# APPLICATION OF MILITARY LOGISTIC TECHNIQUES TO INDUSTRIAL APPLICATIONS

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## ABSTRACT

The main reason for the low production efficiencies at North Coast Milling is the frequent stoppages due to equipment breakdowns and the requirement for unscheduled maintenance. In order for this factory to be able to reach the desired efficiencies, it is imperative that downtime and cost drivers in the production lines be identified and rectified.

In order to achieve world-class performance, more and more companies are replacing their reactive strategies for maintenance with proactive strategies like Preventive maintenance (PM), Reliability-centred maintenance (RCM) and Condition based maintenance (CBM) and aggressive strategies like Total Productive Maintenance (TPM). While these newer maintenance strategies require increased commitments to training, resources and integration, they also promise to improve performance. New asset management philosophies are being implemented world-wide in an effort to improve industrial system reliability as well as to reduce maintenance costs. Concepts such as TPM, RCM and CBM are being customised for implementation in various industries. Real-time condition monitoring via computerised maintenance management systems has helped make it possible to transfer from a time-based maintenance strategy to a condition-based maintenance strategy. Detecting possible future failures is now a cost-effective reality that reduces considerably the risk of catastrophic failures and system breakdowns.

The aim of the study is to apply military logistic techniques to the industrial environment of North Coast Milling in order to identify downtime and cost drivers. It will be shown that more of the military logistics techniques can be incorporated into some of the existing maintenance techniques at this factory, which would aid in the achievement of maximum plant utilisation and minimum downtime.

*Keywords:* Logistics, life-cycle costs, system, TPM, total productive maintenance

## PREFACE

The research detailed in this thesis was carried out at the University of Natal in the Graduate School of Business. I became involved in military logistics while working for a company involved in the military industry, as a logistics engineer. Subsequent to my departure from the military industry and into an industrial company, I saw that a great deal of the military logistics techniques could be adapted to the industrial environment, especially to fill some of the gaps in TPM.

The first part of the research included mostly literature study. During this part of the studies, I have had the pleasure of working with Professor Elsa Thompson at the University of Natal on the subject of applying some of the military logistic techniques to the commercial environment. The reader is referred to the original publications in this regard, as highlighted in the list of references. The next part consisted of a case study, where the company's maintenance procedures were analysed. The subsequent period consisted of writing some simulation and analytical software, conducting some simulation that finally culminated in the compilation of this thesis. I have had the pleasure to be involved in the study of a subject matter that is both interesting and practical.

## ACKNOWLEDGEMENTS

I wish to express my gratitude to my supervisor for her useful comments and guidance throughout the work. My warmest thanks also go to her for providing me with the opportunity to work on this interesting topic.

I am grateful to my mother and late father for the help, support and love they have provided me throughout my life. The positive attitude towards education in our home has been a motivating and driving force for my postgraduate studies.

Finally, I wish to express my deepest thanks to my dear friends (who are too many to mention) for the support and encouragement they have given me during my MBA studies.

Durban, June 11, 2002 Navin Runjit Singh

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## LIST OF SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| $\lambda$ | Failure rate |
| °C | Degrees Celsius |
| % | Percentage |
| $A_a$ | Achieved availability |
| $A_i$ | Inherent availability |
| $A_o$ | Operational availability |
| CBM | Condition based maintenance |
| e | Exponential function |
| FF | Failure finding task |
| FMECA | Failure modes, effects and criticality analysis |
| FRACAS | Failure reporting, analysis and corrective action system |
| JIT | Just in time |
| K | Quantity of parts used of a particular type |
| Kg | Kilogram |
| LCC | Life-cycle cost |
| LDT | Logistic delay time |
| LL | Discard task |
| Ln | Natural logarithm function |
| LRU | Line-replaceable unit |
| LSA | Logistics Support Analysis |
| $\bar{M}$ | Mean active maintenance time |
| MA | Maintenance action |
| Mct | Mean corrective maintenance time |
| MDT | Maintenance downtime hours |
| MIL-STD | Military Standard |
| MMH | Maintenance man-hours |
| $MMH_c$ | mean corrective maintenance manhours |
| $MMH_i$ | Average maintenance manhours |
| MTBF | Mean time between failure |
| MTBM | Mean time between maintenance |
| $MTBM_s$ | Mean time between scheduled maintenance |

| | |
|---|---|
| $MTBM_u$ | Mean time between unscheduled maintenance |
| MTTF | Mean time to failure |
| MTTR | Mean time to repair |
| OC | On-condition task |
| OH | Operating hour |
| P | Spare part probability |
| PE | Production efficiency |
| PM | Preventive maintenance |
| R | Rands |
| R(t) | Reliability function |
| RAM | Reliability, availability and maintainability |
| RCM | Reliability-centred maintenance |
| RW | Rework task |
| t | time |
| TPM | Total Productive Maintenance |
| TQM | Total Quality Management |
| US | United States of America |

CONTENTS

# CHAPTER 1

# INTRODUCTION

## 1.1. Introduction

Historically, the concept of logistics stems from the specific facets of military and industrial management. In the military sense, logistics is concerned with the various aspects of distribution and system support, particularly from the point in time when systems are in operational use. In the industrial sector, logistics has been defined to include such activities as material flow, the physical distribution of products, transportation, warehousing and inventory control. The emphasis of this thesis is on the military logistics techniques.

A major integrated logistic support objective is to assure the integration of the various elements of support. A more precise nature, the US Department of Defence defines it as: A disciplined, unified, and iterative approach to the management and technical activities necessary to (1) integrate support considerations into system and equipment design; (2) develop support requirements that are related consistently to readiness objectives, to design, and to each other; (3) acquire the required support; and (4) provide the required support during the operational phase at minimum cost.

The purpose of this thesis is to provide a new emphasis in logistics in the commercial environment - an emphasis on logistics in the total system design and development process. The design of an industrial system for supportability has a tremendous impact on what resources will later be required to support that system. Through the proper planning and emphasis on logistics early in the system life cycle, the necessary characteristics can be incorporated to ensure that the resultant system can be effectively and economically supported from the time that the system is initially introduced until phase-out of it occurs. Logistic support should be a major consideration in the establishment of system requirements, in the development of design criteria, and in the evaluation of alternatives leading to the selection of a firm design configuration. The objective is to develop a system that will fulfil its functions at the lowest overall life-cycle cost.

Some of the equipment have already been designed and it is too late for the inclusion of military logistics techniques right from the design stage. The thesis will concentrate on this scenario and highlight those military logistic techniques that can be applied to equipment in the operational phase.

## 1.2. Background

To gain insight of the various elements supporting the study a discussion will follow to highlight the importance.

### 1.2.1. Motivation for the research

The production efficiency at North Coast Milling is very low. Similar factories elsewhere in the world are achieving efficiencies in excess of this. The problem is not with the poor design of the equipment, but with the way it is maintained and operated. If the problem was with the equipment, then it is better to get rid of the old ones and get new ones. The equipment is neither old nor outdated as other mills are using identical equipment. The main reason for the low production efficiencies at this factory seems to be frequent stoppages due to equipment breakdowns and the requirement for unscheduled maintenance. In order for this factory to be able to reach the desired efficiencies, it is imperative that downtime and cost drivers in the production line be identified and rectified.

### 1.2.2. Value of the research

It is hoped that this study will shed some insight into some of the cost and downtime drivers with regards to that production line. It is hoped that this research will go some way in assisting the company in achieving world class efficiencies that it needs to achieve if it is to maintain its market leadership in the milling industry.

### 1.2.3. Company Background

North Coast Milling began its oil milling operations in 1982 and began to diversify its operations into the manufacture of animal feeds in 1988. Animal feed is one of the by-products of its oil milling process. The mill is located near the wharf in Durban and this is beneficial as all the oilseeds are shipped from other African countries and from abroad. North Coast Milling aims to produce high quality oil and animal feed by using carefully selected oilseeds in its production process. The company firmly believes that innovation and quality have played an important part in the success of the business.

The oilseeds used for the production of oil and animal feed at North Coast Milling are that of groundnuts. The groundnut oil is refined to form edible vegetable oils, of which the main importance is their value. Oils and fats are important ingredients for a well balanced diet and these edible oils are consumed in many different ways. In their natural liquid state they an be used for cooking. They can also be eaten in a spreadable form as a margarine. As such, the main demand for the oil from North Coast Milling comes from the margarine industry. Other food industries that need vegetable oils include the manufacture of cooking fats and oils, salad dressings and ice cream. Because groundnut has a high protein content, the residue after the oil has been extracted provides a protein-rich cake for animal fodder.

North Coast Milling does not design any of its production equipment but purchases them from reputable suppliers. The company prides itself in having the latest equipment in its production process. The company has adopted the total productive maintenance (TPM) philosophy in the early nineties. However, the production efficiencies at the company still seem to be quite low when compared to other oil milling companies that are using identical equipment. Because of these low production efficiencies, North Coast Milling finds itself at a severe disadvantage in its market as its oil and animal feed products are overpriced.

## 1.3. Objectives

The following are the objectives of this study:

- To evaluate the current maintenance techniques being used by North Coast Milling and determine their current production efficiency.
- To highlight and apply the relevant military logistic techniques to the equipment in the production process at North Coast Milling to aid in the identification of cost and downtime drivers.
- To develop the relevant analytical models and apply them to North Coast Milling
- To check if any improvement in reliability and production efficiency can be obtained by the application of the military logistic techniques
- To investigate whether a combination of military logistic techniques and current maintenance practices at North Coast Milling can be used.
- Finally, to make recommendations on the reliability and maintenance route forward for North Coast Milling.

## 1.4. Limitations of the study

- Due to the analysis being time consuming and requiring a great deal of effort, only relevant and significant equipment in the production line at North Coast Milling will be analysed.
- Any emphasis will be placed on the military logistics techniques, with very little effort being devoted to looking at the organisation culture at North Coast Milling.
- The analytical models that have been developed, are approximations and will have some shortcomings of their own.
- Due to equipment in the production line having being already developed, there is no opportunity to influence the design of these equipment from a logistics point of view. As such, the logistics effort only applicable to the operational phase of the equipment life cycle will be used.
- The failures in this study do not include process deviations and administrative constraints
- The inputs to the analyses is the average of the data values obtained from North Coast Milling for the last three years. Ideally, it would be better to look at data that has been obtained over a longer period. However, such data is not readily available at North Coast Milling.

## 1.5. Research Methodology

Section 1.5.1 provides an overview of the research methodology while Section 1.5.2 provides details of the research methodology that was followed.

### 1.5.1. Overview of research methodology

An extensive literature survey was conducted in order to locate various sources where optimisation and improvements in production efficiencies have been dealt with. Also the relevant sources of information on military logistics techniques were utilised. Enquiries were directed to the various equipment suppliers to North Coast Milling in order to obtain some important equipment specifications, which served as primary data for the study. Secondary data was also obtained from North Coast Milling, which facilitated the modelling of the production process and the identification of cost and downtime drivers.

### 1.5.2. Details of the research methodology to be followed

- Theoretical models were first developed in order to calculate the reliability, availability and utilisation of the equipment that form part of the production process. The results were then consolidated in order to arrive at the calculation of the production efficiency of the production line.
- Data was requested from the various equipment suppliers to North Coast Milling in order to extract important equipment specifications from their database. With the aid of the theoretical models developed, the theoretical production efficiency of the production line was calculated.
- With the aid of past information on production and equipment downtimes from North Coast Milling, averaged over the last three years, the actual production efficiency for the equipment used in the production process was calculated. From the information collected and modelling performed, an attempt was made to identify several cost and downtime drivers for the production line.
- Finally, recommendations were made as to how the production efficiency at North Coast Milling can be improved in light of the fact that several cost and downtime drivers have been identified.

## 1.6. Structure of the thesis

Chapter 2 of the thesis gives an in-depth discussion of the military logistics techniques, as discussed in various literature sources. Mathematical models will be developed for later use here, as well as conducting in-depth literature survey.

Chapter 3 covers the case study. North Coast Milling will be discussed together with its type of business, production and maintenance procedures, and description of the equipment used in the production line.

In Chapter 4, an evaluation of the current maintenance practices at North Coast Milling is undertaken. The relevant software models are developed here, and use is made of some of the analytical models discussed in Chapter 2. The relevant military logistics techniques are applied to the production line at North Coast Milling in this chapter.

The final chapter is Chapter 5, where recommendations are made as to how North Coast Milling can improve its production efficiency. This chapter ends with concluding remarks.

## 1.7. Conclusion

This concludes Chapter 1 of the thesis, where an overview has been given of North Coast Milling, the problems it faces as well as means of overcoming the lower production efficiencies that this company experiences. Limitations of the study have also been given, together with a discussion of the research methodology to be followed as well as the structure of the rest of the thesis.

# CHAPTER 2

# MILITARY LOGISTICS TECHNIQUES

## 2.1. Introduction

From the perspective of military logistics, a large proportion of the projected life-cycle cost for a given system is influenced by the decisions made during the early stages of the system planning and conceptual design. Decisions pertaining to operational and maintenance concepts, the selection of new technologies, equipment packaging schemes and diagnostic routines and the selection of manufacturing processes have a major effect on activities and operations in all subsequent phases of the life cycle. Because logistics costs can be quite large, it is essential that logistics support be considered as an inherent part of the decision-making process in the early phases of the system planning and design.

Logistics requirements must be initially planned and thereafter integrated into the system design process. The logistics requirements must be optimised in terms of the production needs and logistics requirements must effectively and efficiently respond to the system maintenance and support activities throughout the operational use period. The ultimate objective is to design, develop, produce and operate a system that will satisfy the user's needs in a satisfactory manner. Success in meeting this objective is highly dependent on logistics.

A system may be considered to be a nucleus of elements structured in such a manner as to accomplish a function to satisfy an identified need. The elements of a system include a combination of resources in the form of materials, equipment, software, facilities, data, services and personnel. These elements are integrated in such a manner as to meet a specified requirement.

The elements of logistics include supply support (spare/repair parts and associated inventories), test and support equipment, personnel and training, facilities, transportation and material handling, computer resources and data. If very little attention has been given to logistics, then the elements of the system will not be well integrated in the development process.

With the introduction of new technologies and the increasing complexities of systems, combined with limited resources and reduced budgets, it is essential that all facets of a system be addressed on an integrated basis. If the results are to be effective, logistics must be considered on an integral basis with all other elements of the system. Logistic support must be initially planned and integrated into the overall system development process to ensure an optimum balance between the system and its related support. This balance must consider the performance characteristics of the system, the input resources required, the effectiveness of the system, and the ultimate life-cycle cost.

The structure of this chapter is as follows:

Section 2.2 discusses the important logistics measures which are used in the development and evaluation of a logistic support capability for a system. These include reliability, maintainability and supply support factors.

Section 2.3 discusses the system operational requirements and the questions that need to be asked in order to define the system operating characteristics.

Section 2.4 discusses the system maintenance concept which serves as the basis for the establishment of supportability requirements in equipment design and provides for the establishment of requirements for total logistic support.

Section 2.5 discusses the system functional analysis and requirements allocation. The system functional analysis constitutes the process of translating system operational and support requirements into specific qualitative and quantitative requirements. The system factors for allocation include reliability factors, maintainability factors, personnel factors, economic factors.

Section 2.6 explains in detail the Logistic Support Analysis (LSA) process.

Section 2.7 discusses the role of logistics in system design. When considering the objective pertaining to design for supportability, the disciplines of reliability, maintainability, human factors, system safety and economic feasiblity are important.

Section 2.8 presents concluding remarks for this chapter.

## 2.2. Logistics Measures

To ensure that logistics is properly addressed throughout the system life cycle, one must establish the appropriate logistic support requirements in the early stages of planning and conceptual design. Logistics requirements must be initially specified, both in quantitative and qualitative terms.

In order to specify and evaluate the system, the appropriate quantitative measures of logistics must be identified. This section introduces some of the commonly used quantitative factors applicable in the development and evaluation of a logistic support capability for a system. The factors of particular importance are those for reliability and maintainability, supply support, test and support equipment, organisational, facility and transportation, economic and effectiveness. In order for one to be able to plan for, design and implement a logistic support capability in an effective and efficient manner, it is essential that these factors be addressed.

### 2.2.1. Reliability factors

Reliability can be defined simply as the probability that a system or product will perform in a satisfactory manner for a given period of time when used under specified operating conditions. Probability, the first element in the reliability definition, is usually stated as a quantitative expression representing a fraction or a percent signifying the number of times that an event occurs, divided by the total number of trials. When there are a number of supposedly identical items operating under similar conditions, it can be expected that failures will occur at different points in time; thus failures are described in probabilistic terms. Satisfactory performance, indicates that specific criteria must be established which describe what is considered to be satisfactory system operation. Time represents a measure against which the degree of system performance can be related. Reliability is frequently defined in terms of the mean time between failure (MTBF), mean time to failure (MTTF), or mean time between maintenance (MTBM); thus the aspect of time is critical in reliability measurement. The specified operating conditions include environmental factors such as geographical location where the system is expected to operate, the operational profile, the transportation profile, temperature cycles, humidity, vibration, shock, etc.

System reliability is a key factor in the frequency of maintenance, and the maintenance frequency obviously has a significant impact on logistic support requirements. Reliability predictions and analyses are required as an input to the logistic support analysis.

Reliability is an inherent characteristic of the design. As such, it is essential that reliability be adequately considered at program inception, and that reliability be addressed throughout the system life cycle. In determining system support requirements, the frequency of maintenance becomes a significant parameter. The frequency of maintenance for a given item is highly dependant on the reliability of that item. In general, as the reliability of a system increases, the frequency of maintenance will decrease, and vice versa. Some of the key reliability quantitative factors used in the system design process for the determination of logistic support requirements are:

#### 2.2.1.1. The reliability function

Reliability has already been defined as the probability that a system will perform in a satisfactory manner for a given period of time when used under specified operating conditions. The reliability function, R(t), may be expressed as:

$$R(t) = e^{-t/M} = e^{-\lambda t} \qquad (2.1)$$

Where $\lambda$ is the instantaneous failure rate and M is the MTBF.

An exponential distribution is commonly assumed in many applications.

#### 2.2.1.2. Failure rate

The rate at which failures occur in a specified time interval is called the failure rate during that interval. The failure rate ($\lambda$) is expressed as:

$$\lambda = \frac{number\ of\ failures}{total\ operating\ hours} \qquad (2.2)$$

A failure is defined as an instance when the system is not operating within a specified set of parameters. Assuming an exponential distribution, the system mean life time between failure (MTBF) is:

$$MTBF = \frac{1}{\lambda} \quad \text{(2.3)}$$

When determining the overall failure rate, particularly with regard to estimating corrective maintenance actions (ie. the frequency of corrective maintenance), one must address all system failures to include failures due to primary defects, failures due to manufacturing defects, failures due to operator and maintenance errors, etc. The overall failure rate should cover all the factors that will cause the system to be inoperative at a time when satisfactory system operation is required.

#### 2.2.1.3. Reliability component relationships

Given the basic reliability function and the measures associated with failure rate, it is appropriate to consider their application in series networks, parallel networks and in combinations thereof. These networks are used in reliability block diagrams and in models employed for reliability prediction and analysis. Reliability prediction is a necessary input for logistic support analyses.

a) Series networks

The series relationship is probably the most commonly used and is the simplest to analyse. In a series network, all components must operate in a satisfactory manner if the system is to function properly. The following figure illustrates a series network:

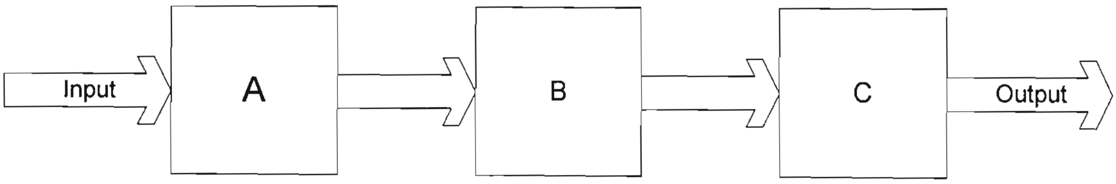



**Figure 2.1** A series network

Assuming that the system includes Subsystem A, Subsystem B and Subsystem C as shown in Figure 2.1, the reliability of the system is the product of the reliabilities for the individual subsystems and may be expressed as:

$$Reliability(R) = (R_A)(R_B)(R_C) \quad \text{(2.4)}$$

b) Parallel networks

A pure parallel network is one where a number of the same components are in parallel and where all the components must fail in order to cause total system failure.

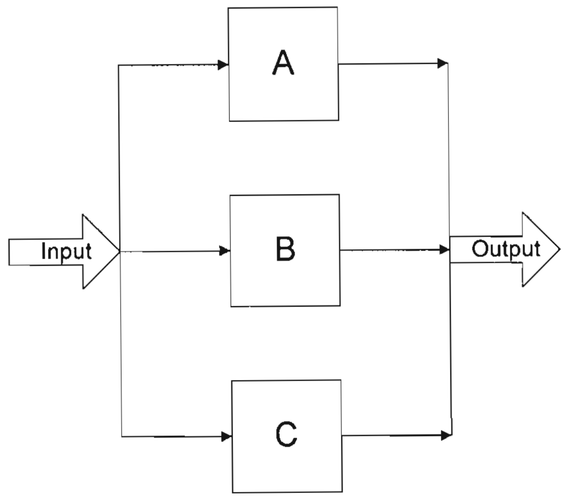



**Figure 2.2** A parallel network

With reference to Figure 2.2, the system will function if either A or B or C, or a combination or all of them are working, and the reliability is expressed as:

$$Reliability(R) = 1 - (1 - R_A)(1 - R_B)(1 - R_C) \qquad (2.5)$$

Parallel redundant networks are used primarily to improve system reliability, as (2.5) indicates. By adding more subsystems in parallel, the overall reliability R improves.

c) Combined series-parallel networks

Various levels of reliability can be achieved through the application of a combination of series and parallel networks. Consider Figure 2.3, which shows a combination of a series and parallel network:

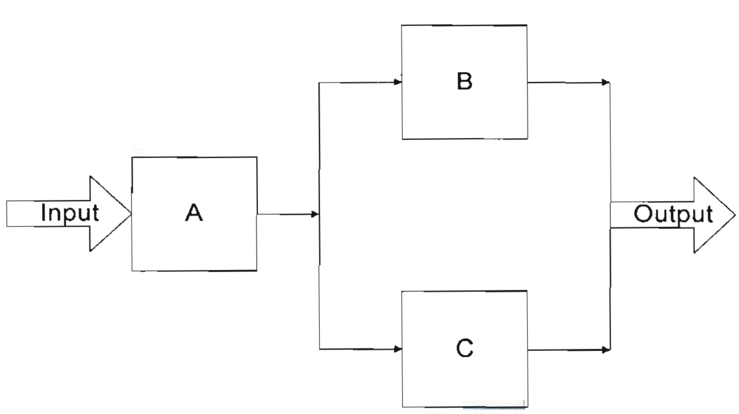



**Figure 2.3** A combined series-parallel network

The reliability of the above network is given by:

$$\mathrm{Re}\,liability(R) = R_A(R_B + R_C - R_B R_C) \qquad (2.6)$$

This is the reliability of the series section multiplied by the reliability of the parallel section. Reliability block diagrams are generated, evolving from the functional block diagram for the system and leading through progressive expansion to individual system components. As a system design progresses, reliability block diagrams are used in reliability analyses and prediction functions.

### 2.2.2. Maintainability factors

Maintainability, like reliability, is an inherent characteristic of system or product design. It pertains to the ease, accuracy, safety and economy in the performance of maintenance actions. A system should be designed such that it can be maintained without large investments of time, cost or other resources and without adversely affecting the mission of that system. Maintainability is the ability of an item to be maintained, whereas maintenance constitutes a series of actions to be taken to restore or retain an item in an effective operational state. Maintainability is a design parameter. Maintenance is a result of design.

Maintainability can also be defined as a characteristic in design that can be expressed in terms of maintenance frequency factors, maintenance times and maintenance cost. These terms may be presented as different figures of merit, therefore, maintainability may be defined on the basis of a combination of factors.

The reasons for implementing the different maintenance strategies are:

- To extend an asset's operating life
- Optimising maintenance expenditure
- Identifying the criteria for maintenance interventions and disposal
- Identifying and assuring compliance with regulatory requirements
- Enhancing reliability and hence productivity and efficiency
- Providing a basis for informed decision-making about assets and equipment

With regard to plant maintenance, there is a need to establish a pro-active capability that will be responsive in the accomplishment of corrective and preventive maintenance actions as they occur throughout the life cycle of the production capability. This need must be addressed if products are to be produced in a cost-effective manner. Breakdowns due to equipment failures, downtime due to setups and adjustments, slowdowns due to minor discrepancies and stoppages, defects resulting in rework, and so on, are costly. This in turn, often results in higher product costs, an undesirable factor in today's highly competitive environment.

Maintainability is an inherent design characteristic dealing with the ease, accuracy, safety and economy in performance of maintenance functions. Maintainability can be measured in terms of a combination of elapsed times, personnel labour-hour rates, maintenance frequencies, maintenance costs, and related logistic support factors.

#### 2.2.2.1. Maintenance elapsed-time factors

Maintenance can be classified in two categories:

- Corrective maintenance: the unscheduled actions accomplished, as a result of failure, to restore a system to a specified level of performance.
- Preventive maintenance: the scheduled actions accomplished to retain a system at a specified level of performance by providing systematic inspection, detection, servicing, calibration, condition monitoring, and/or replacement of critical items to prevent impending failures.

Maintenance constitutes the act of diagnosing and repairing, or preventing, system failures. Maintenance time is made up of the individual task times associated with the required corrective and preventive maintenance actions for a given system or product. Maintainability is a measure of the ease and rapidity with which a system can be maintained, and is measured in terms of the time that is required to perform maintenance tasks. A few of the more commonly used maintainability time measures are defined:

2.2.2.1.1. Mean corrective maintenance time ( $\overline{M}ct$)

Each time that a system fails, a series of steps is required to repair or restore the system to its full operational status. These steps include failure detection, fault isolation, disassembly to gain access to the faulty item, repair, etc. Completion of these steps for a given failure constitutes a corrective maintenance cycle.

Throughout the system use phase, there will be a number of individual maintenance actions involving a series of steps. The mean corrective maintenance time ( $\overline{M}ct$), or the mean time to repair (MTTR) which is equivalent, is a composite value representing the arithmetic average of these individual maintenance cycle times.

2.2.2.1.2. Mean preventive maintenance time

Preventive maintenance consists of the actions required to retain a system at a specified level of performance and may include such functions as periodic inspection, servicing, scheduled replacement of critical items, calibration and overhaul, etc.

Preventive maintenance may be accomplished while the system is in full operation, or could result in downtime. In this instance, the concern is for preventive maintenance actions which result in system downtime. Again, mean preventive maintenance time, includes only active system maintenance times and not logistic delay and administrative delay times.

2.2.2.1.3. Mean active maintenance time

This is the mean or average elapsed time required to perform scheduled (preventive) and unscheduled (corrective) maintenance. It excludes logistics delay time and administrative delay time.

2.2.2.1.4. Logistic delay time

This is the maintenance downtime that is expended as a result of waiting for a spare part to become available, waiting for the availability of an item of test equipment in order to perform maintenance, waiting for transportation, waiting to use a facility required for maintenance, etc. It does not include active maintenance time, but does constitute a major element of total maintenance downtime.

2.2.2.1.5. Administrative delay time

This refers to the portion of downtime during which maintenance is delayed for reasons of an administrative nature. It does not include active maintenance time, but often constitutes a significant element of total maintenance downtime.

2.2.2.1.6. Maintenance downtime

This constitutes the total elapsed time required (when the system is not operational) to repair and restore a system to full operating status, and/or to retain a system in that condition. It includes active maintenance time, logistics delay time and administrative delay time. The mean or average value is calculated from the elapsed times for each function and the associated frequencies.

Figure 2.4 shows a composite view of the various elapsed time factors:

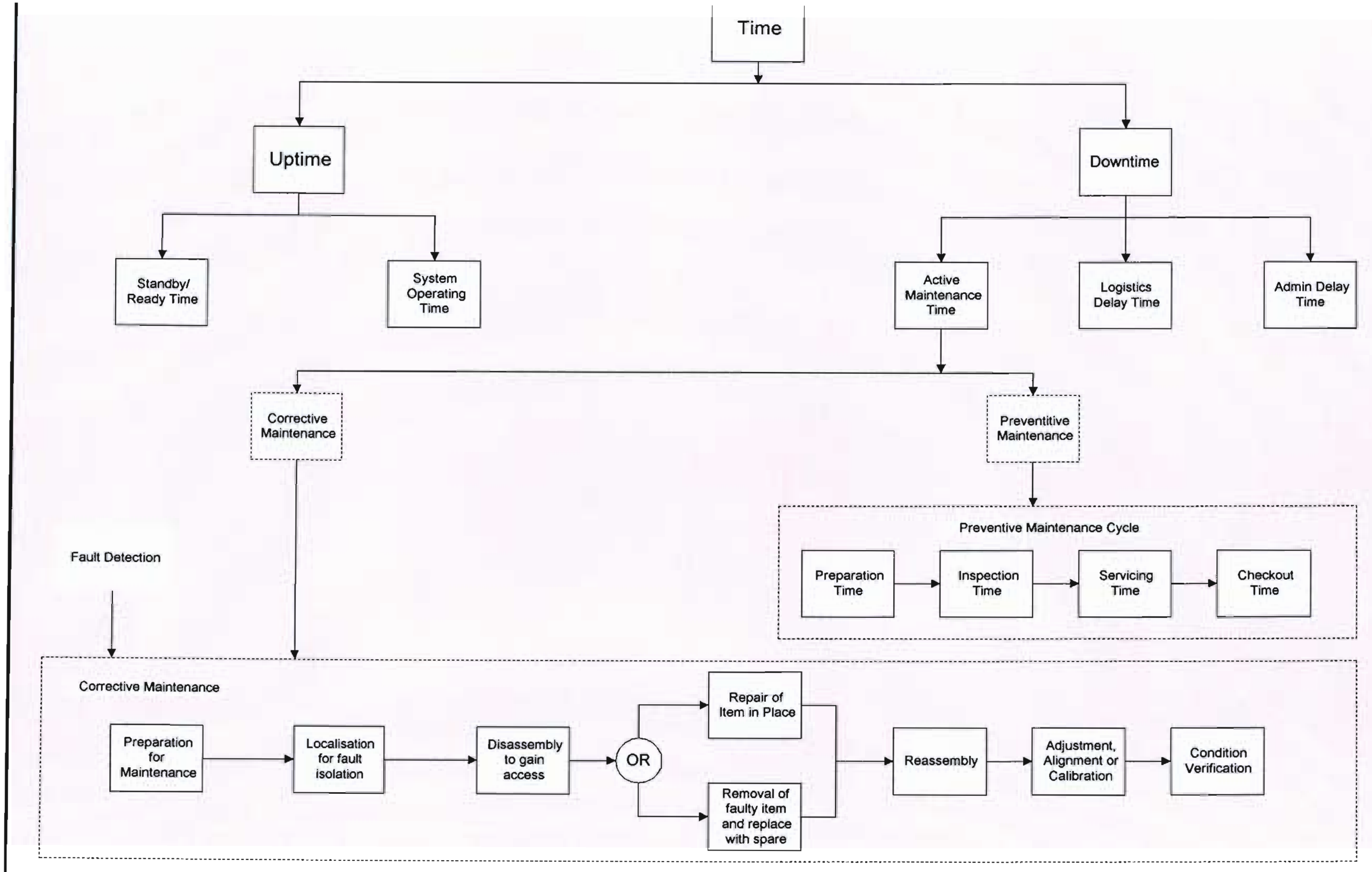



**Figure 2.4** Uptime/downtime factors

### 2.2.2.2. Maintenance Labour-hour factors

The maintainability factors covered in the previous paragraph relate to elapsed times. Although elapsed times are extremely important in the performance of maintenance, one must also consider the maintenance labour hours expended in the process. Elapsed times can be reduced by applying additional human resources in the accomplishment of specific tasks. Maintainability is concerned with the ease and economy in the performance of maintenance. As such, an objective is to obtain the proper balance between elapsed time, labour time and personnel skills at a minimum maintenance cost.

When considering measures of maintainability, additional measures such as the following, must be employed:

- Maintenance manhours per system operating hours (MMH/OH)
- Maintenance manhours per cycle of system operation (MMH/cycle)
- Maintenance manhours per month (MMH/month)
- Maintenance manhours per maintenance action (MMH/MA)

Any of these factors can be specified in terms of mean values. For example, $\overline{MMH}_c$ = mean corrective maintenance manhours, expressed as:

$$\overline{MMH}_c = \frac{\sum(\lambda)(MMH_i)}{\sum \lambda_i} \qquad (2.7)$$

Where: $\lambda_i$ is the failure rate of the ith item (failures/hour)

$MMH_i$ is the average maintenance manhours necessary to complete repair of the ith item.

Additionally, the values for mean preventive maintenance manhours and mean total maintenance manhours (to include preventive and corrective maintenance) can be calculated on a similar basis. These values can be predicted for each level of maintenance, and are employed in determining specific support requirements and associated costs.

### 2.2.2.3. Maintenance frequency factors

It is evident that reliability and maintainability are very closely related. The reliability factors, MTBF and $\lambda$, are the basis for determining the frequency of corrective maintenance. Maintainability deals with the characteristics in system design pertaining to minimising the corrective maintenance requirements for the system when it assumes operational status later on. Thus, in this area, the reliability and maintainability requirements for a given system must be compatible and mutually supportive.

In addition to the corrective maintenance aspect of system support, maintainability also deals with the characteristics of design which minimise (if not eliminate) preventive maintenance requirements for that system. Sometimes, preventive maintenance requirements are added with the objective of improving system reliability. However, the introduction of preventive maintenance can be quite costly if not carefully controlled. Further, the accomplishment of too much preventive maintenance often has a degrading effect on system reliability, as failures are frequently induced in the process. Hence, an objective of maintainability is to provide the proper balance between corrective maintenance and preventive maintenance at least overall cost.

2.2.2.3.1. Mean time between maintenance (MTBM)

This is the mean or average time between all maintenance actions (corrective and preventive) and can be calculated as

$$MTBM = \frac{1}{1/MTBM_u + 1/MTBM_s} \quad \text{.......(2.8)}$$

Where: $MTBM_u$ is the mean interval of unscheduled (corrective) maintenance

$MTBM_s$ is the mean interval of scheduled (preventive) maintenance

The reciprocals of $MTBM_u$ and $MTBM_s$ constitute the maintenance rates in terms of maintenance actions per hour of system operation. The maintenance frequency factor, MTBM, is a major parameter in determining system availability and overall effectiveness.

### 2.2.3. Supply support factors

This includes all spares, repair parts, consumables, special supplies, and related inventories needed to support prime mission-oriented equipment, software, test and support equipment, transportation and handling equipment, training equipment and facilities. Supply support also covers provisioning documentation, procurement functions, warehousing, distribution of material, and the personnel associated with the acquisition and maintenance of spare/repair part inventories at all support locations.

Supply support includes the spare parts and the associated inventories necessary for the accomplishment of unscheduled and scheduled maintenance actions. At each maintenance level, one must determine the type of spare parts and the quantity of items to be purchased and stocked. Also, it is necessary to know how often various items should be ordered and the number of items that should be procured in a given purchasing transaction.

Spare part requirements are initially based on the system maintenance concept and are subsequently defined and justified through the logistic support analysis (LSA). Essentially, spare part quantities are a function of demand rates and include consideration of:

- Spares and repair part covering actual item replacements occuring as a result of corrective and preventive maintenance actions. Spares are major replacement items which are repairable, while repair parts are nonrepairable smaller components.
- An additional stock level of spares to compensate for repairable items in the process of undergoing maintenance. The test equipment capability, personnel, and facilities directly impact the maintenance turnaround times and the quantity of additional spare items needed.
- An additional stock level of spares and repair parts to compensate for the procurement lead times required for item acquisition.
- An additional stock level of spares to compensate for the condemnation or scrapage of repairable items.

In reviewing the foregoing considerations, of particular significance is the determination of spares requirements as a result of item replacements in the performance of corrective maintenance. Major factors involved in this process are:

- The reliability of the item to be spared
- The quantity of items used
- The required probability that a spare will be available when needed
- The criticality of item application with regard to mission success
- cost

### 2.2.3.1. Probability of success with spares availability considerations

Assuming various combinations of operating components and spares, the system success factors can be determined by using:

$$1 = e^{-\lambda t} + (\lambda t)e^{-\lambda t} + \frac{(\lambda t)^2 e^{-\lambda t}}{2!} + \frac{(\lambda t)^3 e^{-\lambda t}}{3!} + \cdots\cdots + \frac{(\lambda t)^n e^{-\lambda t}}{n!} \quad \text{.............................(2.9)}$$

(2.9) can be simplified into a general Poisson expression

$$f(x) = \frac{(\lambda t)^x e^{-\lambda t}}{x!} \quad \text{.............................(2.10)}$$

The objective is to determine the probability of x failures occurring if an item is placed in operation for t hours, and each failure is corrected (through item replacement) as it occurs. With n items in the system, the number of failures in t hours will be nλt, and the general Poisson expression for the f(x) becomes:

$$f(x) = \frac{e^{-n\lambda t}(n\lambda t)^x}{x!} \quad \text{.............................(2.11)}$$

### 2.2.3.2. Spare part quantity determination

This is a function of a probability of having a spare part available when required, the reliability of the item in question, the quantity of items used in the system, etc. An expression, derived from (2.1) and (2.11), useful for spare part quantity determination is:

$$P = \sum_{n=0}^{s} \left[ \frac{R(-\ln R)^n}{n!} \right] \quad \text{.............................(2.12)}$$

Where:

P = probability of having a spare of a particular item available when required

S = number of spare parts carried in stock

R = composite reliability (probability of survival); and

$R = e^{-K\lambda t}$

K = quantity of parts used of a particular type

Ln R = natural logarithm of R

In determining spare part quantities, one should consider the level of protection desired (safety factor). The protection level is the P value in (2.12). This is the probability of having a spare available when required. The higher the protection level, the greater the quantity of spares required. This results in a higher cost for item procurement and inventory maintenance. The protection level, or safety factor, is a hedge against the risk of stock-out.

When determining spare part quantities, one should consider system operational requirements (eg. System effectiveness, availability) and establish the appropriate level at each location where corrective maintenance is accomplished. Different levels of corrective maintenance may be appropriate for different items. For instance, spares required to support prime equipment components, which are critical to the success of a mission may be based on one factor; high-value or high-cost items may be handled differently than low-cost items; etc. In any event, an optimum balance between stock level and cost is required.

### 2.2.4. Availability factors

The term availability is often used as a measure of system readiness (ie. the degree, percent or probability that a system will be ready or available when required for use). Availability may be expressed differently, depending on the system, and its mission. Three commonly used figures of merit are described further.

#### 2.2.4.1. Inherent Availability ($A_i$)

Inherent availability is the probability that a system or equipment, when used under stated conditions in an ideal support environment (ie. readily available tools, spares, maintenance personnel, etc), will operate satisfactorily at any point in time as required. It excludes preventive or scheduled maintenance actions, logistics delay

$$A_i = \frac{MTBF}{MTBF + \bar{M}ct} \quad \text{.........(2.13)}$$

time, and administrative delay time, and is expressed as

Where MTBF is the mean time between failure and $\bar{M}ct$ is the mean corrective maintenance time, as described before.

### 2.2.4.2. Achieved availability ($A_a$)

Achieved availability is the probability that a system or equipment, when used under stated conditions in an ideal support environment (ie. readily available tools, spares, personnel, etc.) will operate satisfactorily at any point in time. This definition is similar to the definition for $A_i$ except that preventive (ie. scheduled) maintenance is included. It excludes logistics delay time and administrative delay time and is expressed by:

$$A_a = \frac{MTBM}{MTBM + \bar{M}} \qquad (2.14)$$

Where MTBM is the mean time between maintenance and $\bar{M}$ is the mean active maintenance time. MTBM and $\bar{M}$ are a function of corrective (unscheduled) and preventive (scheduled) maintenance actions and times.

### 2.2.4.3. Operational Availability ($A_o$)

Operational availability is the probability that a system or equipment, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon. It is expressed as:

$$A_o = \frac{MTBM}{MTBM + MDT} \qquad (2.15)$$

Where MDT is the mean maintenance downtime.

If one is to impose an availability figure of merit as a design requirement for a given equipment supplier, and the supplier has no control over the operational environment in which that equipment is to function, the $A_a$ or Ai might be appropriate figures of merit against which the supplier's equipment can be properly assessed. On the other hand, if one is to assess a system or an equipment in a realistic operational environment, then $A_o$ is a preferred figure of merit to employ for assessment purposes. Further, the term availability may be applied at any time in the overall mission profile representing a point estimate, or may be more appropriately related to a specific segment of the mission where the requirements are different from other segments. Thus, one must define precisely what is meant by availability and how it is to be applied.

### 2.2.5. Economic factors

The recent combination of economic trends, rising inflation, cost growth experienced for many systems and products, the continuing reduction in buying power, budget limitations, increased competition, and so on, has created an awareness and interest in total system/product cost. Not only are the acquisition costs associated with new systems rising, but the costs of operating and maintaining systems already in use are increasing at alarming rates. The net result is that less money is available to meet new requirements, as well as maintaining systems that are already in being. In essence, many of the systems/products in existence today are not truly cost-effective.

In dealing with the aspect of cost, one must address total life-cycle cost. One must consider not only system acquisition cost, but other costs as well. When addressing total cost, experience has shown that a major portion of the projected life-cycle cost for a given system or product stems from the consequences of decisions made during the early phases of program planning and system conceptual design. While the greatest proportion of costs may result from activities occuring downstream in the system life cycle (eg. System operation and support), the greatest opportunity for influencing these costs is realised during the early phases of a program.

### 2.2.6. Logistics measures and production efficiency

Availability has been defined as the proportion of time that a piece of equipment is able to be used for its intended purpose, while utilisation measures the proportion of the time that the equipment is available, that it is used for its intended purpose. While availability measures the proportion of the total time that the equipment is available, reliability measures the frequency with which it breaks down. By maintaining both high equipment utilisation and high equipment availability, maximum output can be achieved from the equipment. The discussion below follows from the materail already presented in this chapter.

In (2.15), the MTBM can be defined as:

$$MTBM = Total\ hours - Downtime\ hours = Total\ hours - MDT\ ;$$

In (2.2), the total operating hours can be defined as:

$$total\ operating\ hours = Total\ hours - Downtime\ hours - STandby\ hours;$$

Using these definitions, (2.15) can be re-written as:

$$operational\ availability = \frac{Total\,Hours - Downtime\,Hours}{Total\,Hours} \times 100\% \ldots\ldots\ldots\ldots(2.18)$$

Utilisation can be defined as:

$$utilisation = \frac{Total\,Hours - Downtime\,Hours - STandby\,Hours}{Total\,Hours - Downtime\,Hours} \times 100\% \ldots\ldots\ldots(2.19)$$

(2.2) can be rewritten as:

$$MTBF = \frac{Total\,Hours - Downtime\,Hours - STandby\,Hours}{Number\,of\,Failures} \ldots\ldots\ldots\ldots(2.20)$$

A better measure of overall equipment performance is production efficiency (PE), which is defined as the ratio of actual output from a machine (which meets the required quality standards) to its rated output, during the time that it is operating.

$$PE = \frac{Actual\ Production}{Total\,Hours - Downtime\,Hour - STandby\,Hours} \div Rated\,Capacity(units\,/\,hr) \ldots\ldots(2.21)$$

$$Overall\,Equipment\,Effectiveness = Availability \times Utilisation \times Production\,Efficiency \ldots\ldots(2.22)$$

It is evident that poor reliability, while having some impact on equipment availability, is likely to have a bigger impact on production efficiency, due to the inefficiencies associated with starting up and shutting down the equipment and the time and effort it takes to get the production operation back to a steady state situation. Because the costs of poor reliability generally show up in lower production efficiency, the use of military logistic techniques to improve reliability, can bring about an improvement in production efficiency as well.

## 2.3. System operational requirements

Once a system need has been identified, it is necessary to project that need in terms of anticipated operational requirements. The following questions need to be asked at this point:

- What are the anticipated quantities of equipment and personnel, and where are they to be located?
- How is the system to be utilised and for how long?
- How is the system to be supported, and by whom?
- What is the anticipated environment at each operational site?

The answer to these and comparable questions leads to the definition of system operating characteristics, the maintenance and support concept for the system, and the identification of specific design guidelines and criteria.

## 2.4. System maintenance concept

The maintenance concept evolves from the definition of system operational requirements (Section 2.3) and outlines:

- the anticipated levels of maintenance support
- general overall repair policies and constraints
- the organisational responsibilities for maintenance
- the major elements of logistic support as they apply to the new system
- and the maintenance environment

The maintenance concept basically describes in general terms the overall system support environment in which the system is to exist. It constitutes the baseline for the determination of specific logistic support requirements through the LSA. The purposes of the maintenance concept are:

- It provides the basis for the establishment of supportability requirements in equipment design. It also provides design criteria for major elements of logistic support such as built in self-test capabilities in the equipment.
- It provides for the establishment of requirements for total logistic support. The maintenance concept, supplemented by the logistic support analysis, leads to the identification of maintenance tasks, task frequencies and times, personnel

quantities and skill levels, test and support equipment, spare/repair parts, facilities and other resources.

- It provides a basis for detailing the maintenance plan and impacts upon the supply concept, training concept, logistic support, transportability and handling criteria, and production data needs.

Fulfillment of these purposes in an effective and economical manner requires that the maintenance concept be developed initially in conjunction with the definition of operational requirements prior to the start of system functional analysis (Section 2.5.1) and equipment design. Development of the maintenance concept at this stage will tend to ensure that all functions of design and support are integrated with each other. Support and test equipment should accomplish functions that are compatible to the maintenance tasks accomplished at a given level, assigned personnel skills should be compatible with the complexity of the maintenance tasks performed, maintenance procedures should be oriented only to those tasks accomplished, and so on. If the development of the maintenance concept is not considered at this stage, individual components of the system may reflect different design approaches, and hence there may be a lack of standardisation with the various elements of support being incompatible.

Definition of the maintenance concept evolves from the definition of operational requirements. When developing the maintenance concept, one must analyse the equipment operational requirements and identify repair policies that will support these requirements.

At this stage in the system life cycle, not too much is known about the equipment: thus, one might assume the options of nonrepairable, partially repairable, and fully repairable. Data input factors are based on experience and are obtained from similar systems. Development of the maintenance concept is one of the most important steps in the system life cycle. It is from the maintenance concept that initial design requirements and support criteria evolve. Concept development must be relatively complete to ensure that all significant alternate repair policies are adequately considered. Concept development is further supplemented by the LSA.

## 2.5. System functional analysis and requirements allocation

The functional analysis is discussed in Section 2.5.1. It is intended to facilitate the design, development, and the system definition process in a complete and logical manner and is based on the definition of system operational requirements and the system maintenance concept.

Requirements allocation are discussed in Section 2.5.2. These allocations include reliability factors, maintainability factors, personnel factors, economic factors and others which are applicable to the design for supportability.

### 2.5.1. System functional analysis

A function constitutes a specific action required to achieve a given objective. Such actions may be accomplished through the use of equipment, personnel, facilities, software, data or a combination thereof. The functional approach helps to assure:

- That all facets of system development, operation and support are covered. This includes design, production, test, deployment, transportation, training, operation and maintenance.
- That all elements of the system are fully recognised and defined
- That a means of relating equipment packaging concepts and support requirements to given functions is provided.
- That the proper sequences and design relationships are established, along with critical design interfaces.

Functional analysis is a logical and systematic approach to system design and development. It constitutes the process of translating system operational and support requirements into specific qualitative and quantitative design requirements. This process is iterative.

The functional analysis is intended to facilitate the design, development, and the system definition process in a complete and logical manner. The functional analysis is based on the definition of system operational requirements and the system maintenance concept, and is subsequently used as the basis for detailed design.

The functional analysis is the process of translating system-level requirements into detailed design requirements. System requirements are decomposed and defined in functional terms. Operational and maintenance functions are evaluated with the objective of identifying specific design criteria. The functional analysis serves as a baseline for the definition of, *inter alia,* equipment requirements, software requirements, personnel requirements, maintenance and logistic support requirements, human factors requirements.

### 2.5.2. Allocation of requirements

The functional analysis provides a description of major system functions. The next step involves the allocation of top-level system factors to various subsystems and lower-level elements of the system. In essence, a system can be broken down into different categories of components, each of which must support the overall performance and effectiveness requirements at the system level. The allocation should include reliability factors, maintainability factors, personnel factors, economic factors and others which are applicable to the design for supportability.

#### 2.5.2.1. Reliability allocation

After an acceptable reliability factor or failure rate has been established for the system, it must be allocated among the various subsystems, units and assemblies. The allocation commences with the generation of a reliability block diagram as depicted in Figure 2.5

The diagram should be structured so that each block represents a functional entity that is relatively independent of neighbouring blocks. Referring to Figure 2.5, a simplified reliability block diagram is depicted and the progressive expansion of the system is also shown. Note that the levels can extend beyond Level 2, as shown in the Figure 5. Referring to the diagram, the reliability requirement for the system is specified for the entire system identified at Level 1, and an individual requirement is specified for each individual block in the system. For example, the breakdown of block 4 is shown, then block c can be further broken down. In practical applications, there can be several layers of expansion of the system until one arrives at the level where a single block can be replaced. This is then called a line-replaceable unit (LRU).

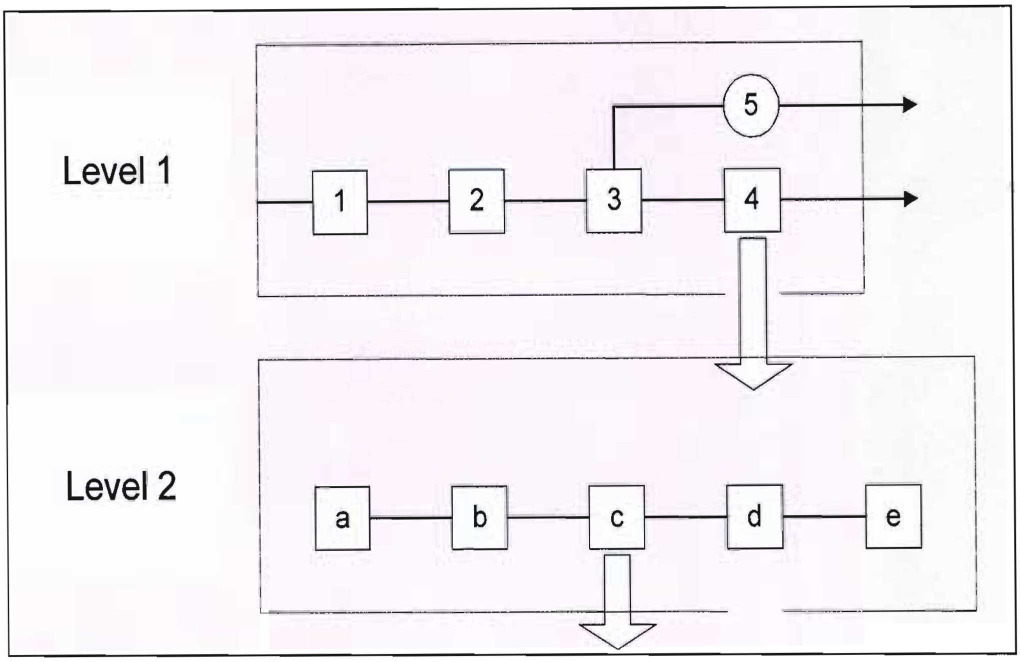



**Figure 2.5** Reliability block diagram method

Block diagrams are generated to cover each of the major functions of the equipment. Success criteria are established and failure rates are estimated for each block, the combining of which provides an overall factor for a series of blocks constituting a function or subfunction. The failure-rate information provided at the unit/assembly level represents a reliability design goal. This, in turn, represents the anticipated frequency of corrective maintenance that is employed in the determination of logistic resource requirements.

The approach used in determining failure rates may vary depending on the maturity of system definition. Failure rates may be derived from direct field and/or test experience or engineering estimates based on judgement. When accomplishing reliability allocation, the following steps are required:

- Evaluate the system and identify areas where design is known and failure-rate information is available or can be readily assessed. Assign the appropriate factors and determine their contribution to the top-level system reliability requirements. The difference constitutes the portion of the reliability requirement which can be allocated to the other areas.

.The end result should constitute a series of lower-level values which can be combined to represent the system reliability requirement initially specified. The combining of these values is facilitated through the application of a reliability mathematical model which have already been described in Section 2.2.1. When allocating a system level requirement, one should construct a simplified functional breakdown. The diagram must reflect series-parallel relationships.

The expected quantity of system maintenance actions due to failure is:

$$expected\ maint eance\ actions = \frac{total\ operating\ hours\ per\ year}{MTBF} \qquad (2.23)$$

### 2.5.2.2. Maintainability allocation

The process of translating system maintainability requirements into a lower-level design criteria is accomplished through maintainability allocation. The allocation requires the development of a simplified functional breakdown. The functional breakdown is based on the maintenance concept, functional analysis data, and a description of the basic repair policy – whether a system is to be repaired through the replacement of a unit, an assembly or a part.

### 2.5.2.3. Logistics factors allocation

In addition to reliability and maintainability parameters and their impact on design, one must also consider other factors that are critical to successful system operation. These factors deal with supply support, test and support equipment, personnel and maintenance organisation, facilities and transportation.

In essence, in defining system operational requirements and the maintenance concept, system supportability factors must be determined along with performance parameters. These factors, established at the system level, may be allocated to the extent necessary to influence design activities.

### 2.5.2.4. Economic factors allocation

Cost factors may be allocated as appropriate to system needs. If the ultimate product is to be cost-effective, it may be desirable to assign cost targets for various equipment items. Cost targets combined with reliability requirements may create a boundary situation for design and one can design to a cost.

## 2.6. Logistics support analysis (LSA)

The LSA constitutes an ongoing level of effort, accomplished on an iterative basis throughout the system life cycle. It includes a variety of tasks, ranging from the initial definition of supportability requirements to the accomplishment of design interface functions, trade-off studies and analyses, the determination of logistic support requirements, and the final assessment of the system in the field. LSA tasks can be tailored to meet a variety of applications, from the acquisition of a new system requiring research and development to the assessment of a system already in use.

Inherent within the LSA requirements is the need to perform a variety of analyses. This necessitates the utilisation of certain of the methodologies and tools. These include life-cycle cost analysis, level-of-repair analysis, maintenance engineering analysis, failure mode, effect and criticality analysis (FMECA), reliability and maintainability analyses, reliability-centered maintenance (RCM) analysis and detailed task analysis. The LSA includes these analysis efforts to varying degrees.

The uses of the LSA are:

- The LSA aids in the initial establishment of supportability requirements during conceptual design through the evaluation of system operational requirements. The LSA methods are employed to help specify a cost-effective solution for system support. Major outputs include the system maintenance concept and supportability design criteria included in the system specification.
- The LSA aids in the evaluation of alternative system/equipment design configurations. It helps influence system design for supportability through the appropriate selection of system components and potential suppliers. The results may affect future procurement decisions as well as the type of contract.
- The LSA aids in the measurement and evaluation of an operating system in terms of its effectiveness and supportability in the user's environment.

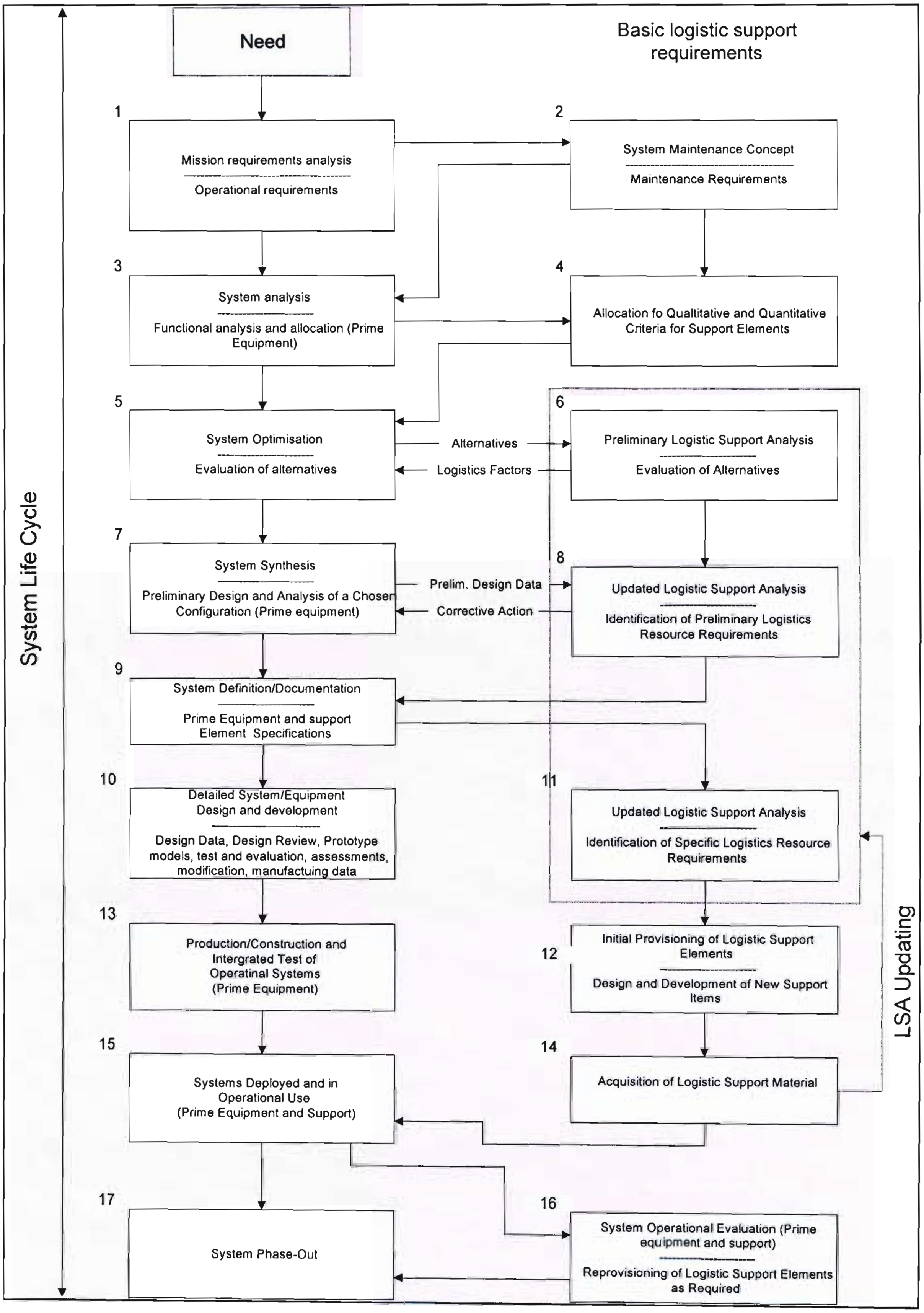
When relating the LSA requirements to the overall system development process in Figure 2.6, each of the blocks to the right in the flowchart is affected. However, the major area of emphasis where LSA activity is the greatest is represented by the dotted block.

In the early phases of the life cycle, the analyst may employ simulation in determining maintenance frequency and developing support equipment requirements. Reliability and maintainability analyses and predictions and analyses, involving the use of statistical forecasting techniques and analytical models, are used as an early input to the LSA. Poisson distribution factors and inventory theory are applied in the early determination of spare-part requirements. Linear and dynamic programming methods are often employed in the allocation of resources, in the determination of transportation and material handling requirements. Cost-effectiveness analysis and life-cycle costing, employing statistical analysis, are accomplished throughout the system development process.

For each identified problem feasible alternatives are identified, evaluation criteria are defined, the appropriate analytical techniques are selected, data are collected, an analysis is accomplished, and recommendations are forwarded based on results. This process may be employed in the evaluation of operational requirements, alternative repair policies, different design configurations, and in the evaluation of logistics resource requirements. During the early phases of a program, the objective is to influence the system design. In the latter phases, the identification of logistic support resources is emphasised.

During the early conceptual stage of a new system development, the LSA is accomplished using rough estimates for input data since the various elements of the system are not adequately defined. As design progresses, or in the event of a commercially available item, the analysis is refined since firm design data and engineering models are available. Detailed predictions, maintenance analyses and test results constitute input data into the LSA process. The LSA is appropriate in all phases of system design and development, and the proper application of LSA is essential if the system produced is to be cost-effective and supportable.

**Figure 2.6**: System development process



### 2.6.1. Analysis approach

The LSA process commences with the identification of a need for analysis supported by the necessary management action to initiate the steps required in fulfilling analysis objectives. The extent of effort and depth of coverage will vary depending on the problem situation. Any item on which the LSA will be conducted, is termed an LSA candidate. An LSA candidate is any component, sub-assembly or end-item which analysis suggests will be repairable and therefore require logistic support, either corrective or preventive or operational support. The LSA candidates are identified from the product breakdown structure for that equipment. LSA candidates are newly developed or modified items, items that contribute to mission critical functions of the system, items that have safety implications or are candidates for preventive maintenance. The basic steps in a typical analysis are illustrated in Figure 7 and discussed below.

A. Definition of Problem

The initial step involves the clarification of objectives and limiting the problem such that it can be studied in an efficient and timely manner.

B. Identification of feasible alternatives

The next step is to identify possible alternative solutions to the problem and then eliminate those candidates which are unattractive or unfeasible.

C. Selection of evaluation criteria

The criteria employed in the evaluation process may vary considerably depending on the stated problem and the level of complexity of the analysis. For instance, at the system level, parameters of primary importance include cost effectiveness, performance, etc. At the detail level, the order of parameters will be different, as illustrated in Figure 2.8.

D. Application of Analytical Techniques

The next step involves the analytical phase. This entails the selection and combining of various analytical techniques in the form of a model or a series of models. The extensiveness of the model will depend on the nature of the problem relative to the quantity of variables, input parameter relationships, number of alternatives being evaluated, and the complexity of the operation. The ultimate objective in the selection or development of a model is simplicity and usefulness.

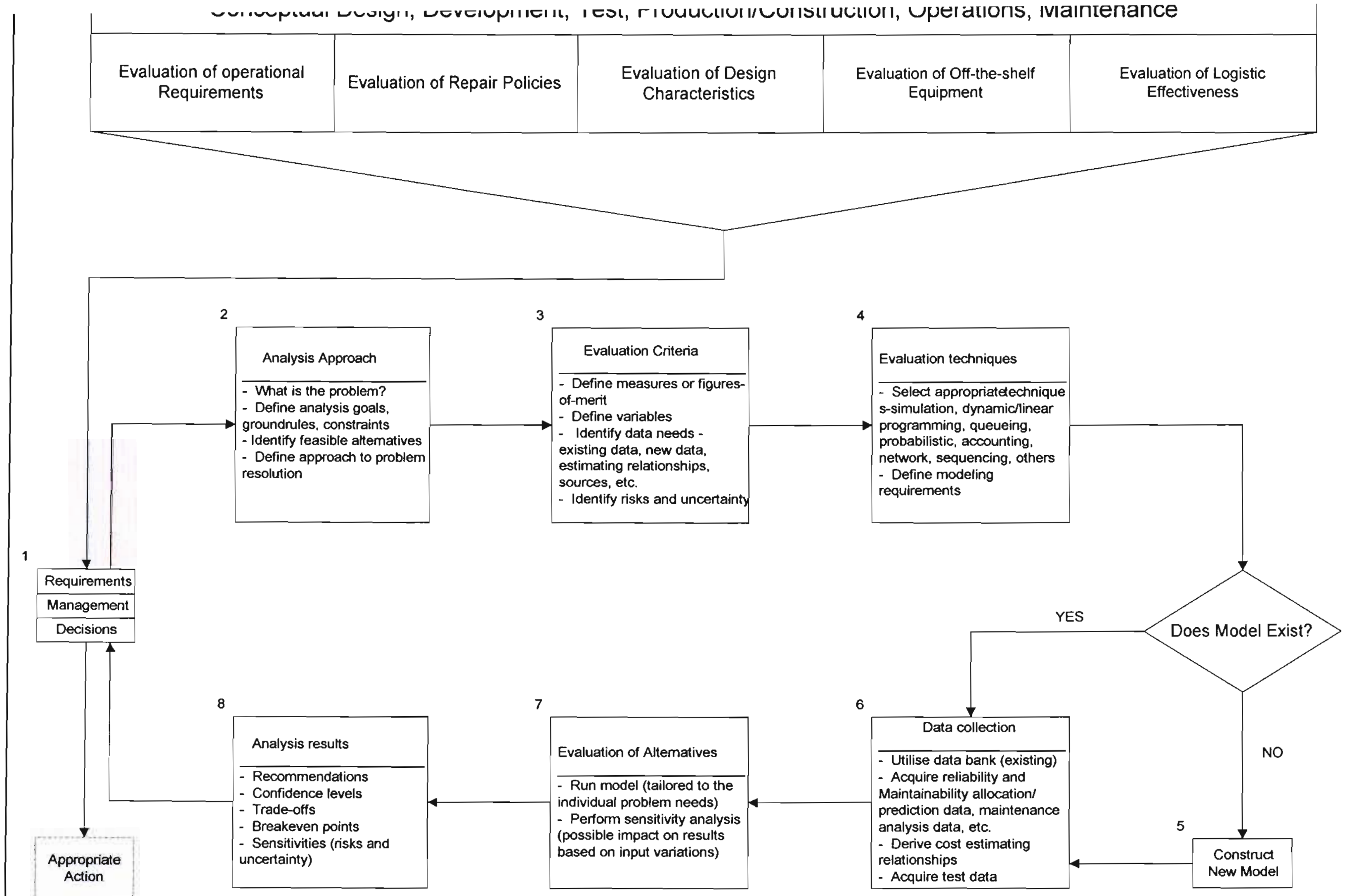



**Figure 2.7** The LSA approach

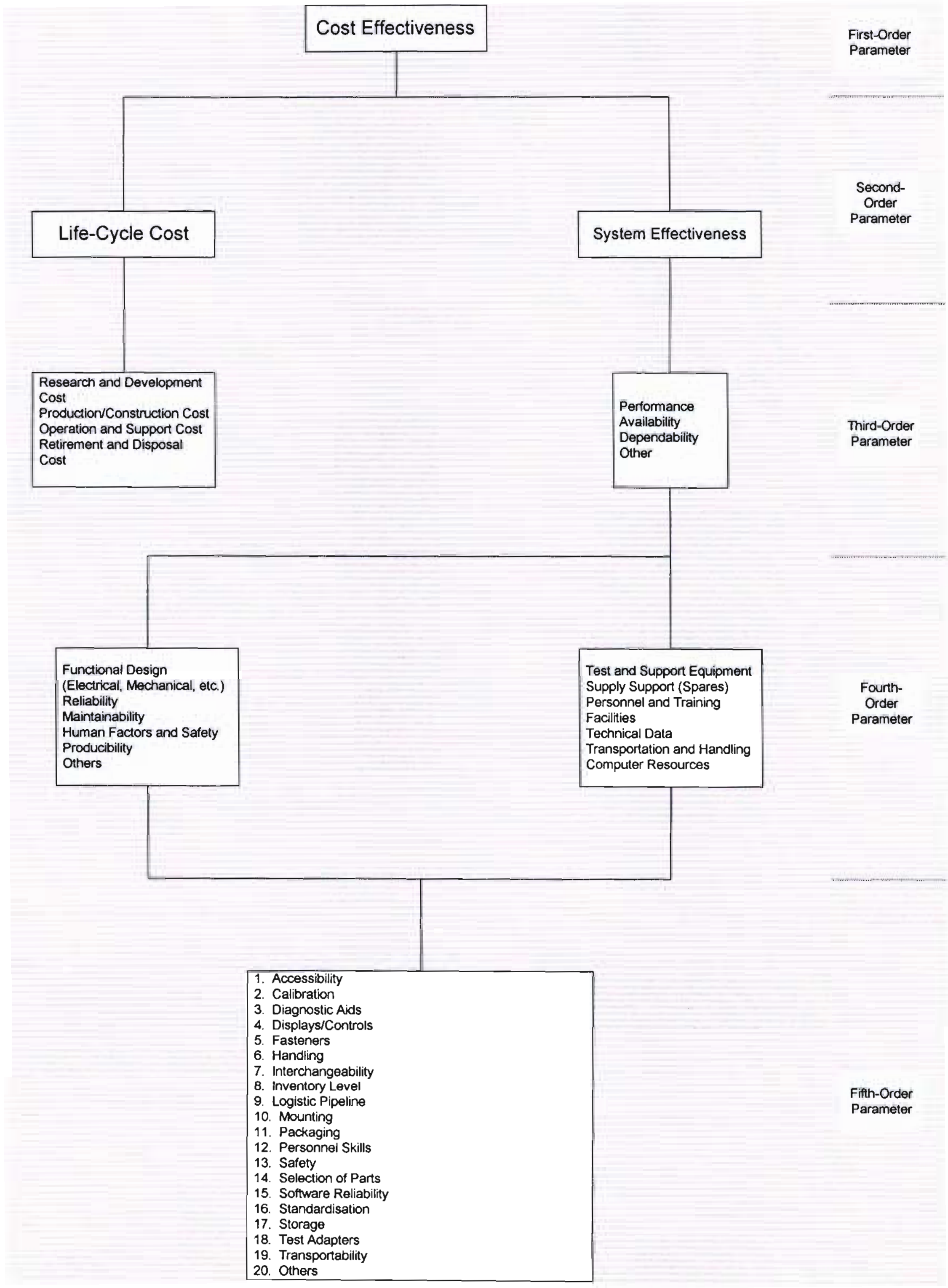



**Figure 2.8**. Order of Evaluation Parameters

E. Data generation and application

One of the most important steps in the analysis process is to assemble the appropriate input data. The right type of data must be collected in a timely manner and must be presented in the proper format. Specific data requirements are identified from the evaluation criteria and from the input requirements of the model used for evaluation purposes. When evaluating a typical system or equipment item, it is necessary to consider operational requirements, the maintenance concept, design features, production plans and anticipated logistic support.

F. Analysis results

The LSA contains a summary of the necessary data to define total logistic support requirements. This includes reliability and maintainability factors, and the cost data necessary to evaluate the effectiveness of the support configuration for a given system.

G. Sensitivity Analysis

In performance of a given analysis, there may be a few key parameters about which the analyst is very uncertain. It needs to be ascertained how sensitive the results or analysis variations are to these uncertain parameters.

H. Contingency Analysis

Closely related with the sensitivity analysis is the contingency analysis, which involves the investigation of decisions in terms of relevant changes in the initial criteria. As new systems are being developed, there is always the possibility that the basic requirements will change. To the extent possible, the analyst must anticipate such changes, apply the LSA appropriately, and alert management as to the impact of the change on the prime equipment and its associated logistic support.

I. Risk and uncertainty

The process of evaluation leads to decisions having significant impact on the future. Inherent in this process are the aspects of risk and uncertainty since the future is unknown. With this in mind, it becomes extremely important to have a good understanding of the underlying concepts associated with the nature of risk and uncertainty. The intent in any evaluation process is to minimise risk and uncertainty.

J. Validity of the Analysis

As a final check on the analysis, a number of questions may be posed as to the validity of the stated assumptions, model parameter relationships, inclusions/exclusions, and stated conclusions.

## 2.7. Logistics in system design

When considering the objectives pertaining to design for supportability, the disciplines of reliability, maintainability, human factors, system safety and economic feasibility are significant.

### 2.7.1. Designing for reliability

Reliability design involves those actions that affect system design from the standpoint of longevity and the successful operation of the system throughout its defined mission. The objective is to design a system that will meet all operational requirements in an effective and efficient manner. This is basically accomplished in design through the proper selection and application of components, the application of de-rating methods as appropriate, the specification of highly reliable processes, the incorporation of redundancy provisions in critical areas, and so on.

#### 2.7.1.1. Reliability functional analysis

The functional analysis is a base upon which many different design analysis activities build. When analysing the possible alternative design approaches for meeting a given functional requirement, trade-off analyses are accomplished and a preferred configuration is selected.

There are many design activities that are based on the system-level functional analysis. This includes the development of reliability models and a reliability block diagram, the development of failure modes, effects and criticality analysis, the development of a fault tree analysis, etc.

#### 2.7.1.2. Reliability allocation

Reliability allocation is one of the first steps in the design process. Once an acceptable reliability or failure rate has been established for the system, it must be allocated among the various subsystems, units and assemblies. This provides criteria for the designer and establishes an initial frame of reference for logistic support in terms of anticipated maintenance rates

#### 2.7.1.3. Reliability models

Throughout the design process, reliability models are used to aid in the evaluation of alternatives and to accomplish the various types of analyses. These models depend on valid input failure-rate information and the appropriate failure-rate distribution. The output from these models are used as inputs to the LSA.

#### 2.7.1.4. Selection of component parts

The reliability of a system is a function of the component parts, part application, stresses, and tolerances intrinsic in the basic design. A fundamental approach in attaining a high level of reliability is to select and apply those components and materials of known reliabilities and capable of meeting system requirements.

#### 2.7.1.5. Failure modes, effects and criticality analysis (FMECA)

The FMECA is an effective design tool and its application is an essential part of the design process, evolving from early system-level functional analysis through detail design and development. The FMECA is tailored to the complexity of the design, and identifies possible system failures, the causes of these failures, the effects of failure on the system and the criticality in terms of safety and mission accomplishment, the anticipated frequency of failure, and special maintainability characteristics that are desirable in system design or unique maintenance procedures that should be followed in the field.

The procedure for accomplishing the FMECA is as follows:

- Based on the system definition through the top-level functional analysis, functional and reliability block diagrams must be developed to illustrate system operations, operational paths, and the functional interrelationships that exist.
- Identify all potential item and interface failure modes and define their effect on the immediate function of the item, on the system as an entity, and on the ultimate mission to be performed.
- Evaluate each failure mode in terms of the worst possible consequences that may result, and assign a severity classification category.
- Identify failure detection methods and the compensating provisions for each failure mode as applicable.
- Identify corrective design measures or other actions required to eliminate the failure or to control the associated risk.
- Identify effects of corrective action in terms of logistic support resource requirements.
- Document the analysis and summarise the problems that could be corrected by design, and identify the special controls which are necessary to reduce failure risk.

From the standpoint of system reliability, the FMECA is employed to evaluate system design in terms of component application, hardware interfaces, stresses, and so on, with regard to operational modes and the mission. The objective is to identify weaknesses and the criticality of such. In general, a bottom-up approach is used where failures are simulated at the component or module level and the impact of such are evaluated at the system level. The FMECA is functionally oriented and should be accomplished in conjunction with the system functional analysis.

The FMECA assists in the identification of failure detection methods and in the development of troubleshooting approaches. With regard to system safety, the FMECA identifies the consequences of failure and the criticality of such. Both personal and equipment safety are addressed. From the standpoint of logistics, the FMECA plays a significant role. Not only is the FMECA used to evaluate system supportability for a given design configuration, but the results of the FMECA often specify corrective maintenance requirements and the need for additional logistic support resources. Furthermore, the FMECA is used to justify scheduled maintenance actions and in the development of a reliability-centred maintenance (RCM) program.

#### 2.7.1.6. Reliability Prediction

As engineering data become available, reliability prediction is accomplished as a check on design in terms of the system requirement and the factors specified through allocation. The predicted values of MTBM, MTBF, or failure rate ($\lambda$) are compared against the requirement, and areas of incompatibility are evaluated for possible design improvement.

Prediction is accomplished at different times in the equipment design process, and will vary somewhat depending on the type of data available. Reliability block diagrams, models, and computer methods are employed to varying degrees depending on the problem at hand. Basic prediction techniques are summarised as follows:

- Prediction may be based on the analysis of similar equipment. This technique should only be used when the lack of data prohibits the use of more sophisticated techniques. The prediction uses MTBF values for similar equipment of similar degrees of complexity performing similar functions and having similar reliability characteristics.
- Predictions may be accomplished from an equipment parts count. There are a variety of methods used that differ somewhat due to data source, the number of

part-type categories, and assumed stress levels. Basically, a design parts list is used and parts are classified in certain designated categories. Failure rates are assigned and combined to provide a predicted MTBF at the system level.

- Prediction may be based on a stress analysis. When detailed equipment design is relatively firm, the reliability prediction becomes more sophisticated. Part types and quantities are determined, failure rates are applied and stress ratios and environmental factors are considered. The interaction effects between components are addressed.

The values obtained through reliability prediction serve as a direct input to maintainability prediction data, logistic support analysis, and the determination of specific support requirements like test and support equipment, spare/repair parts, etc. Reliability basically determines the frequency of maintenance and the quantity of maintenance actions anticipated throughout the life cycle, thus, it is imperative that reliability prediction results be as accurate as possible.

#### 2.7.1.7. Failure reporting, analysis, and corrective-action system (FRACAS)

A significant task in the implementation of any reliability program is the establishment of a procedure for the reporting of failures, performing the necessary analysis for determining the cause of failure, and for documenting recommendations for corrective action. This function, which constitutes the feedback and corrective-action loop in a reliability program, leads to the identification of high failure-rate items and the necessity for a high level of maintenance support. The FRACAS provides an input to the LSA reflecting actual field experience.

Throughout the design process, the tasks defined above are accomplished on a progressive basis, and the results of these tasks are extremely beneficial to the designer and are necessary for an early assessment of total logistic support.

### 2.7.2. Design for maintainability

Maintainability design involves those activities which deal with the ease, accuracy and economy in the performance of maintenance tasks. Maintainability design includes those functions in the design process necessary to ensure that the ultimate product configuration is compatible with the top system-level objectives from the standpoint of the allocated MTBM, MDT, MMH/OH, cost/maintenance action and related factors. Maintainability is concerned with maintenance times, supportability factors in design, and projected maintenance cost over the life cycle.

Because of its objectives, maintainability is perhaps the largest contributor in the design relative to addressing logistic support from an optimum viewpoint. Much of the logistic support stems from maintenance, and maintenance is a result of design. Maintainability is concerned with influencing design such that maintenance is optimised and life-cycle cost is minimised. The following maintenance activities have the greatest impact on logistic support:

#### 2.7.2.1. Maintainability functional analysis.

The basic requirements for maintenance and support evolve from the system maintenance concept. These requirements are iterated from the top down, and the results lead into a number of maintainability design tasks that tie in directly with supportability function.

#### 2.7.2.2. Maintainability allocation.

Maintainability allocation is accomplished, along with reliability allocation, as one of the first steps in the design process. Requirements at the system level, stated both qualitatively and quantitatively, are allocated among the various subsystems, units and assemblies to provide guidelines for the designer.

#### 2.7.2.3. Maintainability prediction

This commences early in system design. The predicted values of MTBM, MMH/OH, etc. are compared with the allocated factors for compatibility with system requirements. Maintainability prediction is a design tool used to identify possible problem areas where redesign might be required to meet system requirements.

Several prediction techniques are available and their particular application will vary somewhat depending on the definition of the design at the time. These are summarised as follows:

- Prediction of corrective maintenance time may be accomplished using a system functional-level breakdown and determining maintenance tasks and associated times in progressing from one function to another. The functional breakdown covers subsystems, units, assemblies and parts. Maintainability characteristics such as localisation, isolation, accessibility, repair and checkout as incorporated in the design are evaluated and identified with one of the functional levels. Times applicable to each part are combined to provide factors for the next higher level.

Maintenance tasks and task times are estimated from experience data obtained on similar systems in the field. Failure rates are derived from reliability predictions.

- Prediction of preventive maintenance time may be accomplished using a method similar to the corrective maintenance approach. Preventive maintenance tasks are estimated along with frequency and task times.

- Prediction of corrective maintenance time may be accomplished using a check-list developed from experience on similar systems. The checklist provides scoring criteria for desired maintainability characteristics in the design. A random sample of parts reflected in the new equipment is identified and the characteristics of design as related to each part are evaluated against the checklist criteria.

The figures derived through maintainability prediction are a direct input to the LSA, particularly the life-cycle cost and maintenance analyses, and form the basis for determining logistic resource requirements for a given design configuration.

#### 2.7.2.4. Logistic Support Analysis (LSA)

As already discussed, the LSA plays a major role in and throughout the system design process. Initially, the LSA serves as an aid in defining the overall requirements for supportability and for the various elements of logistic support. Criteria are established and are provided as an input to the system design process. At this stage in the life cycle, the LSA accomplishes several major purposes:

- It provides a systematic check on equipment design for supportability (eg. Reliability, maintainability and human factors). Areas of poor design that contribute to a high maintenance frequency, lengthy maintenance times, extensive support requirements, and excessive cost readily become evident.
- It provides a basis for the determination of all logistic support requirements to include maintenance functions and tasks, test and support equipment, spare/repair parts, personnel and training, transportation and handling equipment, technical data, software, and facilities. These requirements are then provisioned for follow-on system support.

The LSA is an activity that is extremely important in the maintainability design effort. The analysis provides a systematic evaluation of a proposed design configuration. The evaluation considers size, weight, mobility, packaging, test provisions, standardisation, accessibility and other related maintainability characteristics as incorporated in the design. The evaluation is accomplished through a review of design specifications, layouts and drawings, design data bases, part and material lists, and other information obtained through consultation with the designer.

Reliability, maintainability and human factors design data are generated from engineering data, and the results are compiled as part of LSA. The LSA is reviewed from the standpoint of equipment design for supportability and the associated logistic support requirements for the system. Problem areas are brought to the attention of the designer, and design changes are initiated as appropriate. The LSA is updated on a continuing basis as design matures, and serves as a design assessment tool.

The LSA should be viewed in a conceptual manner, and its application must be appropriately tailored to the problem at hand. The generation of large volumes of data is not practical in this instance, nor are the results timely. On the other hand, the LSA can be effectively applied by selecting specific analysis segments combined with the use of appropriate computerised methods.

#### 2.7.2.5. Reliability centred maintenance (RCM)

RCM is a systematic analysis approach whereby the system design is evaluated in terms of possible failures, the consequences of these failures, the consequences of these failures, and the recommended maintenance procedures that should be implemented. The objective is to design a preventive maintenance program by evaluating the maintenance for an item according to possible failure consequences. The RCM analysis is very similar to the FMECA in many respects, should be accomplished in conjunction with the FMECA, and should constitute a major data input for the LSA. The emphasis here is on the establishment of preventive maintenance requirements.

### 2.7.3. Design for human factors

Until fairly recently, the function of human factors in the design has received little priority in relation to performance, schedule, cost, and even reliability and maintainability. However, for the system design to be complete, one also needs to address the human element and the interface between the human being and the machine. Optimum hardware (and software) design alone will not guarantee effective results. Consideration must be given to anthropometric factors (eg. human physical dimensions), human sensory factors (eg. sight, hearing, feel), human physiological factors (eg. reaction to environment), psychological factors (eg. need, expectation, attitude, motivation), and their interrelationships. Human factors in design deal with these considerations, and the results affect not only system operation but the human being in the performance of maintenance and support activities. Human physical and psychic behaviour is a major consideration in determining operational and maintenance functions, personnel and training requirements, procedural data requirements and facilities.

The human factors effort in the design process is directed toward providing an optimum human interface with equipment and software. Where manual functions are performed, it is necessary to ensure that personnel performance and labour utilisation are maximised, and that personnel attrition and training costs are held to a minimum. Further, the personnel errors in the operation and maintenance of equipment must be eliminated if possible. The inclusion of features in the design that are simple to understand, facilitate task accomplishment, and result in clear-cut decisions is necessary. The relationship between human factors and logistic support is rather pronounced since personnel and training requirements constitute a large factor in the support picture, and these requirements are a direct result of human factor considerations in the design. In addition, the aspect of human factors is very closely allied and integrated with reliability and maintainability, and in some areas an overlap exists.

#### 2.7.3.1. Detail task analysis

This facet of analysis involves a system study of the human behaviour characteristics associated with the completion of system tasks. It provides data basic to human engineering design and to the determination of personnel types and skill-level requirements. Tasks may be classified as being discrete or continuous. Further, there are operator tasks and maintenance tasks. Thus, the analysis effort can be divided into the detail operator task analysis and the detail maintenance task analysis. The portion of the analysis covering maintenance tasks may evolve directly from a combination of the maintainability analysis and LSA.

The following general steps apply to detail task analysis:

- Identify system operator and maintenance functions and establish a hierarchy of these functions in terms of job operations, duties, tasks, subtasks, and task elements.

- Identify those functions that are controlled by the human being and those functions that are automated and controlled by the equipment.
- For each function involving the human element, determine the specific information necessary for operator and maintenance personnel decisions. Such decisions may lead to the actuation of a control, the monitoring of a system condition, or the equivalent. Information required for decision making may be presented in the form of a visual display or an audio signal of some type.
- For each action, determine the adequacy of the information fed back to the human being as a result of control activations, operational and maintenance sequences, etc.
- Determine the impact of the environmental and personnel factors and constraints on the human activities identified.
- Determine the time requirements, frequency of occurrence, accuracy requirements and criticality of each action accomplished by the human being.
- Determine the human skill-level requirements for all operator and maintenance personnel actions.

The purpose of the task analysis is:

- To identify those areas of system design where potential human-machine problems exist
- To identify the necessary personnel skill-level requirements for operating and maintaining the system in the future.

The results from the task analysis for maintenance activities must be integrated with the maintenance analysis and the LSA.

#### 2.7.3.2. Error analysis

One of the major objective in system design is to minimise the possibility of introducing human error in the performance of system operating functions and in the accomplishment of maintenance tasks.

An error analysis may be accomplished in conjunction with the detail task analysis, using a fault-tree approach or a failure mode and effects analysis. Given the requirement for human manipulation in the accomplishment of a task, one must address the question of what else can happen or how a fault might be introduced in the system. After recognising, verifying, and classifying failures, one must determine the effects of these failures on the overall system and on the mission to be fulfilled. Verifying a failure at the operator level and determining its effects at the system level is a prime objective of the reliability FMECA. In this instance, the primary source of failure is the human being.

#### 2.7.3.3. Safety analysis

Human factors are closely aligned with system safety, particularly when personnel safety is involved. Hence, a safety analysis is often accomplished in conjunction with or as part of the detailed task analysis. Possible hazard areas are noted and classified. Critical items are brought to the attention of the designer for corrective action. Items of a less hazardous nature may be covered through the inclusion of a warning notice in the operating or maintenance procedures.

#### 2.7.3.4. Personnel and training requirements

Personnel skill levels are identified by evaluating the complexity and frequency of tasks in the detailed task analysis. Job proficiency levels are established for each location where prime elements of the system are operated and where maintenance support is performed. These requirements are compared against the personnel goals initially specified for the system. In addition, these factors are compared with the maintenance analysis data for compatibility. Areas of difference are corrected through an update of the maintenance analysis data.

Given the requirements for personnel as dictated by the system design, one must determine the personnel resources that actually will be assigned to operate and maintain the system in the field. The difference in skills between the specified requirements and the personnel that will be assigned is the basis for a formalised training program. Training needs are defined in terms of program content, duration of training, training data, software and training equipment requirements.

Human factors engineers are interested in the personnel and training requirements to ensure that these requirements are realistic for the system. If skill level requirements are high and a large amount of training is anticipated, then the equipment design should be reevaluated to see if changes can be made to simplify the situation.

### 2.7.4. Design for economic feasibility

One must view cost from the total life-cycle perspective as previously discussed.

- Cost targets, reflecting life-cycle cost considerations, should initially be established during conceptual design. These target values should be specified in the definition of system operational requirements.
- The specified quantitative economic factors applicable at the system level should be allocated to the appropriate elements of the system, as necessary to ensure that economics is reflected in the design of these elements.
- Life-cycle cost analyses are accomplished throughout the design process, in the evaluation of alternatives, to ensure that the ultimate approach selected reflects economic considerations. Alternative technology applications, operational concepts, support policies, equipment packaging schemes, levels of repair, diagnostic routines, etc. are evaluated through a life-cycle cost analysis.
- Throughout production and during system operational use, life-cycle cost analyses are accomplished to identify high-cost contributors and to aid in determining cause-and-effect relationships, leading to recommendations for system/product improvement. Proposals may be initiated with the objective of reducing life-cycle cost.

### 2.7.5. Design for system supportability

Supportability relates to the degree to which a system can be effectively and efficiently supported throughout its planned life cycle. It includes consideration of both the prime-mission-oriented elements of the system and the elements of support. An individual item of equipment can be reliable and very maintainable, but the assigned test equipment may be highly complex, require extensive calibration, and so on. Hence, the overall degree of supportability may be questionable. Supportability pertains to the entire system, its characteristics and the extent to which it can be supported.

## 2.8. Conclusion

This chapter has gone to great length to describe the process of military logistics. It has discussed the important logistics measures like reliability, maintainability, supply support, availability and economic factors. The link has been established between the production efficiency measure and some of the logistics measures. The importance of the system maintenance concept has been highlighted. Requirements allocation of reliability, maintainability, logistics factors and economic factors have also been thoroughly discussed. The procedure for conduction an extensive LSA has been adequately described. Finally, a discussion has been given of the role of logistics in system design. In particular, the role of logistics in designing for reliability, maintainability, economic feasibility and system supportability has been highlighted.

# CHAPTER 3

# CASE STUDY OF NORTH COAST MILLING

## 3.1. Introduction

This section aims to give a background of North Coast Milling as well as to provide an overview of their type of business. An in-depth discussion is given of the oil milling process. Additionally, a detailed account will be given of their current maintenance procedures as well as some of the problems that the company faces.

The structure of this chapter is as follows:

Section 3.2 provides some background information on North Coast Milling while Section 3.3 provides an in-depth discussion of the oil milling process. Section 3.4 discusses the maintenance philosophy that has been adopted by North Coast Milling. Section 3.5 highlights some of the problems being experienced at North Coast Milling, to which the thesis will try to offer some solutions. Finally, Section 3.6 concludes this chapter of the thesis

## 3.2. Company Background

North Coast Milling began its oil milling operations in 1982. In 1988, the company had begun to diversify its operations into the manufacture of animal feeds, which is one of the by-products of its oil milling process. The mill is located near the wharf in Durban as all the oilseeds are shipped from other African countries and from abroad. The oilseeds are delivered by truck to the mill's silo for storage, once the ships have arrived at Durban harbour. The company's aim is to produce high quality oil and animal feed from carefully selected oilseeds. The company firmly believes that innovation and quality have played an important part in the success of the business. The company's oil production capacity is 5 tons per hour, and its animal feed capacity is 6 tons per hour.

The oilseeds used are that of groundnuts. The groundnut oil is refined to form edible vegetable oils. The main importance of vegetable oils is their food value. Oils and fats are important ingredients for a well balanced diet. These edible oils are consumed in many different ways. In their natural liquid state they are used for cooking. They can also be eaten in a spreadable form, with the main demand for oil coming from the margarine industry. Other food industries that need vegetable oils include the manufacture of cooking fats and oils, salad dressings and ice cream. Because groundnut has a high protein content, the residue after the oil has been extracted provides a protein-rich cake for animal fodder.

The company does not design any of its production equipment but purchases them from reputable suppliers. The company has prides itself in having adopted the TPM philosophy in the early nineties. However, the production efficiencies at the company still seem to be quite low when compared to other oil milling companies that are using identical equipment. Because of these low production efficiencies, North Coast Milling finds itself at a severe disadvantage in its market as its oil and animal feed products are overpriced.

## 3.3. The oil milling process

Section 3.1 serves to introduce some basic concepts in the oil milling process whilst Section 3.3.2 serves to provide the in-depth discussion of the equipment used in the oil milling process.

### 3.3.1. Process overview

The oil from the groundnuts is obtained from the microscopic cells of its seeds. In a single seed there are thousands of cells. The methods of removing the oil are in principle very simple. It is either squeezed out of the seeds by sheer physical pressure or dissolved out by means of a spirit. But these simple principles are not easy to apply as the walls of the cells that contain the oil are hard to penetrate. It requires the expensive machinery and elaborate processes of an oil mill to achieve this.

In an oil mill, the two basic methods of squeezing out the oil or dissolving it with a spirit are often combined. The result is that, in the case of groundnuts, 46 percent of the seed's weight can be extracted as oil, and the remaining 54 per cent contain less than 1 per cent of oil. A diagrammatic representation of the oil milling process at North Coast Milling is provided in Figure 3.1

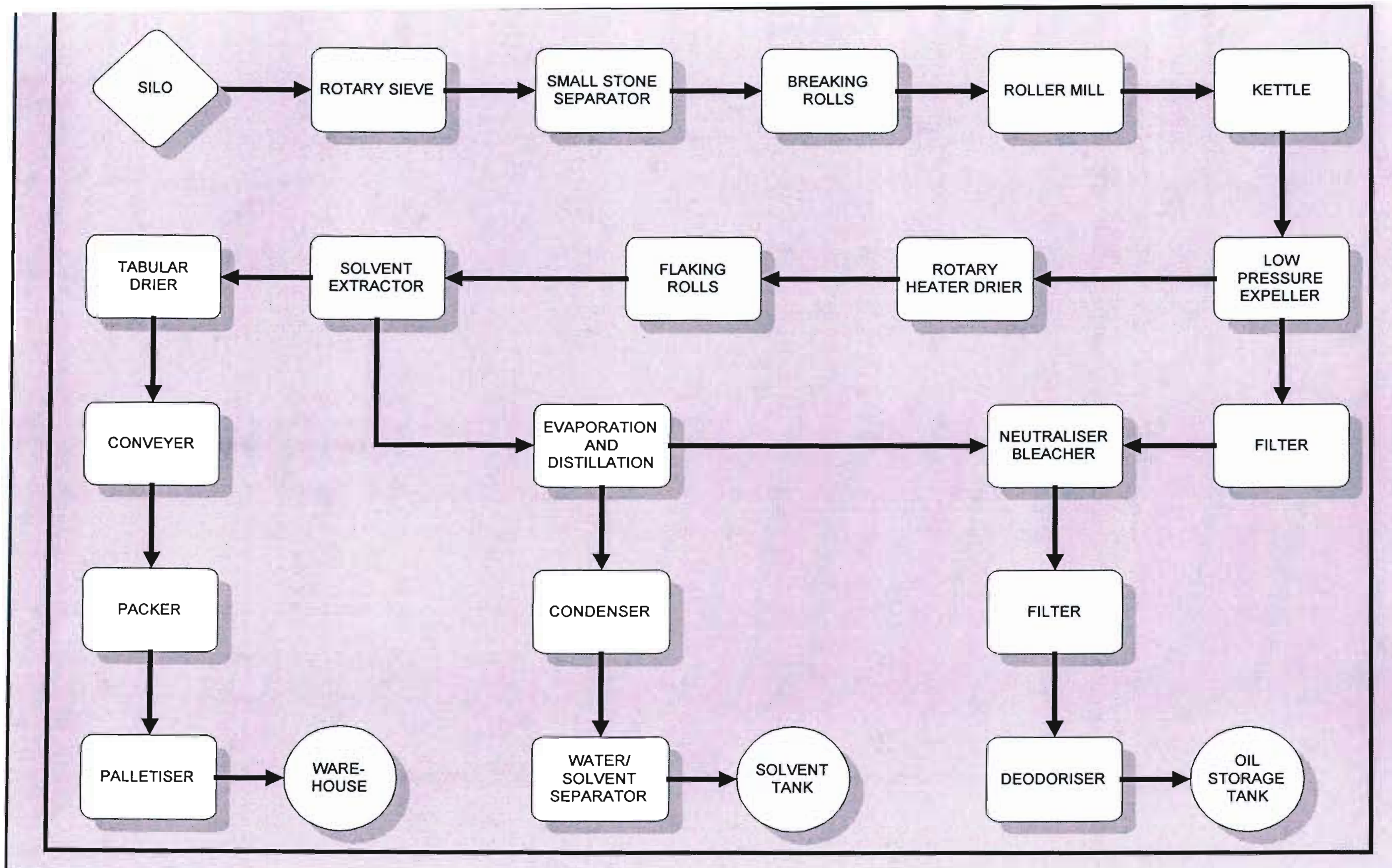



**Figure 3.1**: Oil Milling Process

### 3.3.2. Equipment used in the oil milling process

With reference to Figure 3.1, the processes involved in oil milling at North Coast Milling are as follows:

#### 3.3.2.1. Cleansing process

Milling cannot begin until the nuts have been cleaned. As it passes on a conveyer belt from the storage silos to the mill, the nuts travel under electromagnets which lift out stray scraps of metal which may have found their way amongst the nuts from the harvesting machinery or from the ship. Additional electromagnets are situated at various points throughout the production process to remove any remaining ferrous material. The nuts are thereafter put through rotary sieves that allow the nut itself to pass but stop anything bigger, such as small stones. The nuts then go to a blowing chamber, where a current of air lifts the nuts, while grit, being heavier than the nuts, falls to the bottom of the chamber.

#### 3.3.2.2. Breaking process

The grain is broken up next by the rollers. This helps the heat to penetrate during cooking, which takes place at a later stage. Also, the oil flows more readily out of broken cells when they are put under pressure. The nut seeds go through a pair of heavy, plain rollers that break them up by their weight alone. These rollers are mounted one on top of the other. Groundnut seed, which has very little fibre in the walls of its cells, is effectively broken up by this method.

#### 3.3.2.3. Cooking process

To burst the walls of the oil cells the seed is now cooked. It is led through a series of kettles, closed pans piled on top of one another. Between each kettle is a steam-heated jacket. Metal arms inside the kettles stir the seed as the temperature rises to a maximum of 71-110°C according to the type of seed.

#### 3.3.2.4. Expelling process

The seed next passes to the expeller, where most of the oil is squeezed out. Figure 3.2 is a diagrammatic representation of the expeller used at North Coast Milling.

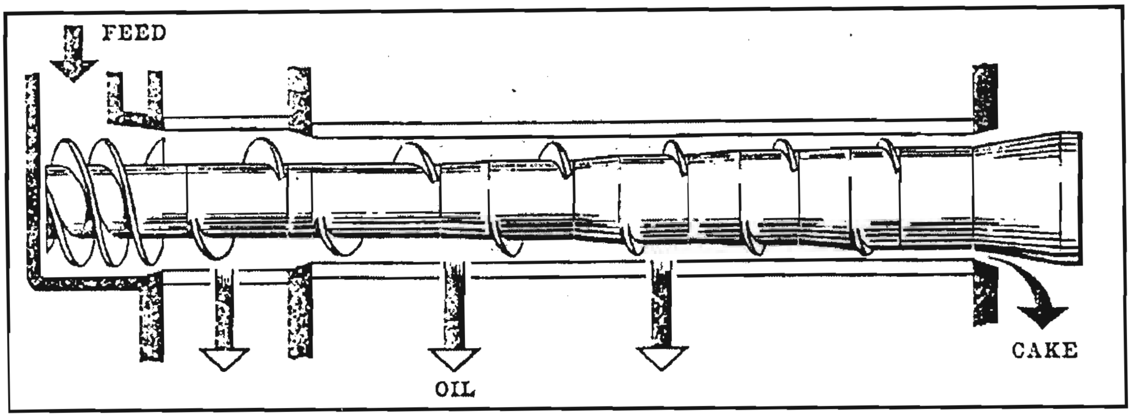



**Figure 3.2**. The expeller

The nuts, that have been previously heated to aid in the release of oil, are fed continuously to the expeller where it is fed by the worm shaft into a horizontal cylinder. A controllable pressure is built up in the cylinder by means of an adjustable choke at the cylinder exit. The internal pressure ruptures oil cells in the nut and oil flows out through perforations in the cylinder cage. The press cake is forced out as pellets through a changeable nozzle at the end of the cylinder. The oil that has trickled through the slots in the cylinder cage is pumped through screens and filters where all traces of vegetable fibre are removed.

Some important considerations during pressing include the chamber temperature, rotation speed of the screw and size of the cake outlet. The outputs of the expeller include the press cake and oil. Important considerations here are the yield of oil, capacity, oil temperature, phosphor and solids content in the oil.

The optimum for the nozzle diameter, through which the cake is forced out, varies between 6 and 8 mm. The width of the cake strips can be standardised according to the requirements by making necessary adjustments in the circular gap of the nozzle cone from where the cake comes out. With 6 mm nozzle diameter and a nozzle temperature of 60°C and a low humidity in the seed, this will minimise the phosphor content in the oil. On the other hand, there is a higher risk for blocking the nozzle under these conditions.

The chamber bars, which form the cylindrical boundaries of the expeller chamber, are fitted in such a way by nuts and bolts that very thin gaps remain between the worm projections and the inner surface of these bars. This helps in cutting and crushing of oil-seeds by the edges of bars, pushing them in the forward direction under pressure through the gaps, simultaneously squeezing the crushed mass for the separation of oil through the outer openings of chamber bars.

The oil produced using the expeller method is of very high quality, since oil alone is expelled. The main disadvantage of the screw-press process is its relatively low yield of oil recovery. Even the most powerful presses cannot reduce the level of residual oil in the press-cake below 3 to 5%. Most of the oil left in the cake is recovered by the next stage in the process, which is the stage of solvent extraction.

#### 3.3.2.5. Solvent Extraction process

Extraction by solvent provides the best means of getting the last possible drop of oil from material that has already gone through a low-pressure expeller. The seed is dried and then run through special flaking rollers that flatten the fragments into thin flakes so that the solvent can soak into them.

The flaking machine consists of a pair of horizontal counter-rotating smooth steel rolls. The rolls are pressed one against the other by a controlled hydraulic system. The nuts are fed between the rolls and are then flattened as the rolls rotate one against the other. The roll-to-roll pressure can be regulated and it determines the average thickness of the flakes. The main purpose of flaking is to increase the contact surface between the oilseed tissues and the solvent used in the extraction process, and to reduce the distance that the solvent and the extract will have to travel. Flaking disrupts the oilseed cells to some degree and thus makes the oil droplets more available for solvent extraction. If the flakes are too thick, the amount of solvent needed to extract oil from the flakes is increased. A larger quantity of solvent will have to be evaporated for each ton of oil, hence more money is spent on energy.

Figure 3.3 is a diagrammatic representation of the solvent extraction process used at North Coast Milling.

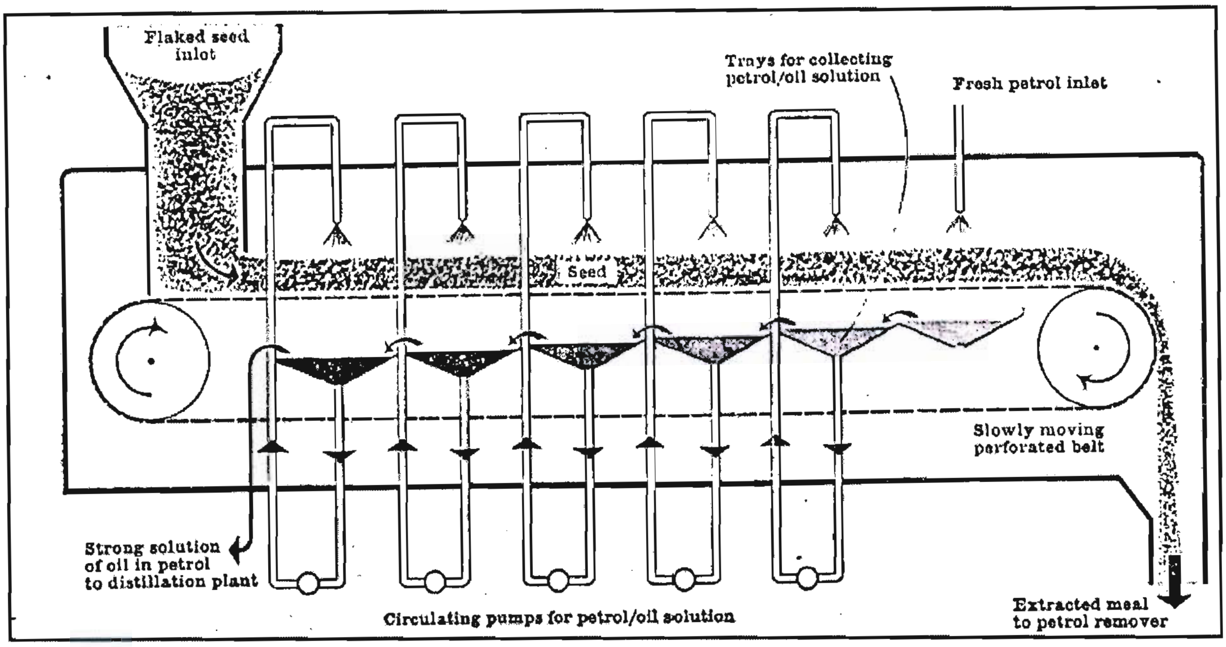



**Figure 3.3**. The solvent extraction process

Solvent extraction consists of washing the flaked oilseed in petrol until practically all the oil has dissolved out of its tissues. There are several ways of doing this, all based on counter-current principles whereby seed moving in one direction is washed by petrol moving in the opposite direction. The most up-to-date are continuous systems in which the seed passes automatically through all stages. The flaked seed is carried along on a continuously circulating belt of fine wire mesh. It is sprayed at intervals with jets of solvent, usually petrol, which wash the oil out of the seed and through the wire mesh. The petrol is pumped from the inlet jets and moves in the opposite direction to the flow of seed. Thus, fresh seed coming in is washed first by petrol from the left-most inlet jet, that has already been used five times and is rich in oil. The strong solution of oil in petrol falls through the mesh into the first (leftmost) tray. The flaked seed keeps moving along the belt, and is next washed by petrol from the next jet, used four times previously and therefore slightly less rich in oil. The oil/solvent solution falls through into the second tray, then overflows into the first tray, since the trays are set on a descending level. From the first tray, it is pumped up to the left-most jet. The process continues until the seed reaches the right-most jet, where completely fresh petrol removes practically every trace of oil. As the oil/solvent solution overflows from the lowest tray in the series, it is pumped away to the distilling plant, where heat causes the petrol to evaporate. The petrol vapour is condensed for re-use, while the crude oil is sent on its way for refining. The remaining flaked seed becomes meal or cake for animal fodder after the residue of solvent has been removed and condensed.

### 3.3.2.6. Refining process

The refining of vegetable oil for edible purposes has three stages. Certain natural acids must be removed, the colour of the oil must be lightened, and its taste and smell must be improved. The first process, neutralising the acids, is required because natural changes have taken place in the chemical structure of the oil since the crop was harvested. An alkali such as caustic soda is used to remove these acids. The oil is heated, stirred and sprayed with a solution of the alkali in water. The acids and soda combine to form a soap that sinks slowly to the bottom of the tank and is then run off, leaving purified oil. To make sure that all traces of soap have been removed, the oil is washes several times with hot water and allowed to settle, while the water and any emulsion formed are run off.

Next comes bleaching with carbon. The tank of hot oil is dried under vacuum, the carbon mixed into it, and the solution is stirred for 15 minutes with large metal paddles. Then the oil is pumped off through filters and comes out clear.

Lastly, the oil is deodorised by passing steam through the hot oil under high vacuum so that the odorous substances are swept away as vapour, resulting in neutral oil.

### 3.3.2.7. Monitoring and control process

The function of the control system is to ensure that the production process runs smoothly and within predefined limits. The sensors used at various point in the production process interface and pass valuable information to the control system. The control software uses these inputs in order to manipulate the important variables in the production process, like temperature of the seed and oil, pressure in the expeller, speed of the screw assembly in the expeller, humidity of the seed stored in the silo and throughput control on the expeller oil and cake outputs. Without correct readings from the sensors, these important variables will not be correctly varied and this will result in problems in the production process.

The pre-treatment of the seeds before going to the expeller consists of the adjusting of humidity and temperature. To get a good oil-quality for technical use, especially a low phosphor content, the temperature and the humidity of the seed is important.

Some important function of the control system in the production process is detailed below.

a. Control of seed humidity

The oil cleaning process removes an important amount of phosphor and should be done for this reason properly. If the seed humidity is reduced, the yield of oil rises and the phosphor content goes down. However, the capacity goes down and the content of solids increases. Besides, the energy demand will increase by processing a too dry seed. More humidity of the seed will lower the friction between seeds during the pressing and increase the throughput (capacity). However, the yield of oil will decrease. The humidity of the seed should be between 6,5 and 7,5 weight-percentage. In this range, one gets an optimum of capacity, yield of oil and content of phosphor and solids in raw oil.

b. Control of seed temperature

Pre-warming of the seed should only go up to 20°C. There are no positive effects with a higher seed temperature. However, there are negative effects such as increasing phosphor content if the seed is pre-heating over 60°C. If the seed is too cold (<10°C), the oil yield will be low (a lot of unbroken seeds in the press cake is visible) and more solids are in the oil.

c. Control of nozzle temperature

In order to avoid blockage of the press cake outlet in the expeller, it is necessary to heat this part of the expeller. This heating should be in the range between 60 and 80°C. A higher temperature on the press cake outlet will lead to a higher phosphor content in the oil. This temperature has an effect on the oil temperature, which should not rise over 40°C. With a lower temperature on the cake outlet, the solid content in the oil rises.

d. Control of screw speed in the expeller

If the throughput is reduced (screw rotation speed is reduced), yield of oil is increased but solid content in the oil is also increased. Alternatively, when the throughput is increased, the yield is reduced and the solid content in the oil is reduced. It is possible to find an optimal compromise according to ones individual aims with a revolution-regulated press-screw. Favourable rotation speeds for the screw is between 20 and 50 rpm. In this range of rotation, a minimum of energy demand is required. The higher the throughput of seed, the greater the capacity of the oil cleaning installation must be. With this increasing oil production, the total quantity of solids in the oil rises also.

e. Correctly reading level switches

The level switches in the storage silos must give the correct reading for the amount of seeds stored in the silos.

f. Control of the rotary valves

The rotary valve is an important device. It permits the meal or feed to be injected in the conveying system at the feed point where there is a tendency for the air to leak to the atmosphere. Besides loss of pressure, this results in considerable dust nuisance and necessitates a larger air pump and higher power consumption than would otherwise be required. In order to overcome this problem, the rotary valve is used as an air lock and the correct control of it is important.

g. Correctly reading the load cells:

From the silos, the seed is conveyed to a hopper, that has a pneumatically operated gate. The hopper is supported on load cells and is provided with a weight indicator. According to the load cell reading and the signal from the control system, the correct weight of seeds is released at the correct time. The accuracy of the load cells must be within 5% of the real weight. The load cell helps in ensuring faster weighing cycles. It allows for more efficient use of manpower and reduced unscheduled down time.

Table 3.1 displays the effect of increasing some of the important variables discussed in this section on the phosphor and particles content of the oil, throughput of oil, yield of oil and energy demand for the oil production. Note that the effect is the opposite if that specific variable is decreased.

| Item affected | Variables | | |
|---|---|---|---|
| | **Increasing RPM** | **Increasing seed humidity** | **Increasing seed temperature** |
| Phosphor content | Increase | Increase | Increase |
| Throughput | Increase | Increase | Decrease |
| Content of particles | Increase | Decrease | Decrease |
| Yield of oil | Decrease | Decrease | Increase |
| Energy demand | increase | decrease | Increase |

**Table 3.1.** Effect of specific variables

## 3.4. Current Maintenance Philosophy

North Coast Milling had adopted total productive maintenance (TPM) as its current maintenance philosophy since 1992. TPM is a Japanese concept involving an integrated approach to maintenance, with the objective of maximising productivity. More specifically, TPM:

- Aims to maximise overall equipment effectiveness and to improve overall efficiency
- Aims to establish a complete preventive maintenance program for the entire life cycle of equipment
- Is implemented on a team basis and involves various departments, such as engineering, production, operations and maintenance
- Involves every employee, from top management to the workers on the floor. Even equipment operators are responsible for maintenance of the equipment they operate.
- Is based on the promotion of preventive maintenance through motivational management

TPM aims at getting the most efficient use of equipment by establishing a total maintenance system including maintenance prevention, preventive maintenance and improvement-related maintenance for the company. The essence of TPM is teamwork which requires a participation of equipment designers, equipment operators and maintenance department workers to focus on their facilities, their everyday problems and their environment in order to improve product quality, increase equipment availability and equipment reliability.

TPM aims to build a close relationship between Maintenance and Productivity, showing how good care and up-keep of the equipment will result in higher productivity. TPM is not only a strategy but also a philosophy of continuous improvement and teamwork that creates a sense of ownership in the operators of each machine as well as in their supervisor and the maintenance people involved. All participants assume a real commitment.

Autonomous maintenance is an important aspect of TPM. It is where the user of the machine really becomes the owner of the machine, he can take it apart and repair it and he takes care of it. The equipment undergoing TPM will be brought up to its optimal performance, correcting any discrepancies that may be found. It will also be customised with modifications mostly suggested by the operators and supervisors, and analysed and approved by the whole team. Such modifications or improvements will cover not only the machine itself, but its surrounding areas as well. It is well understood that a cleaner and better up-kept piece of equipment is less likely to break down. Any discrepancy that could have ended up as a major problem will be detected and solved in the earliest stages.

The concept of zero breakdowns seeks to root out the factors causing breakdowns. The approach flows from the recognition that total plant profitability is sensitive to uptime and maintenance costs. Management decisions must reflect both the cost of maintenance and the cost of a failure.

The five components necessary for a true TPM strategy are:

- Maintenance prevention – designing or selecting equipment that will run with minimal maintenance and is easy to service when necessary
- Predictive maintenance – determining the life expectancy of components in order to replace them at the optimum time
- Corrective maintenance – improving the performance of existing equipment or adapting new equipment to the manufacturing environment
- Preventive maintenance – using schedules or planned maintenance to ensure the continuous, smooth operation of equipment
- Autonomous Maintenance – involving production employees in the total machine maintenance process

With TPM, a great deal of attention is paid to the reliability of production lines and their efficient functioning. Although many companies automate most of their manufacturing operations, maintenance activities depend profoundly on human inputs. TPM focuses on scheduling maintenance as an integral part of the manufacturing process. The goal is to minimise and eventually eliminate emergency and unscheduled maintenance.

## 3.5. Problems faced by North Coast Milling

Even though North Coast Milling claims to have adopted the TPM philosophy, there is very little indication that the company is actually practising it. This section serves to highlight some of the major problems that exist at North Coast Milling, which serve as stumbling blocks to the successful implementation of TPM.

### 3.5.1. Lack of formal analyses procedure

In spite of having formally adopted the TPM maintenance philosophy, there are still no formalised maintenance procedures in place and the company relies on the experience and expertise of its maintenance staff in order to maintain the plant efficiency. As such, the production efficiency using this approach is very low as the emphasis is on corrective maintenance, which has led to frequent production stoppages. At present, the production efficiency is in the region of forty percent. However, in order for North Coast Milling to be competitive in its market, this figure needs to substantially improve.

The company does not use a formal reliability analysis, which requires the use of analytical methods, proper data logging, and failure analysis. The maintenance schedules are often based on educated guesswork. Any reliability engineering or failure analysis is done in an informal manner

The company claims to be using planned/predictive maintenance together with corrective maintenance. In spite of this, the equipment downtime is still too high. As such, there seems to be more corrective maintenance taking place than predictive maintenance. A large percentage of the maintenance hours at North Coast Milling are dedicated to emergency work orders. A large proportion of the maintenance hours is consumed by unplanned maintenance.

The preventive maintenance requirements often exceed the labour resource available. Preventive maintenance is missed, preventable failures occur and unplanned maintenance work consumes more labour than necessary. The number of temporary repair grows out of control and the costs of repairing additional damage caused by them wastes more resources.

The common problem with the maintenance programs at North Coast Milling is that were never designed correctly in the first place. Often, in an attempt to be seen to be doing something about high profile reliability problems, maintenance personnel create and perform tasks that are supposed to prevent failures but, in reality, serve no realistic purpose. Some of the other shortcomings of the preventive maintenance program seem to be that many tasks duplicate other tasks and some tasks are done too often.

Spare part stocks are usually kept according to some old hearsay formula that very seldom has any relation to the reliability of failure rate of components of the production system. As a result, old production lines are often scrapped with an inventory full of original spares in stores. On the other hand, spares are often unavailable when urgently needed, which results in the high logistic delay times.

### 3.5.2. Lack of ownership by equipment operators

The attitude of machine operators at North Coast Milling seems to be that they merely run the equipment and that when the equipment breaks, then the maintenance department will fix it. They have not been made responsible for their equipment performance and productivity. Sufficient and appropriate training has not been provided to help the operators become very knowledgeable about their equipment and perform normal daily maintenance of the equipment. As a result, the operators often demonstrate a lack of care for the equipment that they operate.

### 3.5.3. Poor co-operation between relevant departments

There seems to be an absence of co-operation and mutual understanding between the maintenance and production department. There is no effective maintenance policy for planning, controlling and directing all maintenance activities. The maintenance department is not well organised, adequately staffed and the personnel are not sufficiently trained to carry out the work. There is no progressive effort to reduce or eliminate breakdown.

Equipment utilisation is not optimal at North Coast Milling. The organisational and functional separation between maintenance, production and engineering departments results in inefficiency, lower productivity and higher costs. The organisational structure at North Coast Milling is one of departmentalisation where the maintenance and production departments have separate budgets, performance measures and management structures. There are conflicting goals and objectives of each department that sometimes result in decisions that are not congruent with the overall business goals. The most common problem being short-term production goals that often conflict with the maintenance objective of reducing the overall cost of maintenance.

### 3.5.4. Company's view of maintenance

North Coast Milling seems to hold onto the traditional view of maintenance. It tries to balance maintenance cost with an acceptable availability and reliability of the plant. Maintenance is seen as an expense that needs to be reduced in relation to the overall business, particularly in the short term. However, the maintenance managers have always argued that to increase the level of availability and reliability of the plant, more expenditure needs to be committed to the maintenance budget. However, with the availability and efficiency problems at the plant, top level management has realised that giving more resources to the maintenance department is not going to produce a cost-effective solution. The cost of maintenance at North Coast Milling is now the highest element of operating costs and it has now become a cost control priority.

### 3.5.5. Problem of having self-appointed experts

At North Coast Milling, there are many self-appointed and self-trained "experts" in the art of finger diagnostics. These people should be identified and informed of the consequences of their actions because they are spending a lot of time doing unnecessary, wasteful, often dangerous and sometimes very destructive things. These finger analysts often declare an emergency that results in shutting the machine off to perform unnecessary maintenance. There is a good chance that another fault can be created if maintenance has to be repeated on a job just completed. When maintenance tasks are performed with no specific procedures for guidance, mistakes often happen. Maintenance-caused problems can be averted when rules are enforced to protect the machine and its components from negligent people who should know better.

Production supervisors assume the role of maintenance experts when they dictate how long maintenance people should take to do repair work. They are in fact, contributing to potential failures that could otherwise be avoided by allowing maintenance to have enough time to do the job properly. There always seems to be enough money and time available to do unscheduled repair work, and never enough to do the job right the first time.

Most purchasing departments have their fair share of "experts" who determine what parts have to be purchased by adhering to the general rule that the lowest bidder gets the contract. The buyers are not engineers and do not seem to realise that using unspecified parts can create problems. They fail to realise that substitution of the correct parts can not be tolerated.

### 3.5.6. Other obstacles to TPM implementation

Like any improvement initiative, implementation of TPM also has a few obstacles, crucial among them being lack of:

- Management support and understanding
- Sufficient training
- Time for evolution of TPM

The low regard that preventive maintenance has at North Coast Milling is derived from a lack of quality and focus on the effort. Lots of time goes into the initial sale of the preventive maintenance program, but little time into the actual work performed.

## 3.6. Conclusion

This chapter has provided some background information on North Coast Milling. A detailed description has been provided of their production process. Additionally, a discussion has been given on the philosophy on which their maintenance practices are based. The chapter concluded with a discussion of some of the major problems faced by North Coast Milling. It is clear that North Coast Milling is not following the TPM maintenance philosophy properly, which they seem to pride themselves on. The aim of the study is to highlight some of these areas of non-compliance and provide some recommendations to North Coast Milling in Chapter 5 so as to try and overcome some of these problems.

# CHAPTER 4

# ANALYSIS AND EVALUATION OF THE MAINTENANCE PRACTICES

## 4.1. Introduction

Following from the discussion of the problems faced by North Coast Milling, a great deal of effort will be spent doing a formal logistic analysis of all the production equipment, using the analyses methods discussed in Chapter 2. The analysis will be performed using the actual data from North Coast Milling, which has been averaged over the past three years.

The structure of this chapter is as follows:

The relevant data from North Coast Milling, as obtained from the production and maintenance departments, is displayed in Section 4.2. The various logistics measures and production efficiency for the entire production system is computed in Section 4.3. The RAM analysis is conducted in Section 4.4. The results of the RAM analysis serve as inputs to the LSA analysis conducted in Section 4.5. The FMECA, RCM, corrective maintenance, spare parts and manpower and training analyses are conducted in this section. Finally, the chapter concludes with Section 4.6.

## 4.2. Production and Maintenance data

Table 4.1 displays the data received from North Coast Milling's production and maintenance departments. It displays the production volume of oil for each of the months (averaged over the last three years) as well as the downtime, standby and operating hours of the production process. Figure 4.1 is a graphical display of the production volumes of oil while Figure 4.2 is a graphical display of the downtime in the production process at North Coast Milling. Note that the analysis has been limited to only the oil production, as the production of the feed or cake would yield very similar results.

Table 4.2 and Figure 4.3 allocates the downtime hours (averaged over the past three years) to all the equipment in the production process. Table 4.3 lists the actual cost and number of failures for each part, which will be used in the subsequent analyses. The lost production cost is the opportunity cost of having produced finished products during those downtime hours at a cost of R3.00 per finished product.

| MONTH | PRODUCTION (Kg's) | TOTAL HOURS | DOWNTIME HOURS | STANDBY HOURS | OPERATING HOURS |
|---|---|---|---|---|---|
| | | | | | |
| January | 344,000 | 240 | 70 | 20 | 150 |
| February | 307,000 | 240 | 80 | 30 | 130 |
| March | 372,000 | 240 | 60 | 40 | 140 |
| April | 267,780 | 240 | 40 | 50 | 150 |
| May | 329,000 | 240 | 100 | 10 | 130 |
| June | 329,900 | 240 | 50 | 30 | 160 |
| July | 378,040 | 240 | 90 | 30 | 120 |
| August | 311,080 | 240 | 70 | 20 | 150 |
| September | 366,780 | 240 | 30 | 10 | 200 |
| October | 289,320 | 240 | 100 | 30 | 110 |
| November | 319,840 | 240 | 90 | 20 | 130 |
| December | 131,470 | 120 | 60 | 25 | 35 |
| | | | | | |
| Total | 3,746,210 | 2,760 | 840 | 315 | 1,605 |

**Table 4.1**. Oil production and maintenance data for North Coast Milling

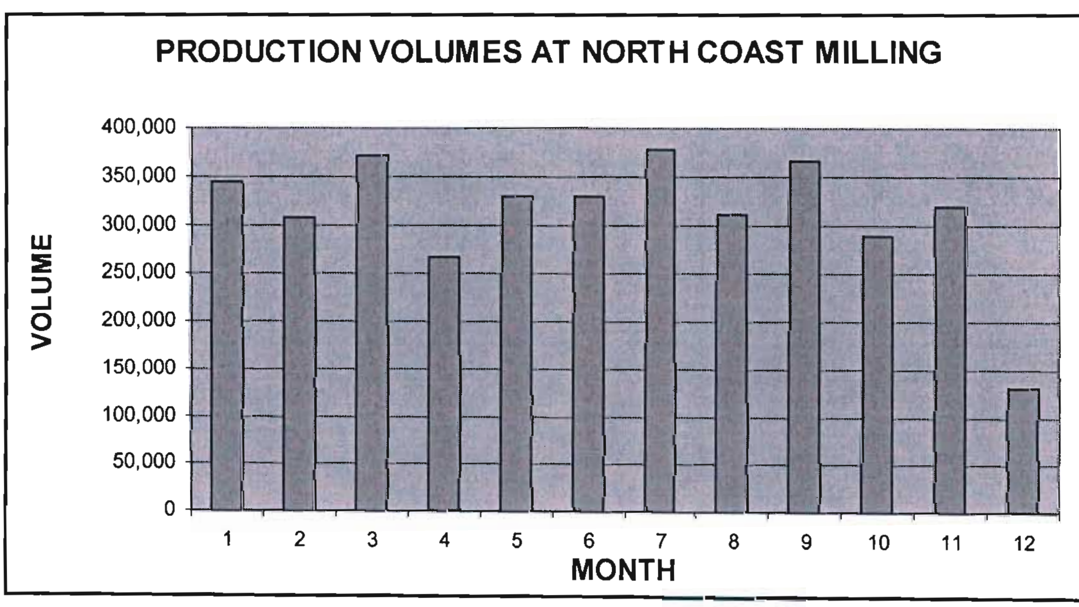



**Figure 4.1**. Production volumes of oil at North Coast Milling

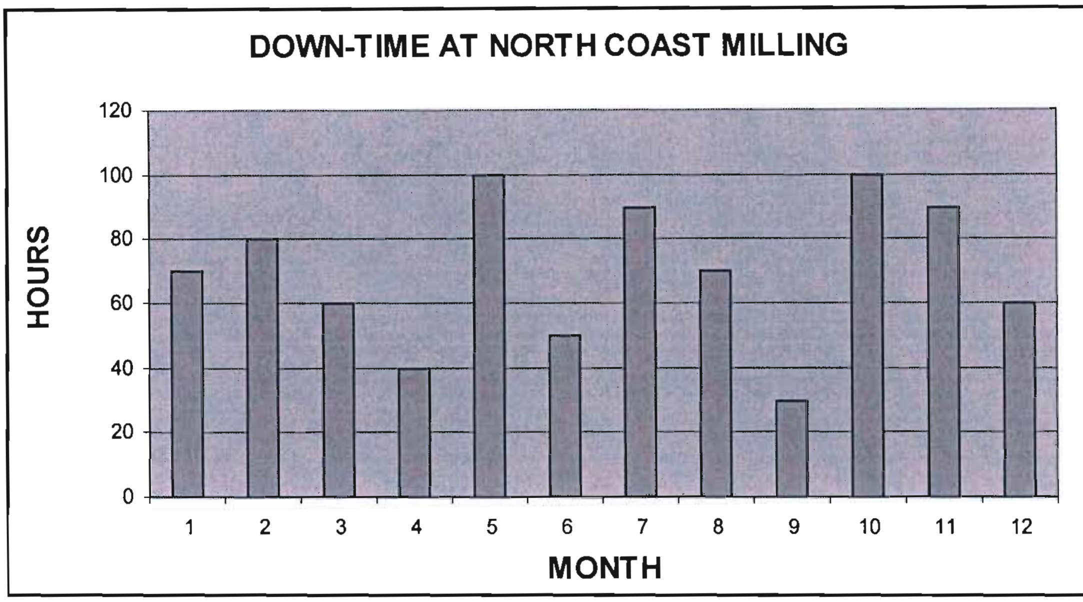



**Figure 4.2.** Downtime hours at North Coast Milling

| | DOWNTIME (HOURS) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
| EQUIPMENT | | | | | | | | | | | | | |
| 1. rotary sieve | 2 | 0 | 0 | 0 | 3 | 3 | 1 | 1 | 0 | 1 | 0 | 0 | 11 |
| 2. small stone seperator | 0 | 2 | 0 | 0 | 5 | 1 | 2 | 0 | 0 | 3 | 0 | 0 | 13 |
| 3. roller mill | 1 | 0 | 0 | 0 | 3 | 0 | 0 | 4 | 0 | 2 | 1 | 0 | 11 |
| 4. kettle | 2 | 1 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 9 |
| 5. low pressure expeller | 28 | 23 | 35 | 13 | 29 | 17 | 20 | 22 | 17 | 20 | 29 | 19 | 272 |
| 6. breaking rolls | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 4 |
| 7. rotary heater drier | 3 | 4 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 5 | 2 | 0 | 19 |
| 8. Conveyer | 0 | 0 | 0 | 3 | 1 | 0 | 2 | 4 | 0 | 9 | 0 | 0 | 19 |
| 9. solvent extractor | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 12 |
| 10. tabular drier | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 11. packer | 8 | 10 | 14 | 6 | 15 | 7 | 12 | 8 | 5 | 16 | 18 | 13 | 132 |
| 12. Flaking rolls | 7 | 12 | 6 | 8 | 8 | 5 | 14 | 5 | 5 | 10 | 21 | 9 | 110 |
| 13. palletiser | 0 | 3 | 0 | 1 | 0 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 10 |
| 14. filter | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 5 | 8 |
| 15. neutraliser bleacher | 3 | 2 | 0 | 0 | 8 | 1 | 6 | 5 | 0 | 1 | 0 | 0 | 26 |
| 16. evap & distillation | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 3 | 4 | 0 | 12 |
| 17. condenser | 2 | 2 | 0 | 0 | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 3 | 15 |
| 18. water/solvent separator | 0 | 5 | 0 | 1 | 4 | 0 | 2 | 3 | 0 | 7 | 6 | 0 | 28 |
| 19. deodoriser | 1 | 0 | 0 | 0 | 0 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 6 |
| 20. control system & sensor | 7 | 9 | 5 | 8 | 18 | 6 | 17 | 15 | 3 | 13 | 9 | 11 | 121 |
| | | | | | | | | | | | | | |
| Total | 70 | 80 | 60 | 40 | 100 | 50 | 90 | 70 | 30 | 100 | 90 | 60 | 840 |

**Table 4.2.** Downtime hours allocated to all the equipment

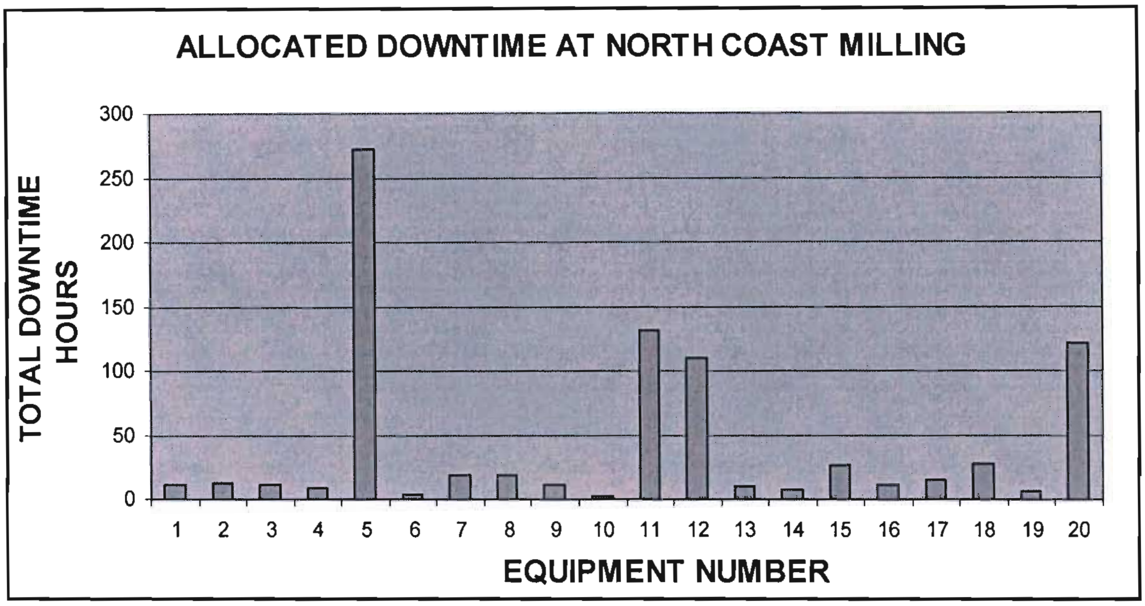



**Figure 4.3.** Downtime hours allocated across all the equipment

| EQUIPMENT | Total failures for the year | Total maintenance cost for the year | Total lost production cost | Total cost of failures |
|---|---|---|---|---|
| | | | | |
| 1. rotary sieve | 1 | R 25,876.19 | R 77,022 | R 102,898.19 |
| 2. small stone seperator | 1 | R 30,580.95 | R 91,026 | R 121,606.95 |
| 3. roller mill | 1 | R 25,876.19 | R 77,022 | R 102,898.19 |
| 4. kettle | 1 | R 21,171.43 | R 63,018 | R 84,189.43 |
| 5. low pressure expeller | 23 | R 639,847.62 | R 1,904,544 | R 2,544,391.62 |
| 6. breaking rolls | 0 | R 9,409.52 | R 28,008 | R 37,417.52 |
| 7. rotary heater drier | 2 | R 44,695.24 | R 133,038 | R 177,733.24 |
| 8. Conveyer | 2 | R 44,695.24 | R 133,038 | R 177,733.24 |
| 9. solvent extractor | 1 | R 28,228.57 | R 84,024 | R 112,252.57 |
| 10. tabular drier | 0 | R 4,704.76 | R 14,004 | R 18,708.76 |
| 11. packer | 11 | R 310,514.29 | R 924,264 | R 1,234,778.29 |
| 12. Flaking rolls | 9 | R 258,761.90 | R 770,220 | R 1,028,981.90 |
| 13. palletiser | 1 | R 23,523.81 | R 70,020 | R 93,543.81 |
| 14. filter | 1 | R 18,819.05 | R 56,016 | R 74,835.05 |
| 15. neutraliser bleacher | 2 | R 61,161.90 | R 182,052 | R 243,213.90 |
| 16. evap & distillation | 1 | R 28,228.57 | R 84,024 | R 112,252.57 |
| 17. condenser | 1 | R 35,285.71 | R 105,030 | R 140,315.71 |
| 18. water/solvent separator | 2 | R 65,866.67 | R 196,056 | R 261,922.67 |
| 19. deodoriser | 1 | R 14,114.29 | R 42,012 | R 56,126.29 |
| 20. control system sensors | 10 | R 284,638.10 | R 847,242 | R 1,131,880.10 |
| | | | | |
| Total | 70 | R 1,976,000 | R 5,881,680 | R 7,857,680 |

**Table 4.3.** Allocated cost and number of failures

## 4.3. Logistics measures and production efficiency

A computation is performed for the various parameters discussed in Section 2.2.6 under the logistic measures and production efficiency for the entire production system.

Some important technical details of the production process are the following:

- The expeller capacity and seed capacity is 5000 kg/hour
- The oil yield is 33kg oil per 100kg seed
- The actual oil production is 2350 kg/hour
- The required operating time per year is 2760 hours

With reference to the data in Figure 4.1, the oil production for the year is 3746210 kg. Information was received from the production department that the average amount of groundnut seeds crushed over the three years was 10 406 138 kg. This represents an average recovery of oil of 36%.

$$average\ \ oil\ \ recovery = \frac{3746210kg}{10406138kg} = 36\%$$

The average production of cake over the three years is 6 451 806 kg, which represents 62% of the total of the oilseed mass crushed. The total waste from the production process was 208 123 kg which represents 2% of the total of the oilseed mass crushed. Using (2.21), the production efficiency (PE) is computed as:

$$PE = \frac{3746210\ Kg's}{1605\ hours} \div 5000\ kg's\ /\ hour = 47\%$$

Using (2.19), the utilisation is:

$$utilisation = \frac{1605\ hours}{1920\ hours} = 83{,}6\%$$

Using the definition in (2.18), the operational availability is computed as:

$$operational\ availability = \frac{1920\ hours}{2760\ hours} = 69{,}6\%$$

From the definition of (2.22), the overall equipment effectiveness is computed as:

$$overall\ \ equipment\ \ effectiveness = 69{,}6\% \times 83{,}6\% \times 47\% = 27\%$$

## 4.4. Reliability, availability and maintainability (RAM) analysis

It is evident from Figure 4.3 and Table 4.2 that the major contributors to the downtime in the production process are the low-pressure expeller, bagging machine (or packer), flaking rolls and control systems and sensors. Referring to the production process in Figure 3.1, it is evident that all these systems are in series (as discussed in Chapter 2) and these four downtime drivers bring down the overall reliability of the system. In this regard, all the analyses will be confined to just these four systems.

The RAM analysis for the expeller is conducted in Section 4.4.1 while the RAM analysis for the bagging machine is conducted in Section 4.4.2. For the control system sensors, the RAM analysis in conducted in Section 4.4.3, while the RAM analysis for the flaking rolls is conducted in Section 4.4.4.

### 4.4.1. The low pressure expeller

Figure 4.4 depicts the product breakdown structure of the expeller, following from Section 3.3.2.

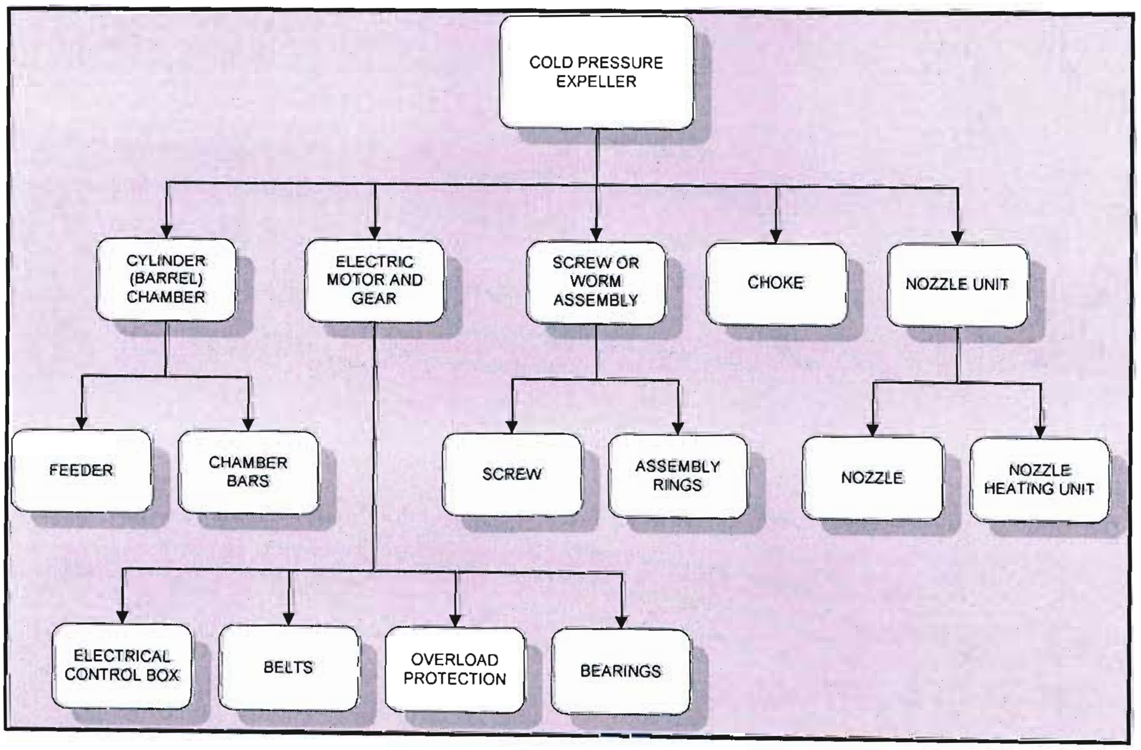



**Figure 4.4.** Product breakdown structure of the expeller

### 4.4.1.1. Analysis using actual data for the expeller

The number of failure of the expeller for the year totalled 23 in a total operating time of 1605 hours .

a. failure rate:

$$\exp eller\ failure\ rate = \frac{23}{1605} = 0{,}0143$$

b. mean time between failure:

$$\exp eller\ MTBF = \frac{1}{0{,}0143} = 69{,}93\ hours$$

c. reliability:

$$\exp eller\ \ reliability = e^{-(0{,}0143)(240)} = 0{,}032$$

There is a 3,2% chance that the expeller will not break down over a month of 240 hours.

$$\exp eller\ \ reliability = e^{-(0{,}0143)(10)} = 0{,}87$$

There is a 87% chance that the expeller will not break down over a single day consisting of 10 hours of operation.

d. Allocated failure rate and MTBF:

The expeller failure rate and MTBF is apportioned down to its subsystems in Table 4.4. From the field data provided in Table 4.4, it is evident that of the total number of expeller failures, the cylinder chamber contributed 4%, the electric motor and gear contributed 56%, the choke contributed 5%, the nozzle unit contributed 5% and the screw assembly contributed 30%.

| EQUIPMENT | ANNUAL FAILURES | PERCENTAGE OF TOTAL FAILURES | CALCULATED FAILURE RATE | CALCULATED MTBF (HOURS) |
|---|---|---|---|---|
| | | | | |
| **EXPELLER** | **23** | **100%** | **0.0143** | **70** |
| | | | | |
| CYLINDER CHAMBER | 1 | 4% | 0.000621739 | 1608 |
| FEEDER | 1 | 4% | 0.000621739 | 1608 |
| CHAMBER BARS | 0 | 0% | 0 | 0 |
| | | | | |
| MOTOR & GEAR | 13 | 56% | 0.008082609 | 124 |
| CONTROL BOX | 8 | 35% | 0.004973913 | 201 |
| BELTS | 1 | 4% | 0.000621739 | 1608 |
| OVERLOAD PROTECTION | 0 | 0% | 0 | 0 |
| BEARINGS | 4 | 17% | 0.002486957 | 402 |
| | | | | |
| CHOKE | 1 | 5% | 0.000715 | 1399 |
| | | | | |
| NOZZLE UNIT | 1 | 5% | 0.000715 | 1399 |
| NOZZLE HEATING UNIT | 1 | 5% | 0.000715 | 1399 |
| NOZZLE | 0 | 0% | 0 | 0 |
| | | | | |
| SCREW ASSEMBLY | 7 | 30% | 0.004246478 | 235 |
| ASSEMBLY RINGS | 2 | 9% | 0.001243478 | 804 |
| SCREWS OR WORMS | 5 | 21% | 0.003003 | 333 |
| | | | | |

**Table 4.4.** Expeller failure rate and MTBF allocations

e. maintenance hours computation:

| EXPELLER | ACRONYM | MAINTENANCE TIME (HOURS) |
|---|---|---|
| | | |
| maintenance downtime | MDT | 272 |
| mean active maintenance time | M | 163 |
| logistics delay time | LDT | 95 |
| administrative delay time | | 14 |
| mean time to repair | MTTR | 139 |
| preventive maintenance time | | 24 |
| | | |

**Table 4.5.** Maintenance hours allocation for the expeller

With reference to Table 4.5, it is evident that the mean maintenance downtime (MDT) is made up of the sum of the mean active maintenance time ( $\bar{M}$), the logistics delay time (LDT) and the administrative delay time. The MDT has been obtained from Table 4.2. It is evident from Table 4.5 that the mean active maintenance time forms 60% of the total mean maintenance downtime. The logistics and administration delay Times form 35% and 5%, respectively, of the mean maintenance downtime. The logistics delay time is the time spent waiting for spares to arrive from the suppliers, and is made up of lead times and delivery times. This figure is too high, and can be greatly reduced if the company can accurately predict the number of spares to be kept in stores, so that the correct spare part is readily available when a failure occurs.

The active maintenance time of 163 hours is made up of corrective maintenance time and preventive maintenance time. From Table 4.5, it is seen that of the 163 hours, 139 hours is spent doing corrective maintenance and 24 hours is spent doing preventive maintenance. It is obvious that North Coast Milling is spending too much time on corrective maintenance (due to the poor reliability of the equipment) and too little time on preventive maintenance.

For the expeller, the total number of failures is 23. The mean time to repair all the failures is 139 hours, obtained from Table 4.5. Hence, the MTTR per failure is approximately 6 hours.

f. operational availability:

From equation (2.18), the operational availability of the expeller is computed as:

$$A_o = \frac{total\ hours - downtime\ hours}{total\ hours} \times 100\% = \frac{2760 - 272}{2760} \times 100\% = 90{,}14\%$$

### 4.4.1.2. Analysis using supplier's specifications for the expeller

The supplier's specification for the MTBF of the various subsystems of the expeller is displayed in Table 4.6.

| EQUIPMENT | SUPPLIERS MTBF (HOURS) | COMPUTED FAILURE RATE |
|---|---|---|
| | | |
| **EXPELLER** | 438.3382071 | 0.002281343 |
| | | |
| CYLINDER CHAMBER | 3000 | 0.000333333 |
| | | |
| MOTOR AND GEAR | 1500 | 0.000666667 |
| | | |
| CHOKE | 2700 | 0.00037037 |
| | | |
| NOZZLE UNIT | 2100 | 0.00047619 |
| | | |
| SCREW ASSEMBLY | 2300 | 0.000434783 |

**Table 4.6.** Supplier's data for the expeller and its subsystems.

a. failure rate

As all the subsystems are in series, and as discussed in Section 2.5.2.1, the total failure rate of the expeller is the sum of the failure rates of its various subsystems. As shown in Table 4.6, the total failure rate of the expeller is 0,00228.

b. mean time between failure

The mean time between failure for the expeller is the inverse of its failure rate. This computes as 438,34 hours. It is evident that the supplier's MTBF figure is much higher than the one achieved in practice, as that figure is obtained assuming ideal conditions. It can be concluded that there are problems in the operation of the expeller in its environment, which needs to be addressed.

c. reliability

$$\text{exp}\,eller\ \ reliabilit\,y = e^{-(0{,}00228)(10)} = 0{,}972$$

There is a 97,2% chance that the expeller will not break down over a single day consisting of 10 hours of operation.

d. maintenance hours

The supplier's maximum MTTR for the expeller for any failure that occurs, is specified as 3 hours. This figure assumes the correct skill level of maintainers and the availability of the correct tools and spares. The actual MTTR per failure at North Coast Milling is approximately 6 hours. This is twice as high as the supplier's specified MTTR value. This discrepancy can be attributed to the low skill levels of the maintainers and operators as well as the unavailability of the correct spares when required during corrective maintenance.

e. inherent availability

From equation (2.13), the inherent availability of the expeller can be computed as:

$$A_i = \frac{MTBF}{MTBF + MTTR} = \frac{438.34}{438.34 + 3} = 0.993$$

The expeller's inherent availability is 99,3%, as calculated using the supplier's data for it.

4.4.2. Packer or bagging machine

The bagging machine is used for the repeated and accurate weighing in bags of mashed feed. The operation of the bagging machine is controlled by the control system. The accuracy of the machine is to 0,2%. The machine ensures faster weighing cycles, increased bag to bag consistency, tighter tolerance and accuracy, more efficient use of manpower.

Following from Section 3.3.2, Figure 4.5 shows that the machine consists of a hopper, a belt feeder with low-speed and high-speed drive, a weighing chute supported on load cells and a pneumatically operated bag clamp. The press cake is transported with a conveyer belt to the bagging machine.

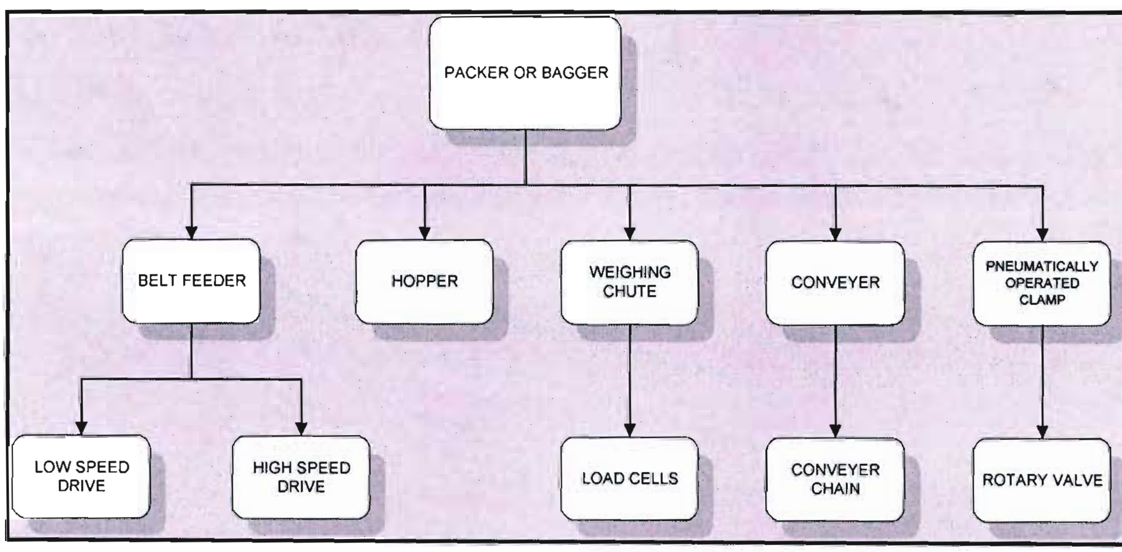



**Figure 4.5.** Product breakdown structure of the bagging machine

### 4.4.2.1. Analysis using data for the bagging machine

The number of failure of the bagging machine for the year totalled 11 in a total operating time of 1605 hours.

a. failure rate:

$$bagger\ failure\ rate = \frac{11}{1605} = 0{,}00685$$

b. mean time between failure:

$$bagger\ MTBF = \frac{1}{0{,}00685} = 146\ hours$$

c. reliability:

$$bagger\ \ reliability = e^{-(0{,}00685)(240)} = 0{,}193$$

There is a 19,3% chance that the bagger will not break down over a month of 240 hours.

$$bagger\ \ reliability = e^{-(0{,}00685)(10)} = 0{,}934$$

There is a 93,4% chance that the bagging machine will not break down over a single day consisting of 10 hours of operation.

d. Allocated failure rate and MTBF:

| EQUIPMENT | ANNUAL FAILURES | PERCENTAGE OF TOTAL FAILURES | CALCULATED FAILURE RATE | CALCULATED MTBF (HOURS) |
|---|---|---|---|---|
| | | | | |
| **BAGGING MACHINE** | **11** | **100%** | **0.00685** | **146** |
| | | | | |
| BELT FEEDER | 2 | 18% | 0.001245455 | 803 |
| LOW SPEED DRIVE | 1 | 9% | 0.000622727 | 1606 |
| HIGH SPEED DRIVE | 1 | 9% | 0.000622727 | 1606 |
| | | | | |
| WEIGHING CHUTE | 4 | 37% | 0.0025345 | 395 |
| LOAD CELLS | 4 | 37% | 0.0025345 | 395 |
| | | | | |
| HOPPER | 0 | 0% | 0 | 0 |
| | | | | |
| CONVEYER | 3 | 27% | 0.001868182 | 535 |
| CONVEYER CHAIN | 3 | 27% | 0.001868182 | 535 |
| | | | | |
| PNEUMATIC CLAMP | 2 | 18% | 0.001245455 | 803 |
| ROTARY VALVE | 2 | 18% | 0.001245455 | 803 |
| | | | | |

**Table 4.7.** Bagging machine failure rate and MTBF allocations

The bagging machine failure rate and MTBF is apportioned down to its subsystems in Table 4.7. From the field data provided in Table 4.7, it is evident that of the total number of bagging machine failures, the belt feeder contributed 18%, the weighing chute contributed 37%, the conveyer contributed 27% and the pneumatically operated clamp contributed 18%.

e. maintenance hours computation:

| BAGGING MACHINE | ACRONYM | MAINTENANCE TIME (HOURS) |
|---|---|---|
| | | |
| maintenance downtime | MDT | 132 |
| mean active maintenance time | M | 65 |
| logistics delay time | LDT | 53 |
| administrative delay time | | 14 |
| mean time to repair | MTTR | 49 |
| preventive maintenance time | | 16 |
| | | |

**Table 4.8.** Maintenance hours allocation for the bagging machine

With reference to Table 4.8, it is evident that the mean maintenance downtime (MDT) is made up of the sum of the mean active maintenance time ( $\bar{M}$), the logistics delay time (LDT) and the administrative delay time. The MDT has been obtained from Table 4.2. It is evident from Table 4.8 that the mean active maintenance time forms 49% of the total mean maintenance downtime. The logistics and administration delay Times form 40% and 11%, respectively, of the mean maintenance downtime. The logistics delay time is too high, and can be greatly reduced if the company can accurately predict the number of spares to be kept in stores, so that the correct spare part is readily available when a failure occurs.

The active maintenance time of 65 hours is made up of corrective maintenance time and preventive maintenance time. From Table 4.5, it is seen that of this 65 hours, 49 hours is spent doing corrective maintenance and 16 hours is spent doing preventive maintenance. It is obvious that North Coast Milling is spending too much time on corrective maintenance with regards to the bagging machine (due to the poor reliability of the equipment) and too little time on preventive maintenance of it.

For the bagging machine, the total number of failures is 11. The mean time to repair all the failures is 49 hours, obtained from Table 4.7. Hence, the MTTR per failure is approximately 4,5 hours.

f. operational availability:

From equation (2.18), the operational availability of the bagging machine is computed as:

$$A_o = \frac{total\ hours - downtime\ hours}{total\ hours} \times 100\% = \frac{2760 - 132}{2760} \times 100\% = 95{,}2\%$$

### 4.4.2.2. Analysis using suppliers specifications for the bagging machine

The supplier's specification for the MTBF of the various subsystems of the bagging machine is displayed in Table 4.9.

| EQUIPMENT | SUPPLIERS MTBF (HOURS) | COMPUTED FAILURE RATE |
|---|---|---|
| | | |
| BAGGER | 547.5880052 | 0.00182619 |
| | | |
| BELT FEEDER | 4000 | 0.00025 |
| | | |
| WEIGHING CHUTE | 1200 | 0.000833333 |
| | | |
| HOPPER | 10000 | 0.0001 |
| | | |
| CONVEYER | 2800 | 0.000357143 |
| | | |
| PNEUMATIC CLAMP | 3500 | 0.000285714 |

**Table 4.9.** Supplier's data for the bagging machine and its subsystems.

a. failure rate

As all the subsystems are in series, the total failure rate of the bagging machine is the sum of the failure rates of its various subsystems. As shown in Table 4.9, the total failure rate of the bagging machine is 0,00183.

b. mean time between failure

The mean time between failure for the expeller is the inverse of its failure rate. This computes as 547,59 hours. It is evident that the supplier's MTBF figure is much higher than the one achieved in practice, as that figure is obtained assuming ideal conditions. It can be concluded that there are problems in the operation of the bagging machine in its environment, which needs to be addressed.

c. reliability

$$\text{exp}\,eller\ \ reliabilit\,y = e^{-(0{,}00183)(10)} = 0{,}98$$

There is a 98% chance that the bagging machine will not break down over a single day consisting of 10 hours of operation.

d. maintenance hours

The supplier's maximum MTTR for the bagging machine for any failure that occurs, is specified as 2,5 hours. This figure assumes the correct skill level of maintainers and the availability of the correct tools and spares. The actual MTTR per failure of the bagging machine at North Coast Milling is approximately 4,5 hours. This is much higher than the supplier's specified MTTR value. This discrepancy can be attributed to the low skill levels of the maintainers and operators as well as the unavailability of the correct spares when required during corrective maintenance.

e. inherent availability

From equation (2.13), the inherent availability of the bagging machine can be computed as:

$$A_i = \frac{MTBF}{MTBF + MTTR} = \frac{547.59}{547.59 + 2.5} = 0.995$$

The bagging machine's inherent availability is 99,5%, as calculated using the supplier's data for it.

### 4.4.3. Control system and sensors

As discussed in Section3.3.2, Figure 4.6 depicts the product breakdown of the control system and its interface with only specific sensors and their function which contribute significantly to the downtime of the production process.

#### 4.4.3.1. Actual data for the control system sensors

The number of failure of the sensors for the year totalled 10 in a total operating time of 1605 hours .

a. failure rate:

$$sensors\ failure\ rate = \frac{10}{1605} = 0{,}00623$$

b. mean time between failure:

$$sensors\ MTBF = \frac{1}{0{,}00623} = 160{,}5\ hours$$

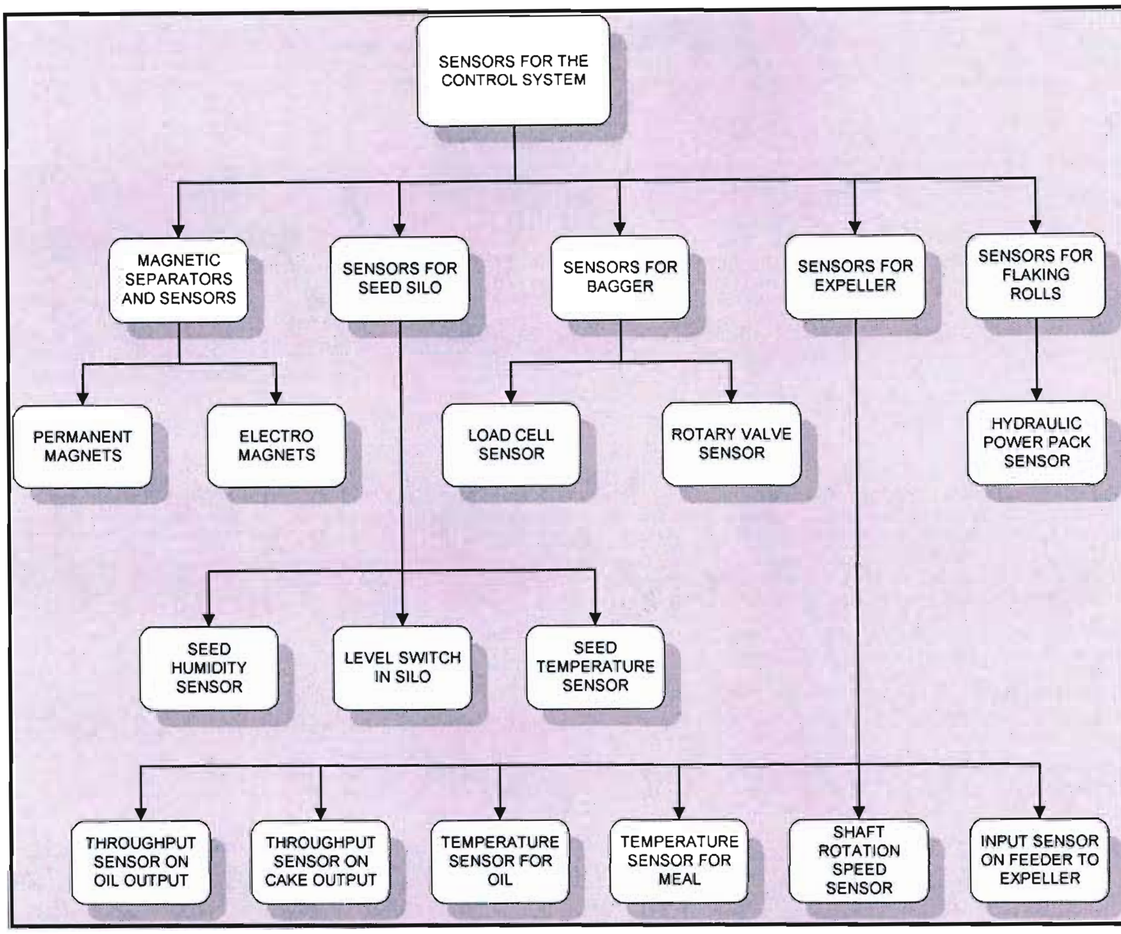



**Figure 4.6.** Product breakdown structure of the control system sensors

c. reliability:

$$\exp eller\ \ reliability = e^{-(0,00623)(240)} = 0,224$$

There is a 22,4% chance that the sensors will not break down over a month of 240 hours.

$$sensors\ \ reliability = e^{-(0,00623)(10)} = 0,94$$

There is a 94% chance that the sensors will not break down over a single day consisting of 10 hours of operation.

d. Allocated failure rate and MTBF:

The sensors failure rate and MTBF is apportioned down to its subsystems in Table 4.10. From the field data provided in Table 4.10, it is evident that of the total number of sensors failures, the seed silo sensors contributed 30%, the bagging machine sensors contributed 20%, the expeller sensors contributed 30% and the flaking rolls sensors contributed 20%. In total, there are three of the same type of volume sensors on the expeller, one for the cake throughput, one for the oil throughput and one for the feeder input to the expeller. There are two temperature sensors on the expeller, one for sensing the cake temperature and one for sensing the oil temperature. In total, there are three of the same types of temperature sensors. The third temperature sensor is used for measuring the temperature of the seeds in the storage silo.

| EQUIPMENT | ANNUAL FAILURES | PERCENTAGE OF TOTAL FAILURES | CALCULATED FAILURE RATE | CALCULATED MTBF (HOURS) |
|---|---|---|---|---|
| | | | | |
| **CONTROL SYSTEM SENSORS** | **10** | **100%** | **0.00623** | **160.5** |
| | | | | |
| MAGNETIC SENSORS | 0 | 0% | 0 | 0.0 |
| PERMANENT MAGNETS | 0 | 0% | 0 | 0.0 |
| ELECTRO MAGNETS | 0 | 0% | 0 | 0.0 |
| | | | | |
| SEED SILO SENSORS | 3 | 30% | 0.001869 | 535.0 |
| SEED HUMIDITY SENSOR | 1 | 10% | 0.000623 | 1605.1 |
| LEVEL SWITCH | 1 | 10% | 0.000623 | 1605.1 |
| SEED TEMPERATURE SENSOR | 1 | 10% | 0.000623 | 1605.1 |
| | | | | |
| BAGGING MACHINE SENSORS | 2 | 20% | 0.001246 | 0.0 |
| LOAD CELL SENSOR | 1 | 10% | 0.000623 | 1605.1 |
| ROTARY VALVE SENSOR | 1 | 10% | 0.000623 | 1605.1 |
| | | | | |
| EXPELLER SENSORS | 3 | 30% | 0.001869 | 535.0 |
| THROUGHPUT SENSOR FOR OIL | 0 | 0% | 0 | 0.0 |
| THROUGHPUT SENSOR FOR CAKE | 1 | 10% | 0.000623 | 1605.1 |
| TEMPERATURE SENSOR FOR OIL | 1 | 10% | 0.000623 | 1605.1 |
| TEMPERATURE SENSOR FOR CAKE | 0 | 0% | 0 | 0.0 |
| SHAFT SPEED SENSOR | 1 | 10% | 0.000623 | 1605.1 |
| FEEDER INPUT SENSOR | 0 | 0% | 0 | 0.0 |
| | | | | |
| FLAKING ROLLS SENSOR | 2 | 20% | 0.001246 | 802.6 |
| HYDRAULIC POWER PACK SENSOR | 2 | 20% | 0.001246 | 802.6 |
| | | | | |

**Table 4.10.** Sensors failure rate and MTBF allocations

e. maintenance hours computation:

| CONTROL SYSTEM SENSORS | ACRONYM | MAINTENANCE TIME (HOURS) |
|---|---|---|
| | | |
| maintenance downtime | MDT | 121 |
| mean active maintenance time | M | 68 |
| logistics delay time | LDT | 48 |
| administrative delay time | | 5 |
| mean time to repair | MTTR | 47 |
| preventive maintenance time | | 21 |
| | | |

**Table 4.11.** Maintenance hours allocation for the sensors

With reference to Table 4.11, it is evident that the mean maintenance downtime (MDT) is made up of the sum of the mean active maintenance time ( $\bar{M}$), the logistics delay time (LDT) and the administrative delay time. The MDT has been obtained from Table 4.2. It is evident from Table 4.11 that the mean active maintenance time forms 56% of the total mean maintenance downtime. The logistics and administration delay times form 40% and 4%, respectively, of the mean maintenance downtime. The logistics delay time is the time spent waiting for spares to arrive from the suppliers, and is made up of lead times and delivery times. This figure is too high, and can be greatly reduced if the company can accurately predict the number of spares to be kept in stores, so that the correct spare part is readily available when a failure occurs.

The active maintenance time of 68 hours is made up of corrective maintenance time and preventive maintenance time. From Table 4.11, it is seen that of the 68 hours, 47 hours is spent doing corrective maintenance and 21 hours is spent doing preventive maintenance. It is obvious that North Coast Milling is spending too much time on corrective maintenance (due to the poor reliability of the equipment) and too little time on preventive maintenance.

For the control system sensors, the total number of failures is 10. The mean time to repair all the failures is 47 hours, obtained from Table 4.11. Hence, the MTTR per failure is 4,7 hours.

f. operational availability:

From equation (2.18), the operational availability of the control system sensors is computed as:

$$A_o = \frac{total\ hours - downtime\ hours}{total\ hours} \times 100\% = \frac{2760 - 121}{2760} \times 100\% = 95{,}6\%$$

### 4.4.3.2. Suppliers specifications for the control system sensors

The supplier's specification for the MTBF of the various subsystems of the sensors is displayed in Table 4.12.

| EQUIPMENT | SUPPLIERS MTBF (HOURS) | COMPUTED FAILURE RATE |
|---|---|---|
| | | |
| **SENSORS** | 740.8418658 | 0.001349816 |
| | | |
| MAGNETIC SENSORS | 10000 | 0.0001 |
| | | |
| SEED SILO SENSORS | 8000 | 0.000125 |
| | | |
| BAGGING MACHINE SENSORS | 3700 | 0.00027027 |
| | | |
| EXPELLER SENSORS | 2500 | 0.0004 |
| | | |
| FLAKING ROLLS SENSORS | 2200 | 0.000454545 |

**Table 4.12.** Supplier's data for the control system sensors

a. failure rate

As all the sensors are in series and a failure of any one of them will result in downtime of the control system and its sensors, the total failure rate of the control system and sensors is the sum of the failure rates of its various subsystems. As shown in Table 4.12, the total failure rate of the control system sensors is 0,00135.

b. mean time between failure

The mean time between failure for the control system sensors is the inverse of its failure rate. This computes as 740,85 hours. It is evident that the supplier's MTBF figure is much higher than the one achieved in practice, as that figure is obtained assuming ideal conditions. It can be concluded that there are problems in the operation of the control system sensors in its environment, which needs to be addressed.

c. reliability

$$\exp eller\ \ reliabilit\ y = e^{-(0,00135)(10)} = 0,986$$

There is a 98,6% chance that the control system sensors will not fail over a single day consisting of 10 hours of operation.

d. maintenance hours

The supplier's maximum MTTR for the expeller for any failure that occurs, is specified as 2 hours. This figure assumes the correct skill level of maintainers and the availability of the correct tools and spares. The actual MTTR per failure at North Coast Milling is 4,7 hours. This is much higher than the supplier's specified MTTR value. This discrepancy can be attributed to the low skill levels of the maintainers and operators as well as the unavailability of the correct spares when required during corrective maintenance.

e. inherent availability

From equation (2.13), the inherent availability of the expeller can be computed as:

$$A_i = \frac{MTBF}{MTBF + MTTR} = \frac{740.84}{740.84 + 2} = 0.997$$

The expeller's inherent availability is 99,7%, as calculated using the supplier's data for it.

### 4.4.4. Flaking rolls

The product breakdown structure of the flaking rolls is shown below.

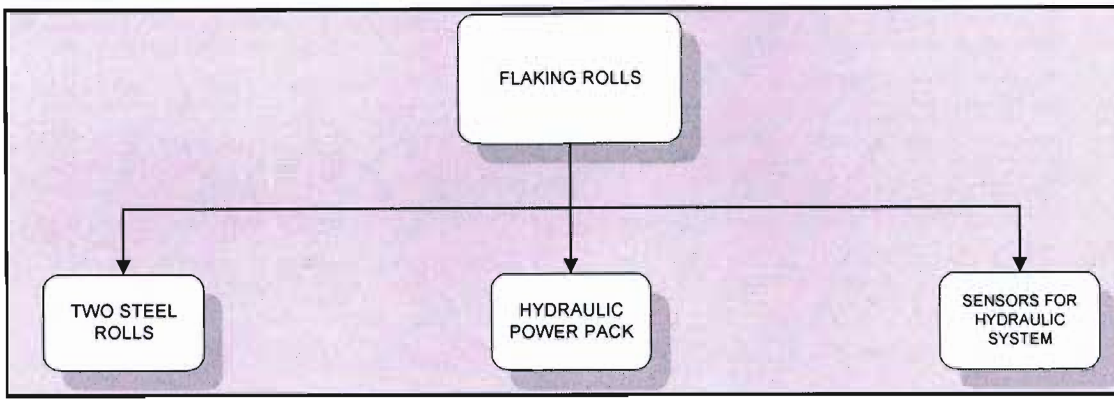



**Figure 4.7.** Product breakdown structure of the flaking rolls

### 4.4.4.1. Actual data for the flaking rolls

The number of failure of the flaking rolls for the year totalled 9 in a total operating time of 1605 hours .

a. failure rate:

$$\textit{flaking rolls failure rate} = \frac{9}{1605} = 0.00561$$

b. mean time between failure:

$$\textit{flaking rolls MTBF} = \frac{1}{0{,}00561} = 178{,}25 \textit{ hours}$$

c. reliability:

$$\textit{flaking rolls reliabilit y} = e^{-(0{,}00561)(240)} = 0{,}26$$

There is a 26% chance that the flaking rolls will not break down over a month of 240 hours.

$$\textit{flaking rolls reliabilit y} = e^{-(0{,}00561)(10)} = 0{,}9455$$

There is a 94,55% chance that the flaking rolls will not break down over a single day consisting of 10 hours of operation.

d. Allocated failure rate and MTBF:

The flaking rolls failure rate and MTBF is apportioned down to its subsystems in Table 4.13. From the field data provided in Table 4.13, it is evident that of the total number of flaking rolls failures, the steel rolls contributed 67%, the hydraulic power pack contributed 11% and the hydraulic system sensors contributed 22 %.

| EQUIPMENT | ANNUAL FAILURES | PERCENTAGE OF TOTAL FAILURES | CALCULATED FAILURE RATE | CALCULATED MTBF (HOURS) |
|---|---|---|---|---|
| | | | | |
| **FLAKING ROLLS** | **9** | **100%** | **0.00561** | **178.25** |
| | | | | |
| STEEL ROLLS | 6 | 67% | 0.00374 | 267.38 |
| | | | | |
| HYDRAULIC POWER PACK | 1 | 11% | 0.000623333 | 1604.28 |
| | | | | |
| HYDRAULIC SYSTEM SENSORS | 2 | 22% | 0.001246667 | 802.14 |
| | | | | |

**Table 4.13.** Flaking rolls failure rate and MTBF allocations

e. maintenance hours computation:

| FLAKING ROLLS | ACRONYM | MAINTENANCE TIME (HOURS) |
|---|---|---|
| | | |
| maintenance downtime | MDT | 110 |
| mean active maintenance time | M | 57 |
| logistics delay time | LDT | 51 |
| administrative delay time | | 2 |
| mean time to repair | MTTR | 42 |
| preventive maintenance time | | 15 |
| | | |

**Table 4.14.** Maintenance hours allocation for the flaking rolls

With reference to Table 4.14, it is evident that the mean maintenance downtime (MDT) is made up of the sum of the mean active maintenance time ( $\bar{M}$), the logistics delay time (LDT) and the administrative delay time. The MDT has been obtained from Table 4.2. It is evident from Table 4.14 that the mean active maintenance time forms 52% of the total mean maintenance downtime. The logistics and administration delay times form 46% and 2%, respectively, of the mean maintenance downtime. The logistics delay time is the time spent waiting for spares to arrive from the suppliers, and is made up of lead times and delivery times. This figure is too high, and can be greatly reduced if the company can accurately predict the number of spares to be kept in stores, so that the correct spare part is readily available when a failure occurs.

The active maintenance time of 57 hours is made up of corrective maintenance time and preventive maintenance time. From Table 4.14, it is seen that of this 57 hours, 42 hours is spent doing corrective maintenance and 15 hours is spent doing preventive maintenance. It is obvious that North Coast Milling is spending too much time on corrective maintenance (due to the poor reliability of the equipment) and too little time on preventive maintenance.

For the flaking rolls, the total number of failures is 9. The mean time to repair all the failures is 42 hours, obtained from Table 4.14. Hence, the MTTR per failure is 4,67 hours.

f. operational availability:

From equation (2.18), the operational availability of the flaking rolls is computed as:

$$A_o = \frac{total\ hours - downtime\ hours}{total\ hours} \times 100\% = \frac{2760 - 110}{2760} \times 100\% = 96\%$$

#### 4.4.4.2. Suppliers specifications for the flaking rolls

The supplier's specification for the MTBF of the various subsystems of the flaking rolls is displayed in Table 4.15.

| EQUIPMENT | SUPPLIERS MTBF (HOURS) | COMPUTED FAILURE RATE |
|---|---|---|
| | | |
| **FLAKING ROLLS** | 864.0139921 | 0.001157389 |
| | | |
| STEEL ROLLS | 1300 | 0.000769231 |
| | | |
| HYDRAULIC POWER PACK | 3800 | 0.000263158 |
| | | |
| HYDRAULIC SYSTEM SENSORS | 8000 | 0.000125 |

**Table 4.15.** Supplier's data for the flaking rolls system

a. failure rate

As all the subsystems of the flaking rolls are in series and a failure of any one of them will result in downtime of the flaking rolls system, the total failure rate is the sum of the failure rates of its various subsystems. As shown in Table 4.15, the total failure rate of the flaking roll system is 0,001157.

b. mean time between failure

The mean time between failure for the flaking rolls system is the inverse of its failure rate. This computes to 864 hours. It is evident that the supplier's MTBF figure is much higher than the one achieved in practice, as that figure is obtained assuming ideal conditions. It can be concluded that there are problems in the operation of the control system sensors in its environment, which needs to be addressed.

c. reliability

$$flaking\ \ rolls\ \ reliabilit\ y = e^{-(0{,}001157\ )(10)} = 0{,}988$$

There is a 98,8% chance that the flaking rolls system will not fail over a single day consisting of 10 hours of operation.

d. maintenance hours

The supplier's maximum MTTR for the flaking rolls for any failure that occurs, is specified as 3 hours. This figure assumes the correct skill level of maintainers and the availability of the correct tools and spares. The actual MTTR per failure at North Coast Milling is 4,67 hours. This is much higher than the supplier's specified MTTR value. This discrepancy can be attributed to the low skill levels of the maintainers and operators as well as the unavailability of the correct spares when required during corrective maintenance.

e. inherent availability

From equation (2.13), the inherent availability of the flaking rolls can be computed as:

$$A_i = \frac{MTBF}{MTBF + MTTR} = \frac{864}{864+3} = 0.9965$$

The flaking roll's inherent availability is 99,65%, as calculated using the supplier's data for it.

## 4.5. LSA analysis

As discussed in Section 2.6, the expeller, bagging machine, control system sensors and flaking rolls satisfy the criteria for LSA candidates in that they are repairable and require logistic support, either corrective or preventive or operational support. Although many of the other systems in the production process will also qualify as LSA candidates, the analysis will only be conducted on these four systems as from the analysis in Section 4.2, they are the major contributors of cost and downtime.

Based on the fact that this LSA analysis is only being conducted once the design has been complete and the systems are in the operational state, there is no chance of influencing the design or doing a redesign. As such, the only tools applicable at this stage in the LSA process are the FMECA, RCM and spare parts determination and task analysis. The LSA methods are employed to help specify a cost-effective solution for system support. Major outputs of the analysis will include the system maintenance concept and supportability criteria. A critical part of the LSA process is to determine the correct type and number of spares to carry for these four systems and their subsystems. It was found in Section 4.2 that a large constituent of the maintenance hours was logistics delay time, that is, not having the correct number and type of spares.

### 4.5.1. FMECA

Maintenance is the result of failures and the criticality of these failures will determine the action to be taken. As stated in Section 2.7.1.5, the FMECA is most useful if conducted during the design stage. The use of the FMECA here in the operational stage is to help North Coast Milling decide on whether corrective, preventive or redesign are most applicable to try and solve the problems of poor reliability of the four systems as discussed in Section 4.2.

Following from the discussion of the FMECA in Section 2.7.1.5, the options available once an FMECA has been completed are the following:

- Redesign: If the failures are unacceptable in terms of safety, availability and cost, then redesign is compulsory.
- Preventive and corrective maintenance: If the failures have a major impact on safety, availability and cost, then it needs to be ascertained whether the failures can be prevented before they actually occur or whether they should be corrected only after it occurs.
- Corrective maintenance: If the failures have an insignificant impact on safety, availability and cost, then the system can be left to function until a failure occurs and then only should corrective maintenance be performed on it.

Examples of the different types of failure modes are:

- Premature operation
- Failure to operate at a prescribed time
- Intermittent operation
- Failure to cease operation at prescribed time
- Loss of output or failure during operation
- Degraded output

The consequences of each failure mode will then need to be investigated in terms of the item's operation, function or system status. It needs to be known whether a single failure of an item leads to secondary damage and other failures in the production process. The impact of the failures will be considered in terms of:

- Local effect: the effect of a failure on the subsystem itself
- Next higher effect: the effect of a failure on the system as a whole
- End effect: this is the effect of a subsystem failure on the entire production process

A criticality analysis will also be conducted in terms of the severity and probability of failure. The severity is the qualitative value to indicate the most severe impact a failure of an LSA candidate can have on the production system. The categories of severity are:

- Catastrophic: a failure causes death of personnel or total system destruction
- Critical: a failure causes severe injury or system damage that results in loss of total system capability
- Minor: a failure that causes minor injury or system damage that results in system degradation or temporary system unavailability
- Marginal: a failure not severe enough to cause injury or system damage but will result in unscheduled maintenance

The probability of failure is the qualitative value to indicate the probability of the failure occurring. It can be:

- Frequent: there is a high probability of occurrence during the item operating time interval
- Reasonably probable: a moderate probability of occurrence during the item operating time interval
- Occasional: an occasional probability of occurrence during the item operating time interval
- Remote: a remote probability of occurrence during the item operating time interval
- Extremely unlikely: a failure whose probability of occurrence is essentially zero during the item operating time interval.

The requirement from the maintenance and production departments at North Coast Milling is that the production system must operate successfully without any failures for a month at a time. On the last weekend of each month, the maintenance team carries out scheduled maintenance actions. As such, the FMECA will be conducted by considering the expected time of operation of each system, without failure, to be a month.

The FMECA analysis will be conducted for each of the four systems and a table will be filled in as depicted in Table 4.16. From the information in Table 4.16, a criticality matrix for the expeller, bagging machine, control system sensors and flaking rolls will be constructed as shown in Figure 4.8. It will be shown on these matrices which quadrants the various subsytems will occupy.

| | | Failure Effects | | | | |
|---|---|---|---|---|---|---|
| Item | Failure Modes and causes | Local effects | Next higher effects | End Effects | Severity | Probability |
| | | | | | | |

**Table 4.16.** Example of the template for FMECA information

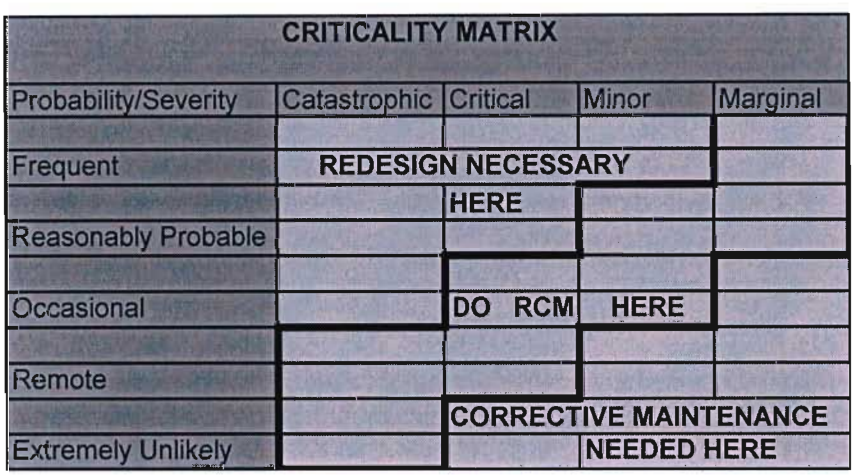



**Figure 4.8.** Example of a criticality matrix derived from the FMECA.

With reference to Figure 4.8, if a subsystem of a system falls into the upper left area of the criticality matrix, then redesign of the system will be necessary. If the subsystem falls into the centre area, then RCM analysis will need to be conducted to determine the required maintenance tasks for that subsystem. Finally, if the subsystem falls into the lower right area of the criticality matrix, then corrective maintenance tasks will need to be devised and maintenance must only be performed once the failure has occurred.

The severity and probability factor for each piece of equipment is obtained using the results of the RAM analysis of Section 4.4.

### 4.5.1.1. FMECA for the expeller

The criticality matrix for the expeller is constructed from the results of the FMECA in Table 4.17.

| CRITICALITY MATRIX | | | | |
|---|---|---|---|---|
| **Probability/ Severity** | **Catastrophic** | **Critical** | **Minor** | **Marginal** |
| **Frequent** | | | | ▪ worms |
| **Reasonably Probable** | | | ▪ Control box<br>▪ Belts<br>▪ Bearing<br>▪ Choke | ▪ Chamber bars |
| **Occasional** | | | | ▪ Assembly rings<br>▪ Nozzle heating unit |
| **Remote** | | ▪ Overload protection | | ▪ Feeder<br>▪ nozzle |
| **Extremely Unlikely** | | | | |

**Figure 4.9.** Criticality matrix for expeller

| EXPELLER | | Failure Effects | | | | |
|---|---|---|---|---|---|---|
| Item | Failure Modes and causes | Local effects | Next higher effects | End Effects | Severity | Probability |
| feeder | Failure during operation due to blockages caused by the seeds | Feeder becomes blocked | Expeller has no seeds to process | No production of oil and cake | marginal | remote |
| Chamber bars | Degraded operation due to wear and tear caused by excessive stresses imposed on the screw | The oil seeds are poorly crushed against the chamber bars | The oil seeds are not optimally crushed by the expeller. | The yield of oil produced by the expeller is very low, maintenance must be done. | marginal | Reasonably probable |
| Control box | Can have degraded operation due to the motor not being supplied with the correct control signals. | The electrical control box may have to be repaired. | The motor of the screw assembly will not be at the required speeds. | Yield of oil and throughput may be adversely affected. Maintenance will be needed. | minor | Reasonably probable |
| Belts | Failure mode is failure during operation. Excessive stresses and wear on the belt will cause it to snap. | The belt will not be able to turn motor and hence the screw assembly. | The expeller will not be able to operate as the screw assembly cannot rotate | The yield and throughput of oil and meal will reduce as maintenance on the expeller will be required. | minor | Reasonably probable |
| Overload protection | Can have the failure to cease operation at a prescribed time. Failure can be caused by the malfunction in the electronics circuitry of the overload protection. | The overload protection unit will be unable to perform its function properly. | The motor can be severely damaged by subjecting it to excessive loads | The production will have to be stopped to replace or repair the motor for the expeller. | critical | remote |
| bearings | Failure mode is degraded operation or failure during operation. Excessive greasing causes the bearings to heat up and pressurise. | The bearing will not be able to support the rotor of motor, hence the motor will need maintenance. | The expeller will not be able to operate as the screw assembly cannot rotate | The yield and throughput of oil and meal will reduce as maintenance on the expeller will be required. | minor | Reasonably probable |
| Screws/worms | Degraded operation due to wear and tear caused by excessive stresses imposed on the worms | The oil seeds are poorly crushed by the screw assembly | The oil seeds are not optimally crushed by the expeller. | The yield of oil produced by the expeller is very low, maintenance must be done. | marginal | frequent |

| | | | | | | |
|---|---|---|---|---|---|---|
| Assembly rings | Degraded operation due to wear and tear on the assembly rings | The oil seeds are poorly crushed by the screw assembly | The oil seeds are not optimally crushed by the expeller. | The quality of the meal and oil produced by the expeller is very low, maintenance must be done. | marginal | occasional |
| nozzle | Degraded operation, such as non-uniform strips of cake, due to incorrect size circular gap set in the nozzle | The strips of meal will be of a non-uniform width. | The solvent extractor won't be able to extract most of the oil from the meal strips. | The yield of oil extracted by the solvent extractor will be low, unscheduled maintenance will be required. | marginal | remote |
| choke | Failure mode is degraded operation or failure during operation. The adjustment on the choke may fail to function properly or it may be broken due to excessive wear on it. | The choke unit will not be able to operate properly if the adjustment on it is damaged. | It will not be possible to build up the correct pressure in the expeller cylinder if the adjustment on the choke is not working. | The yield of oil from the expeller will be very low due to the incorrect pressure in the expeller, which is unable to optimally rupture the oil cells in the nut seeds to release the oil. | minor | Reasonably probable |
| Nozzle heating unit | Degraded operation due to blockage of the press cake outlet in the expeller | The press cake output will be jammed. | The solvent extractor won't be able to extract the oil from the blocked meal | The yield of oil extracted by the solvent extractor will be low, unscheduled maintenance will be required. | marginal | occasional |

**Table 4.17.** FMECA information for the expeller

### 4.5.1.2. FMECA for the bagging machine

The criticality matrix for the bagging machine is constructed from the results of the FMECA in Table 4.18.

| CRITICALITY MATRIX | | | | |
|---|---|---|---|---|
| **Probability/ Severity** | **Catastrophic** | **Critical** | **Minor** | **Marginal** |
| **Frequent** | | | | |
| **Reasonably Probable** | | | ▪ **Conveyer chain** | ▪ **Drives**<br>▪ **Load cells** |
| **Occasional** | | ▪ **Rotary valve** | | |
| **Remote** | | | | |
| **Extremely Unlikely** | | | | ▪ **Hopper** |

**Figure 4.10.** Criticality matrix for the bagging machine

| BAGGING MACHINE | | Failure Effects | | | | |
|---|---|---|---|---|---|---|
| Item | Failure Modes and causes | Local effects | Next higher effects | End Effects | Severity | Probability |
| Low speed drive | Failure mode is the failure to operate at a prescribed time and to provide correct speed for the conveyer chain. Failure cause is malfunction of the electronic drive circuitry or incorrect signal from the control system. | Conveyer speed will not be correctly controlled | Belt feeder will not function properly and will need maintenance. | Production process will have to be halted to correct the failure | marginal | Reasonable probable |
| High speed drive | Failure mode is the failure to operate at a prescribed time and to provide correct speed for the conveyer chain. Failure cause is malfunction of the electronic drive circuitry or incorrect signal from the control system. | Conveyer speed will not be correctly controlled | Belt feeder will not function properly and will need maintenance. | Production process will have to be halted to correct the failure | marginal | Reasonable probable |
| hopper | Failure mode is the failure to operate at a prescribed time. Failure cause is the hopper may be corroded and has a leak and can't store the mashed feed. | Hopper will not be able to correctly store the mashed feed. | There will not be sufficient mashed feed for the bagging machine to feed the bags with. | The production process will have to be halted to correct the fault. | marginal | Extremely unlikely |
| Load cells | Failure mode is degraded output. Failure cause is the electronics transducers in the load cell may malfunction, causing the load cell to give incorrect weight readings. | Incorrect weight readings will be given for the mashed feed that is being fed into the bags. | The weighing chute will have to be repaired. | The production process will have to be halted to correct the fault. | marginal | Reasonably probable |
| Conveyer chain | The failure mode is failure during operation. The failure cause is insufficient lubrication to the conveyer chain, causing excessive wear of it. | The conveyer chain will have to be replaced. | The mashed feed can't be conveyed from the tabular drier to the bagging machine. | The production process will have to be halted to correct the fault. | minor | Reasonably probable |
| Rotary valve | Failure mode is the failure to cease operation when instructed to do so. The failure cause is once the valve has opened to allow mashed feed to fill the bags, it fails to close when given a signal by the control system. The valve does not respond to the control signal | The valve will fail to close after it has open and the correct amount of mashed feed has been passed through. | The pneumatic clamp will have to be repaired immediately. | The production process will have to be immediately halted to prevent the bags collecting the mashed feed from overflowing. | critical | occasional |

**Table 4.18.** FMECA information for the bagging machine

### 4.5.1.3. FMECA for the control system sensors

The criticality matrix for control system sensors is constructed from the results of the FMECA in Table 4.19.

| CRITICALITY MATRIX | | | | |
|---|---|---|---|---|
| **Probability/ Severity** | **Catastrophic** | **Critical** | **Minor** | **Marginal** |
| **Frequent** | | | | |
| **Reasonably Probable** | | | ▪ shaft speed sensor<br>▪ seed humidity sensor | ▪ load cell sensor |
| **Occasional** | | ▪ feeder input sensor | | |
| **Remote** | | ▪ oil temperature sensor<br>▪ silo level switch<br>▪ electro magnets<br>▪ rotary valve sensor<br>▪ hydraulic power pack sensor | ▪ oil throughput sensor<br>▪ cake throughput sensor<br>▪ cake temperature sensor<br>▪ seed temperature sensor | |
| **Extremely Unlikely** | | ▪ permanent magnets | | |

**Figure 4.11.** Criticality matrix for the control system sensors

| CONTROL SYSTEM SENSORS | | Failure Effects | | | | |
|---|---|---|---|---|---|---|
| Item | Failure Modes and causes | Local effects | Next higher effects | End Effects | Severity | Probability |
| Oil throughput sensor | Failure mode is failure during operation and degraded output. Failure can be caused by malfunction of the transducer in the sensor. | The oil throughput sensor will give an incorrect reading for the oil quantity being produced. | The control system may not be able to correctly control the throughput of the oil produced. | Failure to correctly control the throughput of oil produced will result in damage to subsystems in subsequent phases of the production process. | minor | remote |
| Cake throughput sensor | Failure mode is failure during operation and degraded output. Failure can be caused by malfunction of the transducer in the sensor. | The cake throughput sensor will give an incorrect reading for the cake quantity being produced. | The control system may not be able to correctly control the throughput of the cake produced. | Failure to correctly control the throughput of cake produced will result in damage to subsystems in subsequent phases of the production process. | minor | remote |
| Oil temperature sensor | Failure mode is failure during operation and degraded output. Failure can be caused by malfunction of the transducer in the sensor. | The oil throughput sensor will give an incorrect reading for the temperature of the oil produced and may allow the oil to rise above 40°C.. | The temperature of the produced oil from the expeller will be incorrect | Failure to correctly control the temperature of oil produced will result in damage to subsystems in subsequent phases of the production process. | critical | remote |
| Cake temperature sensor | Failure mode is failure during operation and degraded output. Failure can be caused by malfunction of the transducer in the sensor. | The temperature sensor switch can be damaged if its electronic circuitry malfunctions. | A higher temperature on the presses cake results in a higher phosphor content of the produced oil, which is not desirable. | Extreme temperatures in the expeller will destroy the nutritional value of the cake. | minor | remote |

| | | | | | | |
|---|---|---|---|---|---|---|
| Shaft speed sensor | Failure mode is failure during operation and degraded output. Failure can be caused by malfunction of the transducer in the sensor. | The favourable rotation speeds of between 20 and 50 rpm may not be achieved. | If the shaft rotation speed is too high, the motor can be damaged and the expeller will need maintenance. | Incorrectly setting the seed temperature adversely affects the phosphor content in the oil, the throughput of oil, content of particles in the oil, yield of oil and the energy demand. | minor | Reasonably probable |
| Feeder input sensor | Failure mode is failure during operation and degraded output. Failure can be caused by malfunction of the transducer in the sensor. | Failure of the feeder input sensor may cause the feeder to overfill and damage to it may result. | Other parts of the expeller may be damaged by filling the capacity with seed beyond its rated maximum capacity. | The production process will have to be halted so that unscheduled maintenance can be performed. | critical | occasional |
| Seed humidity sensor | Failure mode is failure during operation and degraded output. Failure can be caused by malfunction of the transducer in the sensor. | Incorrect operation of the seed humidity sensor will not allow for the achievement of the optimal seed humidity of between 6,5 and 7,5 weight-percentage. | If the humidity is incorrect, too much friction may arise between the oil seeds and damage to other parts in the expeller may result. | Incorrectly setting the seed humidity adversely affects the phosphor content in the oil, the throughput of oil, content of particles in the oil, yield of oil and the energy demand. | Minor | Reasonably probable |
| Silo level switch | Failure mode is failure during operation and degraded output. Failure can be caused by malfunction of the transducer in the sensor. | The silo level switch can be damaged if its electronic circuitry malfunctions. | Failure of the silo level switch may cause the silo to overfill and damage to it may result. | The production process will have to be halted to correct the fault with the silo switch. | critical | remote |
| Seed temperature sensor | Failure mode is failure during operation and degraded output. Failure can be caused by malfunction of the transducer in the sensor. | The temperature sensor can be damaged if its electronic circuitry malfunctions. | There are no positive effects with higher seed temperature, but phosphor content increases by pre-heating seeds over 60°C. | Incorrectly setting the seed temperature adversely affects the phosphor content in the oil, the throughput of oil, content of particles in the oil, yield of oil and the energy demand. | minor | remote |

| | | | | | | |
|---|---|---|---|---|---|---|
| Permanent magnets | Failure mode is failure during operation and degraded output. Failure can be caused by the permanent magnet loses some of its magnetism. | The seed may not be properly cleaned and there may be scrap metal pieces amongst the seed. | The expeller equipment may be subject to excessive wear if the seeds are not cleaned of all metal pieces. | There may be a risk of these scrap metal pieces damaging other production equipment as well. | critical | Extremely unlikely |
| Electro magnets | Failure mode is failure during operation and degraded output. Failure can be caused by the electromagnet temporarily losing its magnetism due to an interruption of the current supply to it. | The seed may not be properly cleaned and there may be scrap metal pieces amongst the seed. | The expeller equipment may be subject to excessive wear if the seeds are not cleaned of all metal pieces. | There may be a risk of these scrap metal pieces damaging other production equipment as well. | critical | remote |
| Load cell sensor | Failure mode is degraded output. Failure cause is the electronics transducers in the load cell may malfunction, causing the load cell to give incorrect weight readings. | Incorrect weight readings will be given for the amount of seeds to be released in a batch at a single time. | The production process will be affected by having an incorrect batch size to process at any given time. | The production process will have to be halted to correct the fault. | marginal | Reasonably probable |
| Rotary valve sensor | Failure mode is the failure to correctly sense whether the rotary valve is open or closed. Failure can be caused by malfunction of the transducer in the sensor. | The correct control signal will not be sent to the valve to instruct it to close or open as required. | The expeller may overfill with seeds as there the valve will not be correctly instructed to close. | The production process will have to be immediately halted to prevent damage to the expeller. | critical | remote |
| Hydraulic power pack sensor | Failure mode is failure during operation and degraded output. Failure can be caused by malfunction of the transducer in the sensor. | The power pack sensor can be damaged if its electronic circuitry malfunctions. | The voltages and currents from the power pack will not be accurately sensed and fed back to the control systems. | Electrical equipment in the production process may be damaged due to incorrect voltages and currents being fed to it by the power pack. | critical | remote |

**Table 4.19.** FMECA information for the control system sensors

### 4.5.1.4. FMECA for the flaking rolls

The criticality matrix for the flaking rolls is constructed from the results of the FMECA in Table 4.20.

| CRITICALITY MATRIX | | | | |
|---|---|---|---|---|
| **Probability/ Severity** | **Catastrophic** | **Critical** | **Minor** | **Marginal** |
| | | | | |
| **Frequent** | | | | |
| | | | | |
| **Reasonably Probable** | | | ▪ steel rolls | ▪ hydraulic system sensors |
| | | | | |
| **Occasional** | | | | |
| | | | | |
| **Remote** | | | | ▪ hydraulic power pack |
| | | | | |
| **Extremely Unlikely** | | | | |

**Figure 4.12.** Criticality matrix for the flaking rolls

| FLAKING ROLLS | | Failure Effects | | | | |
|---|---|---|---|---|---|---|
| Item | Failure Modes and causes | Local effects | Next higher effects | End Effects | Severity | Probability |
| Steel rolls | Failure mode is degraded output. Due to excessive wear, the flaking rolls make lose their smoothness. | Meal flakes of the appropriate thickness will not be produced | The solvent extraction process will not be able to recover a high percentage of oil from the meal as the flakes are of the incorrect thickness | Due to the low yield of oil from the solvent extraction process, the actual production volume of oil from North Coast Milling is greatly reduced, together with its turnover. | minor | Reasonably probable |
| Hydraulic power pack | Failure mode is failure during operation and degraded output. Failure can be caused by malfunction of the electronic circuitry in the power pack. | The power pack will not be able to supply the required amount of power to the hydraulic system which presses the two rolls together. | The flaking rolls machine will not produce meal flakes | There will be no oil recovery using solvent extraction process as there are no flakes available for processing. | marginal | remote |
| Hydraulic systems sensors | Failure mode is failure during operation and degraded output. Failure can be caused by malfunction of the transducer in the sensor. | The hydraulic system sensor can be damaged if its electronic circuitry malfunctions. | The status of the hydraulic system will not be accurately sensed and fed back to the control systems. The roll-to-roll pressure will not be properly regulated and the average thickness of the meal flakes may be incorrect. | The yield of oil using the solvent extraction process will be low due to the flake thickness being of non-optimal thickness. | marginal | Reasonably probable |

**Table 4.20.** FMECA information for the flaking rolls

### 4.5.2. RCM

RCM provides a maintenance-oriented framework to meet some of the challenges faced by North Coast Milling as was discussed in Chapter 3. RCM can be defined as a structured, logical process for developing or optimising maintenance requirements of a physical resource in its operating context to realise its reliability where inherent reliability is the level of reliability that can be achieved with a maintenance program. The purpose of RCM is to develop a scheduled maintenance program that increases the availability of an item of equipment by identifying failures or potential failures before they degrade equipment effectiveness. An RCM analysis is conducted to determine what maintenance tasks would provide increased equipment reliability over the life of the equipment based on logical selection criteria.

RCM is basically a methodology to balance the resources being used with the required reliability based on the following precepts:

- A failure is an unsatisfactory condition and maintenance attempts to prevent it from occurring
- The consequences of failure determine the priority of the maintenance effort
- Condition-based or predictive maintenance tactics are favoured over traditional time based methods
- Run-to-failure is acceptable, where warranted.

The RCM analysis process considers the significant items that comprise an equipment item. It uses information generated by the FMECA to identify the items most critical to the reliability of the equipment and where a failure would have the greatest effect on availability. Figure 4.13 illustrates the analysis process and shows how both design and field data are used during the analysis process to identify preventative maintenance tasks. In the military environment, the analysis has proven to be effective in planning preventative maintenance programs for new systems during the development process and when upgrading an existing maintenance program for a system that has experienced significant field use.

A great strength of RCM is that it recognises that the consequences of failures are far more important than their technical characteristics. In fact, it recognises that the only reason for doing any kind of proactive maintenance is not to avoid failures, but to avoid or at least to reduce the consequences of failures. The RCM process classifies these consequences into four groups, as follows:

- Hidden failure consequences: Hidden failures have no direct impact, but they expose the organisation to multiple failures with serious, often catastrophic consequences. Most of these failures are associated with protective devices which are not fail-safe.
- Safety and environmental consequences: A failure has safety consequences if it could hurt or kill someone. It has environmental consequences if it could lead to a breach of any corporate, regional, national or international environmental standard.
- Operational consequences: A failure has operational consequences if it affects production (output, product quality, customer service or operating costs in addition to the direct cost of repair)
- Non-operational consequences: Evident failures which fall into this category affect neither safety nor production, so they involve only the direct cost of repair.

The key to the RCM analysis is the RCM decision logic shown in Figure 4.14. Using this decision tree as a guide, a complete analysis of each significant item can be conducted. The results of the analysis provide a clear decision as to what preventative maintenance tasks should be developed to support a system. As shown in the decision diagram, there is a step-by-step process consisting of sixteen yes or no questions that lead the analyst to decide which type of task, if any, is required. In cases where no finite information is available for making the decision, MIL-STD 2173 provides default answers that can be used to complete the analysis. The sixteen questions that lead to an RCM decision are the summary output for recording the results of the analysis process. This iterative process is used to evaluate each maintenance-significant item to determine if a preventative maintenance task is warranted. The nature of the failure characteristic of an item is relevant in deciding what maintenance task is appropriate. If a task is not technically feasible and worth doing, then RCM suggests a series of default tasks. In the case of operational consequences, the default is no scheduled maintenance, with possible redesign. With safety or environmental consequences, the default is compulsory redesign if a failure cannot be prevented. In the case of hidden failure consequences, the default is a failure-finding task, or possible redesign. The consolidated results of the RCM analysis process forms the preventative maintenance program for the system.

From the military specification, MIL-STD 2173, the following definitions are applicable to the RCM decision diagram of Figure 4.14:

a. Scheduled inspections:
   - On-condition task – a scheduled inspection, test, or measurement to determine whether an item is in, or will remain in, a satisfactory condition until the next scheduled inspection.
   - Failure-finding task – a scheduled inspection of a hidden function item to find functional failures that have already occurred but were not evident to the operating crew.

b. Scheduled removals:
   - Rework task – scheduled removal of units of an item to perform whatever maintenance tasks are necessary to ensure that the item meets its defined condition and performance standards.
   - Discard task – scheduled removal of an item and to discard the item or one of its parts at a specified life limit.

The continuing need to prevent certain types of failure and the growing inability of classical techniques to do so, are behind the growth of new types of failure management. The majority of these techniques rely on the fact that most failures give some warning of the fact that they are about to occur. These warnings are known as potential failures, and are defined as identifiable physical conditions that indicate that a functional failure is about to occur or is in the process of occurring. The new techniques are used to detect potential failures so that action can be taken to avoid the consequences that could occur if they degenerate into functional failures. They are called on-condition tasks because items are left in service on the condition that they continue to meet desired performance standards. On-condition maintenance includes predictive maintenance, condition-based maintenance and condition monitoring. Used appropriately, on-condition tasks are a very good way of managing failures, but they can also be an expensive waste of time. RCM enables decisions in this area to be made with particular confidence.

With reference to Figure 4.14, it is evident that RCM recognises three major categories of default actions:

- Failure-finding: failure finding tasks entail checking hidden functions periodically to determine whether they have failed.
- Redesign: redesign entails making any one-off change to the built-in capability of a system. This includes modifications to the hardware and also covers once-off changes to procedures.
- No scheduled maintenance: this default entails making no effort to anticipate or prevent failure modes to which it is applied, and so those failures are simply allowed to occur and then repaired. This default is also called run-to-failure.

In terms of the rest of this section, the RCM analysis will be limited to the items of the criticality matrices that fell into the region of the matrix for items that requires RCM to be performed on them. The sixteen questions of the RCM logic flowchart of Figure 4.14 will be answered for each of these systems.

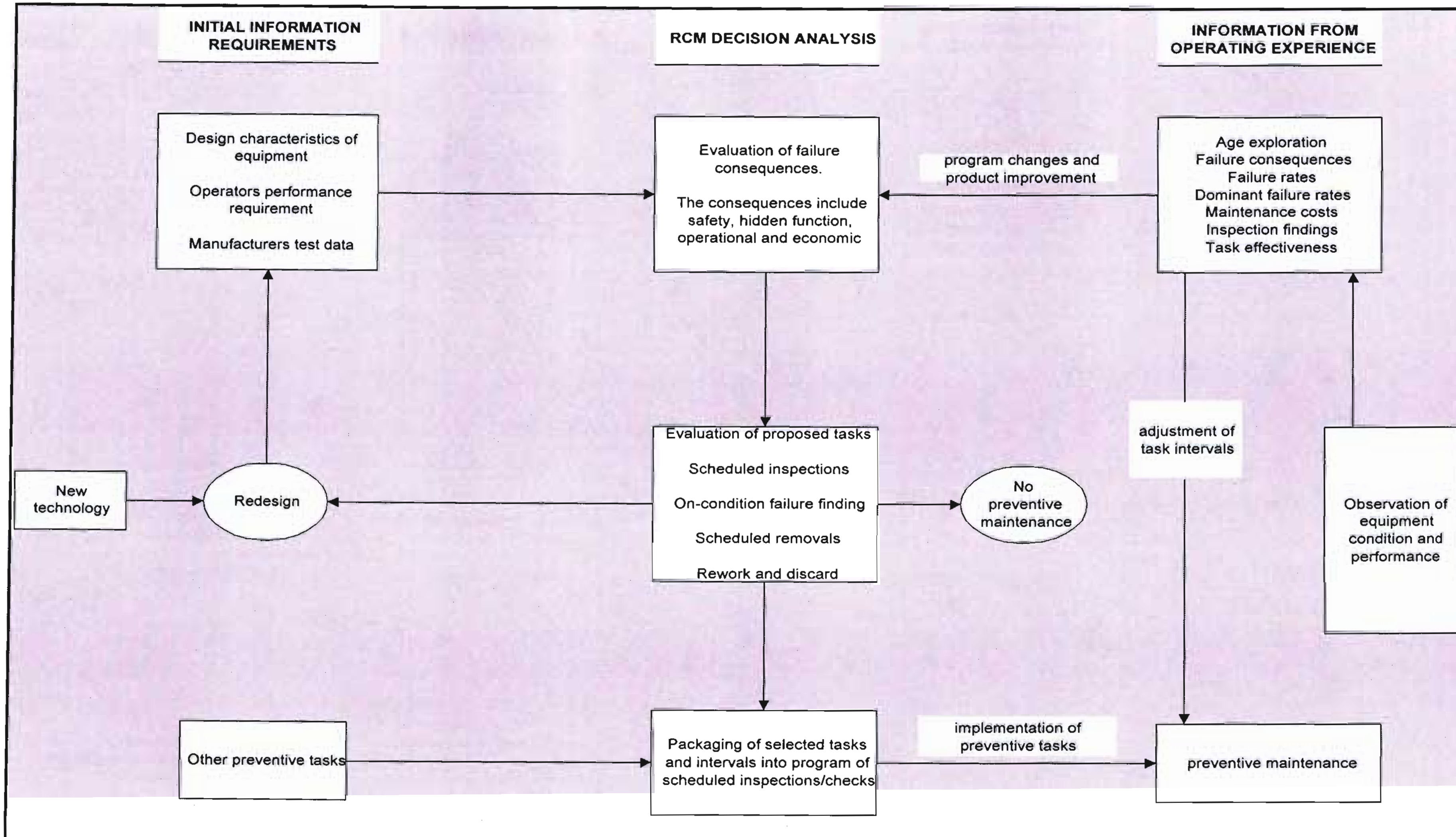
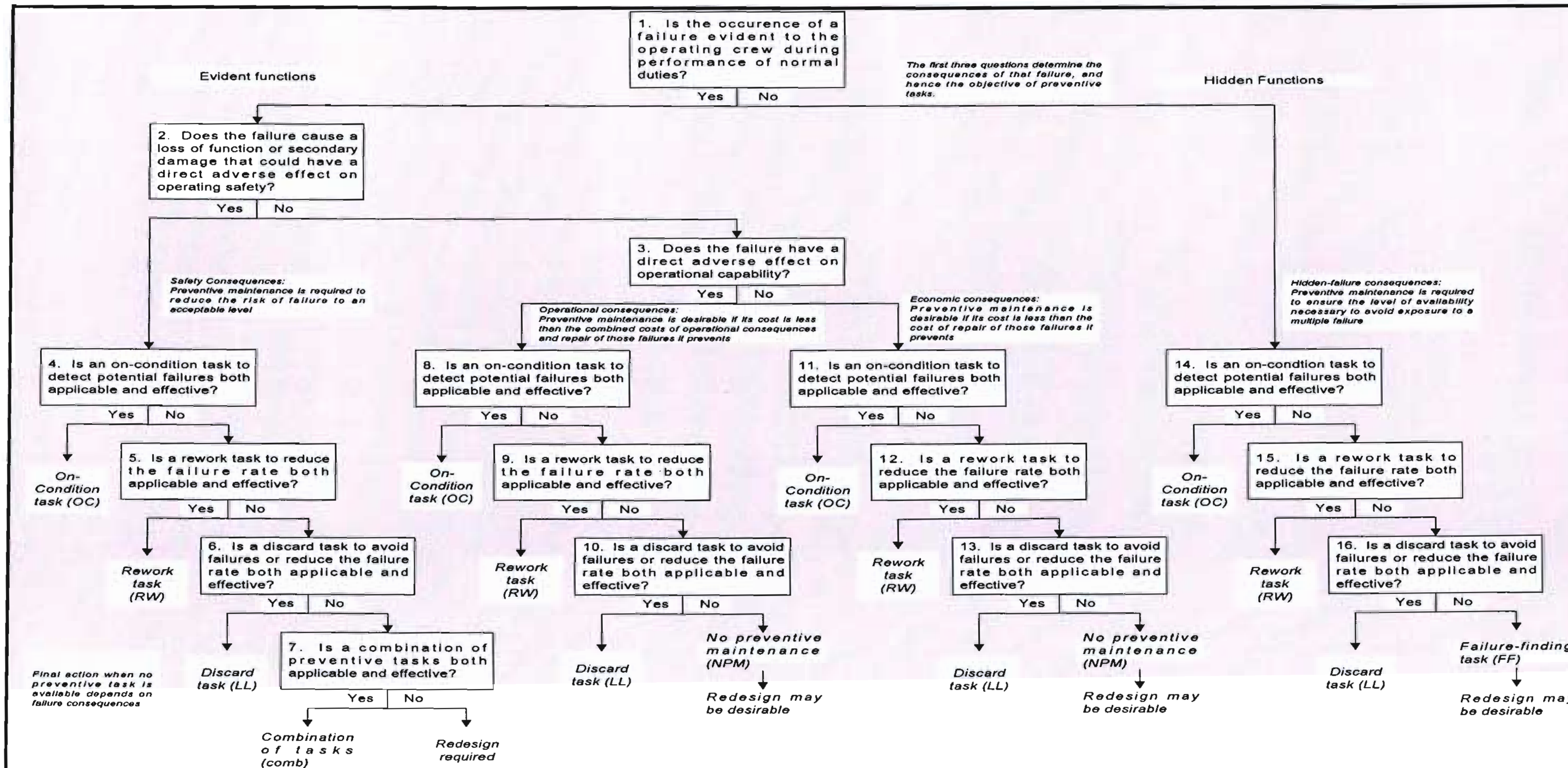



**Figure 4.13.** RCM analysis process

**Figure 4.14:** RCM decision diagram



4.5.2.1. RCM for the expeller

RCM is performed, in Table 4.21, on the following subsystems of the expeller as obtained from the analysis of Figure 4.9:

- Overload protection unit
- Control box
- Belts
- Bearing
- Screw
- Chamber bars
- Choke

| RCM QUESTION NUMBER | Subsystems of the expeller for which RCM is applicable | | | | | | |
|---|---|---|---|---|---|---|---|
| | Overload protection unit | Control box | belts | bearing | Screw or worm | Chamber bars | Choke |
| | | | | | | | |
| 1. | no | no | yes | yes | yes | yes | no |
| 2. | - | - | no | no | no | no | - |
| 3. | - | - | yes | yes | yes | yes | - |
| 4. | - | - | - | - | - | - | - |
| 5. | - | - | - | - | - | - | - |
| 6. | - | - | - | - | - | - | - |
| 7. | - | - | - | - | - | - | - |
| 8. | - | - | no | yes | yes | yes | - |
| 9. | - | - | no | | | | - |
| 10. | - | - | yes | | | | - |
| 11. | - | - | | | | | - |
| 12. | - | - | | | | | - |
| 13. | - | - | | | | | - |
| 14. | no | no | | | | | yes |
| 15. | no | no | | | | | |
| 16. | no | no | | | | | |

**Table 4.21.** RCM decision logic for the expeller

In terms of the failures, only the failures of the belt, chamber bars, bearing and screw are evident. In terms of the bearing, there will be a humming sound audible to the operator when it is nearing its useful life or if it has collapsed. Forces on bearings can be determined by measuring vibration at or near the bearings. Failures of the overload protection unit, choke and control box are not evident. As the overload protection unit and control box are electronic equipment, they must only be repaired when they have failed as trying to do preventive maintenance on them may actually reduce their failure rate. For the choke, an on-condition task is applicable, and inspections should be done to check that the adjustment on the choke is working properly. From Table 4.4, the choke has an MTBF of 1399 hours. Inspections should be performed on the adjustment unit of the choke every 5 months (1200 hours) and minor rework must be undertaken if required.

With regards to the failures that are evident, none of them have safety implications. However, all of them adversely affect operational capabilities. For the belt, a discard task is applicable, the belt should be replaced approximately every 1000 hours (using a safety factor), as the achieved MTBF in the field is 1608 hours as calculated in Table 4.4. For the bearing, an on-condition task is applicable, and inspection should be done to ensure the bearing is correctly lubricated, etc. Similarly, monthly inspections should be done on the screw and chamber bars to ensure that they are not excessively worn. As per Table 4.4, because the MTBF of the screw is 333 hours, inspections every month (240 hours) are adequate. During operation, the worms come under great stress as they have to play a major role in the extraction of oil from the oilseeds and hence their quick wear and tear starts right from the first day of use. It may be best to make best use of even the worn out worms instead of repairing them time and time again. It may be more practical that they be put in use till they are totally damaged and then be replaced with a new set. With the use of expeller, the wear and tear of chamber bars takes place. Inspections every two months (240 hours) should also be performed on the chamber bars, even though the chamber is specified to have an MTBF of 2000 hours in Table 4.6. It may be practical to only replace the chamber bars once they are totally damaged.

### 4.5.2.2. RCM for the bagging machine

RCM is performed, in Table 4.22, on the following subsystems of the bagging machine as obtained from the analysis of Figure 4.10:

- Rotary valve
- Conveyer chain
- Drives
- Load cells

| RCM QUESTION NUMBER | Subsystems of the bagging machine for which RCM is applicable | | | |
|---|---|---|---|---|
| | Rotary valve | Conveyer chain | drives | Load cells |
| | | | | |
| 1. | no | yes | no | no |
| 2. | - | no | - | - |
| 3. | - | yes | - | - |
| 4. | - | - | - | - |
| 5. | - | - | - | - |
| 6. | - | - | - | - |
| 7. | - | - | - | - |
| 8. | - | yes | - | - |
| 9. | - | | - | - |
| 10. | - | | - | - |
| 11. | - | | - | - |
| 12. | - | | - | - |
| 13. | - | | - | - |
| 14. | yes | | no | yes |
| 15. | | | no | |
| 16. | | | no | |

**Table 4.22.** RCM decision logic for the bagging machine

Only the failure of the conveyer chain is evident to the operator. Operational capability of the production system is affected by this failure. Routine inspections will help to improve the failure rate of the conveyer chain, by checking for excessive wear of it. As per Table 4.7, the MTBF of the conveyer chain is 535 hours. Routine inspections every 2 months (480 hours) is adequate.

As per Table 4.7, with the MTBF of the rotary valve being 803 hours, routine inspections every 3 months (720 hours) should suffice. The rotary valves should have dust seals to protect the bearings in it from impurities as well as air seals on the side covers to prevent leakage across the bearings. For the load cells, with an MTBF of 395 hours in Table 4.7, routine inspections and re-calibration every month (240 hours) should suffice. As the drives are electronic, they should be run until they fail. When this occurs, attempts should be made to find the fault and rectify it. Hence, no preventive maintenance should be performed on the drives.

#### 4.5.2.3. RCM for the control system sensors

RCM is performed, in Table 4.23, on the following subsystems of the control system sensors as obtained from the analysis of Figure 4.11:

- Load cell sensor and shaft speed sensors
- Seed humidity and oil temperature sensors
- Feeder input sensor and silo level switches
- Electro magnets
- Rotary valve sensor
- Hydraulic power pack sensor

For all the sensors of the control system, if they fail totally or their performance is degraded, this will not be evident to the operator since these are hidden failures. The only way around this is to use preventive maintenance and inspect and recalibrate the sensors online. For example, the load cells should be checked if they correctly read the weight of a standard weight measure. If it does not, then it should be re-calibrated so that it does. With reference to Table 4.11, all the sensors have high MTBF figures. The lowest MTBF figure is 802,6 hours for the hydraulic power pack sensor. As such, all the sensors should be inspected and re-calibrated where applicable, every 3 months (720 hours).

| RCM QUESTION NUMBER | Sensors for the control system for which RCM is applicable | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Load cell | Shaft speed | Seed humidity | Oil Temp sensor | Feeder input | Silo level switch | Electro magnet | Rotary valve | Hydraulic power pack |
| | | | | | | | | | |
| 1. | no | no | no | no | no | no | no | no | no |
| 2. | - | - | - | - | - | - | - | - | - |
| 3. | - | - | - | - | - | - | - | - | - |
| 4. | - | - | - | - | - | - | - | - | - |
| 5. | - | - | - | - | - | - | - | - | - |
| 6. | - | - | - | - | - | - | - | - | - |
| 7. | - | - | - | - | - | - | - | - | - |
| 8. | - | - | - | - | - | - | - | - | - |
| 9. | - | - | - | - | - | - | - | - | - |
| 10. | - | - | - | - | - | - | - | - | - |
| 11. | - | - | - | - | - | - | - | - | - |
| 12. | - | - | - | - | - | - | - | - | - |
| 13. | - | - | - | - | - | - | - | - | - |
| 14. | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| 15. | | | | | | | | | |
| 16. | | | | | | | | | |

**Table 4.23.** RCM decision logic for the control system sensors

#### 4.5.2.4. RCM for the flaking rolls

RCM is performed, in Table 4.24, on the following subsystems of the flaking rolls as obtained from the analysis of Figure 4.12:

- Steel rolls
- Hydraulic system sensors

It will not be evident to the operators when the steel roll has lost some of its smoothness or when the hydraulic system sensors are giving degraded performance. In both cases, routine inspections are required. Flaking rolls require maintenance as they wear considerably. To maintain the smoothness of the surfaces and to secure good contact between the rolls at every point, the rolls may have to be reground from time to time. This would require expertise and accurate machines. In order to compensate for uneven thermal expansion, the rolls could also be manufactured not as perfect cylinders but with a slightly curved profile, thinner at both ends and thicker in the middle. Some manufacturers can also supply grinding devices which can allow the roll ends to be reground without removal of the rolls. With reference to Table 4.14, the MTBF of the steel rolls is 267,38 hours. Monthly inspections (240 hours) would suffice. The MTBF of the hydraulic system sensor is 802,14 hours from Table 4.14. As such, routine inspections and re-calibration of this sensor every 3 months (720 hours) would suffice.

| RCM QUESTION NUMBER | Subsystems of the flaking rolls for which RCM is applicable | |
|---|---|---|
| | Steel rolls | Hydraulic system sensors |
| | | |
| 1. | no | no |
| 2. | - | - |
| 3. | - | - |
| 4. | - | - |
| 5. | - | - |
| 6. | - | - |
| 7. | - | - |
| 8. | - | - |
| 9. | - | - |
| 10. | - | - |
| 11. | - | - |
| 12. | - | - |
| 13. | - | - |
| 14. | yes | yes |
| 15. | | |
| 16. | | |

**Table 4.24.** RCM decision logic for the flaking rolls

### 4.5.3. Other maintenance actions

Other than the planned and scheduled preventive maintenance actions as recommended by the RCM analysis, other types of maintenance are also applicable to the equipment at North Coast Milling. These other forms of maintenance actions will be discussed in this section.

#### 4.5.3.1. Corrective maintenance

Here, one only attends to maintenance at failure. This can be effective if applied correctly. The advantages of this method are that there is a low cost for maintenance if it is correctly applied and it requires no advanced planning other than ensuring spares are available when required. As obtained from the previous analysis, corrective maintenance will have to be performed on some parts of the expeller, bagging machine, control system sensors and flaking rolls.

##### 4.5.3.1.1. The expeller

Corrective maintenance will have to be performed on the following parts of the expeller, as was given in Figure 4.9:

- assembly rings
- nozzle heating unit
- nozzle
- feeder

##### 4.5.3.1.2. The bagging machine

Corrective maintenance will have to be performed on the following parts of the bagging machine, as was given in Figure 4.10:

- Hopper

##### 4.5.3.1.3. The control system sensors

Corrective maintenance will have to be performed on the following parts of the control system sensors, as was given in Figure 4.11:

- Permanent magnets
- Oil and cake throughput sensors
- Seed and cake temperature sensors

##### 4.5.3.1.4. The flaking rolls

Corrective maintenance will have to be performed on the following parts of the expeller, as was given in Figure 4.12:

- Hydraulic power pack

#### 4.5.3.2. Condition based maintenance (CBM)

There can be maintenance induces failures sometimes, as in the case of electronic equipment, where there is the infant mortality stage in their lifecycle. Traditional planned and time-based maintenance can actually increase failure rates by introducing mortality into otherwise stable systems, as depicted in Figure 4.15.

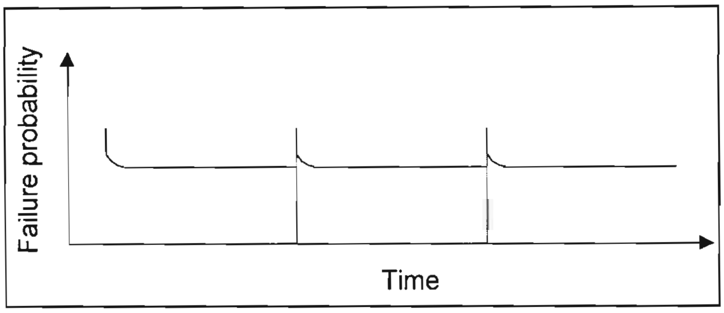



**Figure 4.15.** Failure pattern with traditional Time-Based maintenance

CBM relies on the fact that a majority of failures do not occur instantaneously but develop over a period of time. CBM involves recording some measurement that gives an indication of machine condition, such as a temperature rise or a vibration increase of the machine. Operators who work with equipment everyday can listen to the equipment in order to be able to identify changes in noise levels and vibrations. Temperature changes can be felt, which would serve as a warning sign that there could be something wrong with the equipment. An investigation can then be carried out to identify the exact problem.

Figure 4.16 depicts the failure pattern with condition based maintenance. Unlike time based maintenance, no infant mortality is introduced into the system using CBM.

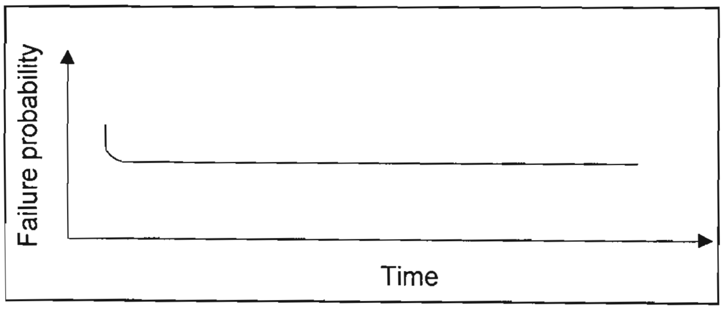



**Figure 4.16.** Failure pattern with condition based maintenance

In the case of North Coast Milling, for the electronic sensors of the control system for which corrective maintenance will be applied, CBM can be applied to them as well. As can be gauged from the above discussion, replacing these sensors at pre-determined time intervals will actually be detrimental to the system on a whole as infant mortality can be introduced into the sensor system.

#### 4.5.3.3. Opportunity maintenance

This is not actually a maintenance strategy, but a combination of planned and corrective maintenance. It can be useful when a forced stoppage at North Coast Milling gives maintenance unexpected access to machinery to carry out inspection and maintenance. Inspections during routine down times can identify unexpected tasks that need to be carried out but time does not allow it to happen. These tasks can be recorded and scheduled into the first available down time.

### 4.5.4. Software for spares calculation

The software program was written in the Borland C++ programming language. The software aims to compute the required number of spares required so as to ensure that production is not unnecessarily disrupted by not having the correct type and number of spare parts available when needed. Equation (2.12) is computed in the program. The user is prompted for various parameters. These include:

- The required percentage availability of spares of this specific part
- The quantity of this specific part used in the equipment
- From the supplier's specifications for this part, the user is prompted for the number of failures of this part and the operating time over which these failures occur. Equation (2.2) is then used for the computation of the failure rate.
- The operating hours per day that the equipment is utilised. This basically indicates the duty-cycle of the equipment.
- The frequency of spares procurement in days. This indicates the time between inventory replenishments. The total operating time of this equipment without failure is the product of the duty-cycle and the time between inventory replenishment.

The reliability function is first computed from Equation (2.1). An error occurs if the subject of the exponent function in (2.1) computes to more than 127. It is important to safeguard against this by ensuring that the user correctly enters the required parameters. Finally, the required number of spares is calculated using (4.3), which is a simplified expression for (2.12).

In order to simplify (2.12), recall that the composite reliability is given by:

$$R = e^{-k\lambda t} \qquad (4.1)$$

Where: k is the quantity of parts used of a particular type

λ is the failure rate of the part

t is the required operating time of the equipment in which this part is used. It is the product of the duty-cycle of the equipment and the time between inventory replenishment of the part.

From the well known mathematical relationship between the logarithmic and exponential functions:

$$Ln(e^{y}) = y \qquad (4.2)$$

Substitution of (4.1) into (2.12) and making use of the mathematical relationship described in (4.2), then (2.12) can be simplified and rewritten as:

$$P = \sum_{n=0}^{s}\left[\frac{e^{-k\lambda t} \times (k\lambda t)^{n}}{n!}\right] \qquad (4.3)$$

Where:

P = probability of having a spare of a particular item available when required

S = number of spare parts carried in stock

n =a dummy variable used in the summation

Hence, the software program computes the simplified expression given by (4.3) instead of the more complicated expression given by (2.12). The software code appears in Figure 4.17 and the flowchart for the software in Figure 4.18.

**Figure 4.17.** Software Listing

```
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <stddef.h>

/*****************************************************************/
// FUNCTION PROTOTYPE DEFINITIONS
/*****************************************************************/
void main(void);              /* arguments are none, and returns nothing */
double factorial(double n);  /* argument is double n, and returns a double result */

/*****************************************************************/
// This is the FACTORIAL subroutine
/*****************************************************************/
double factorial(double n)
{
  double sum=0;

  if ((n==0)||(n==1))
  return 1;    // the factorial of zero is 1

  else
   {
    sum=n;
     do
       {
       n=n-1;
       sum=sum*n;
      }while (n!=1);
     return(sum);
   }
}
```

```
/*********************************************************************/
// This is the MAIN subroutine of the program
/********************************************************************//

void main(void)

{

 double p_calc=0;
 double factorial_value=0;
 double value=0;
 double n=0;
 double R=0;
 double power_term=0;
 float p;                              //user needs to enter this value
 char c;
 float K;                              //user needs to enter this value


 float no_of_failures;                 //user needs to enter this value
 float failure_operating_hours;        //user needs to enter this value
 float equipment_operating_hours;      //user needs to enter this value
 float spares_procurement;             //user needs to enter this value
 float response;                       //user needs to respond with 0 to quit
 float lambda;
 float T;
 float k_lambda_t;                     //this is now a computed value


 clrscr();                             //this command clears the screen
```

```
do
 {
    do                  //this do-while loop is used to prevent overflow errors if
                        //k_lambda_t > 127
     {
     printf("\n Enter the required percentage availability of spares of this part \n");
     printf(" or enter 0 to quit the application: \n");
     scanf("%f",&p);

     if (p==0)  exit(1);      //allow user to quit the application
     p=p/100.0;

      printf("\n Enter the quantity of this part used in the system: \n");
      scanf("%f",&K);

      printf("\n Enter the number of failures of this part: \n");
      scanf("%f",&no_of_failures);

      printf("\n Enter the total operating hours over which \n");
      printf(" these failures occur: \n");
      scanf("%f",&failure_operating_hours);

       lambda = no_of_failures/failure_operating_hours;

       printf("\n Enter the equipment operating hours per day: \n");
       scanf("%f",&equipment_operating_hours);

       printf("\n Enter the frequency of spares procurement (in days): \n");
       scanf("%f",&spares_procurement);

      T = equipment_operating_hours*spares_procurement;
```

```
        k_lambda_t = K*lambda*T;
        clrscr();
        if (k_lambda_t > 127)

        printf("\n\n COMPUTATIONAL ERROR: PLEASE RE-ENTER
                    PARAMETERS \n");

       }while (k_lambda_t > 127);        //this is to prevent overflow errors

    p_calc=0;
    factorial_value=0;
    value=0;
    n=0;
    R=0;
    power_term=0;

    R=exp(-1*k_lambda_t);

    do
    {
    power_term=pow(k_lambda_t,n);
    factorial_value=factorial(n);
    p_calc=p_calc + ((R*power_term)/factorial_value);
    n++;
    }while(p_calc<=p);

    printf("\n\n The required number of spares is %d: \n\n", int(n-1));

  }
  while(1);
}
/*********************************end ***************************/
```

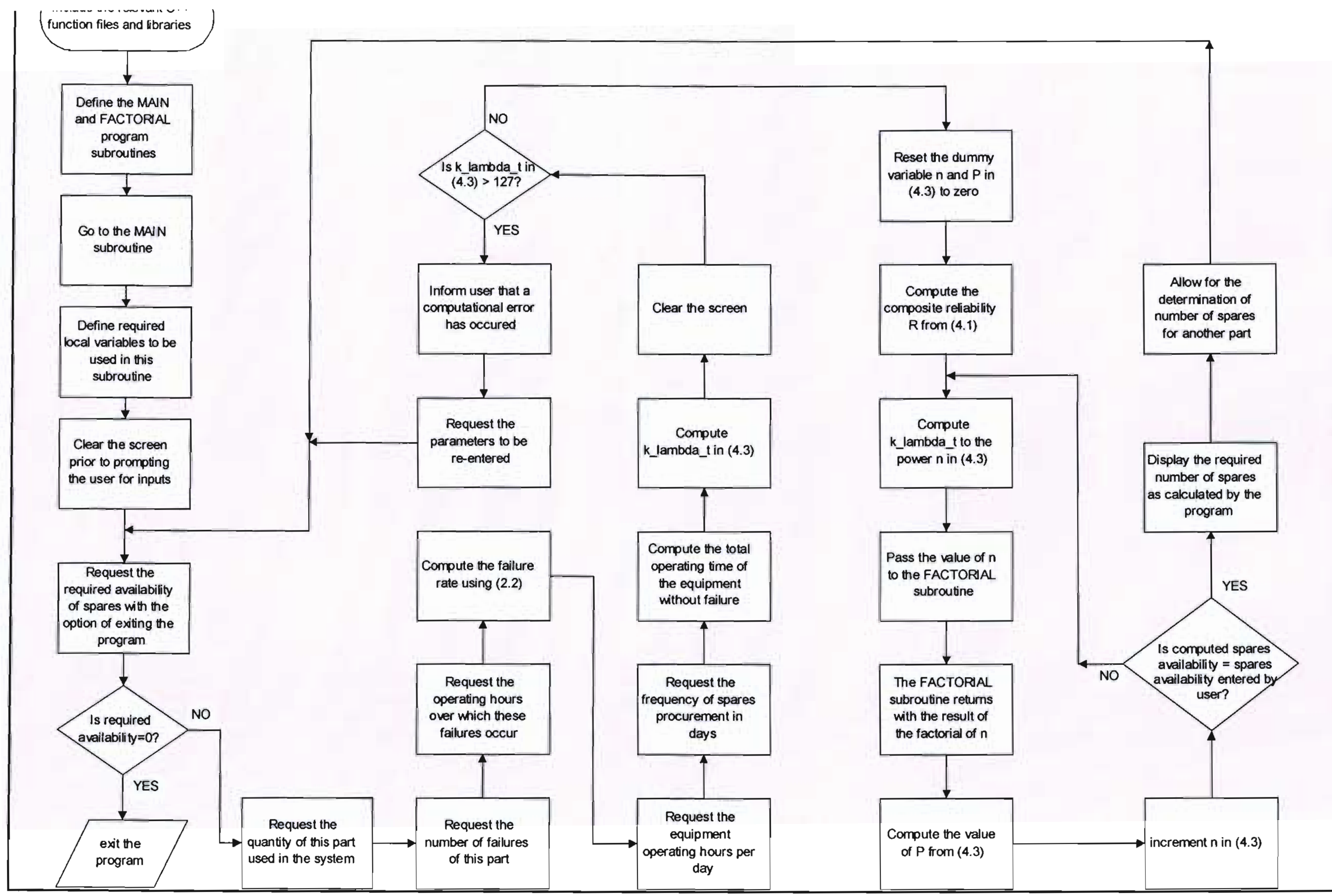



**Figure 4.18.** Software Flowchart

Figure 4.19 is a sample simulation. It is an example of what the user sees on the screen and the parameters that he is prompted for. The program of Figure 4.17 then returns with the required number of spares.

```
Enter the required percentage availability of spares of this part
or enter 0 to quit the application:

95

Enter the quantity of this part used in the system:

20

Enter the number of failures of this part:

2

Enter the total operating hours over which
these failures occur:

10 000

Enter the equipment operating hours per day:

15

Enter the frequency of spares procurement (in days):

180

The required number of spares is 16.
```

**Figure 4.19:** Sample simulation

All the quantities of spare parts are determined using the software model developed as well as using the results of the RCM. The required confidence in having the spare part available at the store at North Coast Milling is 95%. Once the spares are used up, they are replenished every month (30 days). The software simulation calculates the optimum number of spares that should be held in the store at North Coast Milling at any point in time, to ensure that logistics delay times, a major problem at North Coast Milling, is kept to a minimum. The failure rates used in the simulation are the ones actually found to apply to the equipment as they are in the field. As the reliability of the equipment improves at North Coast Milling, the required number of spares will decrease as use will be made of the supplier's failure rate figures.

#### 4.5.4.1. Spare parts requirement for the expeller

| Item | Spares quantity as per simulation | Remarks |
|---|---|---|
| | | |
| feeder | 1 | The ordering of a new feeder has a long lead time of 8 months |
| Chamber bars | 4 | A complete set of chamber bars need to be kept in store |
| Control box | 0 | Repairs should be performed on the existing control box |
| belt | 1 | |
| Overload protection | 2 | Two fuses need to be carried in stock for the overload protection unit |
| bearing | 2 | Failed bearings should be replaced |
| choke | 1 | The choke should be replaced when it fails |
| Nozzle heating unit | 1 | |
| nozzle | 0 | Repairs should be performed on the existing nozzle |
| Assembly rings | 3 | The three assembly rings on the screw assembly are constantly under stress and wear quickly |
| worms | 9 | The 6 worms are constantly under stress and wear quickly |

**Table 4.25.** Simulation result of spares for the expeller

The total cost of failures of the expeller for the year amounted to R2 544 391,62, as shown in Table 4.3. The cost of the spares in Table 4.25 amounts to R345 000, which represents less than 14% of this cost. As such, it is beneficial for North Coast Milling to spend money on holding the correct amount of spares in stock, as the end result is large amount of saving for the company from alleviating the requirement for unscheduled maintenance.

### 4.5.4.2. Spare parts requirement for the bagging machine

| Item | Spares quantity as per simulation | Remarks |
|---|---|---|
| | | |
| Low speed drive | 1 | The old drive needs to be sent to the supplier for repair as it is too complex to repair at North Coast Milling. |
| High speed drive | 1 | The old drive needs to be sent to the supplier for repair as it is too complex to repair at North Coast Milling. |
| Load cell | 2 | |
| Hopper | 0 | Perform repairs on the existing hopper when required |
| Conveyer chain | 2 | |
| Rotary valve | 2 | |

**Table 4.26.** Simulation result of spares for the bagging machine

The total cost of failures of the bagging machine for the year was to R1 234 778,29, as shown in Table 4.3. The cost of the spares in Table 4.26 amounts to R113 000, which represents less than 10% of this cost. As such, it is beneficial for North Coast Milling to spend money on holding the correct amount of spares in stock, as the end result is large amount of saving for the company from alleviating the requirement for unscheduled maintenance.

### 4.5.4.3. Spare parts requirements for the control system sensors

The total cost of failures of the control system sensors for the year was R1131 880,10, as shown in Figure 4.3. The cost of the spares in Table 4.27 amounts to R187 200, which represents less than 17% of this cost. As such, it is beneficial for North Coast Milling to spend money on holding the correct amount of spares in stock, as the end result is large amount of saving for the company from alleviating the requirement for unscheduled maintenance.

| Item | Spares quantity as per simulation | Remarks |
|---|---|---|
| | | |
| Load cell sensor | 1 | Routine inspections will be performed on this sensor |
| Shaft speed sensor | 1 | Routine inspections will be performed on this sensor |
| Seed humidity sensor | 1 | Routine inspections will be performed on this sensor |
| Oil temperature sensor | 1 | Routine inspections will be performed on this sensor |
| Feeder input sensor | 1 | Routine inspections will be performed on this sensor |
| Silo level switch | 1 | Routine inspections will be performed on this sensor |
| Electro magnet | 0 | The electro magnet will be repaired after it fails |
| Rotary valve sensor | 1 | Routine inspections will be performed on this sensor |
| Hydraulic power pack sensor | 2 | Routine inspections will be performed on this sensor |
| Permanent magnet | 0 | The permanent magnet will be replaced after it fails, but as shown in Table 4.11, this is very unlikely. |
| Oil throughput sensor | 1 | No inspections will be performed on this sensor, and it will be replaced after it fails. |
| Cake throughput sensor | 1 | No inspections will be performed on this sensor, and it will be replaced after it fails. |
| Seed temperature sensor | 1 | No inspections will be performed on this sensor, and it will be replaced after it fails. |
| Cake temperature sensor | 1 | No inspections will be performed on this sensor, and it will be replaced after it fails. |

**Table 4.27.** Simulation result of spares for the sensors

### 4.5.4.4. Spare part requirements for the flaking rolls

| Item | Spares quantity as per simulation | Remarks |
|---|---|---|
| | | |
| Hydraulic power pack | 1 | |
| Steel rolls | 0 | Do maintenance on existing rollers |
| Hydraulic system sensors | 2 | |

**Table 4.28.** Simulation result of spares for the flaking rolls

The total cost of failures of the flaking rolls for the year was to R1 028 981,90, as shown in Table 4.3. The cost of the spares in Table 4.28 amounts to R69 800, which represents less than 7% of this cost. As such, it is beneficial for North Coast Milling to spend money on holding the correct amount of spares in stock, as the end result is large amount of saving for the company from alleviating the requirement for unscheduled maintenance.

### 4.5.5. Human factors

Most operators like to clean their equipment by blowing compressed air into it. Without them realising it, they are subjecting the equipment to contamination. This can lead to accelerated deterioration. The operators at North Coast Milling need to be properly trained in the different phases of the maintenance programme. Phase one of a maintenance program is systematic daily maintenance. The machine operator is usually responsible for this part. He simply cleans the equipment, observing anything out of the ordinary and reporting it to the maintenance department. This allows replacement of parts about to malfunction. Phase two is the regularly scheduled maintenance to include changing of fluids, through cleaning of parts not normally seen by the operator and a more detailed inspection for parts about to malfunction. This would include parts that are bent or broken, to include any possible cracks, obvious wear and signs of lack of lubrication. Phase three is the repair function and is a last resort and should only arise at infrequent intervals. The proper performance of phases one and two will greatly reduce the occurrence of phase three, which is the breakdown repair.

The diagnostic element is the largest contributor to active maintenance time. The diagnosis entails the isolation of the defective part. Built-in test equipment in some of the equipment at North Coast Milling will help to reduce the diagnosis time. Fully automated checking devices, which perform computerised testing, are also available. However, skilled technicians are still needed to operate sophisticated testing equipment. Suitable warning devices must be provided to alert the operator that the oil in the system exceeds normal operating temperature or other important variables in the production process have exceeded the maximum allowable values. The operator must then be able to automatically shut the equipment down.

The mean time to repair predicted by maintainability engineering is based on the capability of personnel to accomplish maintenance tasks within a specified amount of time. The design must consider the human interface requirements for performing maintenance. Each maintenance task must be as easy to perform as possible. If personnel cannot easily access items requiring maintenance, excessive time might be required to perform maintenance. Accessibility to the parts requiring maintenance seems to be a major problem at North Coast Milling. Additionally, the maintainers at North Coast Milling must be equipped with the proper tools to be able to carry out speedy minor maintenance tasks.

The operators at North Coast Milling can help in reducing equipment failures during the production process by:

- Keeping work surfaces clean to prevent contamination and wear
- Reporting oil leakages and ensuring that action is taken to prevent recurrence in future
- Being alert and recognising unusual noise, vibrations, smell and temperature which signify impending failure
- Checking bolts for tightness (which maintenance experts consider as the single most important cause of machine failure)
- Reporting any deterioration in product quality before the issue goes out-of-control
- Studying process control charts and taking corrective action before control levels of processes are breached.

## 4.6. Conclusion

This chapter has used the analyses techniques of military logistics techniques discussed in Chapter 2, together with the production and maintenance data to calculate some of the important logistics measures. From the downtime data from North Coast Milling, the expeller, bagging machine, control system sensors and flaking rolls were identified as the major cost and downtime drivers in the production process and all the subsequent analysis were confined to these systems. It was also evident that these equipment were breaking down much more often than was specified by the suppliers.

An LSA was then conducted on all four of these systems. The first tool used in the LSA process was the FMECA. The result of the FMECA was used to fill in the criticality matrix for each of the systems to see whether their subsystems required redesign, RCM or corrective maintenance. The FMECA was shown to be an excellent tool for limiting ones analysis work to only those items that are of significant importance to the production process. One cannot perform root cause analysis on everything, but can use the FMECA to help narrow the focus to what is most important. The main purpose of the FMECA was to identify the predicted ways that an item will fail and what will happen when the failure occurs.

The results of the FMECA served as input to the RCM process, which was the second tool used in the LSA process. This process ensures that preventive maintenance tasks are based on reliability data available on the equipment. Depending on the effect of failure or potential failure preventive or corrective maintenance is performed. If the criticality of the effect is high, preventive maintenance will be done to try and reduce the probability of failure occurrence. If the criticality of the effect is low, then no preventive maintenance will be performed. The system will be operated until the failure occurs and then corrected at a suitable time. The criticality of a failure depends on the severity of the effect considering safety, availability and cost, as well as the probability of the failure. A great strength of RCM is the way it provides simple, precise and easily understood criteria for deciding which of the proactive tasks is technically feasible in any context, and if so for deciding how often they should be done and who should do them. Apart from preventive maintenance, it was also shown that corrective, condition based and opportunity maintenance was also applicable for some of the equipment at North Coast Milling. Because failures occur randomly, it was shown that traditional planned and time-based maintenance systems are not always applicable.

The spares calculation software was used as another tool to help in the LSA process to assist in the computation of the correct amount of spares for the subsystems of the expeller, bagging machine, control system sensors and flaking rolls. This was to ensure that production was not unnecessarily disrupted by not having the correct type and number of spare parts available when needed.

Finally, the section on human factors was used to highlight the importance of have well trained operators and maintainers as well as the right types of tools. It was shown that the equipment at North Coast Milling are failing often because they were not operable as a result of lack of skill of the operators and because they were not effectively maintainable as a result of lack of accessibility.

This chapter served to highlight the fact that maintenance actions cannot be performed without the necessary resources, such as manpower, tools, test equipment, spare parts, appropriate facilities, training and time.

# CHAPTER 5

# DISCUSSION AND CONCLUSION

A discussion of important issues in the thesis is provided in Section 5.1 while the thesis ends with concluding remarks in Section 5.2.

## 5.1. Discussion

The problem at North Coast Milling is not with the poor design of the equipment, but with the way it is maintained and operated. The equipment is neither old nor outdated as other mills are using identical equipment. However, they are experiencing higher production efficiencies than North Coast Milling. If the problem was with the equipment, then it is better to get rid of the old ones and get new ones, rather than to try and optimise the maintenance practices. An attempt will be made in this section to provide solutions to the various problems being experienced at North Coast Milling. Section 5.1.1 discusses the logistics factors of reliability, supply support and human factors. Section 5.1.2 discusses maintenance-related issues that include the different types of maintenance, lubrication and the advantages and disadvantages of the TPM and RCM approaches to maintenance.

### 5.1.1. Logistics factors

#### 5.1.1.1. Reliability and availability factors

Reliability is not only a function of design life. It is a function of the operating environment and the stresses produced within such an environment. From an engineering design standpoint, designers build into every piece of equipment or component, the ability to withstand the deteriorating conditions to be expected in the operating environment, these may be friction, impact, etc. However, the design is limited by the environmental parameters and wear is caused by limiting performance and ultimately failure results. Managing the stress that pushes the equipment beyond its design capabilities will effectively create reliability.

Reliability affects system specification, design, operation, maintenance, spare part stocking, and, in fact, all aspects of a system. It is the factor that ultimately defines the tolerances of the performance and mission of a system. For this reason, it is unfortunate that more consideration is not given to formal analysis of the reliability of the production equipment at North Coast Milling, to assure its use for better system performance. The adoption of formal reliability analysis requires replacement of the current ad-hoc processes at North Coast Milling with analytical methods, proper data logging, and failure analysis. Modern machinery is expensive and therefore must run at high availability and effectiveness that cannot be achieved without an effective maintenance policy. Condition monitoring techniques can be utilised to reduce the rate of deterioration of a system thereby increasing its operating life. The goal of the reliability analyses at North Coast Milling should be to eliminate the risk of recurrence of an undesirable event by identifying root causes and taking corrective action.

Most system failures are consequential and not just the result of a single malfunction, but a sequence of such failures. As a result, reliability and risk analysis must not be conceived as a static exercise performed once, and which provides a unique answer. Reliability and risk analysis is a dynamic process, which must be updated as additional or improved information becomes available. Effective reliability and risk analysis must be performed iteratively by using new and additional information on systems and component performance.

The biggest mistake that most companies in trying to improve its production efficiencies is that they begin with a focus on results approach. Then somewhere just a short distance into the mission, they default to the same old thing – implementing a program on a broad scale – and they lose sight of what they set out to do which is to improve the reliability of a selected piece of equipment. North Coast Milling is guilty of this as they pride themselves on having adopted the TPM philosophy, to which there is very few signs of adherence. The key is to stay focused on the results. North Coast Milling needs to focus on the desired results, and measure the progress every step of the way. They need to engage the people who work in, and around the equipment in the improvement activities every step of the way if they hope to change, or at least influence, the way they operate and maintain the equipment.

The reliability and availability of systems, as well as their capability to perform certain functions during a specified time period, depends not only on their engineering design but also on their maintenance, the repair facilities, the logistics of spare parts and other related factors. All these factors together contribute to the system effectiveness, which is a measure of the ability of the system to perform its intended functions.

#### 5.1.1.2. Supply support factors: spares provisioning

Provisioning of spare parts has great influence in maintenance decisions, operational effectiveness and operating costs. Maintenance decisions are affected, for example, by repair or replacement alternatives, which in turn depend on spare part availability Various objectives can be applied to spare provisioning, such as system availability, operational reliability, operating efficiency, spare part or equipment operating costs, and weight or space taken up by spares when carried. In reality, the objectives used for the determination of a spare part purchasing policy will always include several, if not all, the above considerations. Some, such as weight or space, would be more relevant factors in a spare purchase and carriage policy for weight or volume-limited systems. Other factors such as the impact of the availability of spares on reliability and operating efficiency are harder to determine. It is usual to simply set a minimum acceptable level of equipment reliability, availability and operating efficiency as affected by the ready availability of spares when needed. As a result the objectives used in the determination of a spares provisioning policy will usually be based on costs of purchase, holding, disposal and unavailability of spares. By calculating the spare part reliability of each equipment and system, total spare part reliability can be determined with due regard to systems whose failure, resulting from the unavailability of essential spares would cause reduced performance.

The unavailability of an inexpensive part can cause a system's performance failure just as well as an expensive part. It is best to have a mix of inexpensive and expensive parts to assure optimal total system reliability and availability in terms of spare parts availability by procuring cheaper parts when warranted. North Coast Milling needs to establish the optimum mix of spares for a desired level of probability of not running out of an essential spare part during the period between spare part re-supply.

#### 5.1.1.3. Human factors

A quality maintenance program at North Coast Milling requires highly motivated maintenance crew and equipment operators. To assist in this regard, the following activities are suggested:

- Establish inspection and preventive maintenance as a recognised, important part of the overall maintenance program
- Assign competent, responsible people to the preventive maintenance program

- Provide training in precision maintenance practices and training in the right techniques and procedures for preventive maintenance on specific equipment
- Set high standards
- Publicise reduced costs with improved uptime and revenues, which are the result of effective preventive maintenance.

It is important that the maintenance people at North Coast Milling are not seen only as repairmen, but as up keepers of the equipment. Similarly, equipment operators also have very restricted roles at North Coast Milling and are perceived in a negative light. As such, they lack the feeling of ownership of the equipment that they are operating. People will perform successfully if they are capable, have well defined job roles, know what is expected of them, have the skills and knowledge as well as the tools and resources to perform, and receive feedback and rewards for good performance. Training and skill development is a key component as it enables people to meet the expectations that they face in their changing jobs.

Change programs are not easy to implement particularly when an organisation like North Coast Milling has entered a vicious circle of maintenance. There needs to be some fundamental shift in behaviour and motives at all levels across the organisation. There needs to be a commitment to the long term and if there needs to be some short-term losses, then these will often be well worth it if returns can be generated quickly from the investment in the future.

World-class maintenance relies on leadership providing direction, focus and support. This involves management establishing a clear mission and vision supportive of the organisation's direction and goals. Focusing on a goal such as all failures are preventable or all downtime is preventable, leads plant personnel to identify the causes of failures and discover ways to reduce them. Chances are that North Coast Milling will never identify and solve all its equipment problems, but with an eye on the goal, the company will be headed in the right direction.

### 5.1.2. Maintenance related issues

#### 5.1.2.1. Preventive, corrective and condition based maintenance

The main reason for the existence of the maintenance department at North Coast Milling are to ensure the availability and efficiency of existing plant and equipment in a manner required by the production department.

In terms of plant operation, this means that:

- the plant must be available for start-up when required
- the plant must not break down during production runs
- the plant must operate in an efficient manner at the required level of production
- the downtime for maintenance must not interfere with production schedules or runs
- the downtime which may be caused by a breakdown should be a minimum

To accomplish the above conditions:

- there must be complete co-operation and mutual understanding between maintenance and production departments
- there must be an effective maintenance policy for planning, controlling and directing all maintenance activities
- the maintenance department must be well organised, adequately staffed and the personnel sufficiently trained to carry out the work
- there must be progressive efforts to reduce or eliminate breakdowns

To ensure maximum plant availability and reliability, regular maintenance must be carried out. This maintenance must be carefully planned in conjunction with production requirements and schedules so that it causes the minimum stoppage and loss of production. Inadequate maintenance can lead to damage that is extremely costly not only in repairs but also in lost production. From the analysis performed on the equipment at North Coast Milling, for the majority of equipment, planned preventive maintenance can be used to increase the reliability of that equipment. However, planned maintenance will not compensate for poor workmanship, lack of tools, bad design or the incorrect operation of machinery by the personnel, nor will it convert worn-out obsolete equipment into modern, highly efficient units. However, the mere fact that maintenance is being considered and controlled in a systematic, constructive manner must lead to some positive benefits which are the direct result of this planning. An essential part of the planned maintenance system is the collection, recording and subsequent interpretation of maintenance data.

The inability of preventive maintenance systems to bring about acceptable levels of safety and plant availability has led to a broad acceptance that the maintenance of plant and equipment needs to be reassessed. One of the reasons for this is the recognition that plant and equipment can fail in several ways. Equipment failures fall into two broad categories: those failures which are age-related and those where there is no relationship between age and the probability of failure, as in the case of electronic equipment. To those failures that are not susceptible to time-based maintenance, then traditional preventive maintenance is inappropriate. Corrective and condition based maintenance may be appropriate in this case.

Condition based maintenance compares the trend of measured physical parameters against known engineering limits for the purposes of detecting, analysing and correcting problems before failure occurs. Condition based maintenance can be applied to any equipment problem if, first, a physical parameter like vibration, temperature, pressure, voltage, current or resistance can be measured. An engineering limit for the measured physical parameter must be established so a problem can be detected during routine monitoring. Also, the limit should be low enough to detect the problem before excessive damage occurs.

The advent of automation, increased production levels, rigid production schedules, the high cost of capital equipment and increased machine utilisation have all highlighted the fact that maintenance can no longer be considered simply as an adjunct to the production process, but must be regarded as an integral part of it. It is therefore logical that as much planning should be devoted to the maintenance aspect as to any of the other engineering activities. As new production methods and machines are developed and introduced, so the outlook of the maintenance department must be progressive, employing the latest techniques to keep pace with the advancement of production technology.

#### 5.1.2.2. Basic equipment conditions

Three physical conditions that are required for the basic equipment conditions are no looseness of nuts and bolts, no contamination of the lubrication and the correct lubrication must be used. If these three conditions are satisfied, it can eliminate a large amount of equipment failures at North Coast Milling.

It is essential that during scheduled and unscheduled maintenance, all nuts and bolts must be adequately tightened. It is also essential for the lubrication in the production equipment not to be contaminated by dust and dirt.

Proper lubrication provides an interface between moving surfaces. The lubrication wears out as the moving surfaces interact with it. Accelerated deterioration occurs when:

- Lubrication is not present
- Lubrication is incorrect for the application
- Lubrication between surfaces is forced out due to overload
- Lubrication wears out
- Lubrication becomes contaminated

Excess grease is responsible for a large number of bearing failures in the expeller at North Coast Milling as it causes the bearing to heat up, pressurise and it escapes through damaged seals.

The lubrication practices at North Coast Milling should align concisely with the defined, supported goals of the larger maintenance operation. To maximise the limited lubrication resource, the lubrication procedures for a particular machine should fit the broader strategy for that machine. Only high-performance lubricant should be used in the sealed applications where there is no planned routine service to be performed on that equipment.

#### 5.1.2.3. Comparison of RCM and TPM

RCM is generally promoted as a maintenance improvement strategy whereas TPM recognises that just the maintenance function alone cannot improve reliability. Factors such as operator lack of care and poor operational practices, poor operating conditions and adverse equipment loading due to changes in processing requirements of different products, raw materials and process variables all impact on equipment reliability. TPM emphasises that all employees should become actively involved in recognising the need to eliminate or reduce failures, and to focus on defect avoidance or early defect identification and elimination of failures.

TPM does not explore the different requirements of maintenance to a great extent, whereas RCM specifically address the consequences of failure, and thereby looks at a broader range of issues which occur in the event of failure. RCM suggests that maintenance is not about preventing failures, but about avoiding the consequences of failure. Within the RCM strategy, one needs to decide which machines can run-to-failure. Other machines, perhaps similar, must be managed to assure maximum availability. RCM accepts that when the cost of prevention exceeds the cost of failure, it is not cost effective to eliminate all failures. In its quest for zero defects, TPM is effectively seeking functionality of the plant. This is a command for carrying out maintenance at all costs and in all operating conditions, which is clearly not sensible if no production loss is suffered and no secondary damage is incurred.

RCM and TPM are ways in which maintenance can be improved, but both have limitations. RCM is criticised for being too time-consuming. Frequently this is because the organisation does not have the knowledge of its plant and equipment as required by RCM. This should not be perceived as an RCM deficiency, it is the fault of those within the company who are operating and maintaining machines without fully understanding how they work, how they fail and what happens when they fail. The discipline imposed by RCM makes people think beyond the narrow definition of maintenance as preventing failures. Ensuring functionality ensures that the design parameters are related to performance, and vast sums are not wasted on trying to prevent failures that occur, in reality, because designs are inadequate, or machines are too small, or plant is operated incorrectly.

The consequence evaluation in RCM is not addressed in TPM. TPM makes no specific provision for failure-finding tasks. TPM has little to offer on the technical front. Condition based maintenance practices are acknowledged by both RCM and TPM. RCM devotes much attention to the basis of determining the frequency of on-condition tasks. This is not addressed by TPM and it represents a major weakness in TPM as many practitioners in this field believe in the fallacy that criticality of equipment should determine the frequency of condition monitoring.

Both approaches deal with scheduled restoration and scheduled discard to be followed by redesign, although TPM does not require redesign if maintenance cannot prevent a failure which can result in safety or environmental consequences. TPM does not specifically deal with failures that may have safety environmental consequences, presumably because of the belief in zero defects whereby unsafe situations cannot develop from equipment failure. TPM acknowledges that zero defects may be a long-term goal, and that quantified incremental improvements are required. RCM rejects this in the case of safety and environmental consequences because killing less people this year than last year is an unacceptable management practice.

TPM emphasises that the involvement of operators in routine maintenance builds a sense of responsibility, ownership and pride. Better co-ordination reduces delays and downtimes and productivity increases. TPM thrives on the spirit of teamwork and it has a long-range outlook. RCM has a far more prescriptive methodology that relates design capability with desired performance. RCM evaluates failure consequences before suggesting what preventive maintenance is technically feasible and worth doing. It deals specifically with hidden functions and associated failure finding tasks. RCM recommends the use of groups to analyse equipment. TPM proposes some essential features which aim for zero defects through the involvement of all disciplines and the use of groups for autonomous maintenance. It places great emphasis on the human aspect of maintenance.

From the above discussion, it is evident that the use of TPM and analytical techniques from RCM combined, can result not only in superior availability, reliability and maintainability, but can also result in significant improvements in capacity with a substantial reduction in maintenance costs and total operational costs. This approach can then be used to identify and eliminate the source of equipment deterioration.

## 5.2. Conclusion

The objectives of the study have been satisfied, in that:

- The current production efficiency at North Coast Milling has been calculated
- The current maintenance practices at North Coast Milling have been evaluated
- Various aspects of the military logistics techniques have been applied to North Coast Milling in order to identify, evaluate and draw recommendations about the cost and downtime drivers in the production process. The important cost and downtime drivers in the production line at North Coast Milling had been identified and analyses had only been conducted on these items. An in-depth discussion of the military logistics techniques had been provided in Chapter 2, and the applicable aspects of it was applied to North Coast Milling in order to identify, analyse and make recommendations about the cost and downtime drivers in the production line. From the production and maintenance data from North Coast Milling, it was evident that the expeller, bagging machine, control system sensors

and flaking rolls were the major contributors of downtime in the production process.

- Analytical models for the FMECA, RCM and spare part analyses have been developed and applied to relevant equipment at North Coast Milling
- The thesis has highlighted the fact that an improvement in reliability and production efficiency can be achieved at North Coast Milling by the application of some of the military logistics techniques discussed
- It was shown that military logistics techniques can be used to supplement the current maintenance practices at North Coast Milling. The recommendation from the study is that aspects of RCM and TPM be combined to optimise maintenance.

Chapter 3 summarised the key challenges facing North Coast Milling as follows:

- To improve the production efficiency of their equipment in order to be competitive
- To select the most appropriate techniques to deal with each type of equipment failure in order to fulfil all the expectations of the owners of the assets and the users of the assets in the most cost-effective and enduring fashion and with the active support and co-operation of all the people involved
- To develop an integrated approach to maintenance that pulls together all of the design tools and maintenance tools that exist into an integrated whole. This maintenance approach should include and integrate a formal approach to risk assessment, RCM and TPM principles, human factors and a participative approach to equipment design.
- Not only to learn what the relevant maintenance techniques are, but to decide which are worthwhile and which are not in their organisation. If they make the right choices, it is possible to improve asset performance and at the same time contain and even reduce the cost of maintenance. If they make the wrong choices, new problems are created while existing problems will only get worse.
- To develop a culture at North Coast Milling that will be conducive to the attainment of its maintenance and production objectives.

One of the most crucial items in maintenance management at North Coast Milling is the cost effectiveness of maintenance. Without precise figures for the cost of downtime, it is not possible to determine if scheduled preventive maintenance is cost effective. The objective of maintenance is not to avoid the failure of the equipment, but to avoid the consequence of the failure in each case. Hence, the consequences of failure have a large bearing on the appropriate maintenance program to adopt for any item of equipment.

The operators of the equipment should be responsible for its overall effectiveness. This does not mean that operators carry out all maintenance activities, but that they are responsible for knowing when they need to carry out the simple defect avoidance and service work themselves, and when they should call in maintenance experts to repair the problem that they have clearly identified.

Traditionally, the users and purchasers of equipment have focused mainly on the acquisition phase of the equipment's life cycle. However, the thesis has highlighted the fact that in order to produce a successfully competitive product, performance and maintenance must also be considered at the time of the original design. When too great an emphasis is placed on the engineering of a product's primary function, side effects often occur. These negative impacts often manifest themselves in problems dealing with operation. As such, prior to North Coast Milling embarking on purchasing any new equipment, they should rather get their operators and maintainers involved during the design phase of the equipment they require so as to prevent future operational and maintenance problems. By involving the operators in the acquisition phase of the equipment, a greater sense of ownership will be developed by them.

To break the vicious cycle of maintenance, asset managers should focus on the areas of preventive maintenance and defect elimination. To improve their preventive maintenance organisations, there must be a shift to an environment where there is no duplication of preventive maintenance, every preventive maintenance task serves a purpose, all of them are completed at the right interval and with the right mix of condition based maintenance and overhaul.

It has been shown that there is no underlying relationship between failure probability and age of equipment, and replacement at fixed intervals does nothing for the reliability of the system, and can even aggravate the situation. A common focal point of TPM, RCM and CBM (condition based maintenance) maintenance practices, is the elimination of wear to avoid unnecessary or unplanned downtime due to failure. The objective of maintenance management is to ensure the reliability of plant equipment. Knowing that all equipment components will wear, appropriate management can be applied to avoid unplanned failure.

With less maintenance, machinery is available to operate for longer. This translates into less spare parts, a smaller store, fewer operators and maintainers and fewer managers. The benefits gained from having reliable, long-lived plant extend well beyond just having lower maintenance costs.

Tangible but not measurable benefits of a good maintenance program at North Coast Milling will be:

- Reduced equipment downtime
- More informed decision-making
- Focused maintenance initiatives
- Improved maintenance cost effectiveness
- Reduced artisan overtime
- Reduced catastrophic equipment failures, leading to reduced maintenance costs

Competing on product quality and price isn't enough. Today, its how fast products can be delivered to a waiting customer, how fast can the next generation of new products be designed and how fast can one respond to a changing marketplace. The key difference between manufacturing companies has become who can design, produce and deliver the fastest. Speed is manufacturing's new competitive challenge. This thesis has highlighted the point that in order to improve speed of production, it requires high production efficiencies, which means high equipment reliability and maintainability. North Coast Milling needs to realise that enhancing the reliability of its production equipment is not only necessary for their continued growth, but also mandatory for their survival.

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[1] www.breadflour.co.uk

[2] www.emerald-library.com

[3] www.maintenanceresources.com

[4] www.newstandardinstitute.com

[5] www.reliabilityweb.com

[6] www.reliability.com

[7] www.lubetraining.com

[8] www.tpmonline.com

[9] www.sabinet.co.za

[10]www.sre.org