issues and benefits discussed.

2. Methodology

Data were collected by means of semi-structured interviews with owners and senior managers from 36 small and medium-sized manufacturing companies. The aim of the interviews was to identify the possible barriers to TPM implementation within their organisations. TPM was introduced as a methodology shown to deliver effective maintenance and improved productivity. A working definition based upon the five pillars, developed by Bamber, Sharp and Hides (1999), was used to ensure commonality of understanding amongst the respondents. The specific selection of companies was pseudo-random, with 53% being medium and the remainder being small organisations. The companies were from a range of sectors in the Northeast of England, including food and drink, automotive engineering, process manufacturing and textiles. The number of employees within the organisations ranged from 10 to 180.

2.1. Barriers to the adoption of TPM within SMEs

Majority of senior management respondents (87%) stated that their organisations predominantly used reactive maintenance and stated that beyond this they had little knowledge or interest in other maintenance practices. This is reflected through the fact that the majority are satisfied with their current reactive maintenance system and do not want to see it change. This point is interesting as it possibly highlights one of the critical foundations of the reactive system, a lack of awareness and understanding of the benefits from a preventive or predictive system. Table 1 outlines the barriers to the adoption of TPM.

Table 1. The barriers to implementation of TPM within SMEs

Thematic Areas	*Specific Elements*
Finance	• Lack of finance for new equipment and training • Increase in maintenance costs
Time	• Time lapse from implementation to identifiable results • Difficult to plan resource allocation for implementation because of production demands • Training could be time consuming especially on CBM techniques
Skills	• Lack of skilled equipment operators
Management Awareness	• Lack of awareness of alternative maintenance methodologies • Lack of knowledge about the important and beneficial relationship between maintenance and production

Finance

A majority of management responses (80%) claimed that the adoption of a new maintenance initiative is usually constrained by the lack of finance. The belief amongst the respondents is that no clear way exists to overcome this problem, and so the high percentage of unplanned and reactive maintenance places a significant cost burden on businesses, one that is rarely recognized by management. Actually, the owners or senior managers often need to look for quick returns on investment. In addition, the majority of respondents do not view maintenance as an important part of achieving their overall business strategies. This often results in senior management prioritizing production (fabrication-products-tools) or sales and marketing. However, the literature has indicated (Bamber, Sharp and Hides, 1999, and Cooke, 2000) that most maintenance strategies such as TPM need three to five years to provide a return. In addition, 74% of the respondents believed that a new maintenance strategy would require new equipment.

Increase in maintenance costs

The perceived costs to implement a strategy that could possibly require an increase in capital spending for new equipment automatically increases the likelihood that the development of a new maintenance strategy will be based upon the cost of allowing the equipment to run-to-failure. Lambert, Drolet and Abdul-Nour (1999) and Al-Hassan (2002) have stated that most organisations have placed financial constraints upon the manufacturing department for new equipment, and that the majority of senior management believe that the initial cost of any maintenance initiative outweighs the potential return on investment. The introduction of a maintenance system, according to the majority of respondents (84%), would need to be supported by detailed and continual training programmes. However, all the senior management respondents stated that finance would not be made available for training programmes. According to authors such as Wiklund and Wiklund (1999), Tsang (2002) and Finlow-Bates and Visser (2000) organisations need to look at the combination of improving both equipment utilization and operator and maintenance staff performance. This will provide an even greater opportunity for a return on investment. Although this barrier could be the most difficult for organisations to overcome, an investigation by the senior management into the costs of maintenance and a brief examination of the costs to introduce a new initiative may allow the management to allocate finance to where it is required.

Time

Due to the perceived time required to collect and analyse equipment data to determine which maintenance task is best suited to a particular piece of equipment, the majority of respondents (78%) believe that a different maintenance strategy would require six to nine months to develop, plan and implement. Therefore, the length of time to implement and to realize the benefits must be short. According to one senior manager: *"If I were to commit funds and personnel, both of which are limited, to the development of a new maintenance strategy I would have to see a measurable benefit within four weeks, otherwise it would be considered a failure. Unfortunately, finance and operators are fully committed to production activities and not developing maintenance tasks. Therefore, it is crucial that a new approach quickly demonstrates the benefits".*

The development of a maintenance methodology to suit the individual company would allow the implementation to progress at their pace and scheduled maintenance to avoid busy production periods. However, production schedules should incorporate time for maintenance, calculated to be essential to sustain quality and minimize total down time. Our data have shown that, due to the perceived cost of production stoppages for planned maintenance activities, SME managers are reluctant to stop production due to a possible increase in work backlog. In addition, according to Cooke (2000), Nakajima (1988) and Lawrence (1999), this approach would often result in critical Preventive Maintenance activities being neglected due to the increase in production demands. In several companies, most of the operators had only basic training in how the equipment works with little or no training in basic cleaning and inspection. However, a constraint identified by over half of the management respondents is that it is difficult to release employees for training. The shortage of skilled and semi-skilled workers has a direct influence on the amount of planned maintenance activities. The majority of equipment operators, according to the management respondents, do have the necessary skills to diagnose a problem. Instead, they have to wait for the equipment to malfunction. This approach is both costly and time consuming, it also means that parts may be changed or maintenance undertaken which is not necessary.

Skills

The management respondents indicated that maintenance engineers were employed based upon their skills and experience. However, maintenance skills and diagnostic capabilities of equipment operators were not generally considered important when employing operators. Therefore, discussion only centred upon equipment operators and not maintenance engineers, because it is the operators, according to the majority of respondents, who must develop and implement the maintenance strategy. The majority (90%) of companies do not budget for training or education, or do not have the financial resources to employ multi-skilled engineers. In addition, the management respondents stated that, in order to overcome the skills problem, they would need to support operator maintenance, by introducing a basic training initiative based upon operator and engineer suggestions and allocating enough resources for maintenance. The aim is to increase the operator's understanding of the performance of the equipment, thus allowing the operator to identify critical equipment improvement initiatives. According to a senior manger from the largest respondent company: *The lack of skilled equipment operators is attributed to the lack of finance, the key to overcoming this problem is not to wait until the company finds the right person, but to train and educate the operators in maintenance tasks. We have a maintenance department with two staff, while production has forty-nine operators. Does it not make sense to ask them to carry out certain maintenance tasks?*

Many smaller organisations suffer because of the continual migration of workers from one company to another, with skills and knowledge rarely being imparted to the other workers due to the lack of formal and structured training initiatives (Tsang, 2002; Waeyenbergh and Pintelon, 2002, and Wang and Hwang, 2004). Comprehensive training programmes may be required for maintenance engineers and equipment operators to achieve the level of skill required to identify possible maintenance problems and develop diagnostic skills. The management respondents also believed that extended periods of equipment downtime for maintenance would be required and this could only occur at weekends or after the normal working day, therefore requiring finance for overtime payments. However, an approach to maintenance that is developed by utilizing the existing resources and is gradually implemented would remove the need to introduce overtime, or halt production for several minutes or hours a week to carry out maintenance tasks.

Management awareness

According to the respondents, the aim is to develop maintenance objectives, strategies and responsibilities to ensure everyone is involved with the planning and development of TPM. However, management commitment and support is a precondition for implementation and the majority of management respondents stated that commitment would be difficult due to their responsibilities to other departments. The lack of awareness of the problems associated with reactive maintenance and the failure by senior management to recognize that reactive maintenance can be costly and unsafe, are the result of barriers that have hindered organisations in the pursuit of improved maintenance. Our analysis has shown that organisations wishing to improve their maintenance must first understand their current situation. The equipment is examined to determine maintenance needs, the available resources are utilized and performance measures are implemented. Training and skill development are incorporated and the collection, analysis and subsequent improvement initiatives are implemented by all involved with maintenance. However, the main question faced by management is whether the output from increased maintenance activities is produced both effectively, in terms of contribution to company profits, and efficiently, in terms of manpower skill enhancement, but without the basic knowledge in maintenance tasks and methodologies it will prove difficult for management to develop an effective solution (Al-Najjar, 1996).

Lack of awareness of other maintenance methodologies is a recurring theme among managers and supervisors. This could be attributed to the fact that SME management are either unaware of the different maintenance methodologies available and therefore unaware of their potential benefits, or perceive certain barriers as permanent and are therefore powerless to reduce their effect without large investments. A significant challenge to the success of a new maintenance strategy within the respondent companies is the lack of strategic direction, especially with regard to maintenance.

It was also evident that the management respondents would not give priority to TPM because the majority viewed maintenance as a necessary task, which would decrease output, and therefore maintenance tasks would be carried out when production demands were low, or when equipment failed. An interesting point is that the majority of respondents stated that the collection and analysis of equipment data would be the first task in developing a benchmark from which to measure their efforts. In addition, the aim, according to the respondents, would be to use the equipment operators and maintenance engineers to collect and analyse the relevant data. A senior manager stated: *"I would agree that the barriers presented will be difficult to overcome, however, we need to collect some basic equipment data to let us see the current state of our maintenance system and then develop a new system based upon the data. TPM suggests OEE, but does not provide us with the necessary tool to collect the correct data"*

Equipment performance data are not collected or analysed in the majority of companies. In addition, there are generally no written procedures in place to record or analyse equipment problems or quality problems due to poor maintenance. It can be argued that this is why few companies have made progress and still rely on maintenance engineers or equipment operators fixing a breakdown, rather than identifying the root of a problem and presenting a solution. At this stage, it was suggested by the authors that Reliability Centred Maintenance (RCM) should be examined because it provides a structure for determining the maintenance requirement of any physical asset in its operating context, with the primary objective of preserving system function (Wang and Hwang, 2004). In addition, it requires involving the operators and the maintainer, as drawing on operators' intimate knowledge about equipment and developing a team working approach between the maintenance and operators (Hall, 2002).

RCM, in its present context, relies on the need for data, and that a change in the way RCM is perceived may be required for a successful implementation (Finlow-Bates and Visser, 2000). Although RCM focuses on understanding and identifying system functions, functional failures and the consequences of those failures, it does not consider planning and scheduling and people efficiency; neither does it work if the basic equipment condition and the operating standards are not addressed first. The lack of any accurate and historical equipment data should not preclude the use of RCM from the development of a maintenance system but rather support the application of Total Productive Maintenance (TPM). The mixture of the two maintenance methodologies aims to ensure that the basic equipment conditions are established and equipment-competent operators are developed (Wang and Hwang, 2004).

In summary, the research highlighted that TPM is not being adopted within SMEs largely due to the barriers outlined. It has shown that there is a distinct lack of understanding by management of the benefits of TPM. In addition our research indicates that implementation cost with regard to disruption to production, would be too great. It would appear that SMEs require a customized maintenance concept that is designed to overcome or remove the perceived barriers to the adoption of a new maintenance initiative. However, little attention has been paid to maintenance philosophies for SMEs. Therefore, any new SME maintenance model must have the dual role of (a) helping to overcome the barriers that we have identified within SMEs, and (b) increasing the awareness of TPM and other MMPs such as RCM, and their benefits.

3. The development of AIMMS

We have shown that there are a number of barriers, which could potentially prevent implementation of TPM within SMEs. If it is assumed that TPM, due to its focus on planning and involvement of a wider range of employees in maintenance task, is a useful platform on which to develop a new maintenance methodology for SMEs, it is imperative that the barriers identified through discussions with the managers are taken into account when developing its structure and content. The outcomes from the literature and the data analysis were considered. The specific issues regarding inclusion of TPM and RCM elements are now discussed.

3.1. The TPM pillars

The interviews with 36 managers showed that due to the size and internal structure of SMEs, certain pillars of TPM would impede SMEs developing a new maintenance strategy and at the same time would not be essential to developing and implementing an enhanced maintenance strategy. Therefore, the aim is to use only those pillars that would add value to a new maintenance strategy, so that the pillars are now reviewed and their inclusion discussed.

Improve Overall Equipment Effectiveness (OEE) - included in AIMMS

In order to create an OEE calculation an examination is required of the current maintenance system in order to determine availability, performance and quality, so that accurate measurements are required. These data will not only create a basis of equipment performance history, but will also provide a benchmark from which to set priorities, establish clear goals and measure the benefits. Therefore, OEE is included within the AIMMS development.

Autonomous maintenance by operators - included in AIMMS

The involvement of the operators in maintenance activities is seen as the first step in creating and enforcing basic standards. This pillar is also deemed essential by the respondents, due to the fact they have very few, and in some cases no, maintenance staff. Therefore, it is a requirement that operators be involved in developing and undertaking maintenance activities, deployed via the inclusion of autonomous maintenance task selection process embedded within AIMMS.

Planned Maintenance - included in AIMMS

Planned maintenance will allow the operators/engineers to develop their maintenance tasks. In the SME environment, it is essential that scarce resources be used effectively and efficiently when applied to the maintenance task. Hence, this pillar is included in the development of AIMMS.

Train to improve operator and maintenance skills - not included in AIMMS

The skills of the operators and maintenance personnel must be improved if autonomous maintenance is to be successful. However, the aim is to introduce structured training methods, which will increase the skills of both operators, and maintenance personnel before the company develop a new maintenance strategy. In particular, if operator autonomous maintenance is to be successful, operators must understand the structure, function and inspection methods for each piece of equipment. However, due to the barriers outlined previously, this approach would require finance and time for operators to learn and develop new skills, therefore this pillar is not included within the development of AIMMS. AIMMS advocates that maintenance engineers and operators work together in developing the maintenance strategy for a particular piece of equipment and that operator training is achieved through this process and not through stand alone training prior to strategy development.

Early equipment management – not included in AIMMS

The aim is to introduce improvements in the equipment at the earliest possible stage, so as to develop maintenance-free equipment. This approach aims to prevent breakdowns and defects by considering maintenance during the equipment design phase. However, the majority of respondents are unable to use this approach due to the age of their equipment, and if new equipment were to be purchased, the majority would be supplied with maintenance guidelines, not requiring additional maintenance activities. Therefore, this pillar is not included within the development of AIMMS.

RCM Elements

The necessary elements of TPM, required for incorporating in the AIMMS methodology, have been identified above. However, the data analysis showed that TPM might not meet the requirements of SMEs because it does not allow the company to understand where to focus their maintenance efforts and resources. The Reliability Centred Maintenance (RCM) is described in Chan et al. (2005) as a maintenance methodology that allows the company to use a progressive logical approach based upon the collection and analysis of basic equipment data. The primary reason for the development of RCM is to implement a preventive maintenance strategy that could adequately address system availability. However, RCM is time consuming and applying a full-blown RCM methodology requires management commitment and organizational openness (Per Hokstad and Bodsberg, 1996). In addition, RCM requires large amounts of data to be effective, while the data showed that SME management suffer from a lack of historical equipment data.

Step 1: What is the function of the equipment? This process shows that often technically identical equipment may require different maintenance strategies based upon equipment performance or redundancy due to production demands. This stage of RCM is included within AIMMS because it helps the operator or maintenance engineers to identify and record equipment data in a structured format that helps to form the basis of a new maintenance strategy.

Step 2: What causes each functional failure? This proactive approach to maintenance identifies potential system failures and encourages the operators to 'observe' equipment during normal operations to identify any possible pre-failure conditions. This stage of RCM is included within AIMMS because it allows the operator or maintenance engineer to identify all failure states associated with each possible function.

Step 3: What causes each failure and identifies failure modes? The respondents saw this stage of RCM as time consuming and adding little to the development of a new strategy. This task, according to the majority of respondents, would require specialized knowledge of the equipment, was identified as a barrier to maintenance development. Hence, it was not included in the development of AIMMS.

Step 4: What is the failure effect? This includes identifying what would happen if no specific task was carried out to anticipate, prevent or detect the failure. This stage was included in AIMMS because it helps to focus maintenance tasks on specific and critical equipment by examining the possible effect of a failure on the component, the equipment, or the line.

Step 5: What is the consequence of each failure? The aim is to categorise formally each failure mode to determine environmental, health & safety, and economic issues. Each mode is categorised as hidden or evident. Yet, data are often not readily available and so this step is often overlooked. The lack of accessible and accurate data precludes this stage from AIMMS development. However, as the data (collected via the cause and effect of failure) are regularly updated, this stage could be included.

Step 6: What proactive task(s) should be done to predict or prevent each failure? Detailed data is required about each failure and its consequence, in addition to the maintenance engineers and equipment operators having complete understanding of failures, their consequences and methods to reduce such failures. This stage requires data not readily available within the majority of companies. This also requires detailed maintenance task and corresponding task intervals to be developed and available.

Step 7: What default action should be done, if a suitable proactive task cannot be found? The aim is to identify if the equipment should be allowed to run-to failure or that a planned/preventive task should be developed. The data analysis has shown that the majority of respondents do not know which task should be carried out; therefore embedding this stage within AIMMS would only serve to confuse and delay the development of a maintenance strategy.

The interview data identified that the majority of respondents (84%) required the failure modes that cause functional failure be identified, the failure modes be prioritized to reflect their importance to the system function, and that Planned Maintenance (PM) actions and their cost effectiveness be identified. This, according to the respondents is achieved in steps 1-4, and initially steps 5-7 would not support their maintenance strategy development. However, once the new strategy was implemented successfully, the remaining steps would be addressed and included, if necessary. Fig. 1 shows the influences from the current literature and the analysis of the data from the interviews with senior management.

4. AIMMS

The AIMMS methodology provides a list of possible data collection and analysis techniques from which the company can decide to implement. The use of three stages of RCM, Function, Failure and Cause and Effect, in the development of AIMMS provides the means to monitor equipment reliability and determine equipment failure by using logical review steps, structured as an iterative process to identify what the failure is, what caused it and what effect it has on the production process. TPM, in particular autonomous maintenance, planned activities and OEE allow a new maintenance strategy to develop a means of

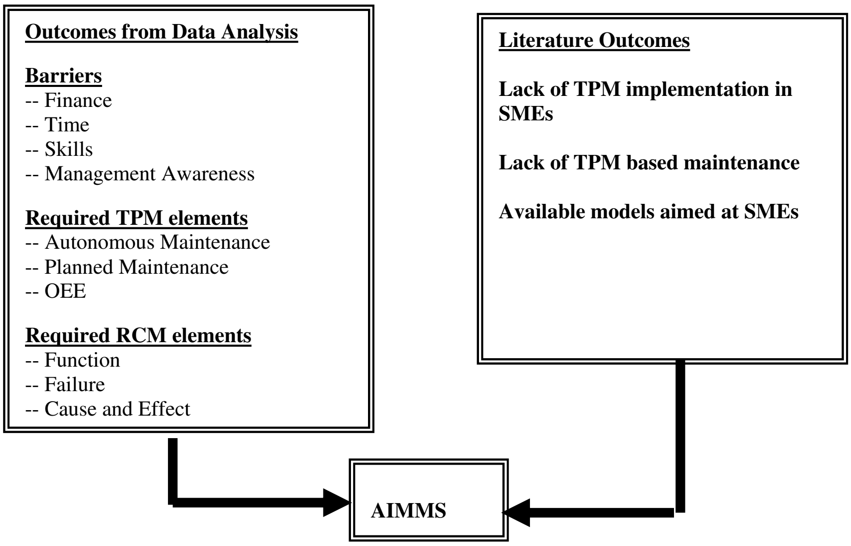


Figure 1. Influence on the AIMMS methodology

measuring the implementation effort (utilizing both OEE and ROI), allow the operators to develop, implement and monitor maintenance tasks and to develop a planned approach to maintenance using the autonomous maintenance tasks provided within the MainMan software. This approach provides a methodical tool, since the processes and subsequent activities that need to be considered when starting to develop a new maintenance initiative have now been identified. A software-enabling tool was also developed. The MainMan software provides the necessary components to develop a maintenance initiative based upon the data collected and analysed using the AIMMS methodology. The software can also be used to measure the improvements by calculating the effects the new strategy has on the equipment performance. The software was developed based upon the need to implement the maintenance decision identified and developed within the AIMMS methodology. As a result, modules that enable the decisions for each individual company can be included and modules that might undermine the true potential of the system can be removed. Therefore, MainMan is versatile enough to integrate new processes as the maintenance function improves within the individual company.

To summarize, Table 2 provides an overview of the barriers, the actions required to reduce their impact and the processes within AIMMS methodology that help SME management to overcome the barriers and develop a tailor-made strategy.

Table 2. Analysis of the processes required to reduce the impact of the barriers to maintenance department

Barrier	Action	Process
Lack of finance due to perceived cost to implement	• Develop an understanding of the costs involved with planned and unplanned maintenance • Examine the costs to implement a new strategy • Develop a ROI	**1**. Establish current maintenance practice **2.** Identify cause and effect of equipment failure **3**. Establish current maintenance costs **5**. Design new strategy based upon ROI
Time required for implementation due to perceived length of implementation period	• Examine the time spent on planned and unplanned maintenance activities • Develop a realistic time to implement based upon ROI • Develop performance measure to measure the benefits	**1**. Establish current maintenance practice **2.** Identify cause and effect of equipment failure **3**. Establish current maintenance costs **5**. Design new strategy based upon ROI
Lack of skilled equipment operators and maintenance engineers	• Involve everyone in the analysis of the current situation • Develop basic skills training programmes including diagnostic and data analysis • Involve everyone in developing maintenance and implementation procedures • Involve everyone in developing performance measures	**1**. Establish current maintenance practice **2.** Identify cause and effect of equipment failure **3**. Examine new maintenance options using AIMMS **5**. Design new strategy based upon ROI **6**. Implement new strategy **7.** Evaluate and refine
Lack of management awareness to the benefits of modern maintenance methodologies	• Management analyse the current situation • Management identify and develop a new maintenance strategy including performance measures • Involve management in implementation and developing a methodology for reviewing and refining the strategy	**1**. Establish current maintenance practice **2.** Identify cause and effect of equipment failure **3**. Establish current maintenance costs **4**. Examine new maintenance options using AIMMS **5**. Design new strategy based upon ROI **6**. Implement new strategy **7.** Evaluate and refine

The systematic process helps to develop a maintenance methodology. This is possible because the barriers are individually addressed, as shown in Table 3, and provide SME management with a systematic process to reduce the perceived impact the barriers may have upon maintenance development within their organization. However, to assist SME management with the implementation, the MainMan software has been developed. The MainMan software enabler for the AIMMS methodology was developed using Microsoft Office applications, Microsoft Excel and Microsoft Access. The Windows compatible and Web operating based system is founded on standard architecture and established within the majority of PCs. In addition, Microsoft Office applications are easily expanded to incorporate more data or additional components, such as text editors.

The advantage of the eleven-stage modules within MainMan is that it allows the development of a Modern Maintenance Practice (MMP) strategy, and the co-ordination of a feedback mechanism. MainMan contains the modules that can provide management with value added information necessary for decision support and decision-making. This allows the maintenance system to develop, thereby prompting a choice of maintenance tasks based upon measurable benefits.

The MainMan software provides the necessary components to develop a maintenance initiative based upon the data collected and analysed using the AIMMS methodology. The software can also be used to measure the improvements by calculating the effects the new strategy has on the equipment performance. All the different processes are linked to a reporting system within Excel and to the Access database. The methodology is intended to encompass a practical and rigorous approach towards improving equipment effectiveness, developing autonomous maintenance and implementing a planned approach to maintenance tasks. In addition, the model is intended to enhance the skill levels of the operators, maintenance engineers and management, and utilize existing expertise, thus addressing the chosen pillars of TPM. Finally, the MainMan software is capable of handling multiple criteria and multiple factors of equipment failures and their cause and effect on the production process. The analysis will show that the case studies used AIMMS to outline their objectives and maintenance strategies considering costs, benefits and risk, as well as resource allocation. Finally, the analysis will show that each case study used AIMMS in a systematic and adaptable approach to determine what specific maintenance tasks to perform.

5. Case study implementation

The case study companies chosen to evaluate AIMMS are considered medium sized (more than 50 employees, but less than 250). The first company approached to evaluate AIMMS (Company A), is a printing press manufacturer, who provides printing machines and spare parts to companies throughout the world. The company has 120 of staff. The maintenance department consists of one maintenance manager, one electrical engineer and one mechanical engineer. The equipment, on average, is between 20 and 30 years old. Equipment and maintenance manuals are missing or inaccurate due to the specialized modifications to suit product changes.

The current maintenance strategy is predominantly reactive, according to the maintenance manager, as a result of lack of staff to service and maintain the equipment and lack of finance to employ skilled operators. The company suffers from an un-willingness of the operators to become involved with maintenance. Three maintenance staff that are solely responsible for the equipment operating condition carry out maintenance. The company is continually plagued by a high number of equipment failures due to minor stoppages caused by oil and dirt contamination, which often lead to longer periods of failure. In order for the maintenance strategy to be successful, it must firstly allow the maintenance manager to formulate maintenance actions based upon the limited available resources. The maintenance manager at Company A had identified two key areas in which AIMMS would be evaluated. (1) Develop and implement a strategy for the Okuna Lathe; (2) Develop training material based upon the strategy development to enhance the skills of the workforce.

The only planned maintenance activities on the lathe consisted of the same task, on the same day at a pre-determined frequency regardless of necessity. Due to the predominantly reactive approach to maintenance, the maintenance manager had not identified the different maintenance tasks available and compared them against the needs of the equipment. The maintenance manager understood the cause of the failures but was not always clear on how to solve the problem. The limited planned maintenance and lack of specific tasks and techniques were inadequate to remove the problem. Using a systematic approach, the maintenance manager recorded the failure, and cause and effect of the failure. The average time required to repair the fault was 50 minutes. However, the task usually required the maintenance engineer to remove, clean and replace the shaft and turntable, and reset the switch. Metal fragments and oil were the main contaminates. Due to limited time, the equipment was rarely cleaned. An analysis of the equipment indicated that the problem was the contaminants in the feed pipe, which, when blocked, created backpressure in the system and thus reduced the amount of oil. In addition, the lathe was found to suffer from the main spindle jamming due to contamination from production.

5.1. Case study outcomes from AIMMS

The maintenance manager and an equipment operator at Company A used the AIMMS methodology in stages. Initially, the aim was to develop a maintenance strategy by utilizing all the process within AIMMS. Once the strategy had proven successful, the maintenance manager would adjust the implementation to suit other equipment. This allows the maintenance system to develop, thereby prompting a choice of maintenance tasks based upon measurable benefits. The results show in Table 3 each process, the MainMan software modules required and the results obtained from the implementation of AIMMS on the Okuna Lathe.

The application of the AIMMS methodology: how each module embedded within AIMMS was used by the case study to develop a new maintenance strategy is now commented in stages.

Table 3. Case study Company A: Outcomes from AIMMS

AIMMS Methodology	**MainMan Software**	**Issues**
1. Establish current maintenance practice (per calendar month)	Equipment Function Plant Register	• 95% Reactive maintenance • 5% Planned maintenance (critical components) • Planned maintenance tasks were carried out on the same day at the same time regardless of necessity • Maintenance carried out by maintenance department • Equipment operators are not involved with maintenance
2. Identify cause and effect of equipment failure	Equipment Function	• Approximately 90% of failures caused by contamination • Main turntable stopped due to dirt • Main turntable stopped due to excess heat • Main turntable stopped due to secondary damage
3. Establish current maintenance costs (per calendar month)	Daily Costs Cost Benefit Analysis	• Average time to repair 56 minutes (each failure) • Average number of breakdowns 8 • Average cost of operator waiting £15 per failure (non productive) • Average cost per spare parts £40 per failure • Average cost per additional parts £30 per failure (non-stock) • Average cost per failure £ 85 • Average cost per month £680 • Average downtime 448 minutes per month • Estimated OEE (availability, reliability and quality) 44%
4. Examine new maintenance options using detailed lists provided within MainMan	Task Selection Modules	• Allow operators to collect equipment history (RCM) • Allow operators to collect equipment availability/reliability (OEE) • Introduce autonomous maintenance to allow operators to undertake routine inspections, cleaning, lubrication etc. (TPM) • Develop planned maintenance schedule based upon equipment data (RCM) • Develop training material for maintenance and equipment operators
5. Design new strategy based upon ROI	Cost Benefit Analysis	• Introduce basic inspections to remove problems due to contamination • Operators carry out daily inspections (cleaning, lubrication etc.) • Operators and maintenance engineers inspect electrical problems • Develop single point instructions (SPI) for training • Calculate cost of new strategy to determine ROI
6. Implement new strategy	Cost Reduction Analysis	• Maintenance manager and operator implement 'new' strategy
7. Evaluate & refine	Cost Reduction Analysis	• Continuous evaluation of strategy • Equipment data collected on a daily basis • Maintenance manager evaluates data and refines tasks • SPI changed to meet equipment needs and operator skills • Initially OEE and ROI calculated on weekly basis

1. Establish current maintenance practice. The operator is required to collect and record the number of hours the equipment is not in production in one calendar month. In addition, the estimated number of breakdowns and an estimate of the percentage of reactive maintenance (if available) are to be included.

2. Identify cause and effect of failure. Fig. 2 shows identification of the normal function of the equipment, how the component fails to perform its function and the cause and effect of the failure. The failure and cause and effect data base on detailed examination of the recent failure.

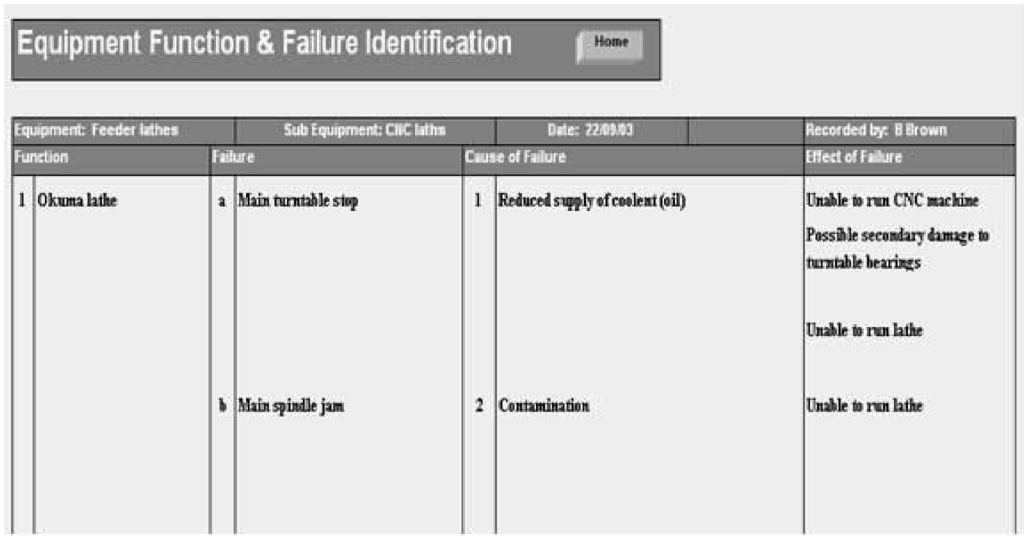
This stage was completed by the manager and equipment operator. This now provides a benchmark from which to determine the new strategy. In addition, this diagram, and subsequent diagrams are placed next to the equipment to enable the maintenance process to develop based upon the previous failure and cause and effect.

3. Establish current maintenance costs. In order to provide accurate information, maintenance costs are collected from direct costs such as labour and materials. Hidden costs or indirect costs that are often harder to measure are identified by examining unplanned breakdowns, changeovers and adjustments, idling and minor stoppages, reduced speed, start-up and quality defects. The calculation of the losses provides the data to determine the overall equipment effectiveness (OEE). To complete the financial analysis, data are recorded on the number of hours operators are unable to perform their production tasks due to stoppages, shown in Fig. 3.

This task was carried out by the management and provides the means to measure the financial benefits from a new maintenance strategy. In several of the case study companies, this was the first time that financial data, with regard to maintenance, had been recorded and therefore provided the management with a different perspective on costs and potential return on investment form a different approach to maintenance.

4. Examine new maintenance options using detailed lists provided within MainMan. Based upon experience and the identified problems the appropriate tasks to develop the optimum solution are selected from a list of tasks that include basic cleaning and inspection, preventive and predictive tasks. The persons, required to carry out the tasks are identified, in this example the operator, and a cost estimate is included to develop the ROI.

Developing a strategy using the basic inspections and adjustment allows the operators and maintenance engineers to specify equipment parameters, determine inspection frequencies, and develop their skills and knowledge to identify symptomatic conditions. In addition, MainMan provides a list, which is not exhaustive, of planned maintenance activities that allows the operator or maintenance engineers to establish ‘guidelines’, which are used to combine maintenance procedures for the chosen piece of equipment. The estimated costs for

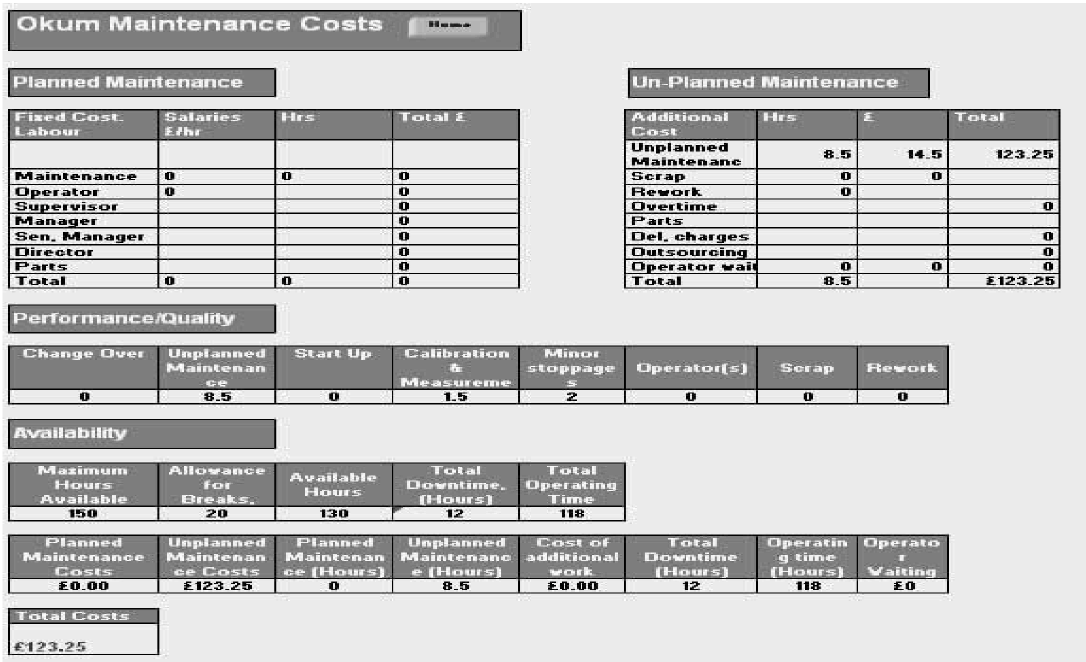


Equipment Function & Failure Identification

Home

Equipment: Feeder lathes	Sub Equipment: CNC laths	Date: 22/09/03	Recorded by: B Brown
Function	**Failure**	**Cause of Failure**	**Effect of Failure**
1 Okuma lathe	a Main turntable stop	1 Reduced supply of coolent (oil)	Unable to run CNC machine Possible secondary damage to turntable bearings Unable to run lathe
	b Main spindle jam	2 Contamination	Unable to run lathe

Figure 2. Equipment function and failure identification



Okum Maintenance Costs

Planned Maintenance

Fixed Cost. Labour	Salaries £/hr	Hrs	Total £
Maintenance	0	0	0
Operator	0		0
Supervisor			0
Manager			0
Sen. Manager			0
Director			0
Parts			0
Total	0	0	0

Un-Planned Maintenance

Additional Cost	Hrs	£	Total
Unplanned Maintenanc	8.5	14.5	123.25
Scrap	0	0	
Rework	0		
Overtime			0
Parts			
Del. charges			0
Outsourcing			0
Operator wait	0	0	0
Total	8.5		£123.25

Performance/Quality

Change Over	Unplanned Maintenance	Start Up	Calibration & Measureme	Minor stoppages	Operator(s)	Scrap	Rework
0	8.5	0	1.5	2	0	0	0

Availability

Maximum Hours Available	Allowance for Breaks.	Available Hours	Total Downtime. (Hours)	Total Operating Time
150	20	130	12	118

Planned Maintenance Costs	Unplanned Maintenance Costs	Planned Maintenance (Hours)	Unplanned Maintenance (Hours)	Cost of additional work	Total Downtime (Hours)	Operating time (Hours)	Operator Waiting
£0.00	£123.25	0	8.5	£0.00	12	118	£0

Total Costs
£123.25

Figure 3. Estimated cost of current approach to maintenance

the activities are included, therefore, in development of a detailed schedule for inspection and planned maintenance tasks and their associated costs.

5. Design new strategy based upon ROI. Fig. 4 shows identification of all of the costs, financial benefits and possible financial losses arising in relation to the new initiative. Having established the processes that will deliver improvements, an applicable system and implementation programme can be constructed and costed. During implementation of the first strategy, further information will be gained and the costs and benefits can be updated through feedback loops placed between the different stages. This allows the Return on Investment (ROI) calculation to be carried out on a continual basis, and hence the most appropriate strategy to be selected.

One of the criticisms, from the respondents, of implementing a new maintenance strategy is that it may be difficult to quantify the benefits. The goal is to collect useful 'before' data that can later be compared to 'after' data. An additional complicating factor is the difficulty in assigning the observed benefits to the responsible improvement activity. However, the software incorporates an analysis of the Overall Equipment Effectiveness (OEE). One of the benefits of OEE is that the data collection itself also provides an opportunity for equipment operators to learn more about their equipment. The final OEE value serves primarily as a basis of comparison to monitor the process improvements resulting from the implementation of the model.

MainMan allows the operator or maintenance engineer to enter the total time the equipment was available, total planned downtime, unplanned downtime due to breakdowns, set-ups, adjustments, and minor stops. This information is used to determine equipment availability, in this case found to be 83%. The performance is determined by calculating the actual production rate with respect to desired production rate.

The completion of this stage is to help the operators to predict the onset of component failure, detect a failure before it has an impact on the function, and develop the skills required to repair or replace asset before failure occurs. In addition, preventive maintenance frequencies can be determined and varied according to deterioration and failure rates, operating strategy (i.e. windows of opportunity), cost of performing the activity and penalty (disruption to production process) associated with asset failure.

6. Implement new strategy. This involves identification of resources and actions required to implement maintenance policies, entailing revising task instructions and specifying restoration or repair procedures. The implementation should include everyone involved with the development of the new strategy. The initial implementation strategy may include basic inspection, adjustments, testing, calibration and replacements. However, these tasks should include a list of tools, parts or instruments required to perform the task. The case study company has now an understanding of the costs involved in addition to increasing their

Return on Investment Home

Average Planned & UnPlanned Maintenance Costs				
Monthly			6 Monthly	Yearly
£123.25			£ 739.50	£ 1,479.00

Alternative						
Option	Daily Cost	Weekly	Monthly	6 Monthly	12 Monthly	Total Yearly Expenditure
A			£100.00	£600.00	£0.00	£ 1,200.00
B	£ -	£ -	£ -	£ -	£ -	£ -
C						£ -

Analysis				
Current	Solution	Cost	Cost Benefit	Yearly % Saving
£123.25	A	£100.00	£23.25	18.86

Figure 4. Returns on investment

understanding of the maintenance issues and problems. They also developed a basic task list, which is placed next to the equipment. On a regular basis, depending upon the tasks, the operator examined the list of tasks and carried out the necessary task. An example is shown in Fig. 5.

Fig. 5 comprises detailed tasks, developed by the operators and equipment engineers using the tasks provided within the MainMan software. However, both the tasks and the frequency are likely to change as the maintenance strategy develops and the task are no longer requited or need to be adjusted to suit the equipment needs.

7. Evaluate and refine. Once the strategy is implemented, the frequency and type of tasks will need to be adjusted. This includes identification of work, which is performed too often. If a task does not remove or reduce the problem, the task frequencies need to be adjusted. If the frequencies are left uncorrected, the benefit will not be shown. To help minimize this problem, the framework allows the user to re-evaluate either the costs involved or the maintenance tasks and the person undertaking these tasks. The key to this approach is maintenance performance reporting. The continual recording of maintenance data (the intensity and cost of tasks) is required to ensure the correct performance measurement. However, this stage will depend on the 'will' of the management to improve continually maintenance activities.

Before the implementation of AIMMS, Company A was experiencing problems with unplanned and unnecessary downtime, and often lacked the skills to examine, identify and repair certain equipment failures. Within one month the maintenance manager claimed that the new maintenance strategy had increased equipment availability and reliability through the steps described above.

To summarize, the companies involved have allowed the authors to illustrate the implementation of the methodology in a systematic and practical approach. In addition, the companies have proven through the evaluation that AIMMS is practical, easy to use and a powerful tool that can help to solve complex maintenance problems. The following describe how each of the perceived barriers has been addressed by the implementation of the AIMMS methodology.

Cost. There was a remarkable reduction in maintenance costs within the one-month evaluation. The number of hours of un-planned maintenance was reduced sufficiently to determine that the implementation was a success. However, the development of the new strategy was not based upon cost to develop, but on the potentially high costs associated with not developing the maintenance system. The management analysed the benefit of carrying out the new strategy by examining the equipment availability.

Time. AIMMS has proven that within one month benefits have been realized. Financial gains have been recorded and the equipment availability has increased. This has significantly increased production time, and a consequence of increased reliability is a decrease in maintenance costs. In addition, within the month the

Okuma Task Selection

Equipment:		Sub Equipment:	Date:	Recorded by:
	Task	Frequency	Additional Information	Time Hours
1	Remove, clean and replace oil feed pipe	As required	Before start up After each switch off	
	Inspect cutoff switch	During oil pipe inspection	As above	
	Inspect turntable Remove and clean	End of working week, after shutdown		
	INSPECT & CLEAN	EVERY DAY	AS REQUIRED	

Figure 5. Task selection process

operators have:

- Increased their skills and knowledge.
- Developed a detailed task selection process.
- Focused improvement activities on increasing the effectiveness of the equipment.

The completion of the task selection processes required the team at the companies involved to identify the factors that describe the interrelations between the different maintenance methodologies as well as the factors which describe the function, and cause and effect of failure. It is clear that the contribution of the AIMMS methodology is that it can assist in the development of a company specific maintenance strategy, which can implemented with the benefits realised within a short period. The success of the strategy is dependent upon the companies using AIMMS to determine technically effective maintenance tasks. Within the decision process, the teams considered constraints imposed by the available maintenance resources (tools, and spare parts) and quantified the frequency of basic inspections based upon a criticality analysis.

Skilled personnel. Lack of skilled operators and maintenance engineers could contribute to the lack of developed maintenance strategies. AIMMS allowed the operators in both companies to develop a maintenance strategy based upon their interpretation of the faults and the possible solutions. Information was collected and analysed by the people, who operate the equipment daily and have detailed knowledge as to how it works and what problems occur which would allow the equipment to fail. To the knowledge of the authors, no other available maintenance model included the equipment operators in the decision-making, thus depriving the development of a new strategy the tacit and inherent knowledge the operators poses.

Management awareness. Overseeing changes in their maintenance strategy has created new challenges for senior and middle managers involved with the implementation. After examining AIMMS, many of the managers have recognized that their roles must change and have modified their approach to maintenance to support the new strategies. The management teams have attempted to move decision making down to lower levels to empower the employees with appropriate ownership and authority. The AIMMS methodology has not only helped to educate and train the equipment operators but has helped the management teams to realize the costs and problems associated with maintenance.

6. Conclusion

The research has identified that there is a strongly held perception by Small & Medium Enterprises (SMEs) that a reactive maintenance system is acceptable as it ensures that the only time spent on maintenance is when faulty equipment is being repaired. This is considered beneficial to the needs of production. However, the cost of repairing the equipment in reactive mode can be three times higher than the cost of repair using a preventive maintenance strategy. In addition, the equipment has a lower performance. This is because a reactive maintenance strategy, which cannot tackle the root cause of the problem, always results in repetitive failures. It would appear that the inherent perceptions and practices, which underpin reactive maintenance, also act as a constraint upon the acceptance and implementation of modern maintenance practices. The existing maintenance practices within SMEs are not dynamic or evolving, but are static and conditioned by the existence of barriers. The increased dependence on the production equipment to manufacture repeatedly high quality products has created within SMEs the need for a new approach to equipment management. Maintenance models have been developed, yet these models are often complicated and industry specific, and rarely consider the constraints of an SME. Specific maintenance models have been developed using TPM and or RCM that have proven to be successful, albeit limited. However, these models are often based upon known parameters, are rigid, inflexible, do little or nothing to improve the reliability of complex equipment. SMEs suffer from a lack of awareness regarding the benefits forthcoming from the adoption of a modern maintenance philosophy.

To be successful, a new SME maintenance methodology should:

1. Help to overcome the barriers that exist within SMEs.
2. Increase the awareness of MMPs concepts and their benefits.

In order to implement an approach to maintenance that suits the inherent character of SMEs the authors developed, implemented and evaluated a new maintenance methodology called AIMMS, supported by the software system MainMan. AIMMS and MainMan were developed through an examination of the available maintenance models and the perceived barriers SMEs may face when adopting a new methodology. AIMMS includes the necessary elements of MMPs that will allow SMEs to develop and implement a new approach to maintenance. In short, the goal of AIMMS is to advocate a better way of managing maintenance by optimizing schedules and integrating the maintenance function with the rest of the company's activities. The methodology offers a contribution to the development of maintenance strategies within SMEs.

AIMMS is based upon three main objectives. First, it allows the user to formulate a maintenance strategy. Second, it transforms the limited data available into knowledge to develop maintenance tasks. Third, it allows the user to record and measure the effect of the new maintenance strategy to allow future decisions to be based upon factual and accurate data. The successful testing and implementation of the model has proven the structure and elements of the model create an efficient and effective maintenance strategy for SMEs.

Finally, the results have shown that AIMMS has helped SMEs to develop a tailor-made maintenance strategy utilizing their available skills and resources. In addition, the results have shown that data collection and analysis is possible by utilizing the necessary components of AIMMS. However, introducing this new maintenance strategy has created far-reaching changes in the case study companies. This change has drastically affected the roles and responsibilities of production employees, as well as those of the production support people. The successful implementation of AIMMS has shown that any new process benefits from a coordinated approach using pilot implementation, and then full-scale deployment. Accomplishing this requires clear direction and priorities from upper management. The goal was to remove the ad-hoc approach, where each case study could decide if they wished to implement the new strategy and then develop their own unique approach. This process occurred within all the case study companies with the added bonus of the transfer of knowledge, tools, and maintenance procedures.

A problem in the development of a maintenance strategy is the lack of relevant documentation, and an ineffective analysis of the data available. The reasons for this can be a lack of time to understand the available technologies and human attitudes in general. In particular, getting staff to record their deeds and actions relevant to the problem and to measure the quantifiable benefits in the short term has proven difficult at times. Progress can be made if a simple recording and analysis system is available, which can be readily accessed and updated. This research has shown that the technology is available, but it requires innovative adaptations to resolve and implement the above problems. What is required is the extension of AIMMS to facilitate the development of a maintenance strategy by integrating Condition Based Maintenance. This should include developments on hand held devices such as a Personal Digital Assistant (PDA) to provide support for maintenance management in all types of industry. The use of hand held devices would allow the equipment operators to conduct maintenance and record the tasks via the PDA. The information is sent to a main computer via the internet or intranet. Data is collected from multiple sensors, to identify problems for diagnosis. The aim would be to develop the software to include a “learning feature”, which would in turn suggest possible solutions.

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