Practical implementation of reliability centered maintenance principles and practices: A hot strip mill as case study

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Abstract

Reliability-Cenetred Maintenance (RCM) is a well-known maintenance process developed in the aviation industry. It has yielded great success and hence was the process adapted to be used in the more industrial environments, such as the process developed by Moubray (1997) called RCM2. The RCM process is considered by many to be a very effective and comprehensive maintenance process that can, if implemented correctly, improve reliability and plant availability substantially.

However, many maintenance practitioners and maintenance experts who have used RCM will tell you that it is an overcomplicated process and that it is difficult to implement. In many cases the process is abandoned and left incomplete due to the amount of resources required and the slow initial results delivered by the process. This dissertation investigates the reason for this and considers the viability of implementing the RCM process on an industrial level.

The Hot Strip Mill (HSM) at the ArcelorMittal Vanderbijlpark plant was used as a case study. The viability of using RCM to improve the HSM maintenance practices was investigated. A suggested maintenance improvement plan was developed that is more suitable for the HSM maintenance environment and culture.

Key words

- Maintenance
- Plant reliability
- Plant availability
- Sustainability
- Safety
- Equipment function
- Functional failure
- Assets (equipment)
- Maintenance improvement plan

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List of abbreviations

Abbreviation	Definition
AMSA	ArcelorMittal South Africa
CBM	Condition-Based Maintenance
CMMS	Computerized Maintenance Management System
COFA	Consequence of Failure Analysis
EFS	Electric Feeder System
FMEA	Failure Mode & Effect Analysis
FMECA	Failure Mode, Effect and Criticality Analysis
HSM	Hot Strip Mill
IAEA	International Atomic Energy Agency
KPI	Key Performance Indicator
MSG	Maintenance Steering Group
NASA	National Aeronautics and Space Administration
NDT	Non-destructive Testing
OEM	Original Equipment Manufacturer
PM	Preventative Maintenance
PSA	Probabilistic Safety Analysis

PT&I	**Predictive Testing and Inspection**
QCP	**Quality Control Plan**
RBM	**Reliability-Based Maintenance**
RCA	**Root Cause Analysis**
RCM	**Reliability Centered Maintenance**
RM	**Reactive Maintenance**
RRCM	**Reliability & Risk Centred Maintenance**
RTF	**Run To Failure**
SAE	**Society of Automotive Engineers**
TPM	**Total Productive Maintenance**
WCM	**World Class Maintenance**

1. Introduction

Reliability-Centered Maintenance (RCM) is a well-known maintenance approach developed in the United States of America and widely used over the world. However, the applicability of the process in heavy industries is sometimes put into question. Many industry experts consider the process as being effective but overcomplicated when it comes to implementation in the industrial environment.

Chapter one of this dissertation will point out the origin, history and the very basic principles of the RCM process. Furthermore, the research aims and objectives will be discussed followed by an outline of the rest of this dissertation.

1.1 Problem statement and motivation

RCM (Reliability Centered Maintenance) is a systematic approach to maintenance implementation, developed in the late 70s. Initially it was developed for the aviation industry; from there it was further developed to fit into other industrial environments. There are many books available about the RCM process; one of the more renowned books is the one entitled RCM 2, Reliability Centered Maintenance (Moubray 1997). NASA also has its own version, called *RCM guide, Reliability Centered Maintenance Guide for Facilities and Collateral Equipment*.

The universal ideas and concepts of RCM are very much the same for industries all over the world while their implementation and maintenance may differ from industry to industry. According to NASA's RCM guide, RCM comprises the maintenance approaches RM (Reactive Maintenance), PM (Preventative Maintenance), PT&I (Predictive Testing & Inspection) and Proactive Maintenance.

How the RCM process works

According to John Moubray, applying RCM to an asset or a facility involves seven basic questions or steps. Successful formulation of these questions/steps will enable the user to operate and maintain the asset as best possible. These questions/steps are:

1. What are the asset/equipment **functions** and the performance requirements?
2. What are the possible **functional failures** that can occur?
3. What is the **cause** of each of the functional failures of an asset/equipment?
4. What are the **consequences** of the functional failure?
5. What is the **effect** of the asset/equipment failure?
6. What actions can be taken to predict or **prevent** each of the failure modes?
7. What is the next step in the case where no Proactive Task is suitable for the functional failure?

Moubray’s book focuses intensely on answering these questions and offers a very detailed and descriptive maintenance process that should yield successful results if implemented and used as intended.

RCM implementation success

The RCM process covers basically all the types of maintenance methods and can be applied to any type of industry with any type of equipment. This perhaps is why RCM is considered by many to be the best developed maintenance process available to the industry. However, according to Neil Bloom, author of “RCM-implementation made simple”, only 5 % to 10 % of all attempts to implement the full RCM process succeed, while 90 % of all attempts to implement a RCM system fail.

According to Idhammar (n. d.), reliability and maintenance management consultant and vice president of IDCON, many companies try to implement the RCM program before they are ready for it. According to Idhammar’s RCM analysis of various RCM implementations, a lot of resources are wasted on intense and very lengthy criticality and failure-mode analysis while the basics of maintenance and equipment history could have yielded the same results for that equipment.

Maintenance basics

Idhammar’s suggestion is to focus on getting the basics in place before considering implementing RCM, especially in an industrial environment where tight budgets and cost-cutting prevail. These basics are:

- Ensure that preventative maintenance tasks are executed properly;
- Ensure that all basic inspections are executed properly;
- Ensure that all predictive maintenance tasks are executed properly.

Idhammar argues that these basics are already found in most maintenance strategies and should have a smaller cost implication and easier acceptance by plant personnel. To illustrate this, Idhammar made the following comparison:

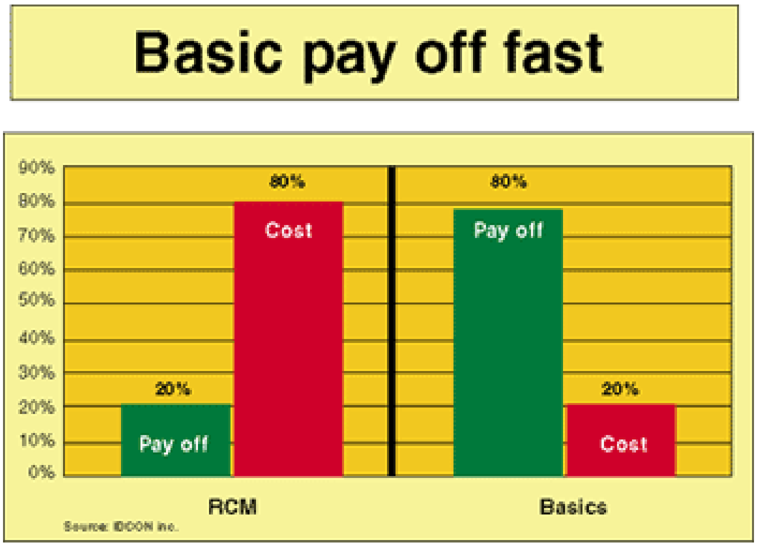


Figure 1: Cost of RCM vs. "getting basics right" (Christer Idhanmar. The Reliability Centered Maintenance (RCM) trap)

From Figure 1 it is clear that RCM has a high initial capital cost with a low initial yield, whereas with minimal investment in your existing maintenance program and basics, you can achieve much more progress and success in a shorter period of time.

Idhammar reckons that many RCM implementations can take up to 6 months without showing any change or improvement, making it a long and tedious process prone to premature failure. For this reason he states that RCM must be used carefully for critical and very complicated systems and should not be considered as a complete reliability and maintenance system.

Problem statement

The research problem is therefore stated as follow: **If the RCM process is so difficult to implement, how does one systematically implement the basics of RCM principles and tools such that success is demonstrated in the shortest period of time, given the small amount of resources available.** In order to illustrate this, the Hot Strip Mill (HSM) at ArcelorMittal Vanderbijlpark was used as a case study. A complete maintenance improvement plan was developed, specifically for the HSM, in Chapter 5 of this dissertation.

The HSM underwent various attempts to develop a more effective maintenance strategy. These attempts contributed to the already more successful maintenance strategy being used. However, there are a lot of shortcomings, causing this maintenance strategy to be far from a world-class standard.

For the past three years, the HSM has been using the RCA (Root Cause Analysis) process as part of the reliability process, with great success and good improvements. There are also reliability engineering teams working with a reliability plan to improve the plant's asset reliability, yielding improved plant availability.

When considering the maintenance approach and process of the HSM, shortcomings and stumbling blocks that prevent the successful execution of various elements of the current maintenance strategy, can easily be identified; plant key performance indicators (KPIs) will vouch for this. Interviews with HSM managers, superintendents, technicians, planners and engineers confirmed the suspicion while more long-term concerns and problems became apparent. From the interviews it was noted that there does exist a need for improved maintenance practices and processes.

1.2 Research aim

The aim of this project is to develop a maintenance improvement plan for a HSM (Hot Strip Mill) in order to improve on existing maintenance strategies. This maintenance improvement plan considers the very basics of RCM; however, an alternative implementation procedure was also proposed. This was achieved by a thorough investigation into the current maintenance strategies and procedures being used. Hence, a proposal for practically implementing RCM principles at the HSM was developed by moving away from the prescribed conventional methods and by making it HSM plant-specific by evaluating the plant requirements and available resources.

1.3 Research objectives

The objectives of this research study were to:

- obtain a comprehensive understanding of the RCM process, concepts, elements, implementation strategies and successes, advantages and disadvantages and feasibility as an complete maintenance system;
- determine why previous attempts to RCM had failed at ArcelorMittal and other world class companies;
- investigate the RCM implementation success stories to evaluate these companies' approach to RCM to ensure successful implementation;
- determine whether it was possible to implement RCM principles and philosophies at an old plant such as a Hot Strip Mill and how.

1.4 Dissertation outline

Chapter 1 – Introduction:

Chapter 1 serves as the introductory chapter to this dissertation and formulates the problem statement and motivation of the study. The research aim and objectives are discussed, followed by an outline of the subsequent chapters in this dissertation.

Chapter 2 – Literature review:

In this chapter the focus is on the literature and background of the RCM process. The traditional RCM implementation strategies and recommendations are also considered. The advantages and disadvantages are discussed, while an alternative to simplified RCM approaches and their implementation is also considered. Success and failure stories are considered, to determine the do's and the don'ts when implementing RCM and to identify the key elements that have led to success in the past. Finally the reason for ArcelorMittal's RCM attempt being unsuccessful is also discussed.

Chapter 3 – Empirical investigation:

In Chapter 3 the experimental design and objectives of this research study are discussed. The experimental method used for data collection is by means of a questionnaire and individual interviews with two industry experts. The basic design and content of the questionnaire is discussed as well as the verification and validation of the questionnaire data obtained.

Chapter 4 – Experimental results:

In this chapter the results from the experiment are discussed. The sample group for the experiment is also identified. The results from the questionnaire and the individual interviews are then summarized. Finally a questionnaire assessment is discussed in order to verify the quality of the experiment.

Chapter 5 – Discussion and interpretation:

Development of final HSM maintenance improvement plan. This plan is a comprehensive step-by-step plan for the practical implementation of RCM principles and practices at the Hot Strip Mill. The purpose of this maintenance improvement plan is to help the process of implementing RCM principles in order to improve the sustainability and efficiency of the current maintenance program at the Hot Strip Mill.

Chapter 6 – Conclusion and recommendations:

The last chapter of this dissertation concludes the study and gives recommendations for preparation when the HSM implements the recommended maintenance improvement plan.

2. Literature review

In Chapter two of this dissertation the very basics of the RCM process are considered. A brief discussion on the history and origin of RCM is followed by the very basic principles of the RCM process and the applicability of standard maintenance practices within the RCM methodology. The advantages and disadvantages are then discussed, followed by the well-known RCM models as developed by John Moubray and Neil Bloom. From these models a universal RCM process is discussed to highlight the world-wide concept of the RCM process. Finally the history of the Hot Strip Mill (HSM) and of RCM is discussed while the current maintenance approach of the HSM and the need for improved maintenance processes are also considered.

2.1 What is RCM

The predecessor of the RCM process as we know it today was the Maintenance Steering Group (MSG) with its MSG1, MSG2 and MSG3 methodology, developed in the airline industry in the 1960s. After that, Stanley Nowlan and Howard Heap, considered as the fathers of RCM, developed the very basics of the RCM process in the late 70s and published their RCM document "Reliability Centered Maintenance" in 1978. Finally in the 1990s John Moubray developed his version of RCM for industries other than the aviation industry, known as RCM 2. In 2006 Neil Bloom published a book named "Reliability Centered Maintenance, implementation made simple". In his book he describes a simplified, yet just as effective model as the RCM model by John Moubray. From years of experience as RCM engineer, Bloom identified certain pitfalls leading to premature failure of RCM implementation projects. His book is dedicated to easing the implementation process and to helping the sustainability of the process.

Moubray (1997: 3) in his book RCM 2 describes the changing world of maintenance. During the 1930s to 1950s, maintenance was considered to consist of RTF (Run To Failure) based maintenance, described as first-generation maintenance. In the period from the 1950s to the late 1970s, the second generation of maintenance, focus was placed on higher plant availability, longer equipment life and lower costs. From the 1980s, the third generation, focus was placed on safety, quality, equipment life, reliability & availability and even greater cost efficiencies. With this change, a greater demand for effective maintenance strategies emerged, leading to the development of the RCM program.

According to Moubray, RCM (Reliability Centered Maintenance) is: **"a process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context."**

Maintenance (to maintain), according to John Moubray, is to ensure that a physical asset continues to do what its users want it to do. According to Nowlan & Heap (1978: 28) this can be achieved by following the basis of an RCM program which consists of the following three phases:

1. For identified assets or equipment in a facility, how can these assets fail, or stop to produce their function at a desired level of performance.
2. For these failures of the identified assets, what are the expected consequences of the failures.
3. Can an appropriate Preventative Maintenance (PM) task be executed in order to prevent failures and preserve the functional operation at the required level of performance.

Requirement guidelines for the way the above phases should be implemented in an RCM model are stipulated by the SAE JA1011 standard. This standard was developed by the Society of Automotive Engineers (SAE) to define the requirements for a maintenance process to be classified as an RCM process.

RCM is more a combination of various maintenance methods than a single maintenance method by itself. It consists of various traditional maintenance tools that are selected and implemented based on the requirements of a specific asset. Some assets must be treated and maintained differently than others, and a wide variety of maintenance tasks will ensure that each asset is maintained optimally. The following figure, developed by the International Atomic Energy Agency, gives an illustration of the maintenance components of RCM:

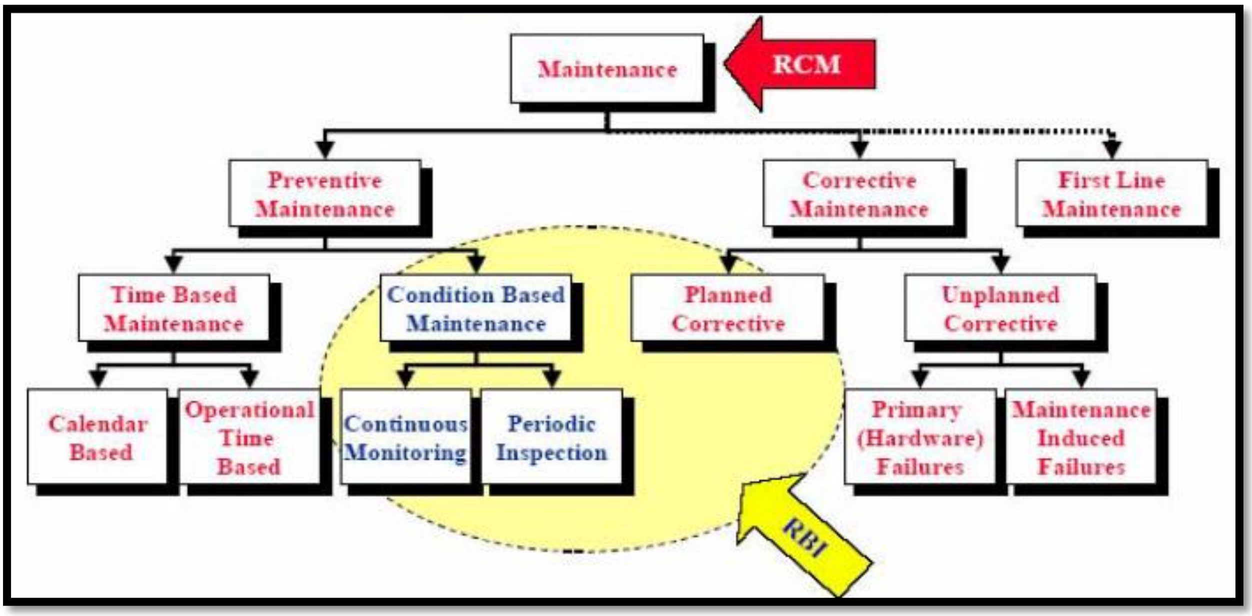


Figure 2: RCM maintenance process (International Atomic Energy Agency (IAEA), 2007)

RCM is thus a combination of Preventative Tasks (scheduled maintenance and condition monitoring), Corrective Tasks (reactive maintenance), and First-line Tasks (proactive maintenance such as Root Cause analysis and design change). The above basic maintenance methods is universal for all RCM programs used.

The following sections will consider the basic elements of any RCM program. Then, the models developed by John Moubray and Neil Bloom will be discussed to illustrate the elements of an RCM program and its implementation.

2.1.1 RCM models

The RCM process underwent a lot of development over the past years. There are many derivatives from the original RCM process developed by Nowlan & Heap (1978). This happened due to different adaptability requirements over a broad spectrum of industries. The list below summarizes some of the currently used RCM processes.

1. RCM 1, the original concept by Nowlan & Heap developed for the aviation industry.

2. RCM 2, developed for industries other than aviation by John Moubray

3. Streamlined versions, developed to reduce the resource intensiveness and difficult implementation of the traditional RCM process (Bloom 2006:142). Some examples follow:

- **Total Productive Maintenance (TPM):**

  Teams are appointed from production, maintenance and engineering. These groups determine what equipment has to be considered and prioritized. This implies that no formal analysis is done and relies on personnel experience and knowledge.
- **Reliability-based maintenance (RBM):**

  Here a facility will analyse its current PM program and make improvement projections achieved through RCM. Then RCM will be employed on certain identified equipment to achieve this vision.
- **Probabilistic safety analysis (PSA) based maintenance**

  The PSA approach will consider the probability of major safety related equipment/facility failure. This will then prevent safety-related issues; however, the normal non-safety-related, routine maintenance requirements on assets are neglected and ignored.
- **80/20 rule (Pareto principle)**

  In this approach it is considered that 80 % of the facility's maintenance problems are caused by 20 % of the equipment. Thus one will focus first on these 20 % of the assets. The disadvantage here is that the other 80 % of the equipment, when not attended to, can become part of the 20 % due to hidden and unforeseen failures.

- **RCM Light**

  RCM light, as its name suggests, is a lighter, less intensive version of the traditional RCM process. It focuses only on the critical equipment of a facility and not all the equipment. A less intensive approach to the FMECA process is also adopted in order to safeguard resources and to yield faster results.

Bloom (1997: 143) strongly advises not to use these streamlined versions since that creates the risk of certain vulnerabilities in a facility's maintenance strategy by overlooking critical plant requirements. He advises to use the traditional and comprehensive RCM approach to assure that all equipment in a plant is accounted for.

2.1.2 RCM implementation approaches

According to Moubray (1997: 277) there are three basic approaches to RCM implementation that a facility can follow:

1. **Task force method:**

   In this approach a small dedicated group is assembled to identify and target certain specific areas of equipment or sections of the facility. This team is then responsible for reviewing the requirements and the roll-out of the project. The rest of the personnel are not really involved or responsible for the development of the process, leading to quick short-term results but poor long-term involvement of the rest of the facility personnel. This will most likely result in loss of interest in the sustainability of the program after the disassembly of the task force or group.

2. **Selective method:**

   The selective method allows a facility to identify the most critical equipment. In many cases there are thousands of assets that have to be considered with the RCM analysis. This is not always possible and thus the most significant assets with the highest priority will be attended to first. This basically works on the 20/80 % rule, where 80 % of the plants problems originate from only 20 % of the plants equipment. Thus the analysis can start with the highest-priority equipment first.

   According to Bloom (2006: 144) this method could be problematic since critical equipment could be missed, and it creates opportunities for many other failures that were not initially identified as having a high priority. This then could lead to poor equipment reliability and plant availability.

3. **Comprehensive method**:

   This approach is the most intensive approach of them all. Here it is desired to cover most, if not all the assets in the facility. This implies that large groups with anything from four to 40 facilitators could exist. This extensive approach can last up to 18 months or even more. The problem with this approach is that it is very resource intensive. This means that the implementation is slow and results are not shown for a long period of time. This causes the process to become “sloppy” and in many cases the process is abandoned before it is even completed. The advantage however is that upon completion the facility will have a comprehensive maintenance managing process that is very effective.

In all the above methods, it is crucial to use the facility’s own personnel and resources for the development of the RCM process. Should an RCM consultant be used, the facility should maintain all in-house control over the process. Neil Bloom (2006: 18) emphasises this concept. Bloom reckons that the consultant does not have extensive knowledge and experience of the equipment and operations of the plant required for in-depth equipment analysis. This could lead to insufficient identification of equipment functions and functional failures, leading to possible gaps or inefficiencies in the facility’s RCM program.

Outsourcing the development of a facility’s RCM program can also lead to poor ownership of the program by facility personnel since they have not contributed their own knowledge and experience in the development of the program. This can lead to poor ownership and eventual project failure in the long term.

There are different views surrounding the implementation of the original RCM process and deviation from it in the case of streamlined versions. Neil Bloom is of the opinion that deviation from the comprehensive or traditional method could be disastrous for a RCM program.

2.2 Advantages and disadvantages of RCM

According to an Oracle Asset Life Cycle Management seminar, in an Oracle Open World seminar on 11-15 November 2007, the following advantages and disadvantages of RCM have been highlighted

Advantages:

- RCM has the potential to be the most efficient maintenance strategy when implemented, applied and maintained correctly.
- Comprehensive equipment analysis will reduce maintenance cost by eliminating unnecessary asset maintenance.
- Optimized scheduling of equipment will lead to reduced maintenance frequency.

- Improved plant reliability by reduced probability of sudden equipment failure.
- Can be used to improve critical system equipment.
- Improved overall plant reliability.
- Root Cause Analysis used as powerful tool for PM action identification.

Disadvantages:

- High initial cost, personnel training and resource intensive.
- Low initial yield in terms of facility performance and maintenance savings.

2.3 Equipment failure

One of the fundamental concepts of RCM is to have control over the failure behaviour of an asset. Successful identification and classification of the failure behaviour of an asset will help to determine the appropriate PM (Preventative Maintenance) tasks to maintain that asset as efficiently as possible.

Equipment probability of failure is classified in the following failure patterns:

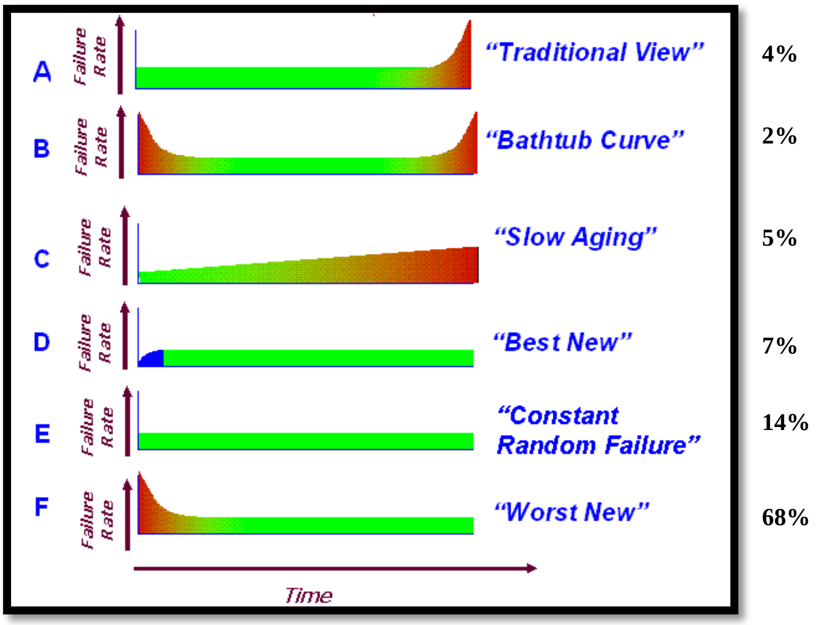


Figure 3: Equipment failure patterns (Reliability Hotwire, 2007)

According to Nowlan & Heap (1978: 68) in their RCM report, only 6 % of the failures they analysed indicated a definite wear-out phase, while 5 % did not indicate a definite wear-out region. Most failures were found to be infant failures (infant mortalities) as indicated by the 68 % of pattern F. These failure pattern percentages were found in the aviation industry in the late 70s and may differ for other industries.

Figure 4 illustrates a basic P-F curve for most equipment throughout their operating life. The P-F curve shows how the condition of an asset deteriorates with time reaching the point of functional failure. It is desirable to determine or predict the condition of an asset on its path of deterioration. If this could be achieved, PM tasks could be used to utilise the asset for maximum economical life and performance before it fails.

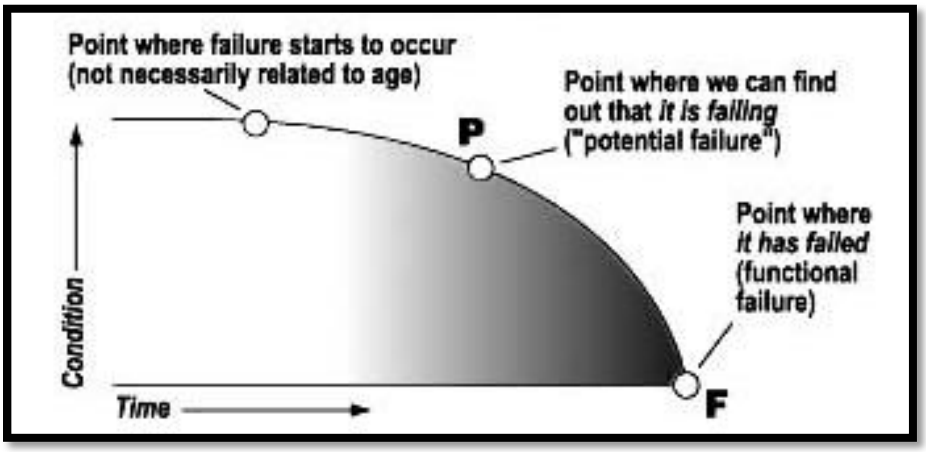


Figure 4: P-F Curve (Moubray, J, 1997)

One method used for achieving this is Condition-Based Maintenance. This process basically implies that the physical condition and the performance of the asset are tracked in order to determine the wellbeing and functionality of the asset. This could be thermal readings, oil sampling, vibration monitoring, NDT (Non-Destructive Testing) etc.

The advantage of condition-based maintenance is that the actual condition of the asset is known and thus a more accurate decision can be taken on the maintenance required. This proved to be much more effective than the traditional Preventative Maintenance approach where maintenance schedules are based on the operating time of the asset and not the actual condition. This provides for efficient asset optimization and the elimination of unexpected failures on monitored equipment. The only disadvantage is that on a large facility it is not always possible to do condition monitoring on all the equipment.

2.4 Universal RCM principles

Regardless of the RCM approach used, the basics of any RCM process are very much the same. Accordingly, the SAE JA1011 standard lists certain requirements in order for a maintenance process to be classified as an RCM process:

2.4.1 Three phases of the RCM process

According to Neil Bloom (2006: 80), there are three phases in any RCM program.

Phase 1 – Equipment analysis. The first phase when using an RCM program is to analyse the facility's equipment and the need for improvement in equipment reliability. Equipment can be identified according to their impact on safety, production or asset protection. This phase considers a process of identifying the function of an asset and the consequence of a failure of such an asset. By identifying these failures and taking the correct maintenance approach toward such equipment one can improve asset reliability and ultimately plant availability. The logical process of Phase 1 is as follow:

1. ***Function:*** Identify the purpose of the asset. What are the functions of this asset. What is it used for.
2. ***Functional failures:*** For these functions of the identified asset, determine how each one can fail.
3. ***Failure modes:*** Identify all the different failure modes for each functional failure.
4. ***Failure effect:*** What effect does each type of failure have on the plant's operability, safety, cost etc.
5. ***Consequence of failure:*** Identify the consequence of the failure of an asset.

The traditional method of determining these answers is the use of an FMEA (Failure Mode & Effect Analysis) or FMECA (Failure Mode, Effect & Criticality Analysis). These methods will be discussed later on.

Phase 2 – Task development: Develop and determine the Preventative Maintenance tasks that will best maintain your equipment or facility identified in Phase 1. The figure below summarizes the basic tools used for asset maintenance.

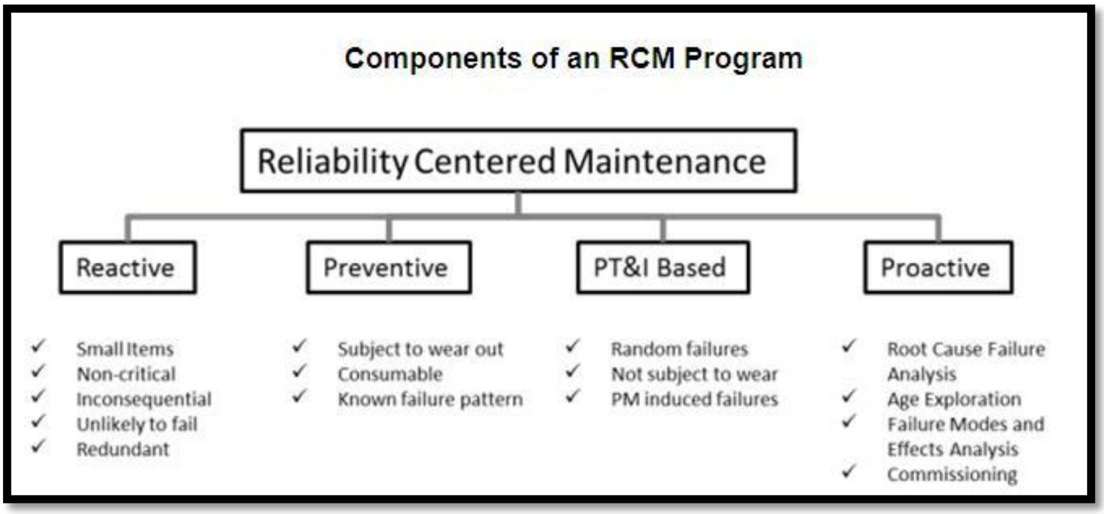


Figure 5: Components of an RCM Program (NASA, 2008)

The maintenance tasks that are normally used in RCM consist of Reactive maintenance (also sometimes referred to as breakdown maintenance), Preventive (scheduled based maintenance), Predictive testing & inspection maintenance (Condition Based maintenance) and Proactive maintenance (Root cause analysis and redesign). It is the combination of these maintenance methods that makes the RCM process such a reliable and effective maintenance approach.

Phase 3 – Task scheduling: Phase 3 is the process of allocating the PM tasks to the specified equipment. After allocating the required PM tasks, they must be planned and scheduled in order to ensure that each one is executed at the correct time. The PM tasks can be scheduled daily, weekly, yearly etc. It is also important to use a system capable of keeping track of the scheduling of the tasks and of receiving feedback from executors. This will also initiate continuous feedback to and improvement of the system.

2.4.2 Three types of equipment failure analysis

One of the fundamental and critical steps in the RCM process is the correct identification of the failure modes of an asset and the correct consequence classification of such failures. Without proper classification there exists the possibility that certain failures of an asset are not accounted for, leading to potentially disastrous unexpected failures. Equipment with safety-related failures is especially important and failures must not be missed.

For this reason Bloom (2006: 32) distinguished three important methods of failure identification and classification:

1. Single failure analysis: For a given asset or equipment, single-failure mode is said to occur when the failure is known and can easily be identified. Such a failure can be identified by maintenance or production personnel via alarms or control messages and indications and in most cases has a direct operational or business impact. One must ascertain that a single failure is acceptable in such a case.

2. Hidden failures: These are cases where no obvious indication or warning of the failure is apparent to maintenance or production personnel, unlike the case of a single failure. It is of utmost importance to identify such hidden failure modes in order to eliminate any unforeseen failures.

3. Multiple failure analysis: This happens when a single failure mode remains hidden. Determine whether multiple failure analysis is required.

2.5 John Moubray's RCM approach

John Moubray developed RCM 2 based on the RCM model of Nowlan and Heap. He made it more applicable and presentable for industries other than the aviation industry. John Moubray became renowned for his contribution to the maintenance world, and his RCM model forms the basis of most RCM processes used today.

In his book *RCM 2* Moubray lists the seven basic questions upon which the RCM process is based:

1. For a given asset or equipment in a facility, what are the functions and the required standard of performance required?

2. How does this asset or piece of equipment fail to operate within its required function or performance?

3. What causes these failures (also known as functional failures)?

4. What are the consequences of a functional failure of the asset?

5. In what way do the failure of an asset and its consequences matter – what effect does it have on the operations of the facility?

6. What measures can be taken to predict and prevent the failures?

7. What actions should be taken if no suitable PM (Preventative Maintenance) task can be identified?

The process of critically analysing these questions should very efficiently determine how to maintain an asset in the best possible and most economical way possible. Section 2.5.1 will elaborate on this RCM process.

2.5.1 John Moubray's RCM implementation process

Moubray in his book *RCM 2* developed a basic chronological process that could be used to implement the RCM process at any facility. The following sections discuss this step-by-step process and the basic requirements of each step. According to Moubray (1997: 18) the following can be achieved when his RCM process is successfully implemented and maintained:

- **"Greater safety and environmental integrity;**
- **Improved operating performance (output, product quality and customer service);**
- **Greater maintenance cost effectiveness;**
- **Longer useful life of expensive items;**
- **Comprehensive database;**
- **Greater motivation of individuals;**
- **Better teamwork."**

The first step is to analyse the facility's assets and maintenance requirements.

2.5.1.1 List of facility assets/equipment

Moubray (1997: 16) recommends that with any RCM project the first step is to analyse the plant equipment. In order to start evaluating the asset maintenance requirements of a facility, a well-structured plant equipment register is required. This will enable the RCM team to identify the different assets, requirements and functions of that asset within the system. In many cases a facility has hundreds of thousands of different pieces of equipment operating at different places in the plant and used for different functions. Keeping a logical and systematic list of the equipment will help to keep track of all the equipment in the plant.

The purpose of this plant register is also to link this asset, within its equipment structure, to its required information such as manufacturer information, drawings, manuals, maintenance tasks and schedules.

The plant register will usually be structured as follows:

1. Plant
1.1 Operating unit
1.1.1 Operating area
1.1.1.1 System
1.1.1.1.1 Subsystem
1.1.1.1.1.1 Equipment
1.1.1.1.1.1.1 Component

By making use of such an equipment register, each equipment item in the plant can be identified and traced, which makes the identification of the equipment and its function much easier in the RCM process. By using this method, any particular item or component can easily be tracked amongst thousands of other components. One example of such a system is SAP PM (Plant Maintenance Module) where all the equipment of a facility is listed in a functional location structure.

2.5.1.2 Planning, preparation and assembly of RCM team

Moubray (1997: 16) encourages the development of various RCM groups for the implementation process. The group he prefers consists of the following members:

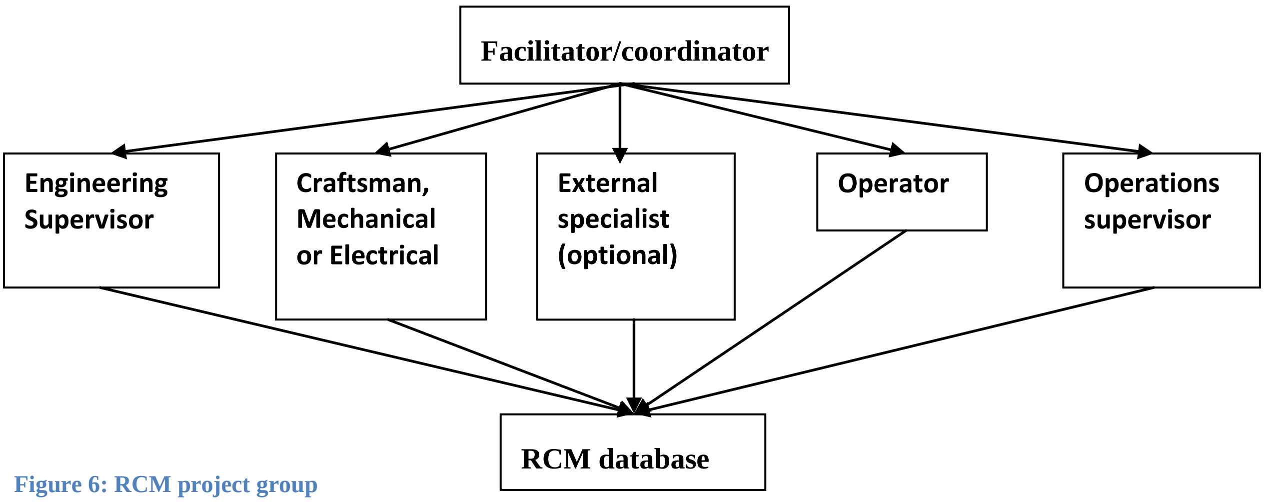


Figure 6: RCM project group

The purpose of the facilitator is to assemble his team and to guide the development of the process. It is thus critical that he should have extensive knowledge and, preferably, experience of the RCM process.

He must also ensure that quality and completeness are achieved. The facilitator can decide on the size of his group, depending on the size of the system being analysed.

The rest of the team consists of members with the knowledge of and experience with the equipment and its operations. This will ensure that the technical properties of the asset as well as its functions, functional failures, consequences and appropriate PM tasks are identified. It is also these team members who will give continuous feedback into the RCM system or data base to ensure improvements and efficiency of the process.

2.5.1.3 Failure Mode, Effect & Criticality Analysis (FMECA)

The Failure Mode, Effect & Criticality Analysis is a systematic analysis method used to determine, for the equipment being analysed, its function, the way it can fail and the consequence of this failure. Below is an example of such a FMECA work sheet developed from Moubray's (1997: 89) FMECA worksheet:

System: ACCU (Air Cooled Condenser Unit)							
Component: Recirculation pump							
FMECA Number: 1.3.6							
Team Members: Heinrich, Shaun, Carel, Evo, Ayanda, Micheal							
Control number	**Function**	**Functional Failure (loss of function)**	**Failure mode (Cause of failure)**	**Failure effect (what happens when it fails)**	**Criticality (how severe is the effect)**	**Probability (how likely will this failure occur)**	**Remarks**
1	To pump condensate back to boiler stage	A. Unable to pump condensat	1. Motor failure	Pump will not be driven, no rotation of centrifugal pump. Thus no water flow. Motor failure could be due to electrical problems, poor connections, worn out brushes, failed bearings, rotor or field problems, broken	4	4	Do frequent condition monitoring and visual inspections
			2. Coupling failure	No transfer of rotational force from motor to pump. Pump not able to transfer water via centrifugal forces. This could be due to wear, misalignment, no grease, broken shaft, broken key, worn out keyway, total coupling failure.	4	4	Do frequent condition monitoring and visual inspections
			3. Pump failure	In case of pump failure the condensate could not be transferred and thus will no circulation take place. This could be due to casing cracks, bearing failure, shaft damage, seizure, impeller damage, mechanically stuck.	4	4	Do frequent condition monitoring
		B. Unable to produce required flow rate	1. Insufficient electrical supply	Power supply voltage or current problems can lead to insufficient motor efficiency thus reducing the work performed and thus the flow rate of the pump	3	4	
			2. Motor bearing failure	Failure of motor bearings can lead to power losses for the pump that implicated a reduced water flow by the pump. This could be due to age or absence of proper	3	4	Do frequent condition monitoring
			3. Pump failure	Systematic pump failure will lead to reduced work output by the pump, reducing the flow rate for the pump. This could be failing bearings, impeller failure, cavitations etc.	3	4	Do frequent condition monitoring

Figure 7: FMECA example

In order to determine the criticality and probability of a failure, a criticality and probability list should be used. This list consists of certain requirements or rules as specified by the plant. It normally has a severity ranking with corresponding effects, and a description of the events that lead to this effect. Below an example of a criticality/severity and probability matrix:

Criticality/severity categories		
Ranking	Effect	Comment
1	None	No reason toe expect failure to have any effect on safety, health, environment or mission
2	Very low	Minor disruption to facility function. Repair to failure can be accomplished during trouble call
3	Low	Minor disruption to facility function. Repair to failure could be longer than trouble call but does not delay mission
4	Low to moderate	Moderate disruption to facility function. Some portion of mission may need to be reworked or process delayed
5	Moderate	Moderate disruption to facility function. 100% of mission may need to be reworked or process delayed
6	Moderate to high	Moderate disruption to facility function. Some portion of mission is lost. Moderate delay in restoring function
7	High	High disruption to facility to facility function. Some portion of mission is lost. Significant delay in restoring function
8	Very high	High disruption to facility function. All of the mission is lost. Significant delay in restoring function
9	Hazard	Potential safety, health or Environment issue. Failure will occur with warning
10	Hazard	Potential safety, health or environment issue. Failure will occur without warning

Probability of occurrence categories		
Ranking	Effect	Comment
1	1/5000	Remote probability of occurrence; Unreasonable to expect failure to occur
2	1/5000	Low failure rate. Similar to past design that has, in the past, had low failure rates for given volume. Load
3	1/2000	Low failure rate. Similar to past design that has, in the past, had low failure rates for given volume. Load
4	1/1000	Occasional failure rate. Similar to past design that has, in the past, had occasional failure rates rates for given volume/loads
5	1/500	Moderate failure rate. Similar to past design that has, in the past, had moderate failure rates for given volume/loads
6	1/200	moderate to high failure rate. Similar to past design that has, in the past, had moderate failure rates for given volume/load
7	1/100	High failure rate. Similar to past design that has, in the past, had failure rates that has caused problems
8	1/50	High failure rate. Similar to past design that has, in the past, had high failure rates that has caused problems
9	1/020	Very high failure rate. Almost certain to cause problems
10	1/010	Very high failure rate. Almost certain to cause problems

Figure 8: Criticality/severity and probability categories

The FMECA process described here should be applied to all the identified equipment in a facility, to get an overall view of the equipment, failures, failure modes, effects and criticality of the facility. From there, the required relevant maintenance tasks can be identified using the RCM decision worksheet.

2.5.1.4 Failure consequences

Identifying the consequences of certain equipment failure will help to determine what PM tasks should be taken in order to eliminate or mitigate the effect of such a failure. Moubray (1997: 93) classifies the following categories of failure consequences:

1. Safety and environmental consequences: A failure is considered to have safety consequences when the failure has the potential to lead to injuries or a fatality. Environmental consequences arise when a failure leads to the breach of any relevant environmental law or standard at the facility.

2. Operational consequences: An operational consequence directly influences the production elements such as quality, customer service, plant utilization, operational cost etc.

3. Non-operational consequences: This type of failure has no effect classifiable as an environmental or production consequence. It normally implies direct cost of repairs.

2.5.1.5 Maintenance tasks

The list below outlines the possible maintenance tasks used in the RCM process:

Predictive testing (Condition monitoring): This maintenance approach is used to measure the actual condition of the asset at a certain time. These inspections or measurements could be at random or on a scheduled basis. This allows for optimal asset utilization since the asset discard or restoration can be done nearer to the point of expected functional failure.

Preventative maintenance (Schedule restoration or discard): In this maintenance approach the asset is restored or replaced on a certain time and frequency schedule regardless of its actual condition or performance.

Failure finding: This is a process where failures are identified and corrective maintenance tasks are used to eliminate or mitigate the consequence of the equipment failure. In many cases this is achieved by the RCA (Root Cause Analysis) method where the exact point of failure is identified. From there the correct maintenance task will be enforced to ensure that the same failure does not happen again.

Redesign: Failure modes of certain equipment can be eliminated by changing the design.

Run to failure: If there are no proactive or reactive tasks to be done and there are no expected consequences, the asset can be Run To Failure.

2.5.1.6 RCM decision worksheet

After the FMECA is completed for an asset and the consequences have been identified, the next step in John Moubray's approach to RCM is to complete the RCM decision worksheet. This worksheet is used in conjunction with an RCM decision diagram (Moubray 1997: 200), which will lead the analyser to the correct consequence of failure and the most appropriate PM task to be used. Below is an example of such an RCM worksheet:

Example taken from article by Clarke and Young (2011).

RCM II DECISION WORKSHEET © 1994 Aladon Ltd	SYSTEM	*Southwest water reticulation system*	No.	Compiled by TAP	Date 04-Jul-05	Sheet 1
	SUB SYSTEM	*North East Pipeline*	Ref. AC Pipeline	Reviewed by MCW	Date	Of 1

Information reference			Consequence evaluation				H1 S1 O1 N1	H2 S2 O2 N2	H3 S2 O2 N2	Default tasks			Proposed Task	Initial Interval	Can be done by
F	FF	FM	H	S	E	O				H4	H5	S4			
1	A	1	Y	N	N	Y	N	N	N				NSM A response to leak within 2 hours will minimize occurrences	Per event	Response Grp
1	A	2	Y	N	N	Y	Y						Monitor pipe condition during maintenance work and replace as necessary	Per event	Response Grp
1	A	3	Y	N	N	Y	N	N	N				Redesign. Correct installation and modification to appropriate standards at the time of load changes		Site Controller
1	A	4	Y	N	N	Y	Y						Monitor the condition of the pipeline and replace whole pipeline when incidents of fatigue failure increase by more than 10% in any year	1 year	Construction
1	A	5	Y	N	N	Y	N	N	N				Redesign. Respond to incidents as they occur. Educate other utilities to obtain service locations		Response Grp
1	A	6	Y	N	N	Y	N	N	N				NSM. Respond to report of leak within 2 hours. Monitor the pipeline in that area. Maintain AC as priority replacement		
1	A	7	Y	N	N	Y	Y						Manage stress affecting pipeline	1 year	Site Controller
1	A	8	Y	N	N	Y	N	N	N				No known failures		
1	A	9	Y	N	N	Y	N	N	N				No known failures		
1	A	10	Y	N	N	Y	N	N	N				Correct repair in accordance with procedure 2735 will prevent failure		
1	A	11	Y	N	N	Y	N	N	N				Redesign. Provide training on the correct operation of the system by operators, contractors and other utilities		
1	A	12	Y	N	N	Y	N	N	N				NSM		
1	B	1	Y	Y			Y						Monitor system water for asbestos and raise WO for pipeline replacement when level rises by more than 3% in a year	1 Year	Technician
1	B	2	Y	N	N	Y	N	Y					Test water for algae and flush as required	2 weeks	Response Grp

Figure 9: RCM decision worksheet (P. Clarke, S Young, 2011)

In the "Information reference" column the assets are listed as identified in the FMECA by its F (Function), FF (Functional Failure) and FM (Failure Mode). Then the worksheet gives the option of doing a consequence evaluation:

H- Will the loss of function caused by the failure be evident to the operating crew under normal conditions?

S- Does the failure cause a loss of function or other damage that can lead to injury or a fatality?

E- Does the failure cause a failure or loss of function that can lead to a breach of environmental standards or legislation?

O- Does the failure have a direct effect on operability?

From the RCM decision diagram the Yes or No answer will then lead to the sub-consequences, H1-5, S1-4, O1-3 and N1-3. This RCM logic diagram as developed by John Moubray is included in Appendix A.

From here, the proposed maintenance task can be determined. These tasks will then be scheduled to be performed or executed at a certain time or frequency. Maintenance personnel of a certain trade will also be allocated to ensure the tasks are executed correctly.

2.6 Neil Bloom's RCM approach

Neil Bloom in his book (Bloom 2006) explains the pitfalls of the traditional RCM processes as developed by Nowlan & Heap (1978) and Moubray (1997). He also explains why it has always been difficult to implement the traditional RCM process and why this process has such a high implementation failure rate.

He developed his version of the RCM process based on the original RCM principles but focusing on the simplified implementation of the process, in order to make RCM more successful and sustainable.

Bloom (2006: 30) identified three basic phases for an RCM-based Preventative Maintenance program, closely related to John Moubray's version as discussed in the previous section. These three phases are:

Phase 1: Identification of the plant or facility's assets/equipment. These include equipment that is important for safety, production, asset protection etc.

Phase 2: In this phase the cause of equipment failure, the consequences of a failure and the corrective actions should be determined. PM (Preventative Maintenance) tasks should be identified in order to improve the reliability of the asset.

Phase 3: In the final phase proper execution of the PM tasks identified in Phase 2 should take place. It is important that the tasks should be executed by the correct person at the correct time, to ensure the best possible asset maintenance.

Bloom's version of the RCM process then looks as follows.

2.6.1 Classify assets/equipment

As mentioned above, the first phase is to identify all the equipment of a plant and then classify it according to a certain set of criteria. The following are the criteria used by Bloom (2006: 34):

1. **Critical**
   An asset or component is considered critical when its failure becomes immediately apparent and can be detected by plant personnel such as operators or maintenance personnel. Such failures could give immediate indications in the control room and have immediate unwanted plant or operations consequences.
2. **Potentially critical:**
   In this case the asset or component is one whose immediate failure is not apparent, nor does it pose an immediate risk by being critical, but it could become critical under certain defined circumstances.
3. **Commitment:**

A facility can have certain environmental, safety, insurance etc. commitments and thus certain assets must be maintained to ensure that these commitments are not missed and do not lead to certain legislative and financial consequences.

4. **Economic:**

   An economic component is classified as a component whose failure does not have any plant safety or operability consequences, but involves costs such as labour and parts replacement.

5. **Run to failure (RTF):**

   Failure of an RTF component does not have any critical, potentially critical, commitment or economic consequences.

2.6.2 Assemble an RCM team

Bloom (2006: 90) recommends that a RCM team should be assembled that consists of a SPOC (Single Point Of Contact) who will champion the team. The champion will also act as coordinator and will provide leadership for the RCM team. In this team there should be representatives from operations, maintenance and engineering.

It is required that all members of the RCM team should have a basic knowledge and understanding of the RCM process and principles, as well as the process for RCM implementation made simple. Each member should understand the basics of the COFA worksheet and the selection of maintenance tasks.

2.6.3 Obtain equipment data base

As with any other maintenance system, it is required of a facility to have a well-structured database of all the plant equipment. This provides the asset's or component's ID number and thus locates it to a physical position in the plant. Here all the relevant asset information can be linked to it. It also makes it possible to do scheduling from each component's ID number. A CMMS (Computerised Maintenance Management System) is capable of structuring a plant's assets on a data base, making it easy to access and manage.

2.6.4 Identify information resources

Apart from the component ID number, additional component information is required. This information can be: maintenance operations and standards, procedures, manuals, drawings, schematics etc. All available information should be used in the RCM process to ensure that the plant equipment is fully defined and all possible failure modes and consequences are identified.

2.6.5 Do COFA (Consequence Of Failure Analysis)

The COFA is an alternative to a FMECA, developed by Neil Bloom. Unlike the FMECA approach for the classical RCM, which focuses on the system and subsystems, the COFA focuses on the component level only. The figure below illustrates an example of a COFA as developed Bloom (2006: 97)

Component ID and description	What are the functions of the component	How can each function fail	Identify the dominant failure mode for each functional failure	Is the occurrence of the failure mode evident? Use COFA logic tree	System effect of each failure mode	Describe consequence of failure based on asset reliability criteria specified (determined by the COFA logic tree and the PC & ES guidelines	Define component classification

Figure 10: COFA example (Bloom, NB, 2006)

The COFA logic tree used in conjunction with the COFA is given below. The COFA logic tree was developed by Bloom (2006: 113).

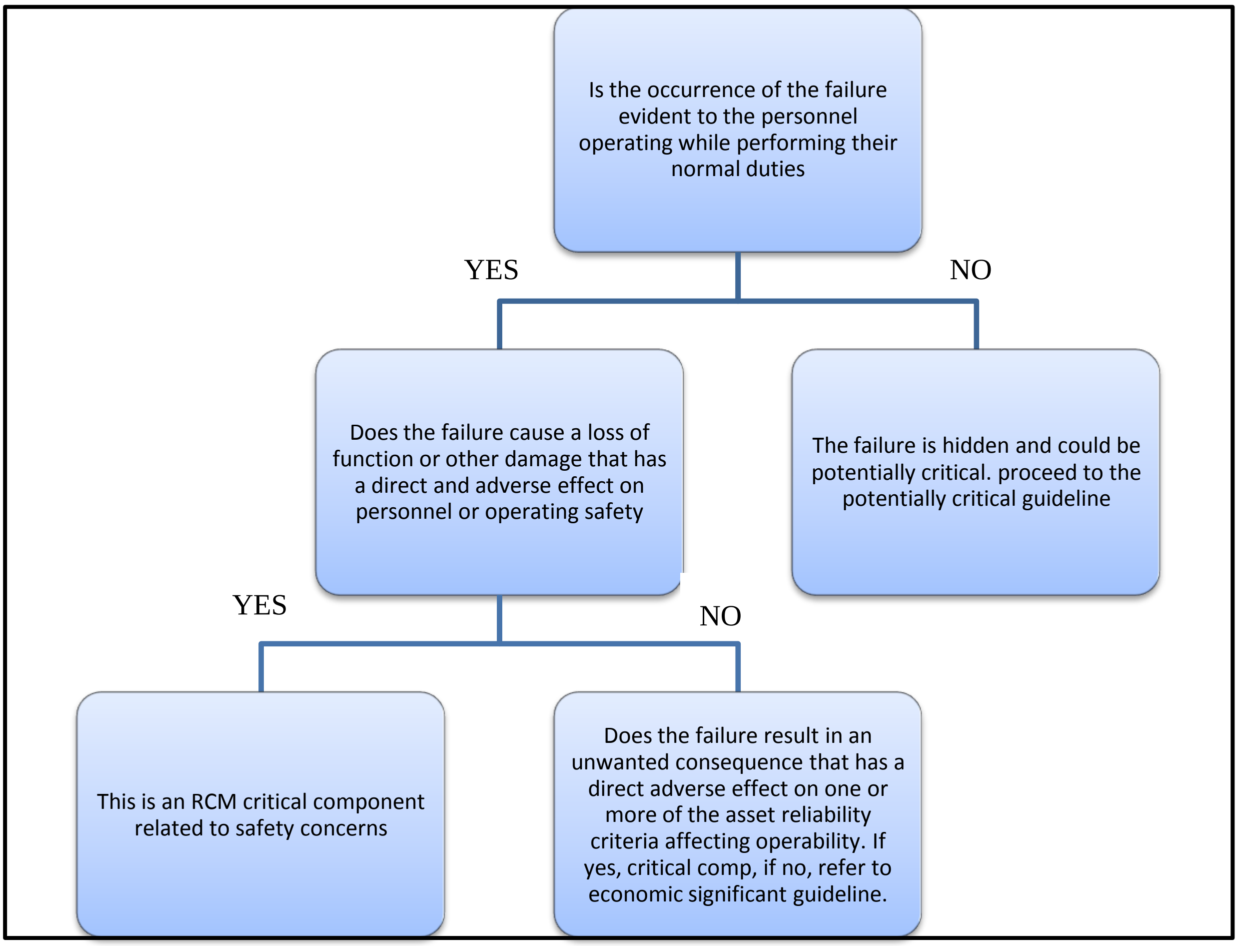


Figure 11: COFA logic tree (Bloom, NB, 2006)

In the COFA logic tree reference is made to a “potentially critical and economical significant guideline”. This guideline can be found in Bloom (2006:114). Basically it distinguishes between failures that have an effect on equipment reliability, and equipment failures with economic implications. The economical evaluation worksheet can be found in Appendix C. If there are no other implications after considering the potentially critical and economical aspect, the asset can be considered for RTF (Run To Failure).

2.6.6 Compile PM task worksheet

After completing the COFA, a PM worksheet must be completed to determine which maintenance tasks will be executed for the asset. The PM worksheet is only used for equipment classified as critical, potentially critical, committed or economic. Below is an example of a PM worksheet as developed by Bloom (2006: 101).

Note: The PM worksheet is only applicable for those components classified as being either critical, potentially critical committed or economic						
Component identification (from COFA)	**What are the consequences of the failure (from COFA)**	**Describe each dominant failure mode (FROM the COFA)**	**Describe the credible failure cause for each dominant failure mode**	**Describe the applicable and effective PM tasks for each failure cause (from PM task logic tree)**	**Define the freq. And interval for each OM task (from PM task logic tree)**	**Is a design change recommended?**

Figure 12: PM worksheet (Bloom, NB, 2006)

The PM logic tree is included in Appendix B

2.6.7 Complete the Economic Evaluation Worksheet

As mentioned before, economical failure consequences have no impact on safety or operations. In order to determine the cost implications of economical failure consequences, an economic evaluation sheet can be used. An example of this evaluation sheet (Bloom 2006: 104) is given in Appendix C. Some of the economical evaluation elements are:

PM maintenance / Run To Failure costs

- Labour worker-hour costs
- Maintenance material cost

- Miscellaneous costs

2.6.8 Select maintenance task

The selection of maintenance tasks is part of Phase 2 of the process as described in Section 2.6. These maintenance tasks are then used to address the failures identified in Phase 1 of the process. Maintenance tasks are typically identified for equipment that is classified as critical, potentially critical, committed or economic.

Neil Bloom refers to the following PM maintenance types (all the maintenance tasks will fall under one of these categories):

1. **Condition direct:** These are also known as condition monitoring where the physical condition of the component is inspected, measured or monitored. Predictive testing such as vibration monitoring, oil sampling etc. is used in this process.
2. **Time direct:** Tasks such as replacements, overhauls and restoration of components at a certain time or interval.
3. **Failure finding:** Failure finding is a strategy used to determine whether a component has already failed so that the failed component can be detected before it results in a plant consequence or failure.

When the PM task worksheet is being filled in, the PM task selection logic tree can be used to follow the logic behind the task selection process, in order to select the most appropriate maintenance task. An example of this PM task selection logic tree in included in Appendix B.

2.7 General RCM process and basic elements

From the two RCM approaches, Moubray's (1997) and Bloom's (2006) approach, the following basic RCM process can be developed. Although each author has his own equipment analysis method, the very basics of the RCM process stay the same. Consider the following summary of the RCM process.

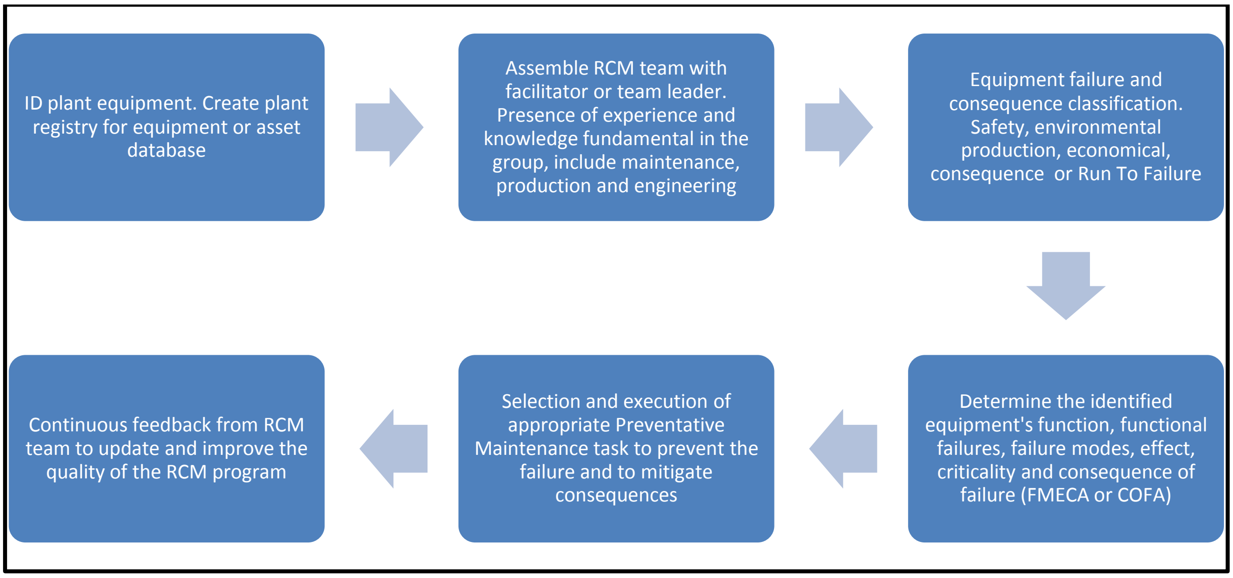


Figure 13: RCM implementation process flow

The above RCM cycle or sequence of events creates a logical process that can be used for all RCM implementation processes. In many cases the user of the RCM process can make slight modifications or adjustments to fit with the plant operational and maintenance requirements. However, in the case where RCM is being implemented, it is advised to stick to the already defined steps. Some modifications and improvement in the RCM process will be discussed later in this chapter.

2.8 Why is the traditional RCM process so difficult to implement?

The universal reasons for RCM implementation failure is that it is a resource-intensive process, it is very expensive, long implementation period, too complicated and the period of time before any results are shown takes too long. According to Bloom (2006: 18) there are several other reasons for RCM implementation failure:

1. Plant does not have full control over process. This happens when a plant outsources the entire project or implementation process to an outside company. The problem with this approach is that the consultant does not have the necessary experience and knowledge of plant equipment, operations and processes. This can lead to incomplete analyses, making the system vulnerable to failures. This also poses the risk that after implementation, the process is not sustained because the plant personnel did not have control over the process and the content of the program.

2. Ineffective RCM team. It is critical that the correct combination of knowledge and skills be combined within the group. It is also critical to ensure that personnel from all disciplines buy into the RCM process and the implementation strategy thereof. Thus is it necessary for maintenance, production and engineering to have consensus and work together to the same goal. Failing to do so will result in poor ownership of the plant personnel and will most likely result in poor maintenance of the system and ultimately in failure of the program.

3. High cost due to prolonged process. Many RCM programs take longer than they should, due to difficult and complicated decision processes such as boundaries for systems, failure analysis and prioritization of assets and tasks. The longer the process takes, the higher its costs.

4. Misunderstanding fundamental RCM concepts. It is very important that when an RCM process is started, all role players should understand the basics of an RCM program. Facilitators should ensure that the RCM rules are followed and executed correctly.

5. Incorrect system function identification. When a large system is considered with many subsystems, it is easy to get confused in identifying system functions and functional failures. This is done to eventually get to the component function and functional failure. This can waste a lot of time and resources and can be eliminated by directly considering the analysis on component level.

6. System boundary and interfaces. To determine the boundaries and interfaces of a system with many subsystems can be time-consuming and confusing. This contributes to longer analysis time and thus analysis cost.

7. Expectation differences between management. Different expectations amongst management could lead to missed targets and reduced efficiency of the process.

8. Analysis convention confusion. Ambiguity in defining equipment, functions, functional failures etc. can lead to confusion, slowing down the process and increasing the project costs. The RCM team should have consensus regarding the methods used for the analysis.

9. Negligence regarding hidden failures and redundancy. It is critical that the concepts of hidden failures and redundancy are understood and that such systems are correctly identified and analysed to ensure all equipment, even the less obvious equipment, is fully defined and accounted for.

10. Wrong application and use of RTF (Run To Failure): In many facilities the use of RTF is misunderstood and certain critical or potentially critical equipment with economical failure consequences are maintained on a RTF basis. This can prove to be highly ineffective and can contribute to large unexpected maintenance costs.

11. Incorrect or poor component classification. Merely classifying components as critical or noncritical is not effective enough. This will lead to ineffective Preventative Maintenance task selection and scheduling requirements of the component.

Bloom (2006: 141) also warns against using streamlined versions of the RCM process. He reckons that these methods induce additional vulnerabilities to the plant, possibly with critical or even fatal consequences. Ideally the RCM process in its full should be used to ensure a complete and comprehensive analysis of all plant equipment.

2.9 Previous research on the RCM process

There are many articles and other research work covering research on RCM. For the purpose of this dissertation, three studies will be considered. One will illustrate the possible advantages of successfully implementing the RCM process, and the other two will illustrate some of the proposed developments and improvements on the RCM process.

2.9.1 Successful RCM implementation example

Yssaad, Khiat & Chaker (2013) used the traditional RCM method to improve on the maintenance strategy for an electrical distribution station in the region of Relizane North West of Algeria. The basic RCM process they followed is illustrated in the flow diagram below.

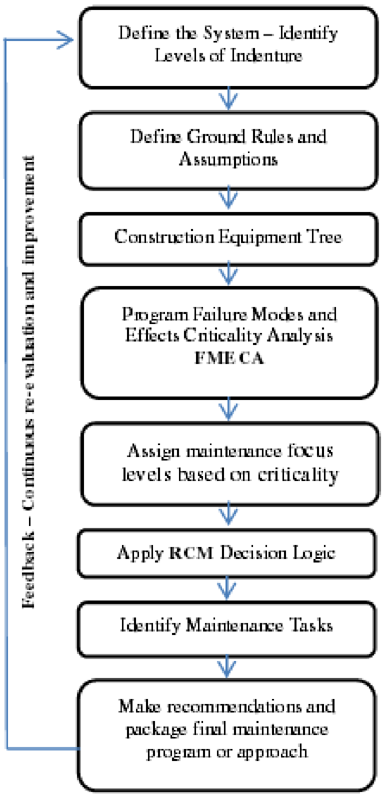
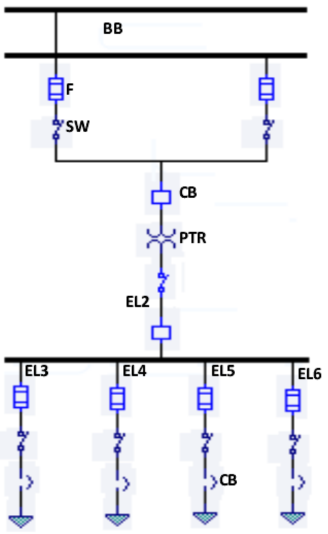


Figure 14: RCM process (B. Yssaad, M. Khiat, A. Chaker, 2013)

From the process illustrated in Figure 14 above, one can see two of the main elements of the traditional RCM process. The first is the use of the FMECA process, and the second is the RCM decision logic diagram from which the decisions on the appropriate maintenance actions are identified. With this process the researchers managed to identify all the equipment in the system, find the failure modes, effects and criticality of equipment failure, enabling them to identify the required maintenance actions for each component. Consider the schematic diagram of the system they analysed:



- EFS – Electrical Feeder System
- BB – Bus Bar
- F – fuse
- SW – Switch
- CB – Circuit Breaker
- PTR – Power transformer
- EL – Electrical line

Figure 15: Electric Feeder System, EFS (B. Yssaad, M. Khiat, A. Chaker. 2013)

The RCM process was developed and simulated on a small electrical distribution system, referred to as an Electric Feeder system (EFS), shown in Figure 15. The system consists of only basic electrical elements such as electrical lines, circuit breakers, switches, bus bars, power transformers, fuses and a sectionalizer. Clearly this is a small subdivision of equipment in a much larger system and cannot really represent a big plant in its entirety. However, the simulated results obtained from this smaller sample of study yielded promising results. Consider the results below as taken from the article.

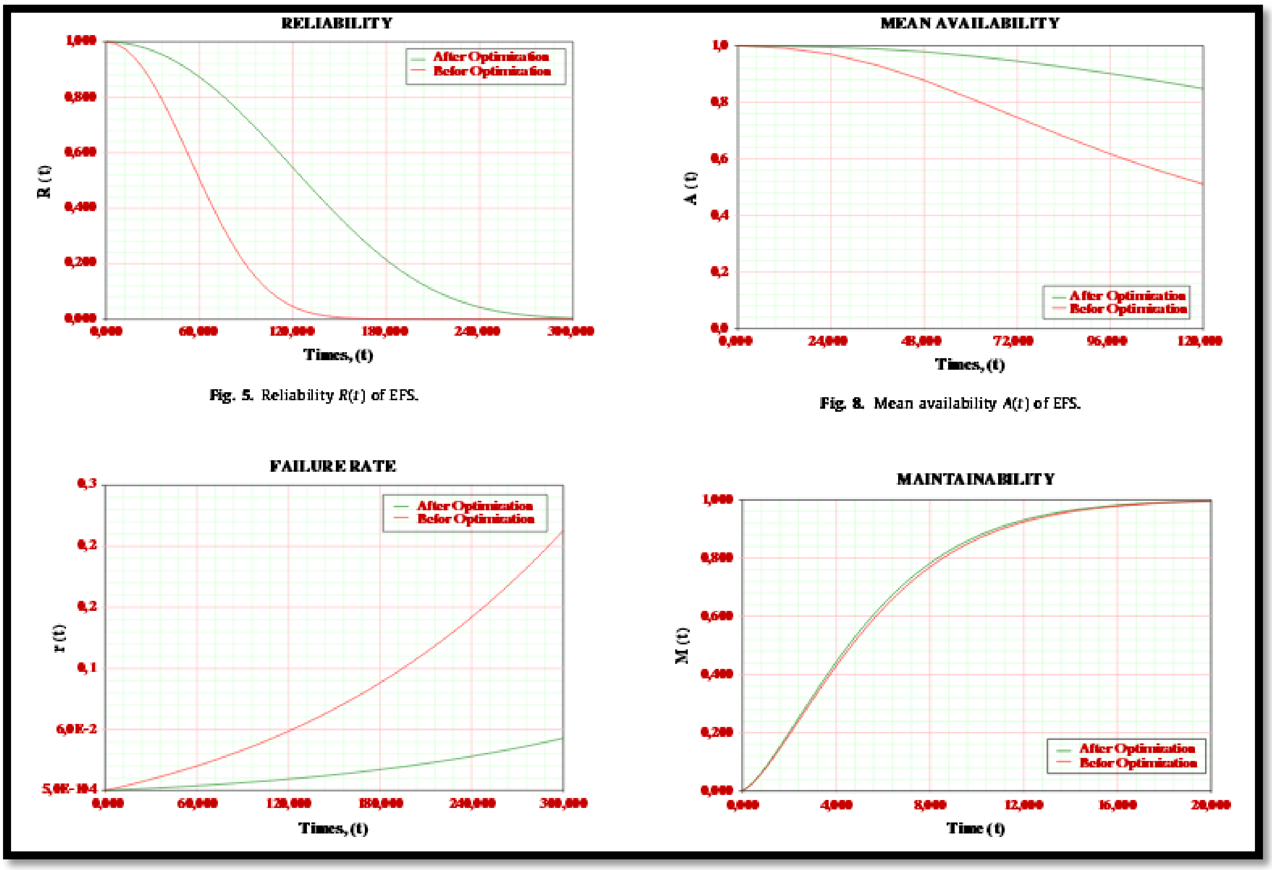


Figure 16: Simulation results (B. Yssaad, M. Khiat, A. Chaker. 2013)

One should note that these results are only simulated results developed from sample data obtained from other similar plants and certain calculated assumptions made by the researchers. However, the results give a good indication of the potential improvements in the system stability over a period of 120 months by considering the delayed reduction in reliability, availability, failure rate and maintainability. The researchers estimated quite a significant cost saving over a period of 120 months by implementing the RCM model they developed, as shown in Figure 17:

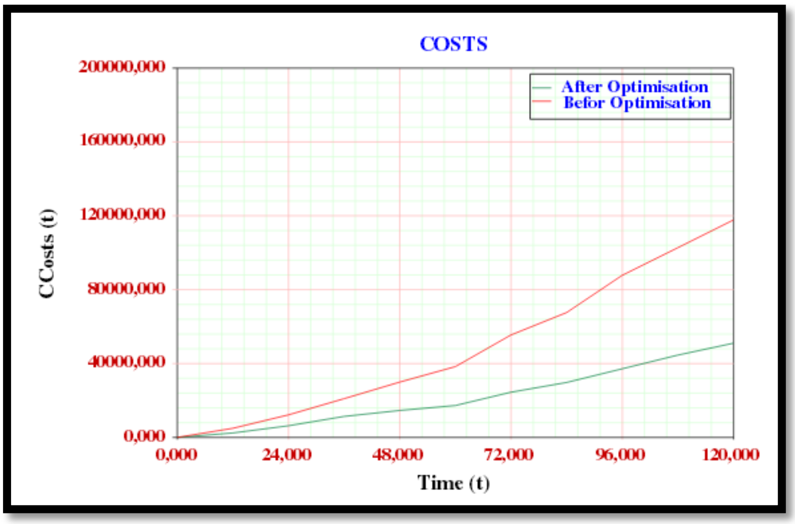


Figure 17: RCM process forecasted savings (B. Yssaad, M. Khiat, A. Chaker. 2013)

The results obtained in the above-discussed article are not surprising since the RCM process has been developed over many years to be a very effective maintenance process. However, the researchers have only considered a small system with only a couple of components. For such a system it is relatively easy to complete the RCM process. The results might differ for a larger system or even a plant in its entirety.

2.9.2 RCM development/improvement

The RCM process has seen many changes and proposed improvements over the years, mostly by maintenance practitioners who used RCM and then identified certain shortcomings and flaws in the process. However, the basic principles stay the same. The RCM process of John Moubray and Neil Bloom at the start of Chapter 2 contains improvements on the original RCM 1 process, but still follows the original basic RCM principles. In this section two proposed improvements on the original RCM / RCM 2 process will be considered to illustrate the past development and improvement work on the RCM process.

2.9.2.1 Modelling of uncertainties in RCM model

Eisinger & Rakowsky (2000) wrote a paper on the idea of a probabilistic approach to reliability centered maintenance. The concept was developed when they realised that there exists certain circumstances at which one cannot just simply choose Yes or No when it comes to the RCM decision-making diagram. In many cases the selection of only Yes or No will lead to inaccurate maintenance actions for want of more realistic decisions.

With their approach, the user is able to give an indication of the extent to which he/she agrees with the decision diagram questions in terms of percentages. The researchers developed a mathematical model with which one could determine the uncertainty regarding the decision being made. This basically implies that if the user agrees only 70 % with the statement in the decision diagram question, there exists a certain uncertainty regarding the flow of decisions in the decision diagram sequence of questions. Allowing the user to follow this approach throughout the entire decision diagram will lead to a final maintenance task selection but with a certain uncertainty.

Using the prescribed formula derived by the researchers, this uncertainty can be calculated. Should the uncertainty be more than one the maintenance strategy should be considered as undetermined. In such a case the maintenance approach should be reconsidered, or the corrective action should be redesigned. Should the uncertainty be less than one, the maintenance strategy selected is well determined and the probabilistic approach is not really required.

The user is able to decide on the decision diagram to be used. It will be different according to the type of industry, equipment type, operational and maintenance requirements. The user is then able to apply the probabilistic approach to the selected decision diagram in order to determine the uncertainties in the task selection process. Below is an example taken from Eisinger and Rakowsky (2000):

Unit	Function	Significant cons. p_1	Other reasons p_2	First line p_3	First line alone p_4	Detectability p_5	Testability p_6	Condition based meth. p_7	Increasing failure rate p_8	Comment	Periodic test r_1	Scheduled m. r_2	Find a better design r_3	Condition based m. r_4	First line m. r_5	Corrective m. r_6	Uncertainty s_r
Detectors	Detect smoke	80 %	50 %	70 %	30 %	0 %	70 %	20 %	90 %	**6**: False alarms difficult. Threshold for alarm. **7**: Sensitivity may be monitored **8**: Due to dust (and/or battery-wearout)	50 %	19 %	2 %	0 %	19 %	10 %	1.5
Manual actuation	Send manual alarm to voter	70 %	50 %	70 %	30 %	0 %	50 %	0 %	0 %	**5**: It is unknown whether personnel is available. **6**: Damaged by test (system dependent)	34 %	0 %	34 %	0 %	18 %	15 %	1.6
Voter	Vote input signals and send alarm if required	100 %	0 %	0 %	0 %	5 %	95 %	0 %	0 %	**5**: Power supply self-detectable. **8**: Maybe even DFR	90 %	0 %	10 %	0 %	0 %	0 %	0.8
Alarm to fire brigade	Send alarm to fire brigade	90 %	70 %	0 %	0 %	0 %	95 %	0 %	0 %	**2**: Confinement of smoke- and water destructions. **6**: Telephone lines must be relied on. **7**: But: self-test should be possible to implement.	92 %	0 %	5 %	0 %	0 %	3 %	0.7
Alarm bell	Alarm for humans in building	90 %	70 %	70 %	30 %	0 %	100 %	0 %	20 %	**2**: Secondary alarm from humans possible.	77 %	0 %	0 %	0 %	20 %	3 %	1.1
Activation	Open main valve if fire detected	100 %	0 %	70 %	30 %	0 %	0 %	0 %	70 %	**6**: Within Norwegian systems there are no test-valves which makes testing impossible.	0 %	55 %	24 %	0 %	21 %	0 %	1.4
Sprinkler	Sprinkle fire if temperature is over set-point	40 %	70 %	70 %	30 %	0 %	0 %	0 %	50 %	**2**: Increased fire- smoke- and water distruction because of late extingushing. **3**: Only visual checks possible. **6**: Test destructive. Visual check by 'first line'. **8**: Pipe-korrosion of old systems.	0 %	32 %	32 %	0 %	17 %	18 %	1.6

All operational modes are standby modes.
Two failure modes for all components: no detection and false alarm

Figure 18: Probabilistic decision diagram (S. Eisinger, U.K. Rakowsky, 2000)

Eisinger and Rakowsky reckon that this approach has the following advantages:

- Analyst or system specialist will be able to be more comfortable with a more accurate answer on the decision diagram and task selection process.
- In the case where more than one maintenance approach is applicable, the probabilistic approach will help to identify the most suitable approach or strategy.
- The probabilistic approach is also useful in helping to identify possible design problems and their causes. This in turn can help to develop or redesign the equipment.
- Standard computer software can be used for determining the uncertainties, making it easier to implement the extra step additional to the existing RCM method and processes.

This probabilistic approach will be helpful in the case of maintenance selection processes where the user or analyst is not able to directly make a clear-cut decision, YES or NO. However, the additional steps and calculation can contribute to the already long and time-consuming RCM process. Therefore, this process should be selectively used to prevent unnecessary extra work.

2.9.2.2 Reliability and Risk Centered Maintenance (RRCM)

J.T. Selvik and T. Aven in their article: "A framework for reliability and risk centered maintenance", propose another addition to the already existing RCM process. Selvik and Aven acknowledge the probabilistic approach as developed by Eisinger and Rakowsky in their paper on the idea of a probabilistic approach to reliability centered maintenance. However, they are of the opinion that there is still room for inadequate maintenance action selection due to uncertainties within the RCM process of FMECA's & decision logic diagrams and task selection choices.

Selvik and Aven refer to their approach as Reliability and Risk Centered Maintenance (RRCM) approach. In their RRCM approach they have used the standard RCM framework as basis for their work. They have not changed anything but only added extra steps to the standard process. This enables their approach to improve on the ability to identify the risks and uncertainties for a system being analysed. With these risks and uncertainties identified the results will be communicated to management in order to make more informed decisions taking a holistical view of the plant/system. Thus, Selvik and Aven's basic process flow looks as follows:

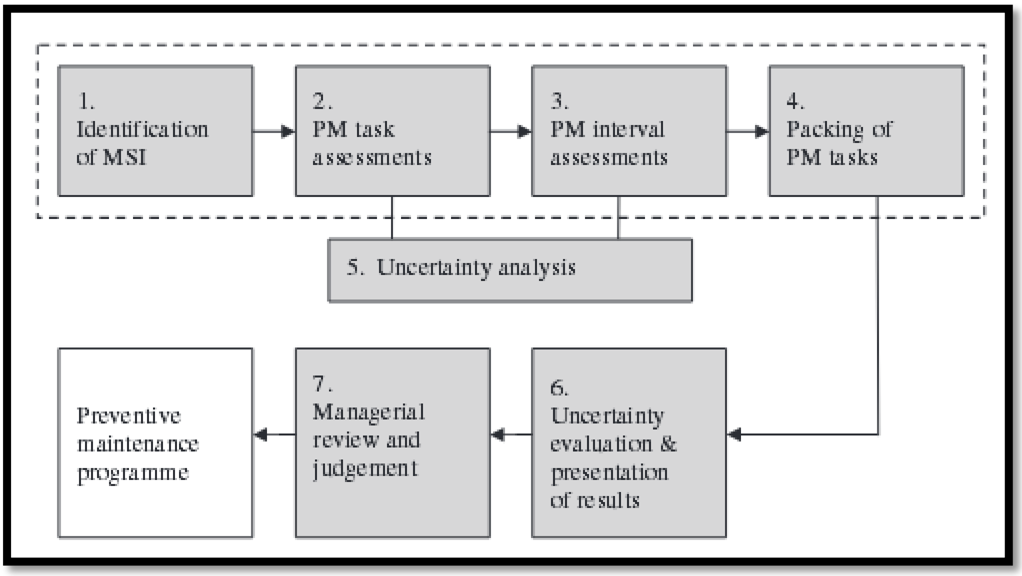


Figure 19: RRCM framework (J.T. Selvik, T. Aven, 2010)

Steps 1 to 4 in the above RRCM framework are the same as the basic framework for the standard RCM process. The difference comes in with the addition of step number five leading to step six and seven. The purpose of the uncertainty analysis in step five is to identify all the uncertainty factors within the RCM analysis and to assess and categorize the uncertainties with respect to the degree of uncertainties, degree of sensitivity and importance of uncertainty factors. Their proposal is just too simply add the uncertainty factors to the existing standard RCM FMECA worksheet (refer to Figure 7: FMECA example, for the standard FMECA template). The following proposed uncertainty factors can be added to the standard FMECA:

- Selected PM task as identified from the RCM logic decision diagram. (See Appendix A for RCM decision diagram example by John Moubray.)
- List all the identified and relevant uncertainties for the PM task assessments.
- Score all the uncertainties for the PM tasks using uncertainty, sensitivity and importance aspects in Table 1 below.
- Consider the sensitivity of the PM task recommendations by checking if the uncertainty factor has the potential to produce an alternative PM task to the one proposed.
- Determine the PM task intervals.
- Indicate the recommended PM interval as decided on from the PM interval analysis.
- Determine all the possible uncertainty factors regarding the PM interval assessment/selection.
- Score all the uncertainties for the PM tasks intervals using uncertainty, sensitivity and importance aspects in Table 1 below.
- Determine if there are uncertainty factors that are capable of changing the PM interval from the originally identified PM interval.

The above steps can simply be added to the FMECA and the results can be presented to the management team for processing and final decision making. The table below illustrates the uncertainty assessment score that can be used in such an analysis:

Table 1: Uncertainty assessment score interpretation (J.T. Selvik, T. Aven, 2010)

Aspect	Score	Interpretation
Uncertainty	Low (L)	One or more of the following conditions are met: • The assumptions made are seen as very reasonable. • Much reliable data are available. • There is broad agreement/consensus among experts. • The phenomena involved are well understood; the models used are known to give predictions with the required accuracy.
	Medium (M)	Conditions between those characterising low and high uncertainty.
	High (H)	One or more of the following conditions are met: • The assumptions made represent strong simplifications. • Data are not available, or are unreliable. • There is lack of agreement/consensus among experts. • The phenomena involved are not well understood; models are non-existent or known/believed to give poor predictions.
Sensitivity	L	Unrealistically large changes in base case values needed to bring about altered conclusions.
	M	Relatively large changes in base case values needed to bring about altered conclusions.
	H	Relatively small changes in base case values needed to bring about altered conclusions.
Importance	L, M or H	Average of the other two aspect scores.

Selvik and Aven in their article use the example shown below, a 20 km flow line with hydraulic valves, with uncertainty assessments:.

Table 2: Uncertainty assessment example (J.T. Selvik, T. Aven, 2010)

No.	Assumption	Degree of uncertainty	Degree of sensitivity	Degree of importance
1	Data selection criterion based on item size (inner diameter) and fluid type	M	M	M
2	Data are able to describe the items' failure characteristics	H	H	H
3	Mobilisation history found in database is representative	H	M	H/M
4	All of the other items are functioning	M	H	M
5	Only one failure occurs at the time / within a short time interval	L	M	L/M
6	Item failures are observed shortly after they occur	M	H	M/H
7	Regular pigging will prevent flowline blockage	L	H	M
8	Use of smart pig provides accurate sensor readings inside the flowline	M	M	M
9	Company and industry requirements are followed	L	L	L
10	Items are properly tested and inspected before and during installation	M	M	M

This addition to the RCM process should yield promising results due to the fact that the analysis will be more detailed and comprehensive. There is however one drawback to this approach and that is the additional work and thus more pressure on resources, especially on the analysis time. Users of this process should thus carefully select the equipment and the systems to be analysed by this approach.

2.9.3 Conclusion from other research projects

The research presented in Section 2.9.2 is merely a high-level illustration of the work done by the authors quoted. More information is obtainable form the actual published articles (see the reference list).

The simulated results of Section 2.9.1 indicated promising advantages of using the traditional RCM process. However, the simulation is a mere theoretical exercise yielding predicted results that can differ a lot from actually implemented RCM processes. The system simulated was a small system with only a couple of components which makes the analysis relatively easy to complete and implement. This result can change drastically when RCM is attempted on a larger scale, such as a plant with thousands of assets. Managing the RCM process becomes a large-scale and long-term exercise with the potential of yielding much fewer results than the simulated system in Section 2.9.1. Thus this simulated model cannot really be used to promote the successful use of RCM in a much larger system.

In Section 2.9.2 two research articles were considered where the one reported on the addition of probabilistic reliability maintenance and the second introduced a method of considering the uncertainties and risks in the RCM process named RRCM. Undoubtedly these two approaches will help the user to select maintenance tasks more accurately. However, both of the proposed methods entail a lot of additional work and calculations. This addition of extra work to the RCM process, which is already resource-intensive, can lead to overcomplicated maintenance task assessments that can take very long to complete. This is a dangerous way to go since it can lead to an even more prolonged implementation process and to loss of interest in the process from the personnel. The user of these two methods is thus urged to very carefully select the equipment where further probability and uncertainty studies must be done.

2.10 The stigma attached to RCM

The RCM program is part of many company's history and unfortunately for most of them, an unsuccessful story or perhaps a very painful and difficult reminder of the past. It is no secret that the changeover to the RCM process is probably one of the most difficult changes in a company's maintenance and engineering department. Most experienced maintenance engineers will testify that they had a bad experience with the RCM process and will state that it is a nice theoretical process, probably the best maintenance process, which is in many cases impossible to implement in practice. Why is it that, according to Neil Bloom, about 90 % of RCM implementation projects fail and are so renowned for their difficult execution? Surely it is not because the process is ineffective or does not deliver quality results. But the RCM process is extremely resource-intensive and slow to yield the required results. For this reason not many maintenance engineers are optimistic when it comes to the RCM process and will most probably discourage its use.

The current economic situation in South Africa forces more and more companies to streamline their expenses and in most cases the first place where costs are reduced is the maintenance personnel and budgets. This makes it difficult to implement any new maintenance programs such as RCM programs since there are very few funds and personnel available to successfully execute such an intensive program. This situation will most probably not change in the near future and what is required most is effective management of current maintenance practices and methods, without any drastic change in maintenance philosophies. This agrees with Christer Idhammar's belief (Idhammar, n.d.) that a company in such a situation should rather focus on what they have and do properly what they are doing. There is however room for improvement and the ideal would be to systematically align plant maintenance practices with the basics of the RCM program. This then implies that a plant should rather systematically develop their current maintenance strategy in the light of RCM instead of attempting to implement the RCM program as a whole.

2.11 RCM at Hot Strip Mill, ArcelorMittal

The Hot Strip Mill (HSM) at ArcelorMittal Vanderbijlpark attempted to implement the RCM process in the early 2000s. Needless to say, the implementation project was systematically abandoned before it was successfully implemented. However, there are still basic RCM principles being used to this day, even though the RCM process in its whole is not used anymore.

Currently at the HSM the basic RCM principles being used are as follow:

- SAP PM (Plant Maintenance) is used for equipment or component registry as well as an information data base for all assets.
- Run To Failure, Reactive maintenance, Preventative Maintenance, Condition Monitoring and Proactive maintenance are practised.
- A reliability engineering programme is followed to improve availability of plant.
- Root Cause Analysis is carried out to improve equipment by maintenance strategy and redesigns.
- Scheduling of tasks is done in SAP PM.

The reason why the HSM failed to complete the RCM project must probably be sought in the large amount of equipment classification and analysis required. For this size of plant there simply were not enough personnel dedicated to the project to ensure its completion. RCM teams were not focused on the process and got involved with other maintenance tasks demanded by the plant, and lost focus on the process of developing the RCM programme. The large amount of resources required and the slow initial yield of the process results also contributed to the negative general feeling and attitude from the maintenance personnel. Implementing a new maintenance program required a change in a plant’s culture in order to ensure that everyone is aligned with the process and its advantages. At the HSM there are maintenance personnel with 30 to 40 years of experience on a steel mill. They have their own way of doing maintenance and the news of a new maintenance program could cause resistance to such a change. If the maintenance personnel do not believe in the program, it is useless to attempt to implement it since the program will not be sustained, and the quality of input will lead to poorer efficiency of the RCM process and thus to poorer reliability results.

The HSM is only one among many other companies that experienced exactly the same difficulties and contributed to the 80 to 90 % failure rate of implementation attempts. There exists a need for developing a systematic approach to RCM that is less resource intensive, easily applied, aligned with current practices and maintenance approaches and has a higher probability of successful implementation of the RCM principles. The next chapters will consider the development of such a system.

3. Empirical investigation

An investigation was conducted in order to determine if the problems associated with RCM apply not only to the Hot Strip Mill in Vanderbijlpark but also to other plants within the ArcelorMittal South Africa (AMSA) group, as well as to other plants outside the ArcelorMittal group. The aim was to obtain a correlation between the experimental data collected and the literature as discussed in Chapter 2 which suggest that the implementation of RCM is not really practical and prone to failure in its early stages of development. Therefore the study was aimed at highlighting the reasons for this phenomenon as well as delivering backing support for the need to develop a practical and sustainable approach for implementing and improving RCM-based maintenance principles.

This chapter considers the objectives of this experimental investigation and the data that needed to be obtained, as well as the experimental method used for this study. Finally the experimental design of the investigation will be discussed in detail, in order to illustrate the data collection procedure.

3.1 Experimental objectives

It is desired to verify the findings discussed in the literature study of Chapter 2. The literature in Chapter 2 indicates that most RCM implementation projects fail even before the initial completion of the project. Chapter 2 further explains why this is and highlights as the most probable cause for this the resource-intensiveness and high cost of RCM implementation projects. The present experimental study will determine if the stigma around RCM, as described in Chapter 2, applies to other local companies as well as to other experienced maintenance practitioners. Thus the overall aim is to verify the literature findings in Chapter 2 and to develop a maintenance improvement plan that has a higher probability of successful and sustainable implementation than the traditional RCM process.

The experimental objectives considered were as follows:

1. To determine the participants' knowledge, history and experience of RCM and other maintenance philosophies.

2. To determine the past history of the HSM with regard to the RCM process. Was there a project to implement RCM at the HSM and how successful was it? The same will be determined for other plants in the AMSA (ArcelorMittal South Africa) group and plants outside the AMSA group.

3. What were the results from the RCM implementation project - was it successful or did it fail? Why did this specific plant obtained the result they obtained? What are the reasons for an RCM project failure?

4. What is the respondents' general mind-set regarding the implementation of RCM or other new maintenance projects? Do they think that it could be done successfully or are they reluctant to consider

maintenance improvement projects? If the response is positive, how do they think can continuous maintenance improvement take place on a plant?

5. Determine if it is possible to successfully implement RCM at the HSM - or is it more practical and sustainable to maintain and improve current maintenance philosophies? Which one of the two approaches will be the most likely accepted by the culture at the HSM?

In order to achieve these objectives, a questionnaire was compiled where ArcelorMittal HSM employees as well as other industry maintenance practitioners participated. The method used is discussed below.

3.2 Experimental method

For this experiment, a **questionnaire approach** was used to determine the data required. The questionnaire guideline used is one developed by Eiselen and Uys (n. d.).

The questionnaire was of the self-administered type where the participants were asked to complete the questionnaire in their own time. A deadline was set for the completion of the questionnaire, to ensure timeous feedback from the participants.

Hard copies of the questionnaires were handed out to the participants that are involved at the HSM while copies of the questionnaire were sent via e-mail for the other involved participants.

The questionnaire was kept short enough to ensure that the participants had sufficient time to complete it, and to ensure accuracy of participants' inputs.

Sample group (participants)

The sample group consisted of the following participants:

- ArcelorMittal HSM maintenance personnel:
    - Managers (Plant, Mechanical, Electrical & Maintenance Progress manager)
    - Engineers (Mechanical and Electrical)
    - ArcelorMittal maintenance development specialists
    - Technicians (Mechanical, Electrical)
    - Senior Planners and Planners
    - Superintendents (Mechanical and Electrical)
- Non-ArcelorMittal maintenance industry experts
- ArcelorMittal Steel plant maintenance expert/consultant

In Addition to the questionnaires, two **individual interviews** were held, one with a local maintenance expert and the second with an international maintenance expert. This was done to obtain a better understanding of the industry's view on the efficiency and sustainability of the RCM process.

3.3 Experimental design

Questionnaire

Two questionnaires were developed, one for ArcelorMittal HSM employees and one for non-ArcelorMittal HSM employees. These questionnaires were then distributed to the sample group as indicated in Section 3.2. The actual questionnaires handed out to the participants can be found in Appendix D and Appendix E.

ArcelorMittal HSM employees were handed out a hard copy of the questionnaire while non-ArcelorMittal HSM employees were supplied with an electronic version, to be completed and e-mailed back for interpretation. Each participant was given two weeks to complete the questionnaire. Reminders were sent at the end of week two and subsequent reminders thereafter for those participants who had not yet completed the questionnaire by then.

The questionnaire was designed keeping the following in mind:

- The participants were given enough time (2 weeks) to complete the questionnaire.
- The length of the questionnaire was limited. Completion time 20-25 minutes.
- Questions were designed so as to make interesting reading for participants, especially for those who had experience and knowledge of the controversial RCM topic. This helped with the accuracy of the feedback.
- The questions were also formulated in such a way that the participant could report on his ideas and feeling toward RCM, as well as report on own experiences and knowledge of the RCM process.
- The sequence of the questions was arranged in such a way that no definite pattern could be seen. This helps to prevent the participant from giving what he might think the right answer should be. The participant must in no way be led to give “expected” answers.
- The questionnaire was also composed in such a way that it has a chronological order, to help the participant to keep track of the relevance of the questions.
- The questions were given a 25 % increment of the extent to which the participant agreed with the statement or question. The question options were: Strongly disagree, Disagree, Agree and Strongly agree. This helps to achieve a better gradation of the participants’ opinion instead of using only Yes-No questions.
- It was also desired to retrieve some feedback on the quality of the questionnaire. The last questions on the questionnaire enabled the participant to comment on the questionnaire completion time, quality and relevance.

Please refer to Appendix E for the questionnaire for ArcelorMittal HSM Employees and Appendix D for the questionnaire for non-ArcelorMittal HSM employees.

Interviews with industry experts

The two interviews with the industry experts were a general discussion where the experimental objectives of Section 3.1 were used as guidelines for the discussion. The results of these interviews can be found in Chapter 4.

3.3.1 Questionnaire design

Two sets of questionnaires were developed for two groups of participants. The questions and results (data collection sheet) of the questionnaires are included in Appendix F. The difference in the two questionnaires is as follows:

- Questionnaire for Hot Strip Mill (HSM) Vanderbijlpark employees: This group completed a questionnaire with questions 1 to 45 (Refer to Appendix E) where questions 1 to 32 cover general RCM principles and questions 33 to 45 are focused on RCM at the HSM.
- Questionnaire for non-HSM employees: This group completed a questionnaire with questions 1 to 32 (refer to Appendix D). These are only general question on the RCM process and do not include the questions aimed at HSM personnel (questions 33 to 45).
- At the end of each of the two questionnaires a questionnaire review consisting of 4 questions and general remarks is included. The purpose of this is to get feedback on the quality and standard of the questionnaire completed by each participant.

Samples of both questionnaires were handed out to proofreaders prior to the official handout of the questionnaires. The feedback from the samples was used to refine the questionnaire content and quality to ensure a good standard of questions issued to the participants.

3.3.2 Data verification

In this section the methods used to verify the accuracy of the experiment will be discussed. The verification of the quality and content of the questionnaire is considered as well as the accuracy and integrity of the feedback received from the participants.

3.3.2.1 Questionnaire design and content

As part of the design of the questionnaires, two samples were sent out to two experienced engineers for proofreading in order to verify the accuracy of the questionnaire content. The proofreaders had to verify that the content was understandable; that there were no double meanings and no grey areas in the interpretation of the questions. The design of the questionnaire and the formulation of the questions underwent many changes on the recommendations of the proofreaders. Finally, after many changes, the questionnaire was sent out to the participants.

3.3.2.2 Participant feedback

Two methods were used to verify the accuracy of each participant's completed questionnaire. These two methods helped to identify any questionnaires that had been rushed off and completed without the participant carefully reading the questions and giving his/her full attention to its content.

Method #1: Give a deliberate instruction to the participant and see whether he/she closely followed the instruction given. The instruction starts with a statement similar to the other questions, in order to prevent the participant from easily identifying the change in the way the question/statement is asked. Should the participant not read thoroughly through the questions, he/she will miss the instruction in which case the integrity of his/her answers will be questioned. For illustration, view the following questions from the questionnaires in Appendix D & E:

- Questionnaire for HSM employees: question 5, 24 and 40 (Appendix E)
- Questionnaire for Non-HSM employees: question 5 and 24 (Appendix D)

Method #2: In this method the same question with the same underlying concept is asked in a different way. The participant should give the same answer to the corresponding questions. Should this not be the case, the integrity of the answers is uncertain and can become questionable. Should the participant have the same opinion on the corresponding questions, this indicates that the participant is reading the questions and paying attention to the questions asked. For illustration, view the following questions from the questionnaires in Appendix D & E:

- Questionnaire for HSM employees : questions (4&19), (3&23) and (6&28) (Appendix E);
- Questionnaire for Non-HSM employees: questions (4&19) and (3&23) (Appendix D).

Note: For the purpose of this questionnaire, "strongly disagree" and "disagree" indicates the same level of agreement for Method #2 questions, and "agree" and "strongly agree" indicates the same level of agreement for the Method #2 questions.

3.3.2.3 Acceptance/rejection of questionnaires

Before the answers of the questionnaires are analysed, each questionnaire is evaluated to see if it is accepted or rejected. The following acceptance criteria were used (refer to Method #1 and Method #2 above):

- If participant's questionnaire complies with Method #1 and Method #2, questionnaire is accepted.

- If participant‘s questionnaire complies with Method #1 and at least 1 of Method #2 (non-HSM) and 2 of Method #2(HSM), questionnaire is accepted.
- If participant‘s questionnaire complies with Method #2 and at least 1 of Method #1(non-HSM) and 2 of Method #1(HSM), questionnaire is accepted.
- If participant partly complies with 50% of Method #1 and Method #2, questionnaire is accepted.
- If participant neglected Method #1 but indicated difficulty in understanding meaning or purpose of the Method #1 question, and at least 1 of Method #2 (non-HSM) and 2 of Method #2(HSM), questionnaire is accepted.
- If none of the above the participant’s contribution and interaction where required is considered, the amount and content of feedback is then considered for completeness and effort.
- If none of the above applies, the questionnaire is considered inaccurate or unreliable and thus rejected.

By using this method, two of the 36 participants’ questionnaires were rejected, meaning that only 34 of the total number of received questionnaires were evaluated.

3.3.3 Solution validation

Two **individual interviews** were held with two industry experts in order to verify that the literature and experimental results correlated with the industry’s perception of the RCM process. Since the final proposed solution for this research project was formulated from the literature findings and experimental results, the feedback from the industry experts was used as a guideline for the proposed solution. In this way the proposed solution can be validated to ensure that the solution is a practical and viable solution for the development of a better sustainable maintenance approach. The results from the interviews are reported in chapter 4 of this dissertation.

3.4 Data analysis

The data retrieved from the questionnaires were analysed as follow:

- Al the participants’ feedback was received.
- The questionnaire itself was used as a template to document all the results. (The data collection sheet is included in Appendix F.)
- All the questionnaires were tested against the acceptance/rejection criteria of Section 3.3.2.3. If the questionnaire did not conform to this criterion, it was discarded.
- All the participants’, HSM and non-HSM, results were then imported to the master template. For each question the count was taken for each answer outcome. For example, for question 3 all the instances of “strongly disagree”, “disagree”, “agree” and “strongly agree” were counted to

determine the distribution of the answers. If 20 participants selected “agree”, then the “agree” option received 20 counts on the template for that question.

- The percentage of the options for each question was determined by taking the total count and dividing each individual choice by the total count. For example, if there were 34 counts (selections from participants), and 20 counts were for the “agree” choice, 20 was divided by 34 and multiplied by 100 to obtain a percentage of that choice from the total.
- The same process was followed for the feedback directed at the HSM personnel only. The data for these participants were added to the template and processed in the same way.
- All the written feedback from the participants was also noted in the template (data collection sheet in Appendix F). From this the general concepts were reported on.

The feedback received from the participants is reported in Chapter 4 while the results are discussed in Chapter 5. Appendix F gives the results in the data collection sheet.

4. Experimental results

For the purpose of this research project, a **questionnaire** was used for the experimental study. The questionnaire issued to HSM personnel contained specific questions additional to those answered by outside (Non-HSM) participants. The aim was to explore the general perception and understanding of the RCM process among maintenance practitioners in various industries. The data obtained from the questionnaires were used to formulate a maintenance approach that is in accordance with the identified needs and expectations of a sustainable maintenance process.

In addition to the questionnaires, two **individual interviews** were held with a local and an international maintenance expert. The purpose of the interviews was to compare the results from the questionnaires against the knowledge and experience of the two industry experts. The results of the interviews will be discussed after the results of the questionnaires.

4.1 Questionnaire participants / sample group

It was desired to obtain information from as many different people from different working backgrounds working in different industries, in order to determine the perception concerning RCM both within and outside the ArcelorMittal group. In order to obtain a wide variety of data the questionnaires were sent to a variety of technical professions working in different companies:

The group of participants consisted of the following titles:

- 13 Mechanical engineers
- 9 Mechanical maintenance managers
- 2 Electrical engineers
- 1 Electrical maintenance manager
- 1 Civil engineer
- 4 Mechanical technicians
- 2 Mechanical superintendents
- 1 Electrical superintendents
- 1 Senior planner

Average years of experience of participants: 19 years

Companies represented:

- ArcelorMittal HSM, Vanderbijlpark. (This group's questionnaire had additional questions for the Hot Strip Mill specifically – refer to questions 33 to 45 in Appendix E). This group consisted of 14 participants.
- ArcelorMittal Vanderbijlpark, which included participants from the other operating units in the Vanderbijlpark Works.
- ArcelorMittal Vereeniging Works.
- ArcelorMittal Saldanha Works.
- NATREF (Sasol).
- Safripol.
- PPC cement.
- Escom Lethabo.

More information on each of the participants is given in Table 4 in Appendix F.

4.2 Questionnaire results

The results of the questionnaires are included in the data collection sheet in Appendix F. In this section the summary of the results of each question is presented. The results are divided into RCM background, RCM projects, RCM efficiency and alternatives and lastly the HSM and RCM (as reported on by the 14 HSM maintenance personnel).

Please note that the subsequent sections only represent the raw data obtained from the questionnaires. The interpretation of the results will be given in Chapter 5.

4.2.1 RCM background

For this section all 34 participants' results are taken into consideration.

Please note that the numbering convention correlates to the numbering sequence of the questionnaire.

1. The distribution of the participants' understanding of RCM is represented in Figure 20:

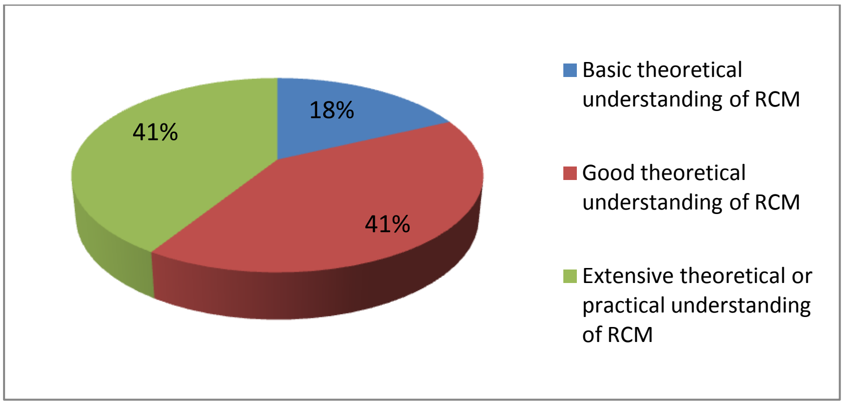


Figure 20: Questionnaire participants' understanding of RCM

2. 74 % of the participants received formal training on the RCM process.

3. 59 % agree and 41 % strongly agree that RCM is a world-class maintenance approach if implemented and used as originally developed and designed for.

4. 59 % consider the RCM process as being an overcomplicated maintenance approach.

5. 32 % agree and 62 % strongly agree that the culture within an organization is very important for the successful implementation of a maintenance management system/strategy.

4.2.2 RCM projects

For this section all 34 participants' results are taken into consideration:

1. 23 participants out of 34 had at some stage been involved in an RCM implementation project.

2. In total, 25 RCM implementation projects were noted. Of the 25 projects, only 16 were considered as being successful.

3. Only 10 of the 25 RCM projects are considered as still being active and functioning as intended.

4. 16 of the 25 projects are considered as delivering the required and expected results/outcome.

5. The average implementation time of the 25 RCM implementation projects is **19 months.**

6. For the RCM implementation projects that failed, it took an average of **22 months** till indication of failure or abandonment of the project.

7. Reasons for RCM projects failure/abandonment as noted by participants.

- Change of one maintenance system to a new system can be resource intensive.
- Culture that is reluctant to change and inability to adapt to new process.
- Instability in company structures and management. People relocate or resign before process/project is completed. Pressure on maintenance budgets and time.
- Lack of top management commitment and drive, inability to convince people of new maintenance project / process.
- Execution of tasks/inspections not done as intended. Feedback accumulated but due to time and manpower constraints the backlog could not be reduced. Not much progress in terms of maintenance improvement was made.
- The RCM process was not followed completely. Due to the high number of equipment items (in excess of 4000 pieces of equipment per plant) the FMECA process is too complex and time consuming. Eventually other maintenance strategies were also employed. People/ resources were not delegated to these projects on a full-time basis.
- Over-complicated and difficult to implement in basic form
- Needs discipline from people and management to drive the development and completion of the process.
- The culture of the people was not changed. General negative feeling on floor level about the project. The moment the dedicated team stopped their efforts, the project started to fail. At a later stage a new management team was appointed and they wanted to do something else. RCM is a too long and stretched-out a process, mainly due to the culture and attitude of the plant personnel.

8. 21 of the 25 projects had a dedicated team allocated to implementing the RCM process.

9. For 19 of the 21 dedicated teams, team members were still responsible for normal daily activities and maintenances duties.

10. Average team size of the 25 RCM projects was 7 members, where most teams consisted of the following members:

- Mechanical engineer/technician
- Electrical engineer/technician
- Instrumentation/systems personnel
- Planning office personnel
- Production personnel
- Maintenance foreman and artisans

4.2.3 RCM efficiency and alternatives

For this section all 34 participants' results are taken into consideration:

1. 91 % of the participants consider RCM as a comprehensive and effective maintenance system.

2. 61 % of participants consider the RCM as practical and relatively easy to implement at most plants.

3. Alternatives to RCM as reported by participants:

- Reliability program. This is a maintenance improvement process currently being used at the Hot Strip Mill.
- First focus on the basic conditions and the basics of maintenance.
- Focus on critical equipment causing largest delays.
- WCM, MUDA elimination, Poka yoke for maintenance, TPM, Five-s, lean MNF, six sigma
- RCM 'light'. Focus on applying the intention of the process and controlling the execution. The strategy is sound but the process is time-consuming.
- Focus on critical equipment and the things that actually went wrong instead of doing all the failure probabilities.
- Proactive maintenance tasks by doing RCA (Root Cause Analysis).
- Condition-based maintenance.
- The RCM principle is sound with proper logical backing for all solutions; however, the process should be streamlined to identify critical equipment and focus on those equipment items rather than a whole plant. Some of the WCM cost deployment principles can be applied here to identify such equipment.
- Needs analysis in each case.
- Modified RCM process (RCM light) or similar internal process, still using the sound principles of RCM.
- First get the basics right, then consider RCM.
- RCM can be good, provided one has the necessary manpower to implement it properly and to maintain the system.
- A combination of RCM, preventative maintenance, and predictive maintenance.
- You have to adapt the environment where you want to apply RCM to make it economical and practical.
- Just adapt all the replace frequencies and measure and inspect and replace more on practical method.
- Short and simplified version of RCM (ARP-Asset reliability program).
- TPM (Total Productive Maintenance), CBM (Condition Based Maintenance).
- General framework of RCM can be followed. The details in doing FMECA's on every single component to determine reliability etc. can be too overwhelming. Most of this information can be easily obtainable from past experience as well as OEM's. This will make life a lot easier and it will fast-track the strategy development process.
- Some of RCM processes are good and useful but some are too complicated and lengthy; sometimes one must just use common sense in a maintenance approach.

4. 76 % of participants say it is not imperative to do a FMECA for each and every component/asset in a "low risk" environment.

5. 83 % of participants say that for most, relatively uncomplicated equipment/assets, the detailed FMECA can be replaced by proper historical analysis and experience.

6. 88 % of the participants are of the opinion that RCM can be successfully used on an old plant 30 to 50 years old.

7. 97 % of participants agree that the buy-in, cooperation and belief of the plant personnel are vital for implementing a new maintenance system.

8. 35 % disagree and 65 % agree that RCM can be implemented at a plant that is under severe pressure in term of resources and budget constraints.

9. 32 % of participants say it is better to keep in-house control by involving only the plant's own people while 68 % says it is better to combine in-house control with external resources and expertise.

10. 70 % of participants are of the opinion that a plant should first work on the basics of its current maintenance and get that right before deciding on a new maintenance program/process.

4.2.4 Hot Strip Mill (HSM) and RCM

This section of the questionnaire was aimed at the 14 HSM personnel specifically (questions 33 to 45 of the questionnaire in Appendix E):

1. 12 of the 14 HSM participants are aware of the fact that the HSM attempted to implement RCM; however, all of the participants consider the implementation attempt as a failure.
2. According to the HSM participants, the reasons for the failure of the project are:
    - Lack of experience of the people on the team. Some not taking part. Roll-out and implementation a problem. Roles and responsibilities not clearly defined.
    - Takes too long, personnel and artisans not really involved as they should have been.
    - The idea of RCM was not maintained over a period of time; different other ideas were tested.
    - Incorrect implementation and not owned by management.
    - Severe pressure in terms of resources. It was difficult to maintain the RCM momentum while being in a fire-fighting (breakdown) mode.
    - The basics were not yet in place.
    - The RCM implementation was never completed.
    - Lack of funds and resources.
    - Lack of discipline and ownership.
    - WCM (World Class Maintenance) was implemented. It was unsuccessful due to lack of buy-in from various discipline experts due to KPI's being unrealistic.

3. 57 % agree and 36 % strongly agree that the HSM needs to improve the current maintenance strategy and processes.

4. 21 % do not think that RCM is a suitable maintenance approach for the HSM, while the remainder of 79 % are of the opinion that RCM can be used at the HSM.

5. The HSM participants consider the availability of the HSM's resources for RCM as follow:

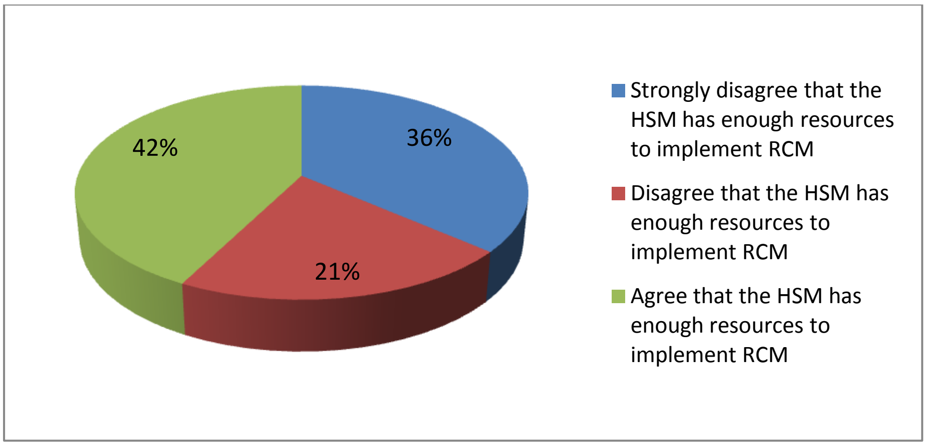


Figure 21: Availability of HSM resources

6. 42 % do not think the HSM has the right culture to implement RCM while 58 % say that the HSM has the culture that will embrace the RCM process.

7. 43 % disagree and 57 % agree that the culture at the HSM is difficult to adapt and reluctant to change. The reasons for this are:

   - Changes come from the top and are delegated to only a certain group to implement and carry out.
   - The culture has changed a lot over the last 5 years, some areas more than others, with still room for improvements.
   - Any changes in structures and systems have to be strongly driven by management to change the culture.
   - People adapt quickly when they know why, how and when there is a positive outcome.
   - Being the bottleneck plant for many years, people accepted that changes are required to keep on reaching targets.
   - Our people can adapt to our surroundings and environment.
   - Lack of ownership and responsibility on artisan level.
   - When you convince people why they need to change it is easy, but the HSM is big and it takes a lot of time.
   - Difficult but can be done, have to maintain the pressure.
   - The culture is not reluctant to change, but rather must be motivated or show the improvements which can be realistic by effective RCM implementation.

8. 93 % of the HSM participants agree that the HSM personnel would rather embrace a systematic improvement and development of the existing maintenance processes than the full implementation of an RCM project.

9. 57 % agree and 43 % strongly agree that the HSM management team is capable of establishing the buy-in and belief of the people in the development of the HSM maintenance program.

10. 35 % disagree and 64 % agree that the RCM process can be successfully implemented at the HSM now or even in the near future.

4.3 Questionnaire assessment

For this section all 34 participants' results are taken into consideration:

1. 93 % of the 34 participants considered the questionnaire as relevant and meaningful to this study.

2. 24 % say that some of the questions and instructions were not clear and he/she did not understand all the questions. The main reasons for this are:

- Questions 5, 24 and 40 unnecessary.
- Yes/no selection not really understood correctly.
- Question 24 was strange.
- The impression is that all questions cannot be answered with the options given (agree / don't agree); it might have yielded better results by using a scale of 1 – 5 in some instances.
- The two questions where it was stated: "ignore the statement and follow the instruction" was confusing.
- Not sure what was the purpose of question: "ignore statement...".
- Some questions require yes/no answers but give 4 options.

3. Average time for completing the questionnaire was 19 minutes.

4. 6 % considered the questionnaire as acceptable, 88 % as good and 6 % as excellent.

4.4 Other general comments from questionnaire replies

In the list of other general comments by the participants the following occurred:

- The RCM principles and philosophies are sound, but the process and implementation requires so much time that it is difficult to maintain the momentum with limited resources and divided attention.

- Devise simple maintenance plan with good planning and good equipment/machine knowledge before considering RCM.

- The success of any project is a function of the commitment and drive of the management team and the involvement of all personnel. There must be a clear vision, chase for change and leading and lagging indicators to measure progress.

- Deciding on implementing a new maintenance approach is a journey, starting at the basics and detail of what exists in terms of business arena, assets, process, people, skills, systems, technology, the objective, the expected return on investment, availability of resources and support, the long-term construction. A localised improvement of an existing system is less complicated and has lower impact. The scale of the project matters.

- To summarize, RCM is still the most powerful method around, and is well supported in many operations, mines, petroleum and chemical environments. You have touched on culture in the work place, this is highly important, for not only maintenance personnel but also for the production team to continuously drive the methodology and the outcome of the results ... take that and build it into your maintenance plans to make it sustainable. In today's flat structure organizations with a lean work force the methodology is actually for us to apply the biggest maintenance opportunities.

- RCM principles should be applied to some of the critical equipment within a plant, especially the main producing units where failure results in substantial downtime and cost.

- Combination of RCM and TPM (Total Productive Maintenance) can also be considered, depending on the maturity of the work force.

- RCM is a strategy that requires a lot of resources in order to be done correctly. Some companies employ modified versions of RCM and only consider some of the RCM tools. Quite often this process can be disastrous.

- If the management team is not committed to implementing a new system and keep the pressure till it becomes a habit, you will struggle to implement anything new. You need to change the people's mind-set before you can successfully implement a new system/strategy.

4.5 Interviews with industry experts

Individual interviews were held with two industry experts, the one a local South African maintenance expert and the other a French maintenance expert with international maintenance experience. The interviews conducted were a general discussion on the topic of maintenance with the main topic of RCM and its efficiency. Consider now the results from the interviews:

4.5.1 Local South African industry expert

An individual interview with a South African maintenance expert in the cement industry produced the following information:

Name: Louis Fouche

Designation: Asset care manager, PPC cement

Years of experience: 28 years

Work experience: Maintenance background in the lime and cement industry. Maintenance systems design, development and implementation. Technical competency and training development.

Louis made the following comments in the interview:

1. The RCM process is very well structured and a comprehensive maintenance approach consisting of very sound maintenance principles and methods. However, Louis is of opinion that the implementation of a full RCM process is more suitable for high-risk industries such as the aviation industry where the slightest error could be disastrous. In the case of a medium-risk industry such as the cement or steel industry, the implementation of the traditional RCM process might be a bit of an overkill and the full implementation thereof is not necessary and will waste a lot of the facility's resources.

2. When a maintenance system is developed, whether the full RCM process or a lighter version of it, it is important to make sure that this method or process is fully adaptable with the current maintenance methods, company procedures and the maintenance culture within the facility. A lot of consideration and design should go into the framework and the basis of the method when implementing a new maintenance system in order to ensure an easier transition process.

3. Before a facility starts with a new maintenance system or program such as RCM, all the basics must be in place. There is no time to struggle with basics during the implementation period and this should be accounted for even before the project has started. One example is the maintenance culture of the personnel. Before the program is started, the people must believe in the process, otherwise they will never have the ownership over it required to implement it successfully.

4. Make sure that the people have the level of skills required by the new process, at all levels. Make sure the execution of tasks and management of the process is at the required level.

5. The system must not be over-sophisticated. Should this be the case, people will lose their interest and faith in the process as soon as it becomes too difficult or complicated.

6. Make sure that the results of the process are noticeable on floor level. People will have more motivation and belief when they see good results due to their inputs and ownership of the process. This will help to ensure that the maintenance loop will be closed that will result in continuous improvements and development.

7. A properly planned process of implementation is required. All the necessary resources and planning should be in place before the start of such a project.

8. Do not try to follow a big-bang approach, rather a systematic approach of development and implementation. Continuous development after implementation is key.

9. Pilot the process. First test it on one part of a plant, make all the mistakes, learn and develop, then implement it at other plants.

10. Identify the areas where the biggest impact can be made with the least initial inputs or effort.

11. Top management should know what is going on, they must give their permission for or consent to the project. This will help with future backing of the project. It is also wise to have a sponsor who is the communicator between middle management and top-top management.

12. Do your homework well. What are the benefits, what have other plants done in the past, what kind of success can be expected. How does one measure the success.

13. Make sure work instructions are complete, and that correctly scheduled and proper feedback and updating of work instructions are done.

14. Use a dedicated team allocated for implementing the process. This team should have all the required training and skills to develop and lead the implementation of the process.

15. Use the 20-80 principle according to which 20 % of the equipment causes 80 % of the delays. This will help especially for the start to identify the equipment that should be considered first.

16. Prepare the culture proactively; make sure everybody is on-board. Get guest speakers to motivate and inspire the people and to demonstrate the benefits. Make sure that sufficient training is given on the process so that everyone knows the process and the requirements and to ensure the correct level of execution.

17. Consider using an RCM light process where the structure of the RCM process is determined through the condition and requirements of the plant. Use history and plant personnel experience and knowledge to determine the maintenance requirements of your assets. Refer to OEM manuals, best practices, methods and procedures etc. Consider which spares are available. Try to keep the process as simple as possible.

18. On more critical equipment a full RCM process can be considered.

Louis, together with his dedicated team, has managed to develop a world-class maintenance development program at PPC cement by using these basic ideas and concepts of maintenance. Their approach has yielded great success and has been a very good example of an effective maintenance system in the cement industry.

4.5.2 International maintenance expert

An individual interview with a French consultant, used by ArcelorMittal Vanderbijlpark, produced the following information:

Name: Dominique Cosset

Designation: Maintenance consultant

Years of experience: 40 years

Work experience: Engineer and works manager in the steel industry in France and Spain (worked on blast furnaces, hot rolling mills and cold rolling facilities for 36 years). Technical and management consultant for 7 years in steel industry all over the world (USA, Turkey, Algeria, Rumania, India, South Africa, Italy, Iran and Belgium). Involved with global improvement of KPI's mainly cost savings, maintenance and production reliability, quality rejection and yield.

Dominique made the following comments in the interview:

1. Dominique was not familiar with the term RCM (Reliability-Centred Maintenance). According to his understanding the RCM process must be an American invention (which it is). Nowhere else in the world did he encounter the term RCM. But after a discussion on the concept of RCM, he admitted that he understands the RCM process but was not familiar with the name RCM, as it is called in the USA and South Africa.

2. Although he is not familiar with the RCM name, he is 100 % familiar with the FMECA process used in the RCM process. He mentioned that it is a very powerful method but also very tedious and long and should not be used for all the equipment on a plant but rather for the most critical, selected equipment, at least for the initial stages of the process. According to him the process of applying an FMECA for all the equipment can slow down the process and will result in slow progress and de-motivated people.

3. Dominique also argues that in a large facility many of the basic equipment items can be analysed by means of equipment history and plant personnel experience. This should enable one to do most of the analysis much more quickly and to prevent overcomplicating the basic equipment maintenance strategies.

4. He agrees that larger more complicated systems or equipment can be analysed with a full FMECA process where failure modes and maintenance requirements are not that obvious and more complicated to determine.

5. Dominique agrees that it is important to get the buy-in of the plant personnel. Management should be able to convince the people of the process, otherwise, if they do not believe, they do not execute.

6. He reckons that with proper planning and resource utilization one could be able to implement and maintain new maintenance strategies in an old plant, even with severe pressure in terms of resources and budget constraints.

7. He stated that it is key that the management team is convinced of the process and that the management team is able to convince the plant personnel of the changes or implementation of a new process.

8. Everybody must be aware of and involved in a new process. All management and top structure management, all technical personnel, production and process personnel and the personnel on execution level must be involved with the process.

9. Even TPM (Total Productive Maintenance) and WCM (World Class Manufacturing) is very difficult to implement at once. A systematic approach is required to change the maintenance approach of a facility.

10. One should not wait until a culture is changed before implementing a new strategy, but should rather use the change in the process or structure to systematically change the culture of the facility.

11. Dominique introduced the process of failure investigations (RCA's) to the Hot Strip Mill. He also made suggestions on the structure of the management and middle management teams to be divided into zones. The changes he proposed for the HSM yielded very good results. It is still an on-going process.

The principles Dominique gave are only the basics of maintenance, but they have helped him to achieve great success in his career. He has helped many plants to develop and improve on their maintenance approach and has delivered significant results. The work he has done at the HSM greatly improved the way the management team is approaching the HSM's maintenance processes and results can already be seen in the reliability and availability of the HSM plant.

4.6 Conclusion from experimental results

Form the results it was noted that the RCM process is a well-known process in South Africa, commonly used over different industries. 82 % of the questionnaire participants consider themselves as having extensive understanding or practical experience with the RCM process and 75 % received formal training in RCM. The RCM model is even taught at the universities in their Maintenance Engineering selective in the final year of a B.Ing degree. However, it seems like this is not the case in many other parts of the world. Dominique Cosset worked for 40 years in France in the steel industry and claims that he has never heard of the term "RCM", neither in other parts of Europe, India or Iran. He is however familiar with the FMECA process which is part of the RCM process, so perhaps they have a similar process as the RCM process but under another name.

The majority of the participants consider the RCM process as a world-class maintenance approach should it be implemented and used as it was intended. Strangely enough, the same number of participants consider RCM to be an overcomplicated and "difficult to implement" maintenance approach. The general perception is that the RCM process is a very good and effective approach, but notoriously difficult to successfully implement, thus causing people to be sceptic about the practicality of the RCM process/method. The suspicion is thus that the theoretical RCM concept seems plausible on paper but the maintenance practitioners, disappointed in actual RCM project failures, will say that is it not really practicable and sustainable in a heavy industry environment. In Chapter 5 the results in this chapter will be interpreted and discussed. The HSM and the industry's perception of the process will be considered. Then the viability of the RCM process at the HSM will be evaluated. Thereafter a proposed solution for the HSM's maintenance improvement process will be discussed.

5. Discussion and interpretation

In this chapter the results of Chapter 4 are discussed. The concept and opinion of RCM from both the Non-Hot Strip Mill and the Hot Strip Mill maintenance practitioners are then used to interpret and understand the requirements of a maintenance system and applicability of RCM for being used in such a system. A proposal for a maintenance system at the Hot Strip Mill is then developed that will best suit the requirements and the environment of the Hot Strip Mill. This proposed model is developed by also considering general maintenance requirements and tools in order to be applicable not only to the HSM but also to similar plants in other industries. These maintenance practices and tools were discussed in Chapter 2.

5.1 The industry's take on RCM

This section considers the results obtained from all the participants of the questionnaire, the HSM and non-HSM participants.

Applicability of RCM

From the questionnaires and individual interviews obtained from various industry maintenance practitioners, the general perception is that RCM is a very well structured maintenance approach and can yield success with great efficiency if implemented and maintained as intended. In fact, 91 % of the participants are of the opinion that RCM is an effective and comprehensive maintenance system, and 61 % believe that the RCM process can relatively easily be implemented at most plants, while 95 % believe that RCM is a world-class maintenance approach. On the other hand, 59 % of the participants are of the opinion that the RCM process is an overcomplicated approach to maintenance. Perhaps it is more suitable for the high-risk industries such as the aviation industry and petroleum industry and not really for lower-risk factories such as the steel and cement industries. However, the general feeling is that the RCM process can be implemented in heavy industries.

RCM Projects

Although the majority (64 %) of the noted RCM projects were considered to be successful to some extent, many were considered to be a complete failure. Many of the projects, after an initial success, were then abandoned and are not functioning as intended any more. On average, the implementation time took 19 months for an RCM project to be completed and 22 months till its failure or abandonment. Such a long implementation period is perhaps one of the biggest reasons why RCM programs fail. The plant personnel has an expectation of this new maintenance program and then it takes 19 months to be completed. This creates a situation where the plant personnel lose faith and momentum in the process, since it takes such long period of time to yield any results or success.

Those participants who noted failures of RCM programs pointed out that one of the major reasons for RCM program failure was the major amount of resources required. One of the resources required is manpower. On average the RCM teams consisted of seven members. In order to appoint such a team one of the following options should be considered:

1. Appoint a new dedicated team from plant personnel. These members should preferably be experienced on the plant, and the team members should be fully dedicated to the new team. This implies that it is not desirable for the team members to still be responsible for their daily plant responsibilities since it would be too labour intensive and time consuming to manage both the RCM program and routine plant work. Should these seven members be dedicated to the RCM ream only, it means that new people must be appointed to take over their work. 90 % of the RCM teams were still responsible for their daily plant responsibilities. This can definitely influence completion time and the thoroughness of the process, posing the risk of project failure.

2. Appoint dedicated team from consulting firm. This option will reduce the impact on plant activities and responsibilities. However, such a team will lack the required plant knowledge and experience, posing the risk of incomplete RCM analysis. It also implies that the plant personnel will not have their inputs and ownership of the new program and as soon as the program is commissioned and handed over, the plant personnel is not motivated to maintain the process and will most probably in such a case abandon the program.

68 % of the questionnaire participants are of the opinion that when a facility wants to implement the RCM process, a combination of both in-house control and outside help should be used. This would ensure that the history and knowledge of the plant, processes and equipment were being considered as well as the expert advice and experience in RCM offered by the consulting firm.

Other reasons cited for RCM program failure were its difficulty, and reluctance to change. To implement a new maintenance strategy can imply that some of the senior personnel must be able to change their way of doing maintenance. Many habits formed over years could be difficult to change and plant personnel can be difficult to convince of success in a new process.

Some of the participants are of opinion that a lack of drive and involvement from the management team can lead to the poor execution and completion of the RCM project. Another concern is that when a replacement plan for the team members is not in place, this leads to incomplete teams, loss of experience and knowledge, and abandonment of the RCM process.

Lastly, a lack of discipline is considered as a contributor to failing RCM projects. If the team members and management team are not committed to being consistent in continuous system and plant analysis and in proper equipment analysis (Failure modes, effect, criticality), the process will be incomplete and less effective than required. Continuous feedback and update of maintenance plans is required to ensure the future development and improvement of the system efficiency.

In general the concern about the RCM process is as follow: The process is considered as being long en tedious, especially in plants where there are thousands of individual components or items of equipment. Following the FMECA (Failure Mode, Effect & Criticality Analysis) is in some cases overcomplicating the maintenance approach and takes too long for successful completion. Lack of resources and commitment to such an extensive process make it more likely to be abandoned before the full advantage and effect of the process is reached.

RCM efficiency and alternatives

One of the fundamental tools of RCM is the use of the FMECA (Failure Mode, Effect & Criticality Analysis). This, perhaps, is one of the reasons why RCM is considered to be very comprehensive and effective since the FMECA of an asset or equipment gives basically everything needed for successfully maintaining that asset. However, this tool takes a lot of time to establish and use correctly, and this may contribute to the fact that RCM is considered to be a long and tedious process.

About 80 % of the questionnaire participants say that it is not imperative to do FMECA's on all of the facility's equipment, especially in a lower risk class (equipment failure does not cause fatalities or serious health & environmental consequences), and that most of the facility's equipment maintenance can be determined through equipment history and maintenance experience. It is therefore not necessary to do FMECA's on each and every piece of equipment within a facility.

From the results of the questionnaire the age of the facility is not really the issue. Most of the participants agree that RCM can be implemented in a plant which is 30 to 50 years old; however, all the participants agree that, more importantly, that all the plant personnel must agree to the implementation of the RCM project and that they must be motivated to successfully implement and sustain the RCM process.

Lastly, as discussed in Chapter 2, it is more important to ensure that a facility does the basics of maintenance correctly before resolving to a new maintenance system such as RCM. 70 % of the participants agree with this. Improving current maintenance methods and systems should yield improvement much more quickly, at a lower cost, than attempting to implement a completely new RCM process. In a company where resources are limited and funding is minimum, this is perhaps the best solution for making a change in a facility's maintenance strategy.

5.2 ArcelorMittal Hot Strip Mill's take on RCM

This section will focus on the need for maintenance improvement at the HSM and the chances of successfully using RCM as a new maintenance approach.

RCM history at the HSM

The HSM did attempt to implement the RCM process in the early 2000s. All the personnel that were either directly or indirectly involved in the process consider that attempt to implement RCM as a failure and will admit that the process was long ago abandoned, only some of its remains still being used today. According to the HSM participants the reason for the failed RCM attempt was a lack of experience and knowledge; in addition, the roles and responsibilities of the team members were not clearly defined and agreed upon.

Also considered to have contributed to the failed RCM attempt are: Lack of funds and resources, lack of discipline and ownership, the long time taken by the process, and the fact that the basics of maintenance had not yet been in place.

HSM maintenance requirements

Most of HSM maintenance personnel think there is room for improvement in terms of maintenance approaches and systems. Almost 80 % of the HSM participants say that RCM can be used as a maintenance program for the HSM. However, the majority of the participants think that the HSM lacks the required resources for a successful RCM implementation. The culture is considered as being open for the RCM process; however, the HSM culture is considered as being difficult and perhaps reluctant towards change, given the past history with the RCM process.

The majority thinks that the HSM will be able to implement RCM and that the HSM has the management to successfully implement it, however, 93 % would rather embrace a systematic development of a maintenance system instead of a once-off implementation project such as for the RCM process.

5.3 Why an RCM implementation project might not work for the HSM

The theoretical research from Chapter 2 and the experimental results from Chapter 4 arrived at very much the same concern around the process of RCM. From the results of the theoretical study as well as from the industry perspective and RCM experience gleaned from the questionnaires, the following reasons would speak against the implementation of an RCM project for the Hot Strip Mill.

1. Failed previous RCM attempt

On a previous occasion, the HSM attempted to implement the RCM process but, as considered by most of the HSM employees, that was a definite failure. There is no indication left of the RCM process of any sort, and after its abandonment it became a memory of a failed attempt. For this reason it would be very difficult to convince and motivate the plant personnel to attempt it for a second time. There is no doubt that they consider RCM to be a very effective and comprehensive maintenance approach; however, the culture at the Hot Strip Mill would most likely not welcome the announcement of another RCM implementation project and would probably not muster enough faith, even long before it has started. Should the HSM personnel consider the RCM process to be a waste of valuable time and effort, it will be difficult to prove them otherwise. If they do not want to commit to the new process, it is highly unlikely that the process will be successfully implemented.

2. Culture

The HSM does not have a culture that is unwilling to change; however, change is a systematic and gradual process that can take many months or even years. One cannot announce the implementation of a new RCM process and expect that everyone is on board right away. Unfortunately the implementation of a full RCM process does not accommodate a slow approach since this will cause the process to become stretched out without yielding the required results. This would probably cause the people to lose faith in the process and to abandon it before it is even completed.

3. Limited resources

The HSM has very limited resources. During the changeover of Iscor (state owned) to ArcelorMittal (privately owned), the personnel on each plant was reduced to a minimum. This means that should any subdivision like the Furnaces, Roughing Mill, Finishing Mill and Coilers at the HSM want to implement RCM, the one Engineer and Technician together with the foreman and artisans must be used for this process. Currently all personnel are under severe pressure and thus it will not do to pull these personnel from their work to do RCM or to add the entire RCM implementation to their current work load. To implement the RCM process the HSM needs a dedicated RCM team at each plant with the required knowledge and experience and unfortunately there are simply not enough personnel to execute the project. Pressure on maintenance budgets does also not allow any room to expend any additional cost that might be required when implementing RCM. It is therefore not viable to devise an RCM team of seven members from the plant personnel. This was the strategy on the previous RCM attempt which has failed in early the 2000s.

4. The condition of the plant.

The HSM is already 40 years old; even the latest plant upgrades (Furnace #4, Finishing Mill stand #7 and Coiler #3) are already 22 years old. This contributes to the fact that breakdown maintenance has become a large part of the maintenance culture at the HSM. A lot of capital is invested in doing major repair work such as large water pipe-lines, gas pipelines, construction, software and civil projects. This is critical work although it only ensures the continuation of the current process while little has been done to ensure continuous plant upgrades. Old equipment is becoming more and more maintenance-intensive as it reaches the end of its economical life. Poor maintenance in the past, due to maintenance budget constraints and poor maintenance strategies, has caused equipment to move towards a critical state and in many cases to be operated to failure. Failure to upgrade critical electrical equipment has led to a state where no spares are available for the old equipment. Therefore most of the maintenance budget is used to maintain the basic conditions in the plant, and little is used for development.

5. Basics not all in place

There are many of the basic maintenance tools and processes that are being used but not utilised to their full potential. Some examples of this are:

- Job cards (work instructions): The HSM's entire maintenance process relies on the execution of job cards. These job cards are scheduled for certain intervals to ensure that all the plant equipment is inspected and serviced when its time is due. Unfortunately the SAP (HSM's Computerized Maintenance Management System) system is flooded with very poorly defined and scheduled cards that do not have all the necessary information, or the information is very poorly presented. There are many duplicates in the system where the same equipment is on different cards with different maintenance frequency intervals. This can actually lead to over-maintenance.
- Poor record-keeping: Poor record-keeping in the SAP system of spares failure and replacements makes it very difficult to do preventative tasks. Spares are drawn from wrong function locations but similar descriptions. It is therefore very difficult to decide on and plan for preventative maintenance tasks when there is no reliable history on equipment failure and failure frequency.
- Using SAP as integrated shutdown manager. Most of the subdivisions at the HSM are not using SAP to its full potential when it comes to shutdown planning and work force utilization. Although SAP offers the complete package, most of the plant personnel prefer to do manual shutdown planning. This over-utilizes many of the resources, especially when it comes to ordering of spares etc.
- Poor shutdown planning. Poor pre-shutdown planning on artisan level leads to longer tool time for certain jobs. Many of the artisans have lost the ability to do proper planning and preparation with regard to spares and tools, in order to make sure everything is in place before the job commences.
- Condition monitoring. There is a reliability engineering department for the entire Vanderbijlpark Works. This department has all the tools and equipment to do all the necessary equipment monitoring required for doing proper condition monitoring. Unfortunately the potential of this department is underutilized, and in many instances a maintenance suggestion made by the condition monitoring experts is ignored, resulting in equipment damage or even failure.

6. Poor execution

Poor execution of maintenance tasks leads to unreliable equipment operation and more equipment failures. In many instances the importance and proper execution of equipment inspection and routine maintenance tasks are neglected. In many of these cases equipment failures occur whereas proper routine maintenance could have prevented this from happening.

7. Lack of skills and ownership

The general perception is that the skills on the plant are of a lower standard than in the past. In the past, artisans received three years of training before qualifying as an artisan, which ensured that they received very good training on the plant. In the past a lot of focus was placed on the development of the artisans' skills and knowledge of the plant. These days it takes only 18 months for an artisan to complete his/her training. The same counts for hired labour. The plant places the execution of important tasks in lower-skilled hands. Re-work are nowadays a normal practice.

A concept present in a lot of discussions is the lack of ownership by the plant personnel and hired labour. It is the perception that "the plant is not my property, so why must I take care of it?. Why must I keep it clean? Why must I give my best efforts and ensure my work is of good quality?" As soon as the personnel loses ownership, the maintenance and condition of the plant will never improve since there is no more sense of responsibility, urgency or initiative to improve and maintain the plant.

5.4 A practical approach to Hot Strip Mill maintenance (Maintenance Improvement Plan)

HSM management should avoid the announcement of a brand new maintenance implementation project such as RCM. They should rather strategically plan the systematic implementation of the different maintenance improvement actions.

The following approach is recommended for the HSM management team and will provide guidance for the improvement and development of the HSM's maintenance processes.

5.4.1 Determine the maintenance needs

Before any actions can be taken, the management team should first determine the maintenance needs and short comings as identified by the plant personnel. This can be done by means of a maintenance audit. Individual interviews can be held with maintenance managers, engineers, technicians, superintendents, planners and operators, asking the following questions:

- Is the current method of doing maintenance effective and comprehensive and if not, why not?
- What are the things that you consider to be stumbling blocks for you, preventing you from doing proper maintenance and managing your resources?

- Has the way of doing maintenance changed from what it was in the past. What previous methods or tools from the past proved to be effective, and would it be helpful to go back to the old methods?
- What tools, processes or resources do you need in order to perform good maintenance and to improve the current way of doing maintenance?
- What other suggestions, if any, can you make that will help with the way and efficiency of doing your maintenance?
- What support do you need from management side?

The idea behind this maintenance audit is to:

- Establish the current efficiency, problems, shortcomings and stumbling blocks of the people's planning and performing plant maintenance on a daily basis. From this audit many small things can be identified which can easily be rectified and yield good results without putting in too much effort. This will help with increasing the efficiency of current maintenance practices, planning and execution without making major changes in the way of doing maintenance. It would merely help the plant personnel with better and more effective maintenance planning and execution. Examples of these could be: Shutdown planning, ordering and store-keeping of spares, quality of reconditioning of spares, turnaround time of spares, cost and quality of services, training etc.
- Identify larger inherent problems and shortcomings in the maintenance strategy. This could be sub-standards of skills, poor execution, poor personnel structures, insufficient personnel and personnel knowledge and skills. These are the more long-term problems which management must plan to improve.

After carefully investigating the needs and requirements from the plant maintenance practitioners and considering the suggestions of improving the maintenance system, the management team should decide on what the most critical ones are and which ones can be easily done, yielding the fastest results. From there then the management team can determine the scope and requirements for further maintenance improvement projects.

5.4.2 Develop a medium-to-long term maintenance strategy

The management team should now consider developing a process or plan with which they want to improve the maintenance strategy of the plant. The management team should consider the following:

- The results from the maintenance audit in order to determine the requirements as set from the plant personnel.
- Consideration of world-class maintenance approaches and practices.
- The use of best and logical maintenance practices.

- Benchmarking against other plants to determine what they have done to achieve success, and to learn from their success.

It is of utmost importance that the plant personnel give their support to the maintenance approach changes that will be implemented. Asking their inputs and implementing their proposals will help with the buy-in and ownership from the plant personnel. Not only that, but many of the personnel have many years of experience and they can give valuable insight as to what can be done to improve the plant maintenance processes.

Should the management team struggle to get support from the plant personnel, they should motivate the advantages and benefits expected from the process and the successes from other plants or industries. Perhaps management can get guest speakers who will help with motivating success stories etc.

The suggestion here would be for the management team to follow a medium-to-long term approach towards a systematic implementation. Major changes in processes and requirements should be planned and implemented over a period of two to five years, allowing enough time for plant personnel to grow with this process, changing their culture and leading to acceptance of the new approach. This will also help with a successful implementation since enough time would become available to rectify any problems.

The management team should have a clear plan of the flowing maintenance goals:

1. What are the plant’s needs.
2. What can be done to address these needs.
3. How are we going to implement it.
4. What tools or processes will we need.
5. What are our objectives.
6. How are we going to motivate the people.
7. What are the capital requirements.
8. They should give their full support to the process and they should make sure everybody is on board.

From here the management team should have a clear view of the way forward and implementation planning can take place.

It is important to prioritize the identified actions. The planning and execution of all the actions should not be announced at once (Big-bang) but should rather be announced systematically one after the other to help convince the plant personnel of the process and to ensure that there is not too much change in a short period of time.

5.4.3 First get the basics right

Before the management team consider implementing new maintenance tools or processes, they should rather first focus on the basics of maintenance. Many of the tools and processes are already being used but not necessarily with great efficiency. Many of the tools already being used by the HSM are tools and processes used in the RCM process, as identified in Chapter 2. It is a matter of focusing on what you have and making sure that it is used and executed correctly and as efficiently as possible. The table below shows the correlation between the HSM maintenance tools and processes and the RCM process, on a high level:

Table 3: HSM maintenance tools

RCM process / tool	HSM current tools
1. Reactive	Yes (+- 70 %)
2. Preventative	Yes (+- 10 %)
3. Predictive testing & inspection (condition-based)	Yes (+- 10 %)
4. Proactive maintenance	Yes (+- 10 %)

Although the HSM is using the above RCM / maintenance tools, a lot of improvements can be made.

5.4.3.1 Reactive maintenance

Most of the maintenance performed at the HSM is reactive maintenance. Due to tight budget constraints much of the equipment is "run to failure" (RTF) and replaced on breakdown basis. In many cases some of the equipment is conditioned-monitored and still operated RTF.

In many cases a RTF approach is sufficient for effective maintenance. The HSM maintenance team should however reconsider which of their equipment can be RTF and which equipment cannot. Consider the following basic requirements for RTF:

- Failure should have no or minimum impact on safety or the environment.
- Failure should have no or minimum impact on production.
- Failure should not lead to secondary equipment impact or damage, more than what is economically acceptable.
- Redundant systems where back-up systems are available that could continue function.

Al the rest of the equipment that does not fit the profile of being reactively maintained should either be proactively maintained or condition-monitored to prevent premature failure.

5.4.3.2 Preventative maintenance

The HSM makes use of SAP PM as a CMMS (Computerized Maintenance Management System). There has been an effort in the past to create PMO8 work instructions where maintenance can be scheduled on a preventative basis. However, this has not been successfully implemented due to insufficient equipment history and equipment failure history. The systems that are being used are manual record-keeping systems on some of the most critical equipment, whereas a system such as SAP is supposed to help with record-keeping and scheduling of preventative maintenance tasks. The HSM can (and should) take the following actions:

- First identify the equipment suitable for preventative maintenance. Not all assets need to be maintained with a preventative maintenance approach. Failure patterns and frequencies should have a definite and consistent pattern. Equipment with high safety, environmental, cost and production consequences in the case of failure can also be preventatively maintained.
- Start with building a database of equipment history and failure frequencies. SAP is capable of keeping all history of the equipment and spares drawn from the system. The key here is to make sure that all the spares are drawn on the correct function location since this is the position of the spare where all historical data is saved.
- If no history is available, an accurate estimation should be made based on personnel experience and history. This should be the initial approach; however, continuous refinement will be required to ensure that optimal maintenance frequencies are achieved. Premature or too late maintenance (failure) will both lead to less cost-effective maintenance.
- In the process of determining the most effective maintenance frequency, the equipment should be monitored in order to prevent premature failures as well as premature change/service.
- Stick to the maintenance frequency and do not postpone the maintenance due to time or budget pressure, especially on the higher-risk and high-consequence equipment.

It is very important to identify only the equipment that is suitable for preventative maintenance. The following basic criteria can be used:

- Equipment with a definite failure pattern and frequency can be preventatively maintained. This is usually equipment that is in direct contact with the product such as rolls, wear liners, shearing blades etc.
- Equipment where the failure consequences are very high in terms of safety, environmental effects, production and cost.

SAP is capable of doing usage-based instead of calendar-based scheduling. The HSM is currently using calendar-based preventative task scheduling. This means that the scheduling does not account for lower production, breakdowns and planned stoppages since the calendar count does not stop. It is therefore suggested that the HSM develop their system so that scheduling can take place by using usage based data. Examples of this would be actual tonnages, litres, counting of switching etc. This will then give a more realistic indication of the equipment operating time, and thus more efficient preventative maintenance will be achieved.

5.4.3.3 Condition-based maintenance

The entire ArcelorMittal Vanderbijlpark works has a reliability engineering department where they can do oil sampling, vibration analysis and thermo-graphic scans. The HSM makes use of their services and receives reports on the oils sampling and vibration report every month. However, some of the sections at the HSM do not make use of the full service offered by the reliability engineering department. In many cases the warnings on the reports are neglected or ignored, leading to deterioration of plant equipment.

AMSA has another department, Materials Engineering, where they have specialists in the field of Non-destructive Testing (NDT). They are capable of doing ultrasonic testing on shafts, casings, rolls etc. in order to determine fractures, cracks and deterioration of equipment material. Even X-rays can be taken for quality assurance when it comes to manufactured spares and welding.

The HSM maintenance personnel should:

- Make sure that all lubrication systems and lubricated equipment are on the testing register for the Reliability Engineering department. Also make sure the scheduling of the sampling / tests is correct and according to equipment requirements;
- Ensure that the reports received are analysed and that the required actions are taken;
- Plant personnel should improve on inspection (visual) procedures and techniques;
- Plant personnel should consider inspections before shutdown or start-up.
- Do post-commissioning inspections to prevent infant failures.

Much of the equipment at the HSM is continuously monitored for temperature and vibration. The accuracy of the equipment and the alarm levels should be inspected and set at the correct allowable settings. The required actions should be planned or taken immediately should there be an indication of extreme equipment damage or deterioration.

The artisans' skills to do condition-monitoring on the plant while doing routine inspections should be developed. Practical training can help the artisans to detect equipment failure by considering changes in sound, temperature and vibration.

5.4.3.4 Proactive maintenance

The HSM is already using proactive maintenance in many facets of its maintenance strategy. Each subsection of the HSM has a reliability pilot with a reliability plan where strategic planning for plant reliability tasks is captured. The pilot of each section analyses the areas where the equipment reliability is lowest and strategically plans the maintenance requirements to improve the reliability of that equipment. These plans could consist of the following proactive maintenance tasks:

- Design changes;
- New equipment;
- More effective processes;
- Improvement of works order quality;
- Adjustment of correct works order frequency;
- Improvement of maintainability through redesign or simple modifications.

The HSM has also started using a process of RCAs (Root Cause Analysis) and short loops (quick version of RCA) in order to analyse the root cause of all the failures on the plant. From this analysis the responsible person should indicate the required actions in order to reduce or eliminate the probability and consequence of the same failure. This is normally achieved by improvement of maintenance plans and their frequency, redesign, and system or equipment improvement.

There are also many capital projects that have been implemented in order to improve the process, quality and the reliability of the HSM. The availability of capital funds, however, is becoming scarcer as economical pressure is applied to the industry. It is therefore critical that the economic benefits of such projects are critically investigated to ensure maximum gain.

The HSM is in this sense very actively busy with the development of their approach towards proactive maintenance, and with great success. Their process of RCAs and Short Loops has proven to be very effective and many design changes/improvements and maintenance considerations have been made which greatly contributed to improved plant maintenance and reliability.

The above-mentioned RCM tools or processes are some of the very basics of plant maintenance and have been used for many years. There are some other basics that should first be put in place before new tools or processes are implemented:

5.4.3.5 Lubrication

In a plant such as the HSM there are many lubrication systems. There are grease systems and oil lubrication systems. Many maintenance experts consider lubrication to be one of the very basics of maintenance. Proper lubrication can not only prolong the life time of an asset but can also contribute to the reliability and functionality of that asset. Here are some lubrication basics the HSM should consider:

- Make sure that the correct type op lubrication is used for the correct application. Also make sure that the lubrication specification fits the requirements of the equipment specifications and operational requirements. Consider the forces, temperatures etc. in order to verify the correct viscosity grade oil etc.

- Make sure that the quantity and frequency of the required lubrication are sufficient.
- Ensure the correct cleanliness level of the lubrication. Manual application procedures should be according to sound engineering practices as well as the lubrication quantities. Automatic systems should be maintained and tested for functionality and adherence to required specifications.
- Automatic systems should have a good filtration system. The quality of the filters being used is of utmost importance. Regular filtration cleaning and replacement should be scheduled optimally.
- Ensure correct operation of warning system (temperatures, levels, flow, cleanliness levels etc,)

The HSM should make use of the oil sampling services and expert advice from the Reliability Engineering department.

5.4.3.6 Work planning and classification

The HSM should focus on the work planning between production and maintenance. The ideal would be a situation where maintenance is planned and executed according to production requirements. However, production planning should be accurate enough that the maintenance team can plan and prepare exactly according to the production requirements. Failure to do so, a lot of opportunity time will be lost.

Better planning for opportunity time during unplanned stoppages on other sections will also help maintenance departments to complete critical work or even backlog work with each and every opportunity time.

A good approach to work planning is to do as much maintenance while running. In the ideal situation only shutdown work will be performed on shutdowns while no running tasks will be performed on a shut down. This will greatly help with the utilization of resources and time management of shutdowns. The HSM maintenance teams should list and evaluate all the tasks that could be done while in production and all the tasks that requires planned shutdowns for execution.

Backlog should be prioritized to ensure that all outstanding work is completed. Prioritization of works orders should consider the probability vs. the impact of a failure.

5.4.3.7 Shutdown planning

In some instances at the HSM there exists significant room for improvement in the planning of shutdowns. A lot of resources are sometimes wasted due to poor planning between the production and maintenance personnel, leading to wasted opportunity time. Below a list of some of the things that can be improved:

- Planning of pre-shutdown tasks and preparation. Make sure that the sequence of maintenance activities are accurately determined in order to utilize resources optimally
- Ensure that enough supervision is appointed over hired labour to ensure workforce utilization and quality of work.
- Make sure all the required tools, spares, consumables are available and in working order to prevent time being wasted due to improper or non-working tools. Ensure specialized tools are also available.
- Ensure the quality of the spares and consumables before the shutdown.
- Work planning should happen on task execution level.
- Quality assurance, including Quality Control Plans (QCPs), should be implemented.
- SAP can be used for workforce planning and ordering of required spares and equipment, according to work orders.
- Make sure service providers such as cleaners are fully utilized.

Project planning software can be used to plan the shutdown and to keep track of all work progress. There should be an appointed facilitator to help with the planning of the shutdowns.

5.4.3.8 Task execution

Quality of task execution should be attended to. Poor task execution leads to improper equipment function and premature equipment failure. Here are some basics:

- Make sure the task executor training fits the work requirements. Do not use low-level artisans to do high-level work such as on intricate lubrication systems etc. Do not waste your resources by using a higher-level artisan to do cleaning work or lower-level tasks.
- Make sure that work performed by inexperienced artisans is double-checked for quality by more senior personnel or supervision.
- Hired labour used should be supervised at all times and quality of work should be double-checked. Unfortunately hired labour does not share the same level of ownership as AMSA personnel and the level of quality is in many cases substandard.
- Focus on alignment such as motors, gearboxes, rollers couplings etc and balancing of fans or impellers etc.
- Focus on good engineering practices and methods, torque of bolts, supporting of pipes etc.
- Prevent re-work due to poorly executed work.

5.4.3.9 Basic conditions

The basic conditions of the plant are of utmost importance. The reasoning should be: The basic conditions of the plant to which it was designed for, should be maintained in order for the plant to perform its original function. In many cases it is a matter of maintaining the original designs of equipment and processes. Basic conditions can also refer to the basic operating and working environment requirements, such as:

- Keeping the plant clean. A clean plant with clean equipment will help with the inspection on equipment and fault-finding. A clean plant will also improve the working environment of the plant personnel. A clean plant will create more pride in the workplace amongst workers and thus a feeling of increased ownership towards the plant.
- Make sure critical equipment is maintained at required condition.
- Make sure all equipment as per original design is in working condition and functions as required.
- The basic condition of workshops, tools and equipment is also important.
- In essence, ensure that equipment is secured, cleaned, aligned, at minimum vibration, lubricated, in the correct operating environment and at correct operating temperature.

The HSM should focus on the basic conditions of the plant. Not only does it promote better plant reliability but also improved ownership by the plant personnel.

5.4.3.10 Quality control

Quality on the maintenance side is very important. Good-quality work can prevent premature failures and saving of valuable resources. Poor maintenance quality can dramatically decrease the reliability of equipment. The following pointers should be considered regarding quality:

- Quality of new products such as replacement spares and consumables should be assured and controlled.
- Quality of reconditioned spares. Develop QCPs with certain hold points for quality inspections.
- Superintendants or more senior personnel must do inspections at hold points on QCPs and they must sign off the hold points before the work can continue.
- Quality control over specialized welding procedures and installations. Materials engineering to assist in procedures and quality control.

5.4.3.11 Feedback and continuous development

A plant's approach to maintenance should never become stagnant. It is very important the HSM should continuously develop their approach to maintenance. Each level of the maintenance structure should contribute to this in their field of expertise. Engineers and technicians should help with the development of the works orders to ensure that the quality of the works orders is on standard. They should always consider best practices and implement sound engineering practices in order to improve on maintenance techniques and efficiency. Engineers and technicians must investigate new products and services to be offered in the market which could be used to improve on maintenance techniques and plant equipment efficiency.

The superintendent must teach his artisans good practices and procedures to help develop their skills and understanding of the plant. His experience should be carried over while his good standard of work, practices and experience should be tools to help to ensure that quality work is done..

The artisans are responsible for good execution of maintenance tasks. They should be familiar with their plant and equipment and their maintenance requirements. The artisans are the people who execute the tasks, it is therefore important for them to develop the maintenance procedures as follow:

- Artisans must learn to do proper measurements and inspection on the condition of the plant equipment.
- They should report on the quality and the content of the works orders and make suggestions how to improve it.
- After the completion of an equipment change works order, they should note and report on ways to improve the procedure and the requirements such as tools and spares. Noting this feedback onto the maintenance system will help with future task execution, quality and resource optimization. It will also help with the development of the best practices for maintaining the plant specific equipment.
- Artisans should also give feedback on the inspection works orders where they can improve on the inspection tasks, inspection routes and inspection techniques according to the equipment requirements.
- Artisans should report back on the efficiency of maintenance frequency and tasks. They should report back on the condition of the removed parts and new spares and the changing frequency. They should give feedback on the quality of spares and services offered by service providers.
- They should identify and improve on equipment designs and processes. In the case where the modification or changes are extensive, they should consult the superintendent, technician or the plant engineer for help with the project.

By noting all this, the HSM can systematically develop and improve on the maintenance tasks and execution of works orders. Continuous development is part of the HSM's reliability strategy where changes and improvements can help with the efficiency of doing maintenance.

5.4.4 Computerized Maintenance Management System (CMMS)

The HSM is using SAP PM as their CMMS. SAP PM is a well-structured and comprehensive maintenance tool/system which is also linked to the financial system of AMSA. The capabilities of SAP are almost endless and cater for all the maintenance needs of the plant. There are a couple of things to be considered:

- Give the required training to planners and plant personnel by focusing on the maintenance tools and capabilities which can help with maintenance planning and execution.
- Plant personnel and planners should ensure the correct scheduling of all maintenance tasks and maintenance cards.
- The most effective maintenance strategy should be allocated to each works order per equipment. This can be done by considering the failure modes of an asset, the effects of the failure and criticality of each asset failure.
- Proper execution and feedback of all works orders are required. Continuous development is required in order to improve the quality and efficiency of the works orders. Correct and accurate feedback from inspections should help with the prioritization of tasks and the efficiency thereof.
- Quality of the works orders content by considering best practices, OEM (Original Equipment Manufacturer), suppliers and specialists to help with the quality and comprehensiveness of the works order content.
- Cleaning of SAP system. Ensure that there are no duplicate work orders requesting the same task at different times and different frequencies. Remove the unwanted and useless works orders that create paper work but do not contribute to the efficiency and quality of the work.
- Train plant personnel and planners to use SAP as a planning tools for shutdowns and work-force utilization.
- Use SAP to automatically order spares according to planned work and due works orders. This will reduce the amount of manual ordering of certain spares and equipment.

The HSM should reconsider their approach to working with Preventative Maintenance tasks. Correct histories should be recorded in order to verify equipment failure patterns and frequencies. This should serve as input to preventative maintenance scheduling. The HSM should consider changing from calendar-based to user-based preventative maintenance tasks. This will allow the scheduling system to better account for production rates, planned and unplanned downtime.

SAP is at the heart of the HSM maintenance system and, if used correctly, can enhance the plant’s ability to do effective maintenance. All plant personnel should be trained to work with SAP.

5.4.5 Failure modes of equipment

The conventional RCM process discussed in Chapter 2 uses a FMECA process to determine the Failure Modes, Effect and Critically of an equipment failure. This is however a long process and it is not required to do a full FMECA process on each and every asset or component. The suggestion for the HSM is to follow the following steps:

1. List all the equipment of the plant. The equipment ”function location” on SAP can be used for this.

2. Identify all the most critical areas with the most critical equipment. Plant personnel experience and history can be used. Use the 20/80 principle to identify first the 20 % that causes 80 % of the delays.

3. Identify all other critical equipment. Plant personnel experience and history can be used. Use the 20/80 principle to identify first the 20 % that causes 80 % of the delays.

4. Plant experience and history can be used to prioritize the equipment being analysed.

5. Assemble group to evaluate each asset as prioritized for the failure modes, effects and criticality of the asset. The team should consist of experienced personnel and personnel with knowledge of the operations and history of the plant.

6. The results of the equipment analysis should then be used to determine the required maintenance approach and scheduling of the task.

7. In the case of critical equipment with greater complexity, the full FMECA process can be used for a full and comprehensive maintenance analysis.

In many instances it could be required to get industry experts or even old employees in the equipment analysis team in order to obtain the most information as accurately as possible. According to a working schedule, the team should meet to discuss the planned equipment analysis and work orders. After work orders content has been finalized, the planner can update the SAP data base.

The FMECA process is not ruled out completely. In the case where the plant engineers or management team identifies a critical asset where the failure knowledge and experience on asset failure is not yet known, a complete and comprehensive FMECA can be completed in order to develop the maintenance requirements as best as possible.

5.4.6 Motivation and communication

Motivation of the plant personnel is critical when the HSM wants to develop its maintenance strategy. The management team should ensure that all role players understand the benefits, the requirements of the process and the roles and responsibilities of each participant. The management team can even invite quest speakers or industry experts to present success stories of various maintenance techniques and processes. As soon as the plant personnel understand and believe in the new maintenance approach and development, they will automatically have more confidence and ownership in the process. The plant personnel must be part of the new development process and they must give their inputs and contribution to its development and refinement.

The HSM management team should ensure that all new maintenance development tasks and decisions are communicated to all the plant role players. Poor communication can lead to de-motivated people and insufficient implementation of maintenance tasks or processes. The roles and responsibilities of each member should be established. Management must decide on the roles and responsibilities of the management team, production, engineers, technicians, superintendents, artisans and planners. Each one should exactly know their function, responsibilities and to whom they must report.

5.4.7 Training

The training of plant personnel is probably one of the most important aspects of operating and maintaining a plant. It is of utmost importance to effectively train the plant personnel in order for them to understand the plant processes and equipment. The following training is key:

- Artisan development in task execution skills. Artisans should know the plant and their equipment in order to do effective inspections, fault-finding and a high technical level of task execution.
- Advanced training in SAP and scheduling for the planers office in order for them to utilize SAP to its full potential according to maintenance and plant requirements.
- SAP training for engineers and technicians.
- Basic training in planning and scheduling skills for artisans.
- Achieve correct competency for each level of work.
- Training in RCM and other maintenance strategies.

Sufficient competency on all levels will help to improve on the quality of work, reduce re-work due to poorly executed tasks, and to better prevent equipment failure by improved inspections and fault-finding techniques. An overall improvement in competence will help the plant to work more cost- and time-effectively.

5.5 Management's responsibility

As stated at the start of this chapter, the procedure provided (maintenance improvement plan) is a proposed guideline which the management team could use for the improvement of the HSM maintenance practices. However, the management team still has to decide how to implement these suggestions. This can be determined by analysing the operating and financial requirements of the plant. This adaptability in the process will enable the management team to focus on the important things first in order to improve the reliability and availability of the plant. Overall it is the management team's responsibility to develop and drive the maintenance improvement plan and to ensure its continuous development.

6. Conclusion and recommendations

6.1 Conclusion

The RCM process is no doubt a very effective and comprehensive maintenance process that will yield success if it is implemented as originally designed and intended. The basic principles of the RCM process are discussed in Chapter 2 and indicate sound maintenance engineering practices. The RCM process has been implemented with great success in the aviation industry where failure risks and consequences are high. By implementing a comprehensive (full) RCM approach the aviation industry managed to have great success in reducing aircraft failures. The advantage of the RCM process is that it enables the user to identify and efficiently manage the maintenance requirements of each and every asset in a facility, to its finest detail. In such a case the maintenance practitioners will learn all the detail and specifications of the equipment leading to improved skills and understanding in the operation and maintenance requirements and procedures of the plant equipment. However, the comprehensive RCM approach is not considered to be the most feasible approach to maintenance in a heavy industry environment where the risks and consequences are lower, such as in the case of steel mills and the mining and cement industry. A lighter or less intense RCM-based approach will help the facility to manage its resources more effectively and to obtain sustainable results in a shorter period of time. This is the basic approach PPC Cement has followed, with great success in their maintenance strategy.

The biggest disadvantage, and perhaps the main contributing factor to failed RCM implementation attempts, is the fact that the comprehensive RCM approach is very resource-intensive and requires a lot of dedication and perseverance from the plant's side to implement it successfully. It can take many months to successfully implement RCM or to yield any results in terms of plant availability and equipment reliability. This causes plant personnel and the management teams to lose faith in the process, and in many cases it is abandoned even before it has been completely implemented. For the HSM this is exactly why their attempt to implement RCM has not yielded sustainable results.

To assist with the process of developing a maintenance improvement plan for the HSM, individual interviews (Chapter 4) were held with two industry experts. From the interviews some insight was obtained on success stories in maintenance development programs. Louis Fouche from PPC Cement shared their process that led to success. He is also of the opinion that a facility should be wary of implementing the comprehensive RCM approach and should rather use an "RCM light" approach together with good maintenance engineering practices that are adaptable and suitable for the facility's needs. This allowed PPC Cement to achieve great success in their newly developed maintenance strategy. Dominique Cosset in his interview highlighted various basic maintenance principles and practices that he has learned over years of experience and success in maintenance development programs in various plants over the world. The ideas and concepts obtained from these interviews were used in the development of the HSM's maintenance improvement plan in Chapter 5.

The RCM process can be implemented at an old plant such as the HSM; however, it is strongly advised not to use the comprehensive RCM approach but rather a systematic maintenance improvement process such as proposed in Chapter 5. The proposed maintenance improvement plan for the HSM consists mainly of sound maintenance engineering practices, processes and tools also to be found in the RCM process. However, the implementation strategy differs greatly and has a more long-term development agenda instead of the full RCM implementation approach. This will help with managing the resources required and to systematically implement the changes without dramatically disturbing the current maintenance approach and culture in the plant. It will allow the management team and plant personnel to gradually make improvements and to systematically change the maintenance culture and processes.

6.2 Recommendations

It is recommended that the HSM management team should first do a detailed analysis of the current maintenance management system and its shortcomings by considering the first step in the proposed maintenance improvement plan in Chapter 5. The management team should do a comprehensive maintenance audit to first identify the problems and inefficiencies of the process. Using the results of the audit the management team can make informed decisions what areas to focus on and where to start with the process. The ideal would be to focus first on the things that can be easily addressed and fixed, yielding greater initial results with the least amount of resources and effort. Only then can the management team start to focus on the more detailed and resource-intensive requirements by considering a longer-term plan and execution strategy.

It is further recommended that the HSM management consult other companies that underwent a similar process in order to learn from their mistakes, achievements and successes in the finer detail of the actual implementation of the maintenance improvement process. This will help to continually develop the maintenance improvement plan and to assure that a tried and tested approach is followed. The required technical skills and knowledge can be learned by involving the expertise of other companies. Further, it is recommended that the HSM management team should ensure that all role-players are on board with this process. It is the management team's responsibility to assure the motivation, drive and continuation of the process.

It is important for the HSM management team to realise that this approach is not a quick implementation approach and should be planned and managed over a period of say two to five years. The entire HSM management team as well as the AMSA Vanderbijlpark management should know about the maintenance improvement plan being implemented, to ensure the sustainability of the development process. Finally, the process itself should be continuously developed and adapted to the current production and financial requirements of the company. Focus should be placed on resource utilization, quality, plant availability and equipment reliability, with safety always to be considered as the number one priority.

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Appendix A

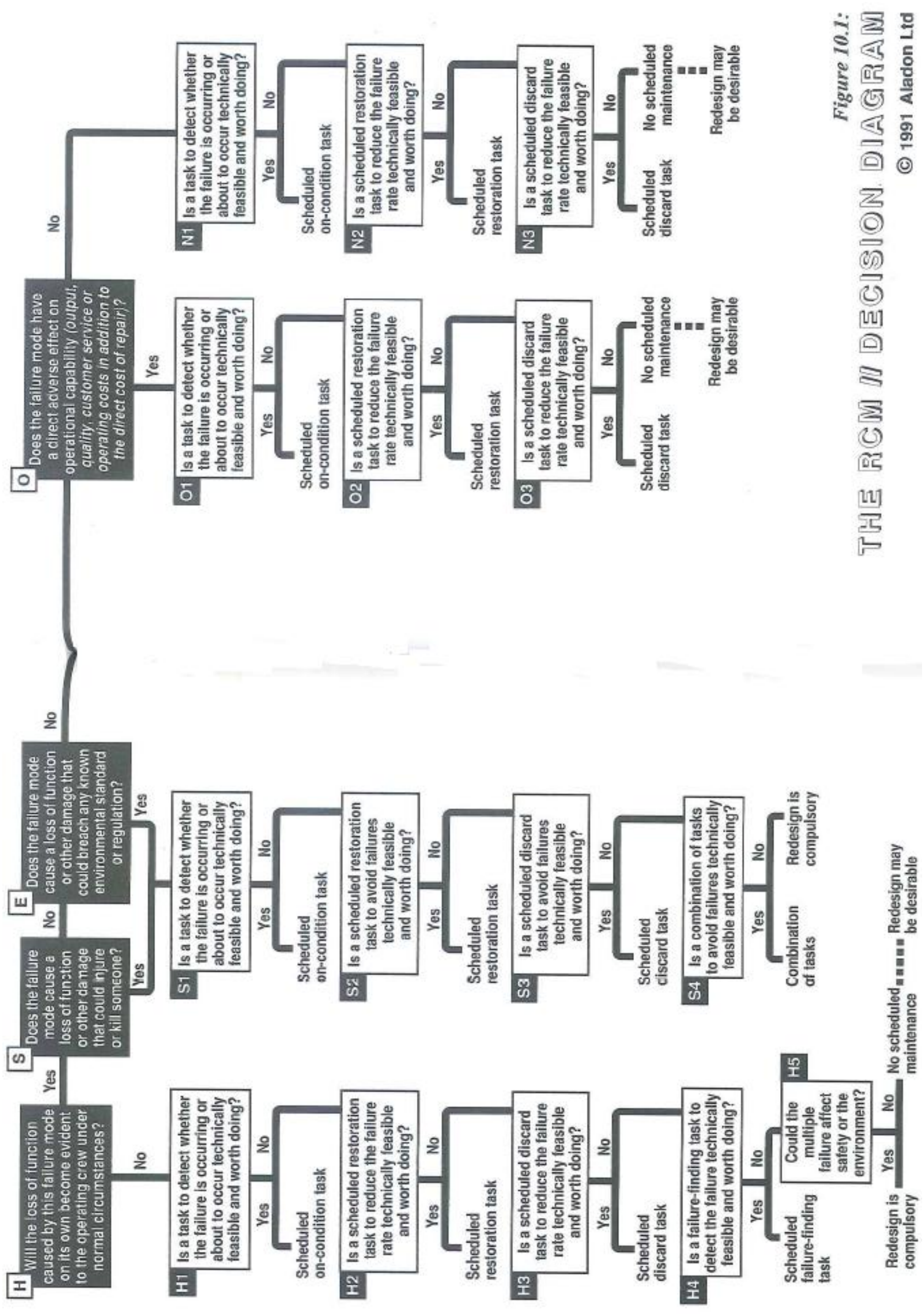

Figure 10.1: THE RCM II DECISION DIAGRAM

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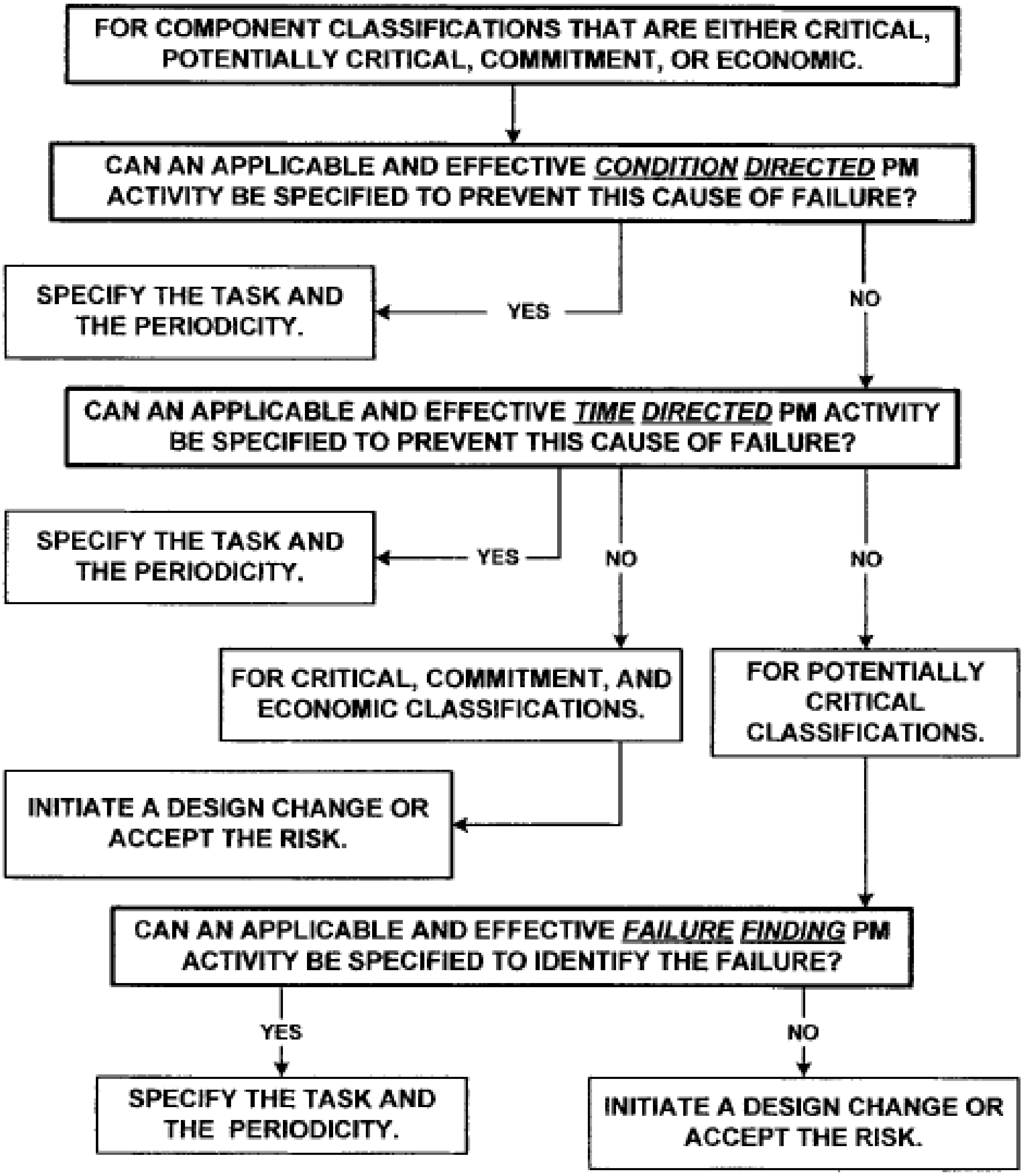
Appendix B



NOTE: A FAILURE FINDING TASK IS NOT APPLICABLE FOR CRITICAL, COMMITMENT, OR ECONOMIC COMPONENTS BECAUSE THE CONSEQUENCE HAS ALREADY OCCURRED WHEN THE COMPONENT FAILED.

Appendix C

PM COST

(A) LABOR WORKER-HOUR (WH) COSTS:

1) MAINTENANCE WHs = ______ @ $______ / WH = $______

2) OPERATIONS WHs = ______ @ $______ / WH = $______

3) OTHER WHs = ______ @ $______ / WH = $______

Total Labor Cost / Yr = $______ × ______ Number of PMs / Yr = $______

(B) PM MATERIAL COSTS:

Material Cost / PM = $______ × ______ Number of PMs / Yr = $______

(C) MISCELLANEOUS COSTS:

1) Rental equipment cost = $______ × ______ Number of PMs / Yr = $______

2) Other misc costs = $______ × ______ Number of PMs / Yr = $______

Total Misc Cost / Yr = $______ × ______ Number of PMs / Yr = $______

TOTAL PM COST PER YEAR = A + B + C = $______ /

NOTE: If the PM is accomplished every 2 years, number of of PMs per year would be 0.5.

RTF COST

(A) LABOR WORKER-HOUR (WH) COSTS:

1) MAINTENANCE WHs = ______ @ $______ / WH = $______

2) OPERATIONS WHs = ______ @ $______ / WH = $______

3) OTHER WHs = ______ @ $______ / WH = $______

Total Labor Cost / Yr = $______ × ______ Number of failures / Yr = $______

(B) MATERIAL COSTS:

Material Cost / failure = $______ × ______ Number of failures / Yr = $______

(C) MISCELLANEOUS COSTS:

1) Rental equipment cost = $______ × ______ Number of failures / Yr = $______

2) Other misc costs = $______ × ______ Number of failures / Yr = $______

Total Misc Cost / Yr = $______ × ______ Number of failures / Yr = $______

TOTAL RTF COST PER YEAR = A + B + C = $______ /

NOTE: If the component fails every 3 years, on average, number of failures per year would be 0.33.

COST COMPARISON

If the PM costs per year are greater than the RTF costs per year, the component should be RTF (in the absence of any safety or operational concerns).

If the PM costs per year are less than the RTF costs per year, the component should be part of the preventive maintenance program.

ANALYSIS PERFORMED BY: ________ / ________ / ________

DATE: ________

Appendix D

Questionnaire for Non-ArcelorMittal Hot Strip Mill maintenance practitioners

Fouche, Heinrich

Please return by: Friday 25 July 2014

I am currently busy with my Masters dissertation for my Masters degree in Engineering Development and Management. The title of my dissertation is: Practical implementation of RCM principles and practices at a Hot Strip Mill. This questionnaire will form part of my experimental research and data collection for my dissertation. From the results I hope to obtain a comprehensive insight in the industry's general perception of the RCM process. Ultimately I would like to determine whether RCM is an effective and practical maintenance strategy which can be implemented in a practical and sustainable manner.

I thank you for your time and effort. I hope that you find this questionnaire interesting and enjoyable. I am looking forward to your inputs and the results of this survey.

Name and Surname: ___________________________________

Designation: ___________________________________

Approximate years of maintenance experience: ________________________

Please provide short description of type of industry and maintenance background/ experience:____

____

____

____

1. Are you familiar with RCM (Reliability Centered Maintenance)? If Not, please select the first option in the selection box below. In this case it is not necessary for you to complete the rest of the questionnaire. If Yes, please indicate the level of your understanding of RCM (Mark correct choice with a X):

I am not familiar with RCM	Mark with x
You have heard about RCM and knows only the very basics of the concept	Mark with x
You have a very good theoretical understanding of the principles and processes of RCM	Mark with x
You have extensive understanding of the RCM process/or have been personally involved with an RCM implementation project?	Mark with x

2. Have you ever received any training on the RCM process?

Yes	No

3. RCM is a world class maintenance approach if implemented and used as intended? To what extent do you agree with this statement?

Strongly disagree	
Disagree	
Agree	
Strongly Agree	

4. RCM is an over complicated approach to maintenance as considered by many? To what extent do you agree with this statement?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

5. The RCM process is considered as a very well-structured maintenance approach originally developed in the aviation industry. Please strictly follow the following instruction: **Ignore** the above statement and please mark the below selection box at disagree and strongly agree.

Strongly disagree	
Disagree	
Agree	
Strongly agree	

6. Do you think the culture of an organisation plays a vital role in the successful implementation of a maintenance management system/strategy?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

7. Have you ever been part of a RCM implementation project? If your answer is No, please ignore question 8 to 18.

Yes	No

8. If your answer to Question 7 is Yes, where and in what type of industry was the RCM project implemented (if more than one, please indicate):

1.____

2.____

3.____

9. For each of the above mentioned project(s), was the implementation successful? Please indicate against each of the examples:

1.	Yes	No
2.	Yes	No
3.	Yes	No

10. For each one of the above projects in Question 8, is the RCM process still active and functioning as intended?

1.	Yes	No
2.	Yes	No
3.	Yes	No

11. For each one of the projects in Question 8, has the RCM program delivered the required and expected outcome?

1.	Yes	No
2.	Yes	No
3.	Yes	No

12. For each one of the projects in Question 8, how long did it take to implement the project (if applicable):

1.	____________Months
2.	____________Months
3.	____________Months

13. For each one of the projects in Question 8, how long did it take before RCM project was abandoned/failed (if applicable):

1.	____________Months
2.	____________Months

3.	___________Months

14. If the answer to Question 9 is no, in short, describe why you think these projects failed:

____
____
____
____
____

15. For the RCM projects in Question 8, was there a dedicated RCM project team allocated to the project?

1.	Yes	No
2.	Yes	No
3.	Yes	No

16. Were the members of the RCM team still responsible for their normal daily plant activities and maintenance duties?

1.	Yes	No
2.	Yes	No
3.	Yes	No

17. If Yes for Question 15, how big was the team dedicated to the different projects?

1.	________Members
2.	________Members
3.	________Members

18. What disciplines were represented on these teams?

____
____
____

19. Would you agree that the RCM approach is difficult to implement and perhaps an overcomplicated maintenance strategy?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

20. To what extent do you consider the RCM process as an effective and comprehensive maintenance approach?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

21. Do you think the RCM process is practical and can be easily implemented at most plants?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

22. If your answer above is No, what alternative would you recommend in the place of RCM?

____

____

____

23. Do you think RCM can be considered a world class maintenance strategy?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

24. RCM is a well-known maintenance approach all over the world. Please strictly follow the following instruction: **Ignore** the above statement and please mark yes and no in the selection box below:

Yes	No

25. Do you think it is imperative to do a Failure Mode, Effect and Criticality Analysis for every component/asset in a typical "low risk" type industry?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

26. Do you think that most of the relatively easy Failure Mode, Effect and Criticality Analysis could be replaced by analysis of personnel experience and equipment failure history?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

27. Do you think that RCM can add value as a maintenance solution for an old plant with old equipment (30 to 50 years old)?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

28. Do you think that the maintenance culture of a plant plays a vital role in the success of RCM implementation?

Strongly disagree	
Disagree	
Agree	

Strongly agree	

29. Do you think that the buy-in of plant personnel is vital for successful implementation of a maintenance program/project?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

30. Do you think it is viable to implement a RCM project on a plant that is under severe pressure in terms of resources and budget constraints?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

31. Which one of the following statements do you prefer?:

1.	It is better to appoint a consulting firm to implement a maintenance improvement project?	Yes	No
2.	It is better to maintain in-house control by involving own people in the development of a maintenance improvement project.	Yes	No
3.	It is better to have a combination of external and in-house involvement in the development and implementation of a maintenance improvement project.	Yes	No

32. Do you think that it is important to focus first on the basics of maintenance before one resolve to maintenance improvements projects such as RCM?

Strongly disagree	
Disagree	
Agree	

Strongly agree	

Questionnaire assessment

The purpose of this section is to reflect on the quality of this questionnaire. Please take another minute or two and complete the following questions:

1. Were the information/questions asked relevant and meaningful to this study?

Yes	No

If No, please indicate why:

____

____

2. Were all the information/questions and instructions clear and understandable?

Yes	No

If No, please indicate why:

____

____

3. How long did it take you to complete the questionnaire? _______________________________

4. Please indicate your rating of the quality and standard of this questionnaire:

Poor	
Expectable	
Good	
Excellent	

Any other general comments:-

____

____

Thank you for participating. Your time and effort in this questionnaire is highly appreciated. Thank you and best regards.

Heinrich Fouche

Appendix E

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Questionnaire for ArcelorMittal Hot Strip Mill maintenance practitioners

[Pick the date]

Please return by: Friday 25 July 2014

I am currently busy with my Masters dissertation for my Masters degree in Engineering Development and Management. The title of my dissertation is: Practical implementation of RCM principles and practices at a Hot Strip Mill. This questionnaire will form part of my experimental research and data collection for my dissertation. From the results I hope to obtain a comprehensive insight in the industry's general perception of the RCM process. Ultimately I would like to determine whether RCM is an effective and practical maintenance philosophy which can be implemented in a practical and sustainable manner.

I thank you for your time and effort. I hope that you find this questionnaire interesting and enjoyable. I am looking forward to your inputs and the results of this experiment.

Name and Surname: ____________________________________

Designation: ____________________________________

Approximate years of maintenance experience: _________________________

Please provide short description of type of industry and maintenance background/ experience:____

____

____

____

1. Are you familiar with RCM (Reliability Centered Maintenance)? If Not, please select the first option in the selection box below. In this case it is not necessary for you to complete the rest of the questionnaire. If Yes, please indicate the level of your understanding of RCM (Mark correct choice with a X):

I am not familiar with RCM	Mark with x
You have heard about RCM and knows only the very basics of the concept	Mark with x
You have a very good theoretical understanding of the principles and processes of RCM	Mark with x
You have extensive understanding of the RCM process/or have been personally involved with an RCM implementation project?	Mark with x

2. Have you ever received any training on the RCM process?

Yes	No

3. RCM is a world class maintenance approach if implemented and used as intended? To what extent do you agree with this statement?

Strongly disagree	
Disagree	
Agree	
Strongly Agree	

4. RCM is an over complicated approach to maintenance as considered by many? To what extent do you agree with this statement?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

5. The RCM process is considered as a very well-structured maintenance approach originally developed in the aviation industry. Please strictly follow the following instruction: **Ignore** the above statement and please mark the below selection box at disagree and strongly agree.

Strongly disagree	
Disagree	
Agree	
Strongly agree	

6. Do you think the culture of an organisation plays a vital role in the successful implementation of a maintenance management system/philosophy?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

7. Have you ever been part of a RCM implementation project? If your answer is No, please ignore question 8 to 18.

Yes	No

8. If your answer to Question 7 is Yes, where and in what type of industry was the RCM project implemented (if more than one, please indicate):

1.____

2.____

3.____

9. For each of the above mentioned project(s), was the implementation successful? Please indicate against each of the examples:

1.	Yes	No
2.	Yes	No
3.	Yes	No

10. For each one of the above projects in Question 8, is the RCM process still active and functioning as intended?

1.	Yes	No
2.	Yes	No
3.	Yes	No

11. For each one of the projects in Question 8, has the RCM program delivered the required and expected outcome?

1.	Yes	No
2.	Yes	No
3.	Yes	No

12. For each one of the projects in Question 8, how long did it take to implement the project (if applicable):

1.	____________Months
2.	____________Months
3.	____________Months

13. For each one of the projects in Question 8, how long did it take before RCM project was abandoned/failed (if applicable):

1.	____________Months
2.	____________Months
3.	____________Months

14. If the answer to Question 9 is no, in short, describe why you think these projects failed:

____
____
____
____
____

15. For the RCM projects in Question 8, was there a dedicated RCM project team allocated to the project?

1.	Yes	No
2.	Yes	No
3.	Yes	No

16. Were the members of the RCM team still responsible for their normal daily plant activities and maintenance duties?

1.	Yes	No
2.	Yes	No
3.	Yes	No

17. If Yes for Question 15, how big was the team dedicated to the different projects?

1.	________Members
2.	________Members
3.	________Members

18. What disciplines were represented on these teams?

____
____
____

19. Would you agree that the RCM approach is difficult to implement and perhaps an overcomplicated maintenance philosophy?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

20. To what extent do you consider the RCM process as an effective and comprehensive maintenance approach?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

21. Do you think the RCM process is practical and can be easily implemented at most plants?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

22. If your answer above is No, what alternative would you recommend in the place of RCM?

____

____

____

23. Do you think RCM can be considered a world class maintenance philosophy?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

24. RCM is a well-known maintenance approach all over the world. Please strictly follow the following instruction: **Ignore** the above statement and please mark yes and no in the selection box below:

Yes	No

25. Do you think it is imperative to do a Failure Mode, Effect and Criticality Analysis for every component/asset in a typical "low risk" type industry?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

26. Do you think that most of the relatively easy Failure Mode, Effect and Criticality Analysis could be replaced by analysis of personnel experience and equipment failure history?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

27. Do you think that RCM can add value as a maintenance solution for an old plant with old equipment (30 to 50 years old)?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

28. Do you think that the maintenance culture of a plant plays a vital role in the success of RCM implementation?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

29. Do you think that the buy-in of plant personnel is vital for successful implementation of a maintenance program/project?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

30. Do you think it is viable to implement a RCM project on a plant that is under severe pressure in terms of resources and budget constraints?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

31. Which one of the following statements do you prefer?:

1.	It is better to appoint a consulting firm to implement a maintenance improvement project?	Yes	No
2.	It is better to maintain in-house control by involving own people in the development of a maintenance improvement project.	Yes	No
3.	It is better to have a combination of external and in-house involvement in the development and implementation of a maintenance improvement project.	Yes	No

32. Do you think that it is important to focus first on the basics of maintenance before one resolve to maintenance improvements projects such as RCM?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

The following questions are directed to the Hot Strip Mill

33. In the past, has the HSM attempted to implement RCM?

Yes	No

34. Was this RCM project successfully implemented?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

35. In your opinion, what was the main contributing factor that led to the result in Question 34?

____

____

____

36. Do you think there exist a need for the HSM to improve on its current maintenance strategy and processes?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

37. Do you think RCM is a suitable maintenance approach for improvement of the HSM maintenance philosophy?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

38. Do you think that the HSM has enough resources to successfully implement a RCM program (availability of funds and people)?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

39. Do you think that the HSM has a culture that will accept the implementation of RCM?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

40. One of the elements of the RCM process is a FMECA. Please strictly follow the following instruction: **Ignore** the above statement and please mark agree and strongly agree in the selection box below:

Strongly disagree	
Disagree	
Agree	
Strongly agree	

41. Is the culture at the HSM one of difficulty to adapt and reluctant to change?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

42. Please motivate your answer in Question 41 in short.

43. Do you think the culture at the HSM would rather embrace a systematic improvement and development of current maintenance processes, than the full implementation of a RCM project?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

44. Do you think that HSM management will be able to establish the buy-in or belief of the people in the development of the HSM maintenance program?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

45. Finally, do you think that it is possible to successfully implement RCM at the HSM now or even in the near future?

Strongly disagree	
Disagree	
Agree	
Strongly agree	

Questionnaire assessment

The purpose of this section is to reflect on the quality of this questionnaire. Please take another minute or two and complete the following questions:

1. Were the information/questions asked relevant and meaningful to this study?

Yes	No

If No, please indicate why:

____

____

2. Were all the information/questions and instructions clear and understandable?

Yes	No

If No, please indicate why:

____

____

3. How long did it take you to complete the questionnaire? _________________________________

4. Please indicate your rating of the quality and standard of this questionnaire:

Poor	
Expectable	
Good	
Excellent	

Any other general comments: -

____

____

____

____

____

____

____

Thank you for your participation. Your time and effort in this questionnaire is dearly appreciated. Thank you and best regards.

Heinrich Fouche

Appendix F

Count: 15(HSM) + 21(Non-HSM) = 36 participants in total

Accepted: 14(HSM) + 20(Non-HSM) = 34 Questionnaires accepted

Rejected: 1(HSM) + 1(Non-HSM) = 2 questionnaires rejected

Failed trick question, 5-24-40	**1 +1**
Inconsistency in answers, (4&19)-(3&23)-(6&28)	0

Discipline:

Mechanical engineer	**5+8 = 13**
Mechanical Manager	2 + 7 = 9
Electrical engineer	2
Electrical manager	1
Sivel engineer	1
Mechanical technician	2 + 2 = 4
Electrical technician	
Mechanical foreman	2
Electrical foreman	1
Senior planner	1

Yellow group = HSM (Hot Strip Mill) group

Green group = Non-HSM group

Table 4: Participants data

Name and surname	Current Occupation	Work Experience	Years of experience
Tony Filizzola	Electrical Supt.	Electrician and contractor electrician at chemical, explosive and fertilizer factory. Electrician and Supt. At steel rolling plant	36
Jaco Visser	Maintenance progress Manager	Mechanical engineer at steel rolling plant. Reliability manager	11
Riaan Coetzee	Maintenance Manager	Plant engineer at steel rolling plant. 4 years Maintenance manager at Hot Strip Mill	22
Johan Lombard	Mechanical Supt.	Fitter and master fitter at Hot Strip Mill Finishing Mill. 3 years as Mechanical maintenance Supt.	24
Benico van der Westhuizen	Senior Mechanical Engineer	Worker as engineer on steel plant. Engineer for Murry and Roberts. Reliability pilot and senior engineer at Hot Strip Mill	16
Schalk	Senior Engineer	Engineer at Direct reduction plant and	33

Engelbrecht		Hot Strip Mill at steel fabrication plant	
Piet janse van Resnburg	Mechanical Supt.	5 & 6 mm temper mills, pickle line and hot strip finishing lines as fitter and master fitter. Mech Supt. at Hot Strip Mill Finishing Mills	35
Harold Venter	Technologist	Hot Strip Mill maintenance technician	25
Sebastien Begue	Hot Strip Mill plant manager	Maintenance engineer, Maintenance manager and Plant manager	18
Willem Bezuidenhout	Mechanical Technician	Maintenance technician at Cold Mills and Hot Strip Mill in steel fabrication industry	3
Bennie van Graan	Mechanical Engineer	Steel industry as reliability/maintenance engineer, Business Improvement section of steel fabrication plant	6
Capie Nel	Snr Planner	Iron and steel manufacturing. Mechanical maintenance on cold and hot rolling plants	40
Dewald Barkhuysen	Electrical Maintenance manager	Steel manufacturing industry. Projects, day to day issues, redesigns, Management	24
Ronald Naidoo	Mechanical Engineer	Steel manufacturing industry. Experienced as palnt/maintenance engineer.	4
Andre Jansen Van Vuuren	Maintenance principle specialist	Maintenance manager and maintenance specialist, developer of AMSA maintenance programs, Iscor	10
JC Pretorius	Maintenance services manager	Engineer and manager at NATREF. Petro chemical plant, rotating equipment, welding, pressure vessels, pressurized equipment, electrical and instrumentation, NATREF	24
Henk Schoeman	Senior accountant	Engineer, maintenance engineer and maintenance manager on various steel fabrication plants, Iscor	12
Joe Naude	Group engineering services manager	Plant engineer, Engineering manager, maintenance system development and implementation in cement industry, PPC cement	23
Llowellen Lombard	Asset care specialist	Maintenance execution and development at cement plant, PPC cement	19
Louis Fouche	Asset care manager	Maintenance background at cement/lime plant. Maintenance systems designer, technical competency and training, PPC cement	28
Riaan Coetzer	Asset care specialist	Maintenance executioner, part of asset care team, maintaining of maintenance systems at PPC cement	20
SJK Fick	Senior engineer	Maintenance and plant engineer, maintenance manager, manager over	28

		planning section and engineers at steel fabrication plant at Iscor	
Thinus Steyn	Maintenance specialist	Maintenance and manufacturing and maintenance support as specialist at SAFRIPOL	37
Louis du Plessis	Maintenance manager	Plant engineer and maintenance manager at steel fabrication plant, Iscor	3
Helmut Serapins	Senior project manager	Plant and projects engineer, engineering development manager, senior project manager, Iscor	35
Abrie Rossouw	Maintenance manager	Engineer and manager at steel fabrication plant, Iscor	8
Barries Barnard	Chief Mechanical engineer	Aircraft industry, design and modifications and maintenance, cement industry, maintenance and engineering projects, PPC cement	15
Nico de Klerk	Snr projects manager	Engineer at various steel fabrication plants, Iscor	25
Jacques Esterhuizen	Maintenance progress manger	Plant maintenance, maintenance strategy development and implementation, Iscor	20
Cheslyn Jones	Maintenance services manager	Petro chemical environment as engineer, projects, pumps and turbines, rotating equipment NATREF	9
Jaco Cronje	Mechanical Engineer	Maintenance in petro chemical plant, NATREF	4
Hannes Venter	Mechanical Technologist	Worked as mechanical technician at Hot strip Mill, Iscor	25
Talita van den Berg	Civil Engineer	Power generation, Involved with maintenance of the civil plant, ESKOM	3
Johann Wilhelm Moller	Electrical Engineer	Worked with Lethabo EMS (Electrical Maintenance Services), units and outside plant for 6 months	1

Average years of experience of sample group = 19 years

Non-HSM employee participants completed: Question 1 - 32 and 1- 4(questionnaire review)

HSM employee participants completed: Question 1 – 45 and 1- 4(questionnaire review)

Question 33 – 45 was aimed at HSM employees only

1. Are you familiar with RCM (Reliability Centered Maintenance)? If Not, please select the first option in the selection box below. In this case it is not necessary for you to complete the rest of the questionnaire. If Yes, please indicate the level of your understanding of RCM (Mark correct choice with a X):

I am not familiar with RCM	**0**	**0%**
You have heard about RCM and knows only the very basics of the concept	6	18%
You have a very good theoretical understanding of the principles and processes of RCM	14	41%
You have extensive understanding of the RCM process/or have been personally involved with an RCM implementation project?	14	41%

2. Have you ever received any training on the RCM process?

Yes	No
25	9
74%	26%

3. RCM is a world class maintenance approach if implemented and used as intended? To what extent do you agree with this statement?

Strongly disagree	**0**	**0%**
Disagree	0	0%
Agree	20	59%
Strongly Agree	14	41%

4. RCM is an over complicated approach to maintenance as considered by many? To what extent do you agree with this statement?

Strongly disagree	**5**	**15%**
Disagree	9	26%
Agree	19	56%
Strongly agree	1	3%

5. The RCM process is considered as a very well-structured maintenance approach originally developed in the aviation industry. Please strictly follow the following instruction: **Ignore** the above statement and please mark the below selection box at disagree and strongly agree.

Strongly disagree	**0**	**0%**
Disagree	34	50%
Agree	0	0%
Strongly agree	34	50%

6. Do you think the culture of an organisation plays a vital role in the successful implementation of a maintenance management system/philosophy?

Strongly disagree	**2**	**6%**
Disagree	0	0%
Agree	11	32%
Strongly agree	21	62%

7. Have you ever been part of a RCM implementation project? If your answer is No, please ignore question 8 to 18.

Yes	**No**
23	11
67%	33%

8. If your answer to Question 7 is Yes, where and in what type of industry was the RCM project implemented (if more than one, please indicate):

1.________25 projects in total____

2.____

3.____

9. For each of the above mentioned project(s), was the implementation successful? Please indicate against each of the examples:

1.	**16**	**9**
2.	Yes	No
3.	Yes	No

10. For each one of the above projects in Question 8, is the RCM process still active and functioning as intended?

1.	**10**	**15**
2.	Yes	No
3.	Yes	No

11. For each one of the projects in Question 8, has the RCM program delivered the required and expected outcome?

1.	**16**	**9**
2.	Yes	No
3.	Yes	No

12. For each one of the projects in Question 8, how long did it take to implement the project (if applicable):

1. 6, 12, 12, 6, 36, 18, 24, 8, 12, 18, 4years, 60, contin, 6, 24, 24, 24, 36, 24, 6, 9, 12, 6, 9, 7	**________Months**
2. Average of 19 months	___________Months
3.	___________Months

13. For each one of the projects in Question 8, how long did it take before RCM project was abandoned/failed (if applicable):

1.12, 40, 40, 12, 48, 18, NA, NA, NA, NA, 24, NA, Cannot say, NA, 6, 12, 12, 18, NA	**________Months**
2. Average of 22 months	___________Months
3.	___________Months

14. If the answer to Question 9 is no, in short, describe why you think these projects failed:

- Change of maintenance system to a new system, tony
- Culture plays a vital role in the implementation of RCM, tony
- Constant moving of staff, tony
- Instability in company, tony
- Will fail due to top management commitment and drive, benico
- Execution of tasks/inspections not done as intended. Feedback accumulated but due to time and manpower constraints the backlog could not be reduced. Not much progress to improvement was made, bchalk
- Some of the stuff implemented was not carried out due to lack of personnel and lack of cooperation between maintenance and operations
- The RCM process was not followed completely. Due to the high number of equipment (in access of 4000 pieces of equipment per plant) the FMECA process is too complex and time consuming. Eventually other maintenance strategies were also employed. People/ resources were not delegated to these projects on a full time basis.
- Over complicated
- Needs discipline
- The culture of the people was not changed. General negative feeling on floor level about the project. The moment the dedicated team stopped their efforts, the project started to fail. At a later stage a new management team was appointed and they wanted to do something else.
- RCM is a to long and stretch out process and a lot was due to the culture and attitude

15. For the RCM projects in Question 8, was there a dedicated RCM project team allocated to the project?

1.	**21**	**4**
2.	Yes	No
3.	Yes	No

16. Were the members of the RCM team still responsible for their normal daily plant activities and maintenance duties?

1.	**19**	**6**
2.	Yes	No
3.	Yes	No

17. If Yes for Question 15, how big was the team dedicated to the different projects?

1. 5, 9, 6, 6, 9, 8, 7, 3, 10, 6, 5, 20, 3, 6, NA, 10, 7, 3, 6, 10, 12, 6	**______Members**
2.	________Members
3.	________Members

18. What disciplines were represented on these teams?

- Manager, Engineer, Supt., Planner, Electrician (tony)
- Engineer, Technician, Fitter, Elect, Planner, Supt (Riaan)
- Mechanical supt, Fitter, Technician (johan)
- Mech, elek, systems, production (benico)
- Mechanical eng, elek eng, elek systems eng, technicians, artisans (schalk)
- Mech technician, elek tec, systems tech, fitters, electrician, harold
- Mech, elect, systems , sebastien
- Elec, mech, industrial engineers, mech, elec technician, fitters, elec, millwrights, welders, planners
- Mainly mechanical
- Elec, Mech, instrumentation and diesel mech
- Artisans, foreman, engineers, specialists
- Mechanical, elec , instrumentation, rel engineer, production person and mechanical tech
- Maintenance, Production and engineering
- Mechanical, electrical and instrumentation
- Mechanical, Electrical, systems, Instrumentation
- Tech, Eng, Artisans and supts
- Engineers, Maintenance and planning

19. Would you agree that the RCM approach is difficult to implement and perhaps an overcomplicated maintenance philosophy?

Strongly disagree	**3**	**9%**
Disagree	14	41%
Agree	11	32%
Strongly agree	6	18%

20. To what extent do you consider the RCM process as an effective and comprehensive maintenance approach?

Strongly disagree	**1**	**3%**
Disagree	2	6%
Agree	22	65%
Strongly agree	9	26%

21. Do you think the RCM process is practical and can be easily implemented at most plants?

Strongly disagree	**1**	**2%**
Disagree	16	36%
Agree	23	52%
Strongly agree	4	9%

22. If your answer above is No, what alternative would you recommend in the place of RCM?

- Reliability program, jaco visser
- Basic conditions, jaco visser
- Focus on critical equipment causing largest delays, jaco visser
- WCM, MUDA elimination, Poka yoke for maint, TPM, Five s, lean MNF, six sigma (benico)
- RCM ‘lite’. Focus on applying the intention of the process and controlling the execution. The philosophy is sound but the process is time consuming.
- Reliability program, piet
- Focus on critical equipment and the things that went wrong instead of doing all the failure probabilities
- Reliability program through RCA’s and short loops
- NA,
- Condition based maintenance, RBI,
- The RCM principles is sound with proper logical backing for all solutions, however, the process should be streamlined to identify critical equipment and the focus should be placed on those equipment rather than a whole plant. Some of the WCM cost deployment principles can be applied here to identify such equipment.
- Needs analysis in each case
- Modified RCM process, (RCM light) or similar internal process still using the sound principles of RCM
- First get the basics right, then consider RCM
- RCM can be good, provided one has the necessary manpower to implement it properly and the to maintain the system
- A combination of RCM, preventative maint, and predictive maint
- You have to adapt the environment where you want to apply RCM to make it economical and practical.
- Just adapt all the replace frequencies and measure and inspect and replace more on practical method
- Short and simplified version of RCM (ARP)
- TPM, CBM

- I belief that the general framework of RCM can be followed. The details in doing FMEC's on every single component to determine reliability etc can be too overwhelming. I belief that most of this information can be easily obtainable from past experience as well as OEM's. This will make your life lot easier and it will fast track the strategy development process.

- Some of RCM processes are good and useful but some is too complicated and lengthy, some time one must just use your common sense in your maintenance approach.

23. Do you think RCM can be considered a world class maintenance philosophy?

Strongly disagree	**0**	**0%**
Disagree	2	6%
Agree	24	71%
Strongly agree	8	24%

24. RCM is a well-known maintenance approach all over the world. Please strictly follow the following instruction: **Ignore** the above statement and please mark yes and no in the selection box below:

34	**34**	

25. Do you think it is imperative to do a Failure Mode, Effect and Criticality Analysis for every component/asset in a typical "low risk" type industry?

Strongly disagree	**10**	**29%**
Disagree	16	47%
Agree	8	24%
Strongly agree	0	0%

26. Do you think that most of the relatively easy Failure Mode, Effect and Criticality Analysis could be replaced by analysis of personnel experience and equipment failure history?

Strongly disagree	**1**	**3%**
Disagree	5	15%
Agree	21	62%
Strongly agree	7	21%

27. Do you think that RCM can add value as a maintenance solution for an old plant with old equipment (30 to 50 years old)?

Strongly disagree	**2**	**6%**
Disagree	2	6%
Agree	21	62%
Strongly agree	9	26%

If basic conditions are not right, jaco visser

28. Do you think that the maintenance culture of a plant plays a vital role in the success of RCM implementation?

Strongly disagree	**0**	**0%**
Disagree	0	0%
Agree	12	35%
Strongly agree	22	65%

29. Do you think that the buy-in of plant personnel is vital for successful implementation of a maintenance program/project?

Strongly disagree	**0**	**0%**
Disagree	1	3%
Agree	6	18%
Strongly agree	27	79%

30. Do you think it is viable to implement a RCM project on a plant that is under severe pressure in terms of resources and budget constraints?

Strongly disagree	**3**	**9%**
Disagree	9	26%
Agree	14	41%
Strongly agree	8	24%

31. Which one of the following statements do you prefer?:

		yes	**no**
1.	It is better to appoint a consulting firm to implement a maintenance improvement project?	0	0%
2.	It is better to maintain in-house control by involving own people in the development of a maintenance improvement project.	11	32%
3.	It is better to have a combination of external and in-house involvement in the development and implementation of a maintenance improvement project.	23	68%

32. Do you think that it is important to focus first on the basics of maintenance before one resolve to maintenance improvements projects such as RCM?

Strongly disagree	**2**	**6%**
Disagree	5	15%
Agree	15	44%
Strongly agree	12	35%

The following questions are directed to the Hot Strip Mill

Count: 15 (HSM personnel)

Accepted: 14 (HSM personnel)

Rejected: 1 (HSM personnel)

Failed trick question, 5-24-40	**1**
Inconsistency in answers, (4&19)-(3&23)-(6&28)	0

Discipline:

Mechanical engineer	**5**
Mechanical Manager	2
Electrical engineer	
Electrical manager	1
Mechanical technician	2
Electrical technician	
Mechanical foreman	2
Electrical foreman	1
Senior planner	1

Participants:

Name and surname	Current Occupation	Work Experience	Years of experience
Tony Filizzola	Electrical Supt.	Electrician and contractor electrician at chemical, explosive and fertilizer factory. Electrician and Supt. At steel rolling plant	36
Jaco Visser	Maintenance progress Manager	Mechanical engineer at steel rolling plant. Reliability manager	11
Riaan Coetzee	Maintenance Manager	Plant engineer at steel rolling plant. 4 years Maintenance manager at Hot Strip Mill	22
Johan Lombard	Mechanical Supt.	Fitter and master fitter at Hot Strip Mill Finishing Mill. 3 years as Mechanical maintenance Supt.	24
Benico van der Westhuizen	Senior Mechanical Engineer	Worker as engineer on steel plant. Engineer for Murry and Roberts. Reliability pilot and senior engineer at Hot Strip Mill	16
Schalk Engelbrecht	Senior Engineer	Engineer at Direct reduction plant and Hot Strip Mill at steel fabrication plant	33
Piet janse van Resnburg	Mechanical Supt.	5 & 6 mm temper mills, pickle line and hot strip finishing lines as fitter and master fitter. Mech Supt. at Hot Strip Mill Finishing Mills	35

Harold Venter	Technologist	Hot Strip Mill maintenance technician	25
Sebastien Begue	Hot Strip Mill plant manager	Maintenance engineer, Maintenance manager and Plant manager	18
Willem Bezuidenhout	Mechanical Technician	Maintenance technician at Cold Mills and Hot Strip Mill in steel fabrication industry	3
Bennie van Graan	Mechanical Engineer	Steel industry as reliability/maintenance engineer, Business Improvement section of steel fabrication plant	6
Capie Nel	Snr Planner	Iron and steel manufacturing. Mechanical maintenance on cold and hot rolling plants	40
Dewald Barkhuysen	Electrical Maintenance manager	Steel manufacturing industry. Projects, day to day issues, redesigns, Management	24
Ronald Naidoo	Mechanical Engineer	Steel manufacturing industry. Experienced as plant/maintenance engineer.	4

33. In the past, has the HSM attempted to implement RCM?

12	**1**

34. Was this RCM project successfully implemented?

Strongly disagree	**3**	**25%**
Disagree	9	75%
Agree	0	0%
Strongly agree	0	0%

35. In your opinion, what was the main contributing factor that led to the result in Question 34?

- Disagree: Lack of experience of the people on the team. Some not taking part. Roll out and implementation a problem. Roles and responsibilities not clearly defines, tony
- Takes too long, personnel and artisans not really involved as should have been, jaco visser
- The idea of RCM was not maintained over a period of time, different other ideas was tested, riaan coezee
- Incorrect implementation and not owned by management, benico
- Severe pressure i.t.o resources. It was difficult to maintain the RCM momentum while being in a fire fighting mode, schalk
- The basic was not yet in place, piet
- RCM implementation never completed, Harold
- Lack of funds, bennie
- Lack of discipline and ownership

- WCM was implemented. It was unsuccessful due to lack of buy-in from various discipline experts die to KPI's being unrealistic

36. Do you think there exist a need for the HSM to improve on its current maintenance strategy and processes?

Strongly disagree	1	7%	
Disagree	0	0%	
Agree	8	57%	
Strongly agree	5	36%	

Managers: Agree, strongly agree, agree

Engineers: agree, strongly agree, agree, agree strongly agree

Technicians: strongly agree, agree

Supts: Strongly agree, agree, strongly disagree,

Planners: Capie

37. Do you think RCM is a suitable maintenance approach for improvement of the HSM maintenance philosophy?

Strongly disagree	2	14%
Disagree	1	7%
Agree	8	57%
Strongly agree	3	21%

38. Do you think that the HSM has enough resources to successfully implement a RCM program (availability of funds and people)?

Strongly disagree	5	36%
Disagree	3	21%
Agree	6	43%
Strongly agree	0	0%

39. Do you think that the HSM has a culture that will accept the implementation of RCM?

Strongly disagree	3	21%
Disagree	3	21%
Agree	7	50%
Strongly agree	1	7%

40. One of the elements of the RCM process is a FMECA. Please strictly follow the following instruction: **Ignore** the above statement and please mark agree and strongly agree in the selection box below:

Strongly disagree	**0**	**0%**
Disagree	0	0%
Agree	14	50%
Strongly agree	14	50%

41. Is the culture at the HSM one of difficulty to adapt and reluctant to change?

Strongly disagree	**3**	**21%**
Disagree	3	21%
Agree	8	57%
Strongly agree	0	0%

42. Please motivate your answer in Question 41 in short.

- Changes come from the top and delegated for only a certain group to implement and carry out. Tony
- The culture has changed a lot over the last 5 years, some area more than others, still room for improvements. Jaco visser
- Any changes in structures and systems have to be strongly driven by management to change the culture, riaan
- People adapt quickly when they know why, how and when there is a positive outcome, benico
- Being the bottle neck plant for many years, people accepted the changes are required to keep on reaching targets, schalk
- Our people can adopt to our surroundings and environment, piet
- Lack of ownership and responsibility on artisan level, Harold
- When you convince people why they need to change it is easy, but the HSM is big and it takes a lot of time
- Difficult but can be done, have to keep the pressure
- The culture is not reluctant to change but rather must be motivated or show the improvements which can be realistic by effective RCM implementation

43. Do you think the culture at the HSM would rather embrace a systematic improvement and development of current maintenance processes, than the full implementation of a RCM project?

Strongly disagree	**0**	**0%**
Disagree	1	7%
Agree	9	64%
Strongly agree	4	29%

44. Do you think that HSM management will be able to establish the buy-in or belief of the people in the development of the HSM maintenance program?

Strongly disagree	0	0%
Disagree	0	0%
Agree	8	57%
Strongly agree	6	43%

45. Finally, do you think that it is possible to successfully implement RCM at the HSM now or even in the near future?

Strongly disagree	2	14%
Disagree	3	21%
Agree	6	43%
Strongly agree	3	21%

Questionnaire assessment

The purpose of this section is to reflect on the quality of this questionnaire. Please take another minute or two and complete the following questions:

1. Were the information/questions asked relevant and meaningful to this study?

Yes	No
33	1
97%	3%

If No, please indicate why:

- Question 5, 24 and 40 confusing, did not understand instruction

2. Were all the information/questions and instructions clear and understandable?

Yes	No
26	8
76%	24%

If No, please indicate why:

- Question 5, 24 and 40 unnecessary
- Yes no selection not really understood correctly
- Question 24 was strange
- My impression is that all questions cannot be answered with the options given (agree / don’t agree) it might have yielded better results by using a scale of 1 – 5 in some instances
- Two questions where stated ignore the statement and follow the instruction

- Not sure what the purpose of question: “ignore statement...”
- Some questions requires yes/no answers but gives 4 options

3. How long did it take you to complete the questionnaire? 45, 20, 20, 30, 15, 35, 15, 15, 30, 15, 10 15, 10, 20, 15, 15, 30, 20, 10, 10, 10, 10, 15, 15, 10, 20, 25, 30, 10, 30, 10

Average = 19 minutes

4. Please indicate your rating of the quality and standard of this questionnaire:

Poor	**0**	**0%**
Expectable	2	6%
Good	30	88%
Excellent	2	6%

Any other general comments:

- The RCM principles and philosophies is sound, but the process and implementation require so much time that it is difficult to maintain the momentum with limited resources and divided attention, schalk
- Devise simple maintenance plan with good planning and plan, and good equipment/machine knowledge, piet
- The success of any project is a function of the commitment and drive of the management team and the involvement of all personnel. There must be a clear vision, case for change and leading and lagging indicators to measure progress.
- Deciding on implementing a new maint approach is a journey, starting at the basics and detail of what exists in terms of business arena, assets, process, people, skills, systems, technology, the objective, the expected return on investment, availability of resources and support, the long term construction. A localised improvement of an existing system is less complicated and lower impact. The scale of the project matters.
- To summarize for you, RCM is still the most powerful method around, and is well supported in many operations, mines, petroleum, chemical environments. You have touched on culture in the work place, this to me is highly important, for not only maintenance personnel bit also your production team to continuously drive the methodology and the outcome of the resulted... take that and build it into your maintenance plans to make it sustainable. In today’s flat structure organizations with a lean work force the methodology is actually for us to apply, one of the biggest opportunities, people to work the project, all of that is the frontend work, to create the strategies for each equipment and then to maintain just that methodology.
- RCM principles should be applied to some of the critical equipment within a plant, especially the main producing units where failure results in substantial downtime and cost
- Combination of RCM and TPM can also be considered depending on the maturity of the work force.
- RCM is a philosophy that requires a lot of resources in order to be done correctly, Some companies employ modified versions of RCM and only consider some of the RCM tools. Quite often this process can be disastrous and ...

- If the management team is not committed to implementing a new system and keep the pressure till it becomes a habit, you will struggle to implement anything new. You need to change the people’s mindset before you can successfully implement a new system/philosophy.