DEVELOPMENT OF A MAINTENANCE STRATEGY FOR POWER GENERATION PLANTS

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Abstract: Effective maintenance of power generation systems is essential to ensure that the variable demand for electricity is satisfied on a daily basis. Equipment used on generation plants, e.g. boilers, turbines, generators, compressors and pumps, are becoming more sophisticated and complex, and therefore require more effective maintenance strategies and tactics. A number of maintenance approaches have been developed in the last 4-5 decades, e.g. reliability-centred maintenance, business-centred maintenance, and total productive maintenance. This paper discusses the results of a research study done to investigate strategy in the maintenance environment of power generation systems. The study found that most power stations have a maintenance strategy and use maintenance approaches and different maintenance tactics like run-to-failure, time-based maintenance and condition-based maintenance. It was also found that the SAP^{TM} information system is used by nearly all power stations.

Keywords: Availability, Reliability, Productivity, Maintenance, Approach, Strategy

1 INTRODUCTION

1.1 Background

Every business enterprise needs a strategy or strategic framework that provides the general vision and overall direction for management and frontline workers. Strategy can be defined as *"a method or plan designed to achieve a desired future state or major goal"*. Campbell and Reyes-Picknell [1] define strategy within the context of maintenance as an *"overall direction and flexible plan that leads to good choices"*.

A business strategy usually involves three key elements, i.e. a vision statement, a mission statement, and key objectives to be achieved within a certain time period, typically 3-5 years. A maintenance strategy should therefore also comprise these three aspects.

The main objective of any company is to generate profit through delivery of products, systems or services. Profit is determined by the productivity of the physical assets (outputs), and the costs of raw materials (inputs) as well as the cost of production or manufacturing. Maintenance can therefore contribute towards higher profits through effective management of the maintenance process, thereby increasing the availability and outputs of the physical assets.

One of the aspects that need to be addressed in a maintenance strategy is whether one of the established and well-documented maintenance approaches should be implemented or whether the company might embark on implementing only certain elements of these approaches. Examples of such approaches are reliability-centred maintenance (RCM) as described by Moubray [2], business-centred maintenance (BCM) that was developed by Kelly [3] and total productive maintenance (TPM) as described by Nakajima [4] and Suzuki [5]. Examples of approaches that are less well known are risk-based maintenance (RBM) [6], availability-centered maintenance (ACM) [7], availability-based maintenance [8], total maintenance management (TMM) [9] and reliability-based maintenance [10].

To be successful a maintenance strategy should be communicated and accepted throughout the entire organisation. A firm commitment is also needed from top management. Maintenance, like safety and quality, is everyone's business and inputs are required from various other departments within the enterprise to be successful.

1.2 The role of maintenance strategy

Maintenance management has evolved significantly in the last two or three decades. These changes are due to:

- Increase in the number of physical assets (plants, equipment, buildings, vehicles)
- Increase in the diversity of equipment required in modern systems
- More complex designs
- Extension of the design life of plants and facilities
- New maintenance techniques and monitoring equipment

Maintenance management needs to incorporate all these changes into better planning, organising and control of the maintenance resources to ensure that business objectives relating to production quantity and quality are met, and that safety, health and environmental goals are not compromised. The changing economic climate in South Africa and the rest of the world has also emphasised the role of the maintenance management team to curb maintenance costs and to evaluate the effect of any changes to processes and tactics on the total maintenance cost.

Deregulation of the power generation and distribution system in Southern Africa in the past decade or two has increased the competition amongst different companies and power generation plants. Power station managers are therefore under pressure to increase availability and to reduce production costs. Graber [11] mentions that maintenance cost could account for about 30% of the total cost of electricity generation. Wang [12] feels that the maintenance function has a key role in achieving higher reliability and availability of generating systems and should therefore receive more attention from maintenance and operations.

1.3 Historical development

Before and during World War II most maintenance was done in a reactive way, i.e. breakdown maintenance. However, some low-level preventive maintenance, e.g. checking oil levels and doing fault-finding on critical equipment, was performed on weapons systems to increase mission availability. The advent of complex systems using new sophisticated technologies necessitated the use of intensive preventive maintenance to increase performance and availability of physical assets.

Older power stations predominantly used breakdown maintenance as a maintenance tactic. Maintenance was therefore performed only after a failure had occurred. The advantage of operating-to-failure is that the full design life of the equipment is utilised and it is therefore often the cheapest option. The disadvantage is that failures often occur randomly leading to safety, health and environmental (SHE) consequences and power supply to customers could be disrupted. Customers, e.g. smelter plants, could suffer huge physical and financial losses if power is not provided continuously.

The disadvantages of breakdown maintenance often outweigh the advantages and preventive maintenance was therefore introduced in the power generation industry a few decades ago. Wang [12] concluded that a reactive, breakdown approach alone cannot satisfy the requirements of high availability and reliability of modern power generation plants any longer.

1.4 Current state

Simple condition monitoring techniques like visual checks and audible monitoring have been in use for a long time, but more sophisticated techniques like vibration analysis and oil monitoring became popular in the early 1970's. Condition-based maintenance (CBM), also known in industry as predictive maintenance, use periodic interventions of the asset to determine certain parameters that relate to the condition or state of the asset (Mitchell [13]). In the past 2-3 decades condition-based maintenance has also been implemented in power generation plants and in many cases a significant increase in performance was achieved as reported by Huang and Huang [14].

Several power generation plants in South Africa have implemented one of the established maintenance approaches like RCM, TPM and BCM. These maintenance approaches have different focus areas, e.g. in RCM the focus is on maximising the built-in reliability of the equipment. In TPM the focus is on improving the quality of the maintenance actions performed and the training of the artisans. In BCM the focus is on achieving corporate objectives through cost-effective maintenance actions and interventions.

1.5 Research objectives

A maintenance strategy provides a road map to achieve the following goals:

- Increased plant availability and reliability
- Optimised cost
- High productivity
- Reduced environmental impact
- Increased return on investment

The main objective of this study was to determine whether the power stations have a maintenance strategy and what the benefits of this strategy are. Sub-objectives that supported the main objective were to:

- Obtain an overview of the maintenance strategy currently being used in power plants.
- Identify industry or best practise for maintenance strategy used in power generating plants.
- Determine which maintenance tactics are used at power plants.
- Determine which of the maintenance approaches like RCM, TPM, BCM or RBM are used at power plants.
- Determine availability values for power plants and benchmark against similar power plants.
- Establish the status of information system usage.

2 LITERATURE

2.1 Overall maintenance strategy

Various authors have proposed frameworks or models for developing and implementing a strategy for maintenance. Kelly [3] explained a systematic process, starting with an assessment of the corporate vision, mission and key objectives and using the top-down-bottom-approach to develop an overall life plan for the items and components of the physical assets.

Campbell and Reyes-Picknell [1] used a "Pyramid of Excellence" framework to progress from a basic level to excellence in maintenance management. The first level of the pyramid is termed a "leadership" level, the second an "essentials" level and a third "excellence" level. The process fully embraces the concept of continuous improvement.

Campos et al [15] propose a new maintenance management model using a combination of elements from existing models and standards. The process starts with the requirements of stakeholders and uses concepts that are aligned with the ISO 9004 [16] standard on a quality management approach for organisations. This model comprises four high-level processes, each containing a number of sub-processes. The four main processes are Planning, Support, Execution & Control and Improvement.

Tsang [17] emphasizes the importance of four strategic dimensions of maintenance management, i.e. service delivery, organisation and structuring, maintenance methods and support systems.

Murthy et al [18] developed the strategic maintenance management approach (SMM) to link maintenance strategy to business performance. A crucial aspect of this approach is to fully understand how equipment degrades with usage or time and to obtain the right data to assess the status or condition of the equipment.

Umar [19] proposed an integrated framework for maintenance strategic planning that combines some individual elements of strategic planning into one model.

Moeko and Visser [20] proposed a framework for maintenance management for utilities of the Southern African Power Pool (SAPP). A survey amongst respondents of the SAPP tested the proposed framework.

2.2 *Maintenance strategy framework*

A strategy is needed in any business enterprise to define how the company will move from a current state to a desired state. A vision statement usually defines the desired state or "dream" for the company. A common vision for all units of a company ensures that efforts are aligned and guided towards achieving specific objectives.

Campbell & Reyes-Picknell [1] provide a framework for developing a maintenance strategy as shown in Figure 1.

The first step in the process is to develop a vision for the maintenance department or division. This vision is usually related to achieving some level of performance, often expressed in relation to a world class benchmark. One way of determining a score on a world class scale is provided by Wireman [21].

The "maintenance review" step refers to a SWOT (strengths, weaknesses, opportunities and threats) analysis. This involves determining the internal strengths and weaknesses, as well as the opportunities and threats related to the external environment of the maintenance department. The output of the SWOT analysis is compared with the vision of the maintenance department and "gaps" are identified. The next step is to develop a "business case" to motivate the funds that are required to bridge the gap between the vision and the current status.

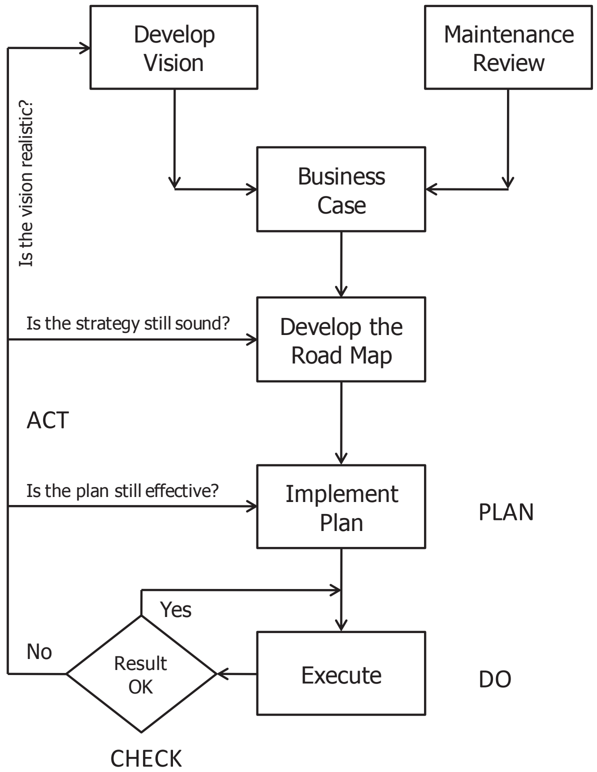

Figure 1: Framework for developing a maintenance strategy (Adapted from Campbell & Reyes-Picknell [1])

The road map defines the actions that are required to achieve the desired state, i.e. the maintenance department's vision.

The next step in the process comprises the development and implementation of a maintenance plan. The maintenance plan defines the maintenance work that should be done while the maintenance information and operational systems support the maintenance operational level to steer the department in the right direction as suggested by Coetzee [22]. This typically involves decisions on the maintenance tactic or type for each item or component of the physical asset or system, the frequency of performing the maintenance task, which trade or specialisation is needed to perform the task, and a rough estimate of the duration of the task.

The final step in the process is the execution of the maintenance plan. This is an on-going process for the life of the asset and periodic checks are needed to ensure that the maintenance plan is providing the correct outcome in terms of the total maintenance cost, availability, reliability and other key performance indicators. If a significant deviation from the objectives is found, action needs to be taken, usually through changes in the maintenance plan.

2.3 Maintenance tactics

Various maintenance tactics or types are applied, usually at the lowest hierarchical system level (components or items). Duffuaa et al [23] list the following six maintenance tactics that are generally used in maintenance decisions.

- Run to failure (RTF) – equipment is run until a failure occurs when repair or replacement is done.
- Time based maintenance (TBM) – replacement or cleaning is performed at predetermined time or usage intervals.
- Condition based maintenance (CBM) – some parameter that indicates the condition of the equipment is measured and action is taken when the condition is no longer acceptable.
- Fault finding maintenance (FFM) – periodic checks are performed to determine whether back-up, redundant or protective equipment is able to function when needed. If not, repair or replacement of the item is performed.
- Opportunity maintenance (OM) – the repair or replacement of an item is determined by a major outage or overhaul of some higher level unit.
- Design-out maintenance (DOM) – the cause of maintenance is removed through re-design or improvement of an item or component.

3 METHODOLOGY

3.1 Background

The operation and maintenance of industrial plants continuously generate performance and other data. This data is typically captured in a data base or information system. Plant data is useful to study some features but some management data usually has to be captured by means of surveys of the operations and maintenance workers. The survey method was selected for this study to determine perceptions and opinions of workers. This method was useful to evaluate the benefits of implementing a maintenance strategy as well as to determine to what extent maintenance approaches and tactics are used at the power plants.

3.2 Data capturing through questionnaires

Considering the objectives of the research as well as issues that were revealed in the literature on maintenance strategy, a questionnaire with 17 questions was developed. The questions were formulated to extract data related to the objectives of the study. For some questions only one option was required from the respondent but in other cases the respondent could tick a number of options that were applicable. The detailed questionnaire is available in the report of Ndjendja [24].

The intent of the research was to obtain an opinion from workers at different types of power plants, from different hierarchical levels and from different countries. Potential respondents were therefore randomly selected from a number of power stations in the Southern African Power Pool. Most of the respondents were from power plants in South Africa since South Africa has a large number of power plants compared to neighbouring countries. Questionnaires were sent by e-mail to power station managers, maintenance managers, engineering managers, operations managers, planners, engineers, technicians and foremen.

Of the 70 questionnaires that were sent by e-mail, 56 completed questionnaires were returned and the analysis of the data is therefore based on this sample of 56. Not all respondents answered all questions and the total percentages for some questions therefore do not add up to 100%.

3.3 Sample profile

No completed questionnaires were returned for the nuclear power plant (only one in Southern Africa). The number of respondents from the other generation plants is shown in Table 1.

Table 1: Final sample profile

Type of Power Station	Number of respondents	Ratio (%)
Hydro	18	32
Coal-Fired	30	54
Diesel turbines	8	14
Total	**56**	**100**

The number of respondents from hydro power plants and diesel power plants were not enough to compare the results with coal-fired plants and all data was therefore analysed for the total group of 56 respondents only.

4 RESULTS

4.1 Background

The results from 10 of the 17 questions of the questionnaire are discussed in this paper. These questions relate directly to the main objective of the study and some of the sub-objectives.

4.2 Role of maintenance strategy

The first question asked the respondent to indicate whether a maintenance strategy was in place. The response was 53 out of 56 (95%) that said yes, indicating that a maintenance strategy was a crucial element in the overall business strategy.

A second question relating to strategy asked the respondents to indicate which benefits could be obtained when implementing a maintenance strategy for a power generation system. A list of 7 possible benefits was provided and respondents could select more than one of these benefits. The list was compiled from various literature sources and the authors' own experience in asset and maintenance management. The results for this question are indicated graphically in Figure 2 below.

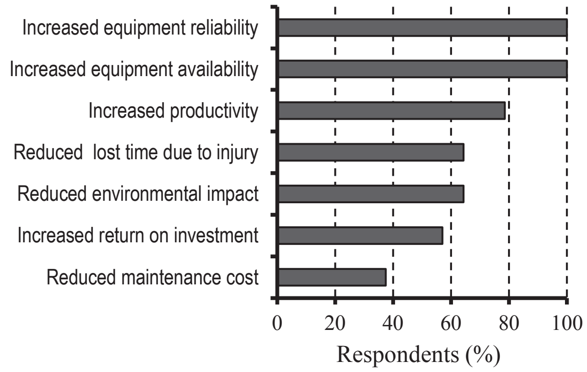

Figure 2: Roles and benefits of a maintenance strategy

It is clear from Figure 2 that all respondents felt that the most important roles for a maintenance strategy were to increase the reliability and availability of the assets. The roles mentioned were not independent and increased reliability and availability should have a positive effect on productivity as well as return on investment. The respondents felt that a reduction in cost is not very important since only about 38% indicated it as important. More than 50% of the respondents indicated that the maintenance department has an important role to play in the reduction of the environmental impact of the physical asset and the improvement of safety.

4.3 Maintenance tactics adopted or implemented

Various preventive and corrective tactics are used for the maintenance of individual items and components of a physical asset. The most effective tactic is determined by factors like the failure rate of the specific item or component, the total cost of using the specific tactic and the consequences of a failure. Respondents were asked to indicate which of the six maintenance tactics, as defined by Duffuaa et al [23], that are generally applied in maintenance are also used at the power station. The results of the survey are indicated in Figure 3 below.

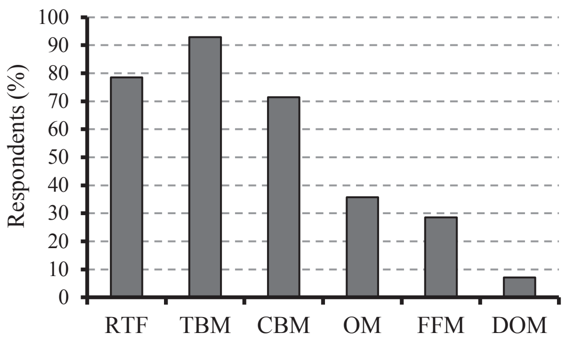

Figure 3: Maintenance tactics used on power plants

Run-to-Failure (RTF) is also known as breakdown maintenance. Time-based maintenance (TBM) is also known as Fixed-time maintenance (FTM). Maintenance departments usually aim to achieve a particular "mix" of the three main tactics, i.e. breakdown, time-based and condition-based maintenance. The optimal mix is unique for a specific plant or system. From Figure 3 it is seen that about 78% of respondents indicated that "breakdown" maintenance is used on the power station, which means that 22% of the power stations do not intend to run equipment to failure. This strategy needs a re-think since it might be too costly to try and prevent all failures from occurring.

It is also seen that 70% of the respondents indicated that the power station uses predictive or condition-based maintenance which means that 30% of the respondents do not use condition-based maintenance. This strategy exposes the powers station to a high risk of unexpected failures and is also not cost effective. However, for some components and items there might not be a parameter that can be measured to indicate the condition of the component. In this case "run-to-failure" is the only option and selected if the consequence of failure is not severe.

Sophisticated and costly equipment require effective asset "health care". Predictive maintenance is therefore used extensively in industry to determine when the condition of an item or component is no longer satisfactory for optimal production.

4.4 Maintenance approaches

Respondents were requested to indicate which of the maintenance approaches RCM, TPM, BCM or RBM had been adopted or implemented at the power station. The results are shown in Figure 4 below.

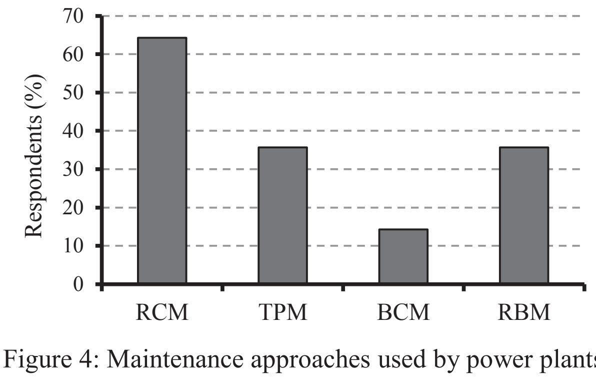

Figure 4: Maintenance approaches used by power plants

It is seen that RCM is by far the most popular approach with TPM and Risk-based Maintenance (RBM) also implemented in some of the power stations. One respondent indicated in the comments that the reliability-based maintenance approach was used [10].

The RCM approach or methodology was developed in the aviation industry and later also implemented in the nuclear power generation industry. It is particularly suited for high-risk systems where the consequence of a failure could be catastrophic in terms of environmental damage and/or safety, as occurred with the Chernobyl power plant in 1986. Fossil fuel power plants can also benefit from the application of RCM to increase reliability, availability and to reduce costs.

4.5 Power plant availability

Availability is an important indicator for most physical assets and respondents were asked to indicate the average availability of the power plant for the past year. Five brackets for availability were given as shown in Figure 5 below.

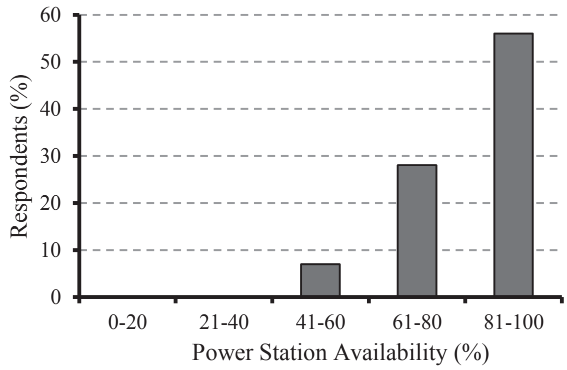

Figure 5: Average availability of power plants

It appears that the majority of power plants have an availability of more than 80% as would be expected. A benchmark value for availability of power plants is given as 85% by Stallard and Curley [25].

4.6 Planned maintenance

An effective maintenance department needs to perform more planned maintenance than unplanned maintenance, which is mostly emergency maintenance that requires immediate attention. These ratios are typically determined as hours spent on planned or unplanned maintenance/total maintenance hours. Respondents were requested to provide an estimate of how much planned and unplanned maintenance was performed at the power station as a percentage of the total amount of maintenance performed. The results for the ratio of unplanned maintenance are indicated in Figure 6.

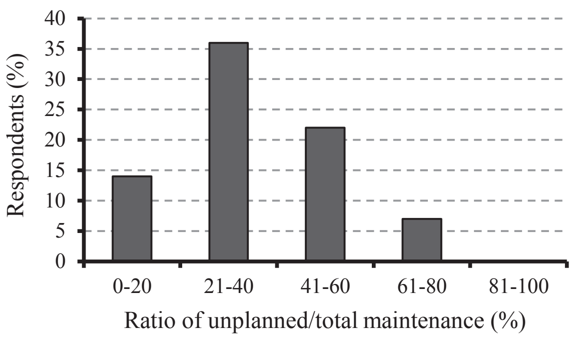

Figure 6: Unplanned maintenance

As seen from Figure 6, about 50% of the respondents indicated that the power station had an unplanned maintenance/total maintenance ratio of less than 40%. However, about 29% of the respondents indicated a ratio of more than 40% unplanned maintenance which indicates too much corrective and emergency work. Mitchell [26] suggests a 'world class' ratio for unplanned maintenance of less than 15%. In this area there is therefore room for improvement by the maintenance departments at the power plants.

4.7 Maintenance cost

One indicator which is closely monitored by all maintenance managers is the direct cost of maintenance as a ratio of the total production or manufacturing cost. This ratio can vary from 3-5% for fabrication and assembly to as high as 50% in the mining industry (Campbell and Reyes-Picknell [1]). Respondents were asked to provide an estimate of the maintenance cost ratio for the power station. The results are shown in Figure 7.

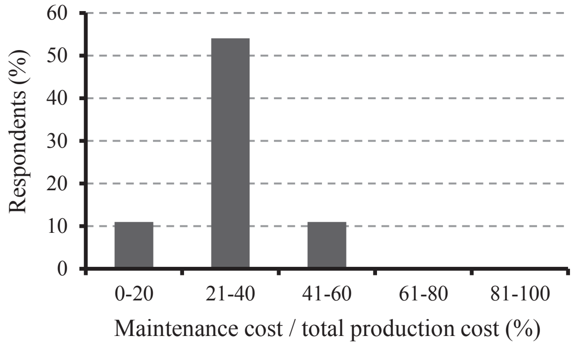

Figure 7: Maintenance cost ratio

The average ratio for maintenance cost as ratio of total cost is typically 21-40%. The plants that reported a maintenance cost ratio exceeding 40% should investigate the cause of the high costs of maintenance and implement corrective measures.

4.8 Condition monitoring techniques

The technical complexity of modern power stations requires condition monitoring on most of the equipment and respondents were requested to indicate which of the three most common condition monitoring techniques were used on the power station. The results are indicated in Figure 8 below.

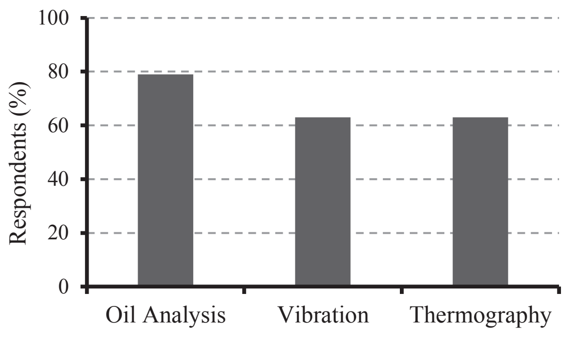

Figure 8: Usage of condition monitoring methods

It is seen that power plants use a combination of all three condition monitoring methods, i.e. oil analysis, vibration analysis, and thermography to predict the deterioration and degradation of equipment. This is useful to perform preventive actions like replacement before actual failures occur.

4.9 Maintenance information management

Management information systems are essential in modern high technology systems and respondents were therefore requested to indicate which information systems were implemented to assist the maintenance manager in analysis and decision making. Three options were provided, i.e. SAP™ [27] which is a general enterprise resource planning system, On-Key™ which is an enterprise asset management system of the Pragma [28] company or WebTA™ which is a web-based employee time tracking, attendance and labour management software package from the Kronos Company in the USA [29].

The results indicated that the maintenance module of the SAP information system is used by nearly all power stations (86% of the respondents) with other information systems only used as a complement to the SAP system. None of the other two information systems mentioned were indicated by any of the respondents.

4.10 Benefit of the information management system

A new technology, software or information system is typically introduced in an organisation since it has some financial benefit. Respondents were therefore asked to estimate the return on investment (ROI) for implementing a maintenance information management system at the power station. The results are shown in Figure 9 below.

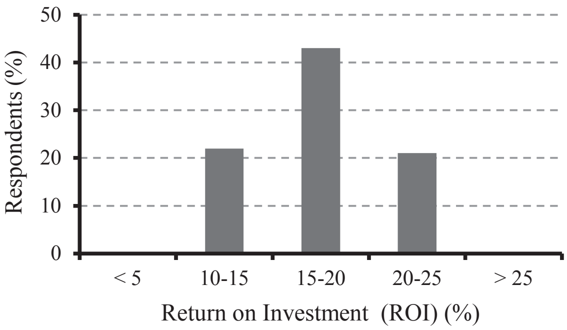

Figure 9: Return on investment for implementing a maintenance information system

The average ROI was 15% but about 20% of the respondents indicated that an ROI of between 20-25% was achieved. Good planning and execution of the implementation project probably contributed to these results for ROI.

4.11 Method for root cause failure analysis

The root cause failure analysis (RCFA) function should form part of any maintenance strategy. This is a special case of the more general root cause analysis (RCA) method. Respondents were requested to indicate which RCFA methods were used at the power station. The Apollo Root Cause Analysis method (ARCA™) [30] is a 4-step process used for thorough incident investigation. The TapRooT® [31] system and software is widely used for the analysis of all types of mission-critical problems. The 5 Why’s methodology [32] attempts to define cause and effect relationships through iterative questioning. The Cause and Effect Tree (C & E Tree) method [33] uses different tree diagrams to establish the root cause(s) after an incident. The results from the survey are shown in Figure 10.

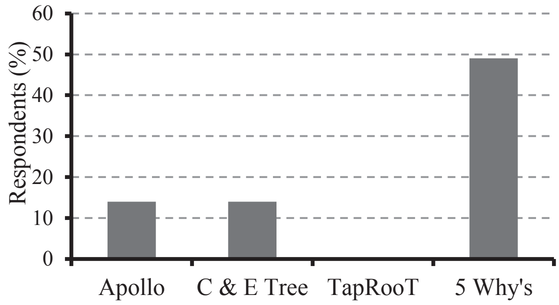

Figure 10: Root cause analysis method used

It is clear that the 5 Why’s method is by far the most commonly used methodology for performing a root cause failure analysis. The other methods are not applied by many power stations and are relatively unknown in industry.

5 CONCLUSIONS AND RECOMMENDATIONS

This study investigated, quantified and classified the role, influence and benefits of a maintenance strategy for power generating plants. The conclusions relate the results to the main and sub-objectives of the research project.

5.1 Conclusions

Most of the respondents were employed in South African power plants and the following conclusions therefore apply to the South African generation industry and not to other regions of Africa.

Benefit or role of a maintenance strategy: The main benefits of a maintenance strategy were reported as:

- Increased equipment availability and reliability
- Reduced environmental impact
- Higher productivity
- Reduced maintenance cost

Maintenance tactics: All power stations use time-based maintenance, condition-based maintenance and operate-to-failure tactics. Other tactics like fault-finding maintenance are used by only a few power stations.

Maintenance approaches: The study found that all power stations have a maintenance strategy in place but the approaches differ from one power station to another. The RCM approach is used by most power plants (64%) but TPM and risk-based maintenance approaches are also used by some plants.

Power station availability: About one third of respondents indicated an availability of less than 80%. The performance of these plants should be improved.

Industry benchmark for maintenance strategy: The study indicated that each power generating plant has its own maintenance strategy. Some strategies are simple, others more complex.

Planned and unplanned maintenance: About 50% of respondents indicated that less than 40% of all maintenance work is unplanned. More planned (preventive) maintenance should be done by the power plants to reduce emergency maintenance.

Maintenance cost: The average cost of maintenance as a ratio of total production cost is about 22% for the respondents that provided cost data.

Maintenance tactics: Time-based maintenance is the tactic that is used most by power stations (93%).

5.2 Recommendations

It is recommended that a similar survey be done with respondents from power plants of all the countries who are members of the Southern African Power Pool (SAPP). The questionnaire could also be expanded to include other performance indicators for maintenance managment. A larger sample size would also be required if comparisons are to be made between different countries or regions as well as between different power plants, e.g. coal-fired, hydro-electric and wind turbines.

It is recommended that the model as outlined in Figure 1 be used for developing a maintenance strategy for power generating plants. The objective of this strategy development framework is to:

- Increase equipment availability
- Increase equipment reliability
- Improve overall productivity
- Increase return on investment (ROI)
- Reduce environmental impact
- Reduce maintenance cost
- Reduce lost time injuries

It is also recommended that the design of new power generating plants should consider the importance of maintenance and reliability decisions at the design stage when there is an opportunity to reduce life-cycle operating and maintenance costs and therefore total cost of ownership (TCO).

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