DEVELOPING A FRAMEWORK TO IMPROVE AVAILABILITY /RELIABILITY ON THE BAGGING MACHINES AT SAFRIPOL

Sifiso Hadebe

B. Eng. (Chemical)

Mini-dissertation submitted in partial fulfilment of the requirements for the degree Masters in Business Administration in the Faculty of Economical Science of the Potchefstroom Universiteit vir Christelike Hoër Onderwys

Supervisor: Mr. P. Geldenhuys

Vanderbijlpark

1998

ACKNOWLEDGEMENTS

I wish to express my deepest gratitude to the following people who made this study come to fruition:

- To the ALMIGHTY GOD for His Love, Faith and Hope He has given me unconditionally.

- To my supervisor, Mr. P. Geldenhuys for his advice, guidance and support.

- To Safripol personnel for making this study a reality.

- To Zinhle, my daughter, and Philasande, my son for their understanding during the hard times.

- To H. Nel for her immense patience and preparation of the document.

OPSOMMING

Produksie uitsette, totale koste en klantediens word deur staantyd beïnvloed. In die geval van vervaardigingsmaatskappye word hierdie probleem deur 'n wereldwye beweging na "Just In Time" stelsels vererger. 'n Groter mate van outomatisering beteken dat falings tot 'n toenemende mate die vermoë van maatskappye om bevredigende kwaliteitstandaarde in diens en produksie te lewer, beïnvloed. Stelselbetroubaarheid en -beskikbaarheid is onmisbaar vir die sukses van bate-intensiewe industrieë. Wetlike vereistes met betrekking tot veiligheid en die omgewing plaas groot druk op maatskappye se instandhoudingsbegrotings.

Die integriteit van fisiese bates word al hoe meer belangrik vir korporatiewe oorlewing. Terselfdertyd neem die koste verbonde aan die besit en bedryf van die bates toe. Industrieë moet gevolglik die maksimum opbrengs op hulle belegging kry deur te verseker dat masjienerie produktief en koste-effektief bedryf word en dat die verlangde lewenduur van bates behaal word. Hierdie behoeftes bring mee dat instandhoudingskoste skerp styg. In sommige industrieë is instandhoudingskoste tans die grootste bedryfsuitgawe.

"Reliability Centred Maintenance" (RCM) is 'n kragtige hulpmiddel tot die handhawing van inherente betroubaarheid en beskikbaarheid van toerusting. RCM word ook "organised common sence" genoem omdat dit 'n sistematiese ontleding van 'n gekose stelsel, wat tot 'n beplande instandhoudingsprogram

lei, is. Die RCM benadering is op afsakmasjiene 5 en 6, wat deel van die Granulasieaanleg by Safripol uitmaak, toegepas. Die hoofdoelwit van hierdie studie is:

Om 'n raamwerk vir die verbetering van die betroubaarheid en beskikbaarheid van afsakmasjiene 5 en 6 by Safripol te voorsien.

Die volgende sekondêre doelwitte is vir die studie geidentifiseer:

- Om 'n plan waarop bestuurspraktyke toegepas kan word te ontwikkel;
- Om 'n raamwerk te voorsien vir die bevordering van interdisiplinêre spangees;
- Om fuksionele funksies en falings, falingsmodusse en falingsgevolge te identifiseer en
- Om 'n raamwerk vir "multi-skilling" van bedryfspersoneel te voorsien.

Die volgende gevolgtrekkings is gemaak:

- Die hoofdoelwit, om 'n raamwerk vir die verbetering van betroubaarheid en beskikbaarheid van die afsakmasjiene te ontwikkel, is bereik. Die statistiese ontleding van data toon dat 90.2% van falings operasionele gevolge het, 8% verborge gevolge het en dat 1.8% veiligheidsimplikasies het.

- Die studie het die behoefte aan multifunksionele opleiding uitgewys. Verder is 'n behoefte toesighouding oor werknemers tydens opleiding uitgewys.
- 'n Tekort aan mannekrag is geïdentifiseer as een van die kritieke faktore wat betroubaarheid en beskikbaarheid beïnvloed. Daar is 'n neiging om vurkhyserbestuurders te gebruik om bedryfspersoneel af te los.
- Die bestryfs- en instandhoudingsprosedures het tekortkomings en word nie op datum gehou nie.

Die volgende aanbevelings word gemaak:

- Die langtermyn kostevoordele van die ontwikkelde raamwerk vir verbetering van beskikbaarheid en betroubaarheid moet geëvalueer word;
- Multifunksionele opleiding van produksie- en instandhoudingspersoneel moet onder noukeurige toesig geformaliseer word;
- Die ontwikkelde raamwerk vir die stelsel moet as 'n springbord vir die ontleding van ander stelsels gebruik word;
- Bedryfs- en instandhoudingsprosedures moet opgedateer word en
- Die gebruik om vurkhyserbestuurders as bedryfspersoneel te benut moet onmiddelik gestop word.

SUMMARY

Downtime affects output, total cost and customer service. In manufacturing this is aggravated by the world-wide move towards Just-in-Time systems. Greater automation means that more and more failures affect the ability of companies to sustain satisfactory quality standards in service and production. System reliability and availability have become pivotal for the success of asset intensive industries. Legal standards regarding safety and environment have put a squeeze on many companies' maintenance budget.

The integrity of physical assets is becoming an issue of corporate survival. At the same time, the cost of owning and operating these assets is growing. This means that industries need to secure the maximum return on investment by ensuring that machinery function productively and last as long as the owner would like them to and that they do not cost too much to operate. The maintenance cost itself is escalating. In some industries, it is now the most costly operating element.

Reliability Centred Maintenance (RCM) has emerged as a powerful tool in maintaining the inherent reliability and availability of equipment. It has been dubbed the "organised common sense" because it enables a systematic analysis of a selected system which results in a planned maintenance programme. The RCM approach was applied to bagging machines 5 and 6, which form part of the Granulation plant at Safripol. The primary objective of this study was:

To provide a framework for improving the reliability and availability on bagging machines 5 and 6 at Safripol.

The following were the secondary objectives of this study:

- To develop a plan on which to base management practices;
- To provide a framework for fostering interdisciplinary team spirit;

- To identify functional functions and failures, failure modes and effects; and
- To provide a framework for multi-skilling operating staff.

From the results of the study, the following conclusions were drawn:

- The primary objective of developing a framework for improving reliability and availability on bagging machines was achieved. The statistical analysis of raw data gave rise to 90.2%, 8% and 1.8% of failure modes with operational, hidden and safety consequences respectively.
- The study highlighted a need for cross-functional training. It further indicated a need for supervision of employees on training.
- The shortage of manpower also emerged as one of the critical elements. There is a tendency to utilise forklift drivers as relief.
- The operating and maintenance procedures are either lacking or not updated.

The following recommendations were made:

- That the long-term cost benefits of the developed framework for improving availability and reliability be evaluated;
- That cross-training of production and engineering crew be formalised under close supervision;
- That the developed framework for the system be a springboard for the analysis of other systems;
- That operating and maintenance procedures be updated; and
- That the utilisation of drivers as relief be terminated immediately.

TABLE OF CONTENTS **PAGE No.:**

APPENDICES

LISTS OF TABLES

LISTS OF FIGURES

CHAPTER 1

STUDY OBJECTIVES AND SCOPE

1.1 INTRODUCTION

All industries are now part of the global village. They are faced with challenges to attain zero accidents, zero quality defects and zero breakdowns. This suggests that for companies to attain a sustainable competitive edge they must achieve long-term plant availability/reliability by reducing component failure rates. It further implies that plant safety and the extending of equipment life have become crucial for the company in meeting market demands.

There is a dire need for companies to attain world-class manufacturing status in order to remain competitive. This means that organisations must compete in world markets on the basis of quality, price and service. According to Kirby (1993:26), world-class organisations are those that can meet the two major conditions: zero breakdowns, that is machinery breakdowns are reduced to a minimum, and low-cost production.

The above conditions mean that greatly improved machine performance has to be obtained at absolute minimum cost. The cost containment represents a particular challenge to South African organisations in view of the country's high rate of inflation. There is a growing demand for companies to respond to:

- Stringent safety and legal environment requirements;
- Quality demand from customers;
- High maintenance costs; and
- Ensuring the availability and reliability of machinery.

These demands are warranted by high machinery automation and rapid market changes in terms of customer satisfaction and the level of competition. To match these challenges, companies are seeking reliable maintenance models that will ensure equipment availability and reliability. NRC commissioner Kenneth C. Rogers cited the role of monitoring and diagnostic analysis as follows: "The discovery and development of new innovative diagnostic and monitoring techniques will help and may be needed as we encounter possibly unknown new age-related degradation mechanisms." (1992:28.)

The maintenance planning is generally more guided by intuitive reasoning than by systematic approach. These typically include:

- *Experience:* Here equipment users continue to diagnose equipment problems the old way. The old crude diagnostic tactics developed from experience result in equipment failures causing huge profit loss.
- *Recommendation:* The users stick to the recommendations from the manufacturers despite the fact that operational conditions might have changed due to market demand. The equipment might be operated at far below or above what it is capable of, thus accelerating its failure patterns.
- *Over-maintenance:* There is a tendency to over-maintain just for the sake of it. This is normally the case where there no clear-cut maintenance is scheduled especially for critical equipment. It is vital for such equipment that accurate databases be developed and strict planning be in place.
- *Expertise:* Most companies believe in hiring a consultant to maintain the equipment. This could be a drain of money if the situation is not financially justifiable.

Maintenance practices are usually based on fixing equipment after they break. There is also a heavy reliance on maintenance schedules supplied by vendors, rather than scientific and analytical methods.

1.2 PROBLEM STATEMENT

The main problem resides with the bagging machines at Safripol, especially numbers 5 and 6 at the bagging plant. The recorded downtimes on the bagging machines amounted to 1350 hours over a six-month period (Table 1.1). It was estimated that 40% of this downtime was caused by problems associated with the operation of bagging machines numbers 5 and 6. The costs incurred as a result of these downtimes were determined and are presented in Table 1.1 below. The total costs amounted to R137.95 million over a six-month period, 51% of which is due to breakdown of bagging machine numbers 5 and 6 (1998: January-June Downtime Register &Accounting Report). This high rate of breakdown directly affects the availability and reliability of the machines.

TABLE 1.1: SUMMARY OF DOWNTIME AND COST INCURRED

PARAMETER	BAGGING MACHINE NUMBER			
	BM1/2	BM3/4	BM5/6	BM7/8
Downtime (hours)	180	414	540	216
Feed rate (tons/hours)	21	14	26	23
Product lost (tons)	3 780	5 796	14 040	4 968
Product cost (R/ton)	5 000	5 000	5 000	4 000
Cost lost (R m)	18.90	28.98	70.20	19.87

(SAFRIPOL DOWNTIME REGISTER AND ACCOUNTING REPORT, January - June 1998)

Another problem is the number of call-outs, which escalated from 32 per month to a record of 56 per month during a period of six months (January - June 1998). This equates to an increase of 57% over this period (Plant downtime register).

The operators currently lack problem-solving skills and have a poor understanding of the machinery functions. Planned maintenance is mainly based on intuition and recommendations from the vendors. Backlogs in upstream and downstream processes of up to 24 hours a day are generally experienced. The machinery reliability/availability is costly and results in customer dissatisfaction. The machines are valued at about R40 million and are highly automated with very high volume outputs.

1.3 OBJECTIVES OF STUDY

The objectives of this study are divided into primary and secondary objectives and are discussed as follows:

1.3.1 PRIMARY OBJECTIVE

The primary objective of this study is to provide a framework for improving availability and reliability on bagging machines 5 and 6 at Safripol.

The author believes that this will improve plant performance and will curtail maintenance costs.

1.3.2 SECONDARY OBJECTIVES

The following are the secondary objectives that will develop from the primary objectives:

- *To develop a plan on which to base management practices*: Maintenance practices are currently based on recommendations in vendors' technical manuals or experience.
- *To provide a framework for fostering interdisciplinary team spirit*: RCM creates the opportunity for the formation of teamwork. This is due to the fact that for a complete analysis of a system, information must receive a concerted effort from all disciplines.
- *To identify functional functions and functional failures:* The machines are designed to perform specific functions. The understanding of these functions will help in identifying failures of the machine and what causes it to fail.
- *To define failure modes and effects.* When a machine fails, the implications of its failure to upstream and downstream processes must be evaluated, that is, the financial impact it has on the business as a whole.
- *To provide a plan for the multi-skilling of operating staff*: The drive in most world-class organisations is to build a flexible workforce. This means multi-skilling

the workforce. This is one of the most important facets in achieving world-class manufacturing standards. Multi-skilling basically implies providing employees with the opportunity to acquire functional skills normally beyond the scope of their current jobs. This differs from multi-tasking, which consists of merely adding tasks together without enlarging the skills base.

Employee co-operation and involvement are crucial for the success of any business. The involvement of employees generally boosts their ego and morale. This eventually cultivates a sense of ownership and the equipment gets its deserved attention and care. There is a great need in the organisation to produce process owners to ensure that the process continually improves.

1.4 SCOPE OF STUDY

The study will only concentrate on the establishment of a framework to improve availability/reliability, and not on the implementation of the framework. It will not include a budgetary analysis of the implementation cost or changes in the managerial structure. The scope within the factory of which availability will be improved is confined to:

- Granule feed hoppers;
- Bagging machine scales;
- Bagging machines 5 and 6;
- Control panels; and
- Protective devices.

1.5 REFERENCE FRAMEWORK

The main objective of Reliability-Centered Maintenance (RCM) is generally to maintain the designed reliability of the system. The RCM method is a very useful tool in preserving safety and environment integrity, improving plant performance, forging cross-functional teamwork, developing technical equipment databases and in promoting a sense of machinery ownership among operating crew. The RCM concept is a valuable asset in curtailing maintenance cost while maintaining or even improving the availability/reliability of the systems. Therefore, through the application of RCM, a framework to improve availability and reliability on the bagging machines will be developed. In an attempt to attain the above-mentioned benefits the information will be sourced from:

- Company notification system which is used to record breakdowns;
- Monthly downtimes and call-out reports;
- Production and engineering users' experience with the equipment;
- Vendors' performance specifications; and
- Available technical data banks and reference to similar equipment.

1.6 RESEARCH METHODOLOGY

The study will apply RCM methodology to bagging machines 5 and 6 at Safripol's bagging system. The approach to this will be as follows:

- Initial data collection and system definition;
- Definition of system functions;
- Identification of functional failures (loss of function);
- Determination of failure modes (causes of failure);
- Definition of failure effects (what happens upon failure);
- Failure consequence evaluation (use of decision-tree diagram); and
- Recommendation of maintenance tasks and frequency.

The unexpected machinery failures that resulted in partial or full plant forced outages will be identified and a framework will be developed. The analysis will be conducted in consultation with production and engineering personal using RCM guidelines.

1.7 HYPOTHESIS

It is deduced that providing a framework for improving availability and reliability on bagging machines, will achieve the following:

- Improved management practices will be realised;
- A spirit of interdisciplinary teamwork will be fostered;
- Failure modes and consequences will be identified; and
- System deficiencies will be clarified and rectified.

1.8 SUMMARY

Improved availability through effective plant maintenance is recognised as the key ingredient to plant operating cost efficiency. This requires adopting and developing the state-of-the-art maintenance programmes. Avoiding forced outages and other operational transients can be counteracted by visible maintenance investment to realise:

- Curtailment of costs;
- Improved safety; and
- Better plant performance.

Kueln (1992:23) points to the fact that the economics realised from the improved maintenance practices will continue to grow while maintenance expenses themselves will decline.

1.9 CHAPTER DIVISION

CHAPTER ONE

This chapter presents the scope, reference framework, hypothesis and the primary and secondary objectives of the study. A problem statement based on the current plant performance is developed. The adopted research methodology is also broadly outlined.

CHAPTER TWO

Here a full background of the reference company is given. The company profile and the type of business environment, that is, processes, technology and company performance, are described in detail.

CHAPTER THREE

The literature study and the RCM concept are described contextually. The RCM approach and its benefits are highlighted. Reference is made to other existing related maintenance programmes.

CHAPTER FOUR

The application of the RCM methodology to the chosen system is undertaken. This involves system analysis. Data analysis is also carried out.

CHAPTER FIVE

Here conclusions and recommendations are made.

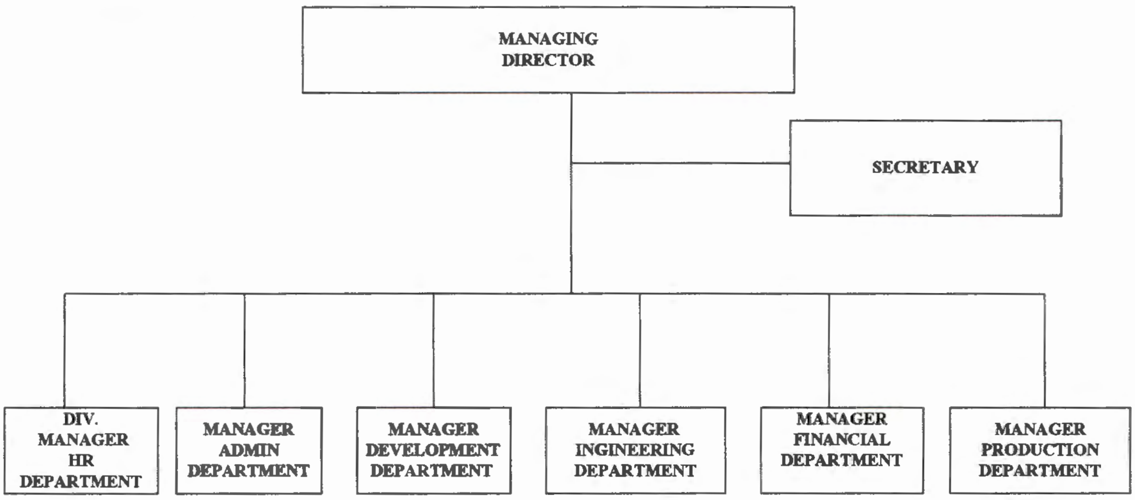
CHAPTER 2

COMPANY BACKGROUND

2.1 INTRODUCTION

Safripol manufactures a full range of high-density polyethylene (HDPE) and polypropylene (PP) products for the plastics conversion industry in South Africa. The organisational structure of the company is presented on figure 2.1 below and basically consists of six functional areas, namely production, development, engineering, administration, finance, and human resources.

FIGURE 2.1: GROUP STRUCTURE



2.2 COMPANY PROFILE

Polyethylene was first produced in 1972 at a capacity of 14 854 tons per annum. In 1974 the first polypropylene was made with a total of 4 040 tons being marketed in that year. Table 2.2 below illustrates the highlights of the company profile. Currently, the production is 210 000 ton on polyethylene and 85 000 ton per annum on polypropylene. Table 2.1 shows the turnover and the volume growth realised by the company over the past seven years.

TABLE 2.1: TURNOVER AND VOLUME GROWTH

YEAR	1992	1993	1994	1995	1996	1997	1998
Turnover (Rm)	472.4	498.5	519.5	666.5	741.5	1 179.5	**
Volume (Tons)	163 500	177 800	195 500	205 100	208 000	245 000	295 000

(SAFRIPOL FINANCIAL STATEMENTS, 1992-1998)

** Data not as yet available for the year

Table 2.2 below highlights Safripol's important events over the past years.

TABLE 2.2: SAFRIPOL'S IMPORTANT EVENTS PROFILE

YEAR	IMPORTANT EVENT
1982/3	Installation of three 80m³ polyethylene reactors and line 6 in granulation plant
1986/7	Expansion of polypropylene capacity to 48 000t per annum
1988/9	Expansion of polyethylene capacity from 80 000-120000t per annum
1989/90	Installation of propylene separation plant at Sapref in Durban to ensure propylene supply
1991/2	Expansion of polyethylene capacity from 128 000 to 140 000t per annum
1992/3	Expansion of polyethylene to 160 000t per annum
1994/5	Replacement of line 3 is in progress
1995/6	Building of a new state-of-the-art polypropylene plant
1996/7	Commissioning of the new polypropylene plant
1997/8	Conversion of old polypropylene to polyethylene process

(SAFRIPOL FINANCIAL STATEMENTS, 1982-1998)

2.3 COMPANY DESCRIPTION

Safripol is a joint venture and privately owned company formed between two leading chemical organisations - Sentrachem/Dow Chemicals of America and Hoechst AG of Germany. Sentrachem/Dow Chemical is a major shareholder with 50 + 1%. Safripol was established in 1972. Safripol manufactures and distributes HDPE and PP under the trademarks of Hostalen and Hostalen PP. These products serve as the raw materials for a variety of plastic products, and include plastic packets, plastic piping, kitchenware, plastic bottles, garden furniture, and motor vehicle bumpers. Plastomark, a division of Hoechst AG, was established for marketing and selling Safripol's products. It also carries out R and D functions. The products account for more than 30% of South Africa's total plastic raw material requirements. The company currently employs about 450 people. HDPE and PP are manufactured in two plants on site. Plastic powdered products are conveyed by means of air and nitrogen into storage silos, which are part of the granulation plant that converts powder into product granules through a process of extrusion.

2.4 STRATEGIC OBJECTIVES

2.4.1 MISSION

The Safripol mission statement reads as follows:

"Our mission is to produce a full range of HDPE, PP, compounds thereof and other selected polymerics within the Hoechst range of know-how to the mutual benefit of all stakeholders. "

2.4.2 VISION

The Safripol vision statement reads as follows:

"Our vision is to be a Total Quality company"

2.4.3 VALUES

Safripol values include:

- *Leadership:* We are dedicated to achieving our corporate vision.
- *People:* We respect the individual rights and dignity of all people. Our individual and collective actions and talents create our competitive advantage.
- *Teamwork:* We believe in a participative work environment in which we work together as a team.
- *Quality:* We challenge ourselves to improve continually.

The Safripol policy statement, employee development strategy and the imperatives are in Appendix B.

2.5 FACILITY LOCATION

Safripol is located in Sasolburg, one of the major centres of industrial activity in the country. It is very close to Sasol Chemical Industries, the source of origin of its primary raw materials (propylene and ethylene). Sasolburg is known as one of the three towns forming the Vaal Triangle. Krajewski (1987:294) lists the following factors, in descending order of importance, discussed in relation to Safripol, that were found to be the most important in location decisions for manufacturing plants:

- Favourable labour climate;
- Proximity to markets;
- Quality of life;
- Proximity to suppliers and resources; and
- Well-developed infrastructure.

2.5.1 FAVOURABLE LABOUR CLIMATE

According to Krajewski (1987:293), the educational and skill levels of the labour pool must match the company's needs. Safripol's labour requirements consist of highly skilled workers (engineers, chemists, accountants, managers, computer programmers), skilled workers (artisans, technicians, mechanics), semi-skilled workers (process operators, clerks) and unskilled workers (cleaners, gardeners). All the categories mentioned above, with the exception of highly skilled workers, are found in abundance in the Vaal Triangle. The Vaal Triangle Technikon offers technical diplomas in engineering and various other disciplines. Formal training for artisans and mechanics may be obtained from any of a number of technical schools in the region. The absence of a major university campus has resulted in the region producing relatively few highly skilled workers. Fortunately, the scarcity of job opportunities in other areas of the country has resulted in this labour pool being easily drawn into the region.

2.5.2 PROXIMITY TO MARKETS

A location close to customers is important because of the ever-increasing need to be customer responsive (Chase, 1995:374), and the high local outbound transportation costs, especially of commodity products (Krajewski, 1987:295), as is being produced by Safripol. These reasons favour Safripol's location in Sasolburg, since the majority of customers are located in the greater Johannesburg region, which is approximately ninety kilometres away from Sasolburg. The road system between Sasolburg and Johannesburg is well developed, with the result that road transportation is utilised to transport products to customers in Johannesburg.

2.5.3 QUALITY OF LIFE

According to Krajewski (1987:295), the quality of life in a region is considered important, especially for highly skilled workers. Attracting and keeping a good engineering staff is critical to a firm's success. A university in the region or an attractive life-style can make a difference. The Vaal Triangle offers a pleasant, peaceful, country lifestyle, low incidence of crime and violence, most facilities found in large cities, and close proximity to the largest metropolis in the country, namely, Johannesburg.

2.5.4 PROXIMITY TO SUPPLIERS AND RESOURCES

This still represents the primary reason for Safripol's location in Sasolburg. According to Krajewski (1987:295), the high cost of inbound transportation makes this a particularly dominant concern for industries relying on bulk or heavy raw material, such as Safripol. The two major raw materials, ethylene and propylene, are transported with the aid of pipelines and rail, respectively. The total ethylene supply is obtained from Polifin, which is also located in Sasolburg. Polifin also supplies Safripol with 8% of its propylene needs, with the other 20% being obtained from Sapref in Durban. This further justifies Safripol's location in Sasolburg.

2.5.5 WELL-DEVELOPED INFRASTRUCTURE

Adequate road, rail, air, and sea transportation are vital. Energy and telecommunication requirements must also be met. Road, rail, energy and telecommunication are essential to Safripol. These systems are well-developed in the Vaal Triangle region and of a sufficiently high standard.

2.6 PRODUCTION PROCESSES

Safripol uses a continuous chemical process, which is characterised by high levels of automation, high-volume output and facilities dedicated to a single product type. HDPE and PP powder are produced by polymerising ethylene and propylene, respectively, with hydrogen. Polymerisation is the process of building long chain molecules (polymers or plastics), from short chain molecules (monomers). Safripol currently operates three HDPE plants with a total capacity of 210 000 tons per annum, and one PP plant with a capacity of 85 000 tons per annum. The three HDPE plants were built using Hoechst technology. One plant operates in a continuous mode, while the other two operate in a batch mode. The continuous process plant produces eleven different grades of HDPE, while the batch process plants produce twelve grades. A new state-of-the-art PP plant, based on Himont technology, was commissioned early in 1997. The plant operates in a continuous mode and produces twelve different grades of polypropylene products. Polymer grades vary with respect to their densities and melt-flow indices (an indication of the ease of flow of a polymer). The different grades have different applications. On the plant, the grades are produced in a fixed sequence, according to their densities. In this way downtime between grade changes is kept to a minimum. The one variable in the process is the period for which a grade runs. This is dependent on market demand. Safripol and Plastomark personnel meet on a weekly basis to review the six-monthly production schedule, compare it with the latest demand forecast and make adjustments to the production schedule if necessary.

Ethylene feed in gaseous form for HDPE production, and propylene feed in liquid form for PP production, enter their respective polymerisation reactors together with specially prepared catalysts and hydrogen. The catalyst forms the nucleus around which a polymer particle is built. The reaction product is a polymer powder suspended in an organic solvent medium. The remainder of the process consists of several steps intended to separate the organic solvent from the polymer powder, and then dry the powder. The dry polymer powder is transferred to storage silos for provisional storage before entering the granulation plant.

Menipaz (1984:50) defines a 'process' as that which accepts inputs and transforms them into outputs of greater value to the organisation than the original inputs were. More formally, *a process is a collection of tasks connected by a flow of goods or services and information that transforms various inputs into useful outputs.* Menipaz goes on to state that the primary components of a process are inputs, output, tasks, flows, storage, and technology.

The inputs to the process include the following: raw materials (ethylene, propylene, catalysts, hydrogen, organic solvent, stabilisers, etc.), utilities (nitrogen, steam, electricity, plant/instrument air, fuel gas), maintenance, and general overheads (including skills, knowledge and expertise of workers). These inputs are utilised in the production process to produce outputs in the form of the final product, namely a variety of polymer grades. Also of importance is adding value to the inputs via the process. The extent to which this is achieved at Safripol is shown in Table 2.3 below.

TABLE 2.3: VALUE ADDED TO INPUTS

Product	Cost of input (R)	Cost of output (R)	Margin (R)
HDPE	3 125	5 400	2 275
PP	2 500	5 100	2 600
**Modifieds	3 550	7 700	4 150

** Modifieds refer to a new product developed recently that utilises the collective properties of both HDPE and PP by combining them.

Safripol clearly achieves considerable value addition to the inputs it utilises in its production process. Expressed as a percentage of the cost of total inputs, the value added in HDPE production is 72.8%, in PP production it is 104%, and in modified production it is 117%. This is expressed as contribution margin divided by the cost of process inputs.

2.6.1 TECHNOLOGY

The superior margin achieved in PP production over HDPE production brings us to another important component of processes, namely technology. Menipaz (1984:55) defines technology as the set of knowledge regarding processes, methods, techniques, and capital goods by which products are made or services rendered. Furthermore, he explains that with the introduction of new technology, it may be possible to change a process and achieve the same output with fewer inputs or to use the same inputs to achieve more output. The concept of achieving the same output with fewer inputs was central to the superior performance achieved in PP production. The old PP plant achieved lower margins than the current HDPE plant. Market forecasts in 1993 revealed that local and international demand for PP was going to rise very steeply and outstrip supply by 1997. In the face of fierce competition, Safripol aimed to capture a fair share of this growing market. However, it was clear from the outset that the old PP plant was not efficient and profitable enough to achieve this. Hence, it was decided to investigate the option of building a new plant. An extensive technology study was undertaken in which the various PP polymerisation technologies were evaluated. At the end of the study, the Himont technology was selected. A R300 million plant was built to replace the old one. The plant was commissioned early in 1997, and is already showing the benefits of investing in new technology.

2.6.2 TASKS

A task is defined as a small part of the whole process. Tasks can be either in parallel or in series. The Safripol production process consists of several tasks, both in series and parallel, which are listed in Table 2.4 below.

TABLE 2.4: SERIES AND PARALLEL PATHS

SERIES PATH	PARALLEL PATH
• The polymerisation reaction • Separation of polymer powder and organic solvent • The drying of the polymer powder • Temporary storage of the dry powder • Addition of stabilisers to the powder • Extrusion and granulation of the powder • Bagging of the polymer granules • Storage of final product	• Off-loading and storage of raw materials • Preparation of catalyst • Recovery of organic solvent for re-use in process • Loading of final product onto trucks for distribution

The two most critical tasks in the process and the tasks responsible for the greatest level of value addition, namely the polymerisation reaction, and extrusion and granulation of the powder, occur on the series path. This is particularly significant because if any of the other 'minor' tasks on the path is interrupted or disrupted, then the critical tasks will not be possible. Hence, it is imperative that all tasks on the series path receive adequate attention to ensure that polymer is produced.

2.6.3 FLOWS

There are two types of flows in each process; the flow of goods and the flow of information. The former is achieved in Safripol with the aid of equipment, namely pumps and compressors, and with the aid of high-pressure nitrogen. The process utilises an organic solvent to facilitate the transfer of powder (in slurry form). In this way pumps may be used instead of more expensive and normally troublesome compressors.

Compressors are, however, used to transfer dry powder and granules. The flow of chemicals that are toxic or highly corrosive to humans is brought about by exerting pressure on source equipment with high-pressure nitrogen. In this way contact with the chemical is avoided.

2.7 GRANULATION PLANT

The polymer powder that the polymerisation plants produces is not stable and hence not suitable for sale. It is the function of the granulation plant to convert it into a form that is stable and suitable for sale. The plant has nine lines, four dedicated to HDPE and five lines to PP. Each of the nine lines is configured to handle only specific grades of product. Stabilisers are added to the powder, which then passes through extruder machines that granulate the powder into pellets that are more stable, easy to handle and suitable for sale. The extruder machines form the heart of the process. They constitute the most highly specialised and expensive equipment in the plant. The plastic granules are then bagged, either in 50 kilogram or one ton bulk bags, according to customer specifications. Both types of bags are loaded onto pallets. The granulation plant is responsible for the mixing, extrusion and blending of granules. The last step in the granulation plant is the packaging of product into 25 kg bags and 1.25 or 1.5 ton bulk bags. The granulation plant flow diagram can be found in Appendix C.

2.8 STORAGE FACILITIES

Storage is a critical aspect of the Safripol process. Large storage capacity, in the form of storage tanks, is required to store a variety of raw materials. The cost of maintaining these tanks, and consequently the cost of storage of raw materials, is exorbitant. The design of the process also requires that intermediate storage be provided for. Storage tanks are used as buffers between specific tasks or unit operations in the process.

Lastly, final products are stored in two huge warehouses. The second of the two warehouses was built about three years ago at a cost of about R10 million. The cost of maintaining and administering these warehouses also amounts to millions of Rands annually, implying that the cost of storing final products is also extremely high. Warehousing receives the finished packaged product, and personnel perform visual inspections to check that the packaging is safe and done in a proper manner. Products with packaging that do not conform to requirements are sent back to the granulation plant for re-bagging. The product that is accepted is stored in two huge warehouses, ready for dispatch.

2.9 QUALITY MANAGEMENT

The Production Department determines the *grade* and *quality of design* of products. Polymer product grades may be either high or low depending on the specific application it is needed for. For instance, polymer required for the manufacture of motor vehicle bumpers will be of a substantially higher grade than that required for plastic bags. At the granulation plant, product grade is influenced by a combination of two factors: (1) the type of extrusion process employed and (2) the type of stabiliser utilised.

There are a total of nine production lines at the granulation plant. Each line is equipped with a specific type of extruder machine that has been designed to handle only specific grades of product. The type of stabiliser utilised also influences the grade of the polymer. The quality, and consequently the cost of stabiliser used, is directly proportional to the grade of polymer produced. The quality of design is related to the various physical properties that customers desire in the polymer. These physical properties have a direct bearing on the degree to which the polymers can be further processed into plastic products. Examples of physical properties of interest to customers are density, hardness and melt flow index (an indication of the ease of flow of a polymer). For instance, in the manufacture of plastic products from a moulding process (tupperware products, motor vehicle bumpers, toys, etc.), polymer of a high level of hardness and a low melt flow index is required. The polymerisation plants are responsible for determining the *quality of design* of polymer products. This is achieved by manipulating the operating conditions of the polymerisation reactors. For instance, if polymer of low density is required, then the polymerisation reaction of ethylene or propylene with hydrogen is brought to an abrupt end by introducing a deactivation agent, namely, pentane or butane into the reactor.

Quality assurance is the system of policies, procedures, and guidelines that establishes and maintains specific standards of product quality. The Quality Assurance Department performs functions that are in line with definition. Safripol has an SABS ISO 9002 Quality System rating. It is the responsibility of the Quality Assurance Department to maintain the quality system and ensure that its twenty elements (Chase, 1997:192) are being practised and upheld at Safripol.

2.10 SUMMARY

Within the Sentrachem group, Safripol has justifiably earned a reputation as being a star performer, a company with a clearly defined vision and excellent level of performance in operational issues. The company has succeeded in being highly profitable, year after year, with exceptionally high earnings. But this winning streak will not go on forever if the company is not pro-active in its operations. Hence, in order for the competitive advantage to be maintained, Safripol should look at improving its maintenance practices by adopting and using reliable programmes that will position the company as a world-class manufacturer.

CHAPTER 3

BACKGROUND AND LITERATURE

3.1 INTRODUCTION

Maintenance is more concerned with preserving the present condition of the asset. In this context, performance of the equipment can be extended or improved. Maintenance means making sure that a physical asset keeps doing what a user wants it to do. This chapter covers the concept of RCM including the analysis methodology. A comparison to other related maintenance programmes is also made.

3.2 RCM DEFINITION

The above definition of maintenance leads to the definition of RCM. It is viewed as a process used to determine what must be done to ensure that any physical asset continues to do whatever its users want it to do in the present operating context. The formal definition of Reliability-Centered Maintenance would be (Moubray, 1997:7):

Reliability-Centered Maintenance is a process used to determine the maintenance requirements of any physical asset in its operating context.

3.3 RCM BENEFITS

In adopting RCM as a maintenance tool it is important to quantify potential benefits in the light of costs. The RCM benefits are actually in costs. RCM helps drive down preventive and corrective maintenance costs. It also drives costs associated with outages and downtimes. RCM helps the company focus on maintenance activities or things that can take it off-line (Smith, 1993:28). The primary reasons for using RCM as part of maintenance programme philosophy are the following:

- *To improve reliability and availability:* This is the most compelling reason to use RCM as a tool for maintenance programme to improve system reliability and plant availability. This has a direct benefit for safety, plant efficiency and reduction of costs.

- *To improve resource allocation:* The RCM focuses on maintenance programme resources to achieve a cost-effective blend of predictive, preventive and corrective maintenance that will remain important system and plant functions (Rogers, 1992:25). Through this analysis the components that need maintenance resources are identified and the most cost-effective maintenance is utilised to address critical component failure modes.
- *To extend useful life of equipment:* The equipment must continue to do what it is designed for. It is vital to have effective maintenance programmes that can help extend equipment life.
- *To collect comprehensive maintenance databases:* RCM is a method that can be used to develop and document bases for maintenance programme elements. The analytical basis for assigning component criticality ranking and selecting maintenance tasks is provided in the typical documentation associated with RCM analysis (Nowlan, 1992:250). RCM, therefore, helps engineers and the operating crew gather and sort information so that they can understand the way components function in a given system, how and when they break, and how they can be maintained cost-effectively.

3.4 BASIS OF RCM CONCEPT

The concept of RCM is based on preventive tasks and default actions. A brief discussion of these principles follows:

3.4.1 PREVENTIVE TASKS

Preventive tasks are divided into the following (Nowlan, 1978:147):

- *Scheduled restoration tasks*: This is the replacement or overhauling of a component at or before its specific age limit regardless of its condition at the time. It is also referred to as scheduled rework task.

- *Scheduled discard tasks:* It is the direct opposite of scheduled restoration task. It involves discarding a component at or before a specified age limit regardless of its condition at the time.
- *Scheduled on-condition tasks*: Equipment is inspected for potential failure, and an action is taken either to prevent the functional failure or avoid the consequences of the functional failures.

3.4.2 DEFAULT ACTIONS

There are three default actions on which a decision can be based (Nowlan, 1978:210):

- *Scheduled failure-finding tasks*: This action is aimed at reducing the risk of multiple failure that occurs if the failure of a hidden function cannot be prevented. The check is normally scheduled at regular intervals.
- *No scheduled maintenance*: Here the equipment is left in service until a functional failure occurs. This is the case only if the failure does not pose a threat to safety and/or the environment.
- *Redesign*: If a suitable failure-finding task cannot be found for a multiple failure with resulting safety hazards or environmental consequences, redesign is the only option.

3.5 OTHER MAINTENANCE PROGRAMMES

The one popular maintenance programme is the Total Productive Maintenance (TPM). TPM combines the American practice of preventive maintenance with the Japanese concept of total quality control and total employee involvement. This yields an innovative system for equipment maintenance that optimises effectiveness, eliminates breakdowns, and promotes autonomous operator maintenance through day-to-day activities. TPM addresses the elimination of major loss areas. In essence, it tries to fulfil the following (Pradham, 1994: 41):

- *Total effectiveness* in equipment maintenance by predictive and preventive maintenance;
- *Total maintenance system* which includes maintenance plan for the life-span of the equipment, and maintenance-free equipment design; and
- *Total employee involvement* in the maintenance process - namely both senior management and the grass-roots workforce.

TPM therefore encourages autonomous maintenance by the operators to correct minor deviations in equipment. It also encourages multi-skilling between trades to reduce reaction time to a maintenance need on operating equipment. It is based on the following principles:

- Establishing the system to improve production efficiency;
- Establishing initial production and flow control system for new products and equipment;
- Establishing the "Hinsitsu-Hozen" system;
- Establishing the system to realise operational efficiency in administration department; and
- Establishing safety, hygiene and working environment protection system.

RCM is basically a systematic approach to maintaining the inherent reliability of any engineering system. The guiding principle is that no preventive maintenance task will be performed *unless it is for safety, availability/reliability and cost-effectiveness in preventing a failure*. RCM focuses mainly on design function, functional failures and their effects and then develops a decision logic tree for each failure mode. The answers to the questions on the logic tree determine the maintenance tasks to be performed.

3.6 RCM METHODOLOGY

The RCM methodology entails asking seven questions about each selected asset, namely (Moubray, 1993:37):

- What are the functions and associated performance standards of the asset in its present operating context?
- In what ways does it fail to fulfil its functions?
- What causes each functional failure?
- What happens when each failure occurs?
- In what way does each failure matter?
- What can be done to prevent each failure?
- What if a suitable preventive task cannot be found?

The entire methodology involves the following aspects:

- Initial data collection;
- Defining system boundary;
- Functions and failures; and
- Failure consequences.

3.6.1 INITIAL DATA COLLECTION

The collection of data about the asset forms the basis of the analysis without which no button can be made to panic. It is of utmost importance that data be reliable. Information about the equipment can be sourced from the manufacturer/vendor of the equipment, technical history records, users of the equipment and other users of the same equipment.

3.6.2 DEFINING SYSTEM BOUNDARY

This requires a clear definition of where a system ends and begins. This can be simplified by drawing up a comprehensive asset hierarchy and deciding on a particular asset to analyse. In awkward cases where assets share control loops, care must be taken that one system includes the whole control loop. The definition of the boundary eliminates confusion during RCM analysis as to which elements must be or not be included.

3.6.3 FUNCTIONS AND FAILURES

The analysis is based on identifying the relevant functions and failure modes of the equipment. The description of the elements involved is given below.

Functions:

There are several functions associated with all equipment, which can be divided into four categories: primary functions, secondary functions, protective devices and superfluous functions (Moubray, 1993:39).

- The *primary function* is the reason for which the equipment was designed and this information is obtained from the vendor or the user. The primary function is usually given by the name of the item. There are other functions that are often less evident than the primary function, called *secondary functions.* These functions can still have serious consequences - in fact, even more serious than the failure of a primary function. These therefore need to be identified just like primary functions.
- *Protective devices* (automatic) are designed with complex system to try to reduce consequences of failure. This is due to the fact that, as the equipment becomes mcre complex, the number of ways in which it can fail grows almost exponentially (Moubray, 1997:41).

Functional failures:

The loss of a function of an asset is called functional failure. Functional failure may not result in complete breakdown of equipment. This may mean not meeting a desired standard of performance. This suggests that there are several functional failures, namely total and partial failures. Total failure will mean an asset stops working altogether, whilst a partial failure hints at the failure of equipment to meet specified performance standards.

Failures Modes:

A failure mode is any event that causes equipment, a system or a process to fail. Moubray (1997:52) distinguishes between a 'functional failure' (i.e. a failed state) and a 'failure mode' (i.e. an event which could cause failed state). He then defines a failure mode as "any event which causes a functional failure".

Systems or equipment generally fail for a number of reasons, and these must be identified because maintenance is managed at the failure mode level.

Failure effects:

It is necessary to know what happens when a failure mode occurs. In describing effects of failure the following questions are asked:

- What evidence (if any) is there that the failure has occurred?
- In what ways (if any) does it pose a threat to safety or the environment?
- In what ways (if any) does it affect production or operations?
- What physical damage (if any) is caused by the failure?
- What must be done to repair the failure?

3.6.4 FAILURE CONSEQUENCES

The extent to which a failure matters to an organisation depends on:

- The operating context of the equipment;
- The performance standards which apply to each function; and

- The physical effects of each failure mode.

Every failure yields a specific set of effects associated with it. This section therefore answers the question: 'In what way does each failure matter?' Failure consequences are broken down into five categories (Moubray 1993:69):

- *Hidden failure consequences:* Any asset can fail in more than one way - in which case it may be more apparent that the failure has taken place, for example, lifting of a safety device on pressure equipment, low or high level alarm on a vessel, quality deterioration, increase or decrease of energy consumption. These types of failures that can be easily detected are categorised as *evident functions* and are defined as (Moubray, 1997:92):

An evident function is one whose failure will on its own eventually and inevitably become evident to the operating crew under normal circumstances.

The other category of failures includes those that occur and are not detectable until such time that other failures occur. For instance, if a stand-by pump fails in this state, it will not be evident until such time that a duty pump fails. These types of failures are classified as *hidden functions* and are defined as (Moubray, 1997:93):

A hidden function is one whose failure will not become evident to the operating crew under normal circumstances if it occurs on its own.

It is important that these failures be distinguished in the application of RCM methodology. This is due to the fact that hidden functions are associated more with protective devices which are not fail-safe.

The following section deals with evident failures which are classified, in order of importance, as:

- *Safety consequences:* Any failure that could injure or kill someone is said to have safety consequences;

- *Environmental consequences:* If a failure could result in a breach of environmental policy or responsible care standards, it then has environmental consequences;
- *Operational consequences:* Failures that affect production or operation output, quality, and service in addition to cost of repair are said to have operational consequences; and
- *Non-operational consequences:* These failures only affect the direct cost of repair and do not affect safety or production.

3.7 RCM DECISION-TREE DIAGRAM

The next task in the RCM analysis is the integration of the consequences and tasks. The RCM decision-tree diagram (Chapter 5) integrates all the decision processes into a single strategic framework. The use of the decision-tree diagram is detailed in Chapter 4.

The decision worksheet is used to record answers to the decision diagram. Here it is listed as:

- Routine maintenance to be done, the frequency and responsible person;
- Failures that warrant serious re-design; and
- Decisions deliberately taken to let failures occur.

The use of the decision worksheet is explained in Chapter 4.

3.8 MANAGEMENT AUDIT

This forms the basis of the RCM concept. The audit is done at the highest level to:

- Solicit top management commitment and resource support;
- Ensure integrity of the whole process; and
- Ensure that deviations are addressed as soon as possible.

3.9 SUMMARY

It is the responsibility of top management to ensure that a suitable maintenance programme for their manufacturing process meets the world-class requirement. It must at the same time be able to meet market demands. The skills of the workforce must in return match the new technology to be able to curb process discontinuities resulting from process breakdowns. The workforce must be flexible and be well-equipped to offer the company a competitive edge.

CHAPTER 4

INVESTIGATION AND DATA ANALYSIS

4.1 INTRODUCTION

This chapter covers data collection and analysis. The methodology used for data collection included structured interviews and leading discussions on the performance of the bagging machines. This involved the bagging machine supervisor, foreman and operators, as well as the instrument technician and a fitter. The following RCM guidelines formed the basis of the analysis:

- The RCM 2 decision-tree diagram (Chapter 5),
- The decision-tree worksheet (Table 4.1), and
- The RCM 2 information worksheet (Table 4.2).

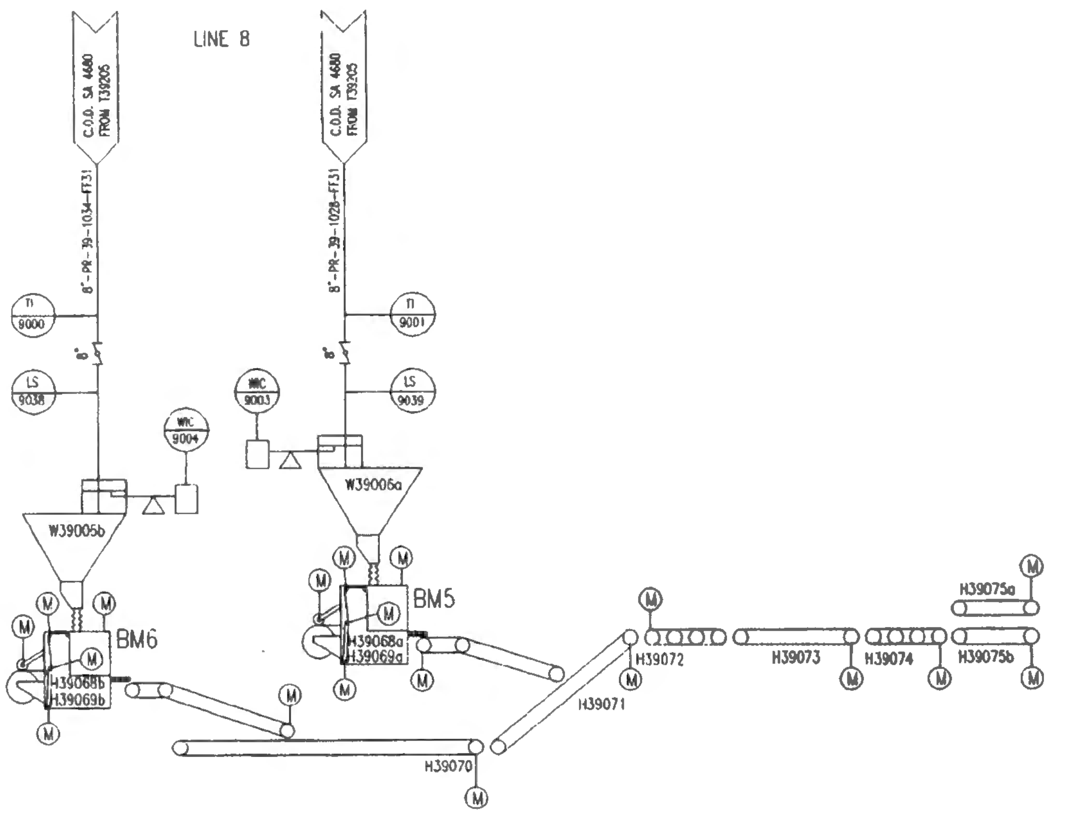
4.2 ASSET HIERARCHY

The asset hierarchy is vital for the RCM analysis. This is basically an asset audit to ensure that all equipment within a system is given the necessary attention. The compilation of the asset hierarchy facilitates the analysis process. The asset hierarchy for the bagging system is demonstrated in Appendix C.

4.3 SYSTEM BOUNDARY

After the compilation of the system's asset hierarchy, a system boundary is defined. The system boundary provides the area of focus in terms of equipment, valves and instruments. Any items not falling within the defined boundary do not form part of the analysis.

FIGURE 4.1: BMS 5 AND 6 BOUNDARY SYSTEM



4.4 SYSTEM DESCRIPTION

The full description of the bagging system is detailed below. The system flow diagram is shown in Appendix C.

4.4.1 BAGGING PROCESS

The bagging-off system fills and seals 25 kg plastic bags with high-density polypropylene (HDPE) at a cumulative rate of 25-32 tons per hour. The system consists of a granule feed hopper, two bagging scales, two automatic bagging machines (BM 5 and 6), and control panels for each of the machines. The plant operates 24 hours per day.

4.4.2 GRANULE FEED HOPPER

The granule feed hopper is situated above bagging machines 5 and 6 and supplies constant flow of granules to the bagging machines via the bagging scales. It has a capacity of 2 tons. If the flow is not constant, the scales will weigh incorrectly (high or low). A high-level and low-level switch controls the level of granules in the hopper. There is a "no product" switch on the outlet pipe from the feed hopper, which will switch off the scales if there is no product. A sight glass in the line allows for visual verification of product flow.

An air strainer gets rid of excess air in the system. It also prevents granules from escaping the feed hopper while the transfer of granules is in progress. A sample point equipped with a pneumatic flap valve on the line allows samples to be drawn. An isolation valve is fitted between the hopper and the weighing scales for maintenance purposes.

4.4.3 BAGGING SCALES

The scales (2) must measure accurately 25 kg (+/- 0.02 kg). When the weighing cycle starts, the pneumatically operated coarse-feed gate opens. This allows 85% of the target weight to enter into the bin, which is suspended from two load cells. The fine-feed gate opens, which allows granules to enter until 100% of the target weight is reached. When a "bag ready" signal is received from the bagging machines PLC, then a pneumatically operated piston opens the weigh bin discharge gates and the weighing cycle is repeated.

The scale has an "overweight" and "underweight" warning display (+/- 0.03 kg). The operator must acknowledge the warning before the scale can release granules to the bagging machine. After the operator has acknowledged the "under- or overweight" warning repeatedly, the weighing scale controller will automatically compensate for the amount of granules that was over- or under-measured.

4.4.4 BAGGING MACHINES

The roll of tubular film on each machine is manually fitted on a shaft with an electric hoist and placed into the bagging machine. The width of the film is 403 mm (+/- 3 mm), the width of the gusset is 77 mm (+/- 1 mm) and the thickness of the film is 150 microns (+/- 10 microns) measured as an average across 10 measurements of the film. The carton core diameter must not be greater than 75 mm. The film must be tightly wound (less than 5 mm of the side of the roll). The film must be embossed on both sides and "corona"-treated on the printed side to allow ink to adhere.

The film is now routed by hand through rollers into the machine into sealer 1. Unwinding is started manually, to straighten the film. Tension is applied to the film by the "ballerina" arm, actuated with a pneumatic piston. The film unwinds in "manual" mode until it is tensioned and straightened. The film is then cut and sealed.

When starting with a new roll the machine is put into "automatic" mode with "empty bag" selected. The machine unwinds the film to make a bag into a pre-set length depending on the time set on timer 2. When the unwound motor stops, the film is cut. Sealer 1 seals the next bag on the bottom with heated elements (timer 10 and 11 control the heater parameters). Pliers then take the empty bag to the hopper (gated feed tube along which product is fed into the bags). Suction cups then open the bag.

The pneumatically operated hopper spout opens in such a way that the spout pushes the bag opening clear. A limit switch then permits the shaker to start shaking. The hopper spout stays open for the pre-set time set on timer 7. The hopper spout closes and the "closed" limit switch permits the bag lifter to lift the bag, from where the carriage positions the bag to sealer 2. At the same time the carriage positions the next bag for filling. Sealer 2 is time-controlled by timer 13 and 14 on the control panel.

Timer 15 determines a cooling period for the seal. The machine then releases the bag. If the operator is satisfied that the bag seal is good (all the way through, not burnt through on the seal and not splitting apart in the gusset area) then he switches the machine to "full bags" operation.

In "full bags" operation the machine will fill the bag according to the same cycle as above. The operator then adjusts the machine for bag length to ensure proper filling of bags with timer 2. After filling, full bags are pushed by the bag pusher onto the idler rollers. After the third bag is pushed onto the idler rollers the front bag will drop onto the conveyor for transport to the palletiser.

4.4.5 CONTROL PANELS

The bagging machines have two control panels situated next to the machines. The individual control panel consists of the PLC, the scale controller and all the manual and automatic selector switches, timers and indications.

4.5 DATA GATHERING

The data gathering process and analysis are based on:

- *RCM2 decision-tree diagram:* The decision-tree diagram (Chapter 5) integrates all the decision processes into a single strategic framework.
- *Decision-tree worksheet:* The decision-tree worksheet (Table 4.1) is used to record answers to the decision-tree diagram. Routine maintenance to be done is listed, as well as the frequency and responsible person, failures that warrant serious re-design, and decisions deliberately taken to let failures occur.

TABLE 4.1: DECISION-TREE WORKSHEET

<table>
<tr><th colspan="3">Information reference</th><th colspan="4">Consequence evaluation</th><th>H1
S1
O1
N1</th><th>H2
S2
O1
N2</th><th>H3
S3
O3
N3</th><th colspan="3">Default action</th><th colspan="2">Proposed task</th><th>Initial interval</th><th>Can be done by</th></tr>
<tr><td>F</td><td>FF</td><td>FM</td><td>H</td><td>S</td><td>E</td><td>O</td><td></td><td></td><td></td><td>H4</td><td>H5</td><td>S4</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

(Moubray, 1997:200)

The meaning of the uppercase letters in Table 4.1 is explained below:

- H, S, E, O and N refer to answers to questions on effects of each failure mode;
- H1, H2, H3 etc. refer to the type of selected proactive tasks; and

- H4, H5 or S4 are used to record default actions.

In the "Proposed tasks" column, the interval at which it must be done and the responsible person are recorded. The required re-design of the system and cases where failure modes do not need schedule maintenance are also recorded in the "Proposed task" column. The recording of the proactive tasks is carried out in:

- H1/S1/O1/N1 column used for on-condition task to anticipate the failure in order to prevent the consequences;
- H2/S2/O2/N2 column used for suitable schedule restoration task to prevent failures; and
- H3/S3/O3/N2 column used for suitable schedule discard task to prevent failures.

For all these cases a task will be suitable if and only if it is worth doing and technically feasible.

- *RCM2 Information worksheet:* Here the functions, functional failures, failure modes and failure effects are identified and recorded in Table 4.2.

TABLE 4.2: The RCM 2 INFORMATION WORKSHEET

F - FUNCTION		FF - FUNCTIONAL FAILURE		FM - FAILURE MODE (Cause of failure)		P	FAILURE EFFECT (What happens when it fails)
	What are the functions and associated performance standards of the asset in its present operating context?		In what ways does it fail to fulfil its functions?		What causes each functional failure?		What happens when a failure mode occurs?

(Moubray, 1997:89)

4.6 DATA ANALYSIS

This section deals with the analysis of raw data as depicted in Appendix A.

4.6.1 FUNCTIONS

The study resulted in one primary function and 25 secondary functions. The primary function is:

To automatically fill and seal 25 kg plastic bags with high-density polyethylene (HDPE) at a rate of 25 to 32 tons per hour.

4.6.2 FUNCTIONAL FAILURES AND FAILURE MODES

The analysis resulted in 35 functional failures, which gave rise to 117 failure modes. The statistical analysis yielded 90.2% failure modes with operational effects, 1.8% with safety effects, and 8% with hidden effects (Table 4.3).

TABLE 4.3: FAILURE CONSEQUENCES TASK BREAKDOWN

FAILURE CONSEQUENCES								
TASKS	**Hidden**		**Safety**		**Environ-ment**		**Operational**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
On-condition	1	0.9	0	0.0	0	0.0	7	6.2
Scheduled restoration	0	0.0	0	0.0	0	0.0	2	1.8
Scheduled discard	0	0.0	0	0.0	0	0.0	0	0.0
Failure-finding tasks	6	5.3	0	0.0	0	0.0	0	0.0
No scheduled maintenance	0	0.0	1	0.9	0	0.0	59	52.2
Redesign/modifications	2	1.8	1	0.9	0	0.0	34	30.0
TOTAL	**9**	**8.0**	**2**	**1.8**	**0**	**0.0**	**102**	**90.2**

4.6.3 MODIFICATION/REDESIGN

The study resulted in 35 design-modification recommendations. 23% of these were ranked in descending order of importance by using pareto analysis. These are shown in Table 4.4 below. The rest is detailed in Chapter 5.

TABLE 4.4: HIGH-PRIORITY PROPOSED MODIFICATIONS

REF.	FAILURE MODE	PROPOSED DESIGN
16A1	• Limit switch left bridged out by maintenance.	• Display warning tag 'Door bridged' on local control panel.
26A1	• Emergency stop fails at each bagging machine.	• Install emergency stop to isolate machines separately from PLC control interlocks.
25A1	• Emergency stop fails.	• Install separate emergency stop to stop all electrical supply independently of PLC control and control interlocks.
1C6	• Trainee operator not competent to operate at full production rate.	• Trainee to work under supervision. A practical certification should be done.
1C9	• Artisans do not receive structured training on the machines.	• Develop and implement formal training to include operations training and competency review by skilled artisan.
1C7	• No relief personnel for operators.	• Re-assess manpower allocation and replenish where needed.
1C4	• Too thin film used (poor quality film).	• Update reject-film procedure. Substandard film to be labelled.
1B15	• Sealer 2 damping on pistons incorrectly adjusted due to compensation made when pneumatic air pressure fluctuated.	• Install air-control valve to control air pressure at 6 bar.

4.6.4 PROACTIVE TASKS

The study revealed 16 failure-finding tasks - listed in Table 4.5 below:

TABLE 4.5: PROACTIVE TASKS SUMMARY

REF. INDEX	PROPOSED TASK	RESPONSI-BILITY	INTERVAL
1A5 1B4 1B11 7B1 10A4	• Update grade change checklist. Clean vent (air strainer) from fines and granules. • On Pre-start checklist, check Teflon condition. If burnt, move Teflon roll till clean Teflon appears. • On Pre-start checklist, check clamp tension. If needed, adjust it. • Check weight of 10 bags on check scale, find average = 25 kg, if not call instrument to calibrate. • Open the filter and clean it.	Operator	Every grade change Every shift change Daily Twice daily Every shift change
1A7	• Remove relief valve and send it for calibration and testing at Sasol.	Fitter	Every 3 years
1B6 7B8 7B9 9B5 9B6 11A8 12A7 13A1 16A1 26A1	• On pre-start checklist, drain solenoids on the pistons for coolant in air. • During SABS scheduled calibration check, check mechanical components of scale. • Check that check scale measures 25 kg with a 25 kg test mass. • Visually inspect oil seals for grease leakage. If leaking, replace seals and re-grease gearbox. • Listen for noise from gearbox. If noisy, replace bearing. • Check gearbox oil seals for grease leakage. If leaking, replace seals and re-grease gearbox. • Check gearbox oil seals for grease leakage. If leaking, replace seals and re-grease gearbox. • Close air-supply line and test if pressure switch contact closes below 5.5 bar. If not, re-adjust pressure switch. • Open one of the doors to verify that bagging-off stops machine completely. • Test the emergency stop to test if one the switches failed.	Instrument technician	Daily 3 years Quarterly Every month Every 6 months Every month Every month Every 4 months Every 2 years Every 3 months

4.6.5 FAILURE CONSEQUENCES

Table 4.6 below presents detailed failure consequences tasks breakdown derived from Appendix A.

4. 6.5.1 HIDDEN AND SAFETY

Table 4.6 indicates nine failure modes identified to have hidden consequences, two of which have safety consequences.

TABLE 4.6: FAILURE MODES WITH HIDDEN AND SAFETY EFFECTS

REF	FAILURE MODES	PROPOSED DESIGN
1A7	• Relief valve on blower opens on high pressure due to switch failure and motor overload set high or fails.	• Remove relief valve, send it for calibration and testing at Sasol.
7B1	• Load cells not calibrated.	• Check weight of 10 bags on check scale, find average = 25 kg, if not call instrument to calibrate.
7B9	• Check scale not measuring mass accurately.	• Check that check scale measures 25 kg accurately with a 25 kg test mass.
8A1	• Scale controller alarm function disabled or failed.	• Adjust in-flight compensation controller.
13A1	• Adjustment on pressure switch set too low.	• Close air-supply line, test if pressure switch contact closes below 5.5 bar or adjust switch.
16A1	• Faulty limit switch or PLC.	• Display warning tag 'Door bridged' on local control panel.
23A1	• Interlock system fails.	• No scheduled maintenance.
25A1	• Emergency stop fails.	• Install separate emergency stop to stop all electrical supply independently of PLC control and control interlocks. The stop switch to sound audible alarm.
26A1	• Emergency stop fails at each bagging machine.	• Display warning tag 'Door bridged' on local control panel.

Table 4.6 identifies three failure modes with serious potential safety consequences. The reference indices being 16B1, 25A1 and 26A1. This refers to the bridging of limit switches of the bagging machines' safety barriers.

4.6.5.2 OPERATIONAL CONSEQUENCES

The analysis yielded three failure modes with serious potential operational or production consequences. They are presented in Table 4.7 below.

TABLE 4.7: FAILURE MODES WITH OPERATIONAL CONSEQUENCES

OPERATIONAL CONSEQUENCES		
REF.	FAILURE MODES	FAILURE EFFECTS
1A3	'No product' switch fails to detect product when there is product present .	To indicate to the scale controller that there is no product indication. Will not weigh at all. It takes 8 hrs to replace level switch with scaffold needed. Level switch contact can be manually overridden to prevent plant stoppage.
1C7	No relief personnel for operators.	Bagging-off - machine is stopped while operator is away for natural breaks. The forklift driver checks the machine and will stop it if any deviation occurs.
3B2	Communication card between the SCADA and PLC faulty.	A downtime of > 8 hrs occurred before R500 000 production loss can increase to > R1 when the upstream plant is factored in. Selection made before communication is lost will be retained. Production will continue with the present run, but no adjustments will be made. Total control system failure and may need reboot. If there is serious damage, it may take some time to find fault. A backup communication system is present. It can be stripped for spares.

4.6.5.3. ENVIRONMENTAL AND NON-OPERATIONAL CONSEQUENCES

Table 4.3 above shows that there were no failure modes identified with potentially serious environmental and non-operational consequences.

4.6.6 TRAINING AND SUPERVISION

Training need is identified by reference indices 1C6 for operators and 1C9 for instrument technician (Table 4.5). This expresses a need for updated training modules and that operators should be trained prior to assuming responsibility. The need for constant supervision, index 1C7 (Table 4.5), to ensure that operating procedures are followed. The newly appointed instrument technician should undergo system formal training coupled with problem solving techniques.

4.6.7 OPERATING PROCEDURES

The study highlighted a lack of or no up-dated checklists for each system, maintenance and operating procedures (Appendix A). These must be properly documented and be accessible to the operating crew.

4.6.8 MANPOWER

The forklift drivers are used as relief for the operation of the bagging machines, index 1C7 (Table 4.5). If the operator takes a break, a competent person should take over.

4.7 SUMMARY

The study indicates that RCM can be a powerful tool in uncovering system defects, and can prove to be an indispensable tool to a company with a highly automated system. The tool also accentuates areas where modifications, operators, technicians and management inefficiencies are. The failure consequences, which can be fatal in the short or long run, are clearly put into perspective. Through this approach, proposed tasks and modifications to the system can be made. On the long term, the developed maintenance programme can yield dividends to the business.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter will draw conclusions and make recommendations based on the results of the study. The extent to which the primary and secondary objectives were achieved through the application of the RCM approach, will be highlighted. It is against this background that recommendations pertaining to the study will be made.

5.2 CONCLUSIONS

RCM has been called the "organised common sense", and this statement has been confirmed by this study. RCM approach has enabled a systematic analysis of the bagging system. This has resulted in the development of a framework to improve reliability and availability on the bagging machines. From the results of the study, the following conclusions are drawn:

- That the primary objective of developing a framework to improve reliability and availability on the bagging machines was achieved. The system's functions, failure modes and their related failure effects were identified. It was also possible to clarify proposed tasks at specified intervals and the responsible persons. The critical areas that warranted modifications were also compiled.
- The statistical analysis of raw data gave rise to 90.2%, 8% and 1.8% failure modes with operational, hidden and safety consequences respectively.
- The study highlighted a need for cross-functional training. It further indicated a need for supervision of employees on training.
- It was shown in this study that manpower shortage is one of the critical elements. There is a tendency to utilise forklift drivers as relief.
- The operating and maintenance procedures are either lacking or not up-dated.

5.3 RECOMMENDATIONS

Based on the findings and the results of the study, the following recommendations are made:

5.3.1 INFORMATION AND DECISION-TREE WORKSHEETS

It is recommended that the worksheets presented in Tables 5.1 and 5.2 and the RCMII decision diagram (Appendix C) be used as framework on which to analyse other systems (Moubray, 1997:89).

TABLE 5.1: RCM INFORMATION WORKSHEET

F - FUNCTION	FF - FUNCTIONAL FAILURE	FM - FAILURE MODE (Cause of failure)	F	FAILURE EFFECT (What happens when it fails)
What are the functions and associated performance standards of the asset in its present operating context?	In what ways does it fail to fulfil its functions?	What causes each functional failure?		What happens when a failure mode occurs?

TABLE 5.2: DECISION-TREE WORKSHEET

Information reference			Consequence evaluation				H1 S1 O1 N1	H2 S2 O1 N2	H3 S3 O3 N3	Default action			Proposed task		Initial interval	Can be done by
F	FF	FM	H	S	E	O				H4	H5	S4				

5.3.2 FAILURE MODES WITH HIDDEN AND SAFETY CONSEQUENCES

It is recommended that the proposed modifications on the failure modes with hidden and safety effects be implemented as a matter of urgency (Table 5.3).

TABLE 5.3: FAILURE MODES WITH HIDDEN AND SAFETY EFFECTS

REF	FAILURE MODES	PROPOSED DESIGN
1A7	• Relief valve on blower opens on high pressure due to switch failure and motor overload set high or fails.	• Remove relief valve and send it for calibration and testing at Sasol.
7B1	• Load cells not calibrated.	• Check weight of 10 bags on check scale, find average = 25 kg - if not, call instrument to calibrate.
7B9	• Check scale not measuring mass accurately.	• Check that check scale measures 25 kg accurately with a 25 kg test mass.
8A1	• Scale controller alarm function disabled or failed.	• Adjust in-flight compensation controller.
13A1	• Adjustment on pressure switch set too low.	• Close air-supply line, test if pressure switch contact closes below 5.5 bar or adjust switch.
16A1	• Faulty limit switch on PLC.	• Display warning tag 'Door bridged' on local control panel.
23A1	• Interlock system fails.	• No scheduled maintenance.
25A1	• Emergency stop fails.	• Install separate emergency stop to stop all electrical supply independently of PLC control and control interlocks. The stop switch to sound audible alarm.
26A1	• Emergency stop fails on each bagging machine.	• Display warning tag 'Door bridged' on local control panel.

5.3.3 PROPOSED PROACTIVE TASKS

It is recommended that the listed proactive tasks (Table 5.4) be formalised and carried out on a routine basis.

TABLE 5.4 PROPOSED PROACTIVE TASKS

REF. INDEX	PROPOSED TASK	RESPONSI-BILITY	INTERVAL
1A5	• Upgrade grade change checklist. Clean vent (air strainer) from fines and granules.	Operator	Every grade change
1B4	• On pre-start checklist, check Teflon condition. If burnt, move Teflon roll till clean Teflon appears.		Every shift change
1B11	• On Pre-start checklist, check clamp tension. If needed, adjust it.		Daily
7B1	• Check weight of 10 bags on check scale, find average = 25 kg, if not, call instrument to calibrate.		Twice daily
10A4	• Open the filter and clean it.		Every shift change
1A7	• Remove relief valve and send it for calibration and testing at Sasol.	Fitter	Every 3 years
1B6	• On pre-start checklist, drain solenoids on the pistons for coolant in air.	Instrument technician	Daily
7B8	• During SABS scheduled calibration check, check mechanical components of scale.		3 years
7B9	• Check that check scale measures 25 kg with a 25 kg test mass.		Quarterly
9B5	• Visually inspect oil seals for grease leakage. If leaking, replace seals and re-grease gearbox.		Every month
9B6	• Listen for noise from gearbox. If noisy, replace bearing.		Every 6 months
11A8	• Check gearbox oil seals for grease leakage. If leaking, replace seals and re-grease gearbox.		Every month
12A7	• Check gearbox oil seals for grease leakage. If leaking, replace seals and re-grease gearbox.		Every month
13A1	• Close air-supply line and test if pressure switch contact closes below 5.5 bar. If not, re-adjust pressure switch.		Every 4 months
16A1	• Open one of the doors to verify that bagging-off machine stops completely.		Every 2 years
26A1	• Test the emergency stop to test if one the switches failed.		Every 3 months

5.3.4 PROPOSED MODIFICATION/REDESIGN

It is recommended that the proposed modifications/redesign in Tables 5.5 and 5.6 be implemented as soon as possible.

TABLE 5.5: *HIGH-PRIORITY PROPOSED MODIFICATIONS*

REF.	FAILURE MODE	PROPOSED DESIGN
16A1	• Limit switch left bridged out by maintenance.	• Display warning tag 'Door bridged' on local control panel.
26A1	• Emergency stop fails on each bagging machine.	• Install emergency stop to isolate machines separately from PLC control interlocks.
25A1	• Emergency stop fails	• Install separate emergency stop to stop all electrical supply independently of PLC control and control interlocks. The stop switch to sound audible alarm
1C6	• Trainee operator not competent to operate at full production rate.	• Trainee to work under supervision. Foreman should do a practical certification.
1C9	• Artisans do not receive structured training on the machines.	• Develop and implement formal training to include operations training and competency review by skilled artisan.
1C7	• No relief personnel for operators.	• Re-assess manpower allocation and replenish where needed.
1C4	• Too thin film used (poor quality film).	• Update reject film procedure. Substandard film to be labelled.
1B15	• Sealer 2 damping on pistons incorrectly adjusted due to compensation made when pneumatic air pressure fluctuated.	• Install air-control valve to control air pressure at 6 bar.

TABLE 5.6: PROPOSED MODIFICATIONS

PROPOSED MODIFICATION SYSTEM LIST		
BAGGING-OFF SYSTEM		
1A1	High-level switch on the hopper stays on (indicating "product present" while in fact there is no product).	Consider the installation of a second HL switch on feed hopper.
1A2	Low level switch on the hopper stays on (indicating "product present" while in fact there is no product).	Consider the installation of a second LL switch on feed hopper.
1A4	Hand-valve above scale left in closed position by maintenance or operations.	Update "Pre-start Checklist". Check hand valve open.
1A6	Feed hopper outlet blocked with fines.	Investigate the source of fines in the palletising (cutting) chamber.
1B3	Sealers do not seal due to incorrect specification of film (width tolerance exceeded).	Initiate a procedure that if the operator finds a problem with the film, he cuts a sample from the roll at that point and sends it to the laboratory for analysis. These results must be discussed with the manufacturer of the film rolls.
1B6	Solenoids on the pistons fail due to poor quality pneumatic air (presence of coolant in oil).	Investigate installation of filter on pneumatic air-supply from compressors to remove oil, coolant and water.
1B8	Broken rod-end bearings (link) on any piston.	Investigate the redesign of the rod ends to be more robust.
1B9	Loose blade or loose blade holder preventing the piston from full motion due to vibration.	Install spring washers with nuts when blades come loose.
1B14	Bag flow-up does not blow up bag due to restrictor valve adjusted incorrectly.	Operator to be provided with the correct tools to adjust the restrictor valve.
1B18	"O"-rings on the clamps worn.	Operators to replace "O"-rings.
1C3	Hopper outlet valve throttled by instrument technician (for coarse or fine-feed) or operator (for different grades).	Investigate using the scale's pre-set values to adjust the time settings to compensate for different product grades instead of using the throttle valve.

TABLE 5.6 continued

1C8	Short production runs (especially development and peroxide-loaded grades).	*Production planning:* After a short production run of a problem grade, the grade that follows should be scheduled for bulk bagging. This will allow time to finish bagging without delaying production. *Operations*: Trials on the revised gusset dimensions must be completed.
2A1	Manhole cover left open by operations or maintenance.	*Operations*: Verify that a check to see if the manhole cover is in place is present on the "Grade change checklist" and on the "Pre-start checklist". *Modification*: Investigate installation of an interlock with the manhole cover on the stop/start of the pneumatic transport system.
3B2	Communication card between the SCADA and the PLC faulty.	Back-up communications system between SCADA and PLC must be repaired.
7B7	Scale controller fails to compensate for different grade sizes.	See 1C3.
9A1	Unwind motor switched off on panel.	Investigate the introduction of an annual currency check for all operators.
9C1	Limit switch on the ballerina arm fails.	Investigate the installation of second limit switch on the ballerina arm.
10A1	Film not treated against static build up.	Revision to "Reject roll procedure": Rolls arrive at Safripol, where Purchasing accepts it into store. The laboratory does analysis and results are sent to granulation manager. Granulation manager may, at his discretion, accept film rolls that are not 100 % according to specification. These excursions also to be recorded and discussed at the 10 minutes Indaba file.

TABLE 5.6 continued

10A9	Cutting blades get too hot when the sealer temperature is set too high.	Investigate the installation of a current limiting circuit on the preheat circuit (control current to < 14 amps).
10A12	Film alignment not correct or embossed strip on bag not located as per film specification.	*Roll reject procedure*: Verify embossing film specifications on packaging specifications (procedure PS15/2).
11A1	Mechanical settings not adjusted to reach the bags.	Revision to grade change procedure (Critical grades): When the bag length is changed (lengthened or shortened), the shaker table height must be adjusted concurrently.
12A1	Incorrect table settings.	Revision "Bagging machine pre-start checklist": The standard operating procedures on this document must be communicated to all. It must be laminated and placed on the machine.
12A2	Carriage motor tripped due to loose fingers that obstruct motion.	Fingers that can be welded into place must be welded into place.
12A4	Bag lifter table not lifted due to solenoid or piston failure.	Investigate a project to replace all current "Joucomatic" solenoids with much cheaper and more reliable "Festo" solenoids.
12A5	Carriage motor does not start due to top brake assembly not releasing.	Original DC brakes to be replaced with much more reliable AC brakes on the carriage motor.
16B1	Limit switch left bridged out by maintenance.	When a bridge is installed, a warning tag "Door bridged" must be placed on the local bagging control panel.
17A1	Faulty sealer cards.	When installing sealer cards, verify that settings are correctly adjusted.

It is further recommended in conclusion that the long-term viability of the developed framework be evaluated. The cross-training of production and engineering crew must also be formalised. Operating and maintenance procedures will have to be updated and the utilisation of drivers as relief must be terminated immediately.

5.4 AVENUES FOR FURTHER RESEARCH

A strategic anticipatory approach to maintenance is the key to attain world-class manufacturing status. Safripol can utilised RCM tool in order to remain competitive and to achieve continuous improvements. The following are recommended for further studies:

- The long-term viability of the programme must be evaluated. The evaluation must focus on the cost benefits that can be derived from the programme against the costs of implementation that can be incurred. The developed framework must not be seen as recipe for success but as a guideline to analysing systems.
- The process of identifying critical equipment for further studies must be initiated. These equipment must be ranked and prioritise for further analysis.
- The improvement of maintenance philosophy, methods and technology, striving for excellence must be an established culture within Safripol. This requires a shift in mindset of management and employees. Therefore, RCM philosophy must be incorporated into vision, mission statements and objectives of Safripol

BIBLIOGRAPHY

- CHASE, R.B. & AQUILANO, N.J. 1995. Production and operations management - Manufacturing and services. 7th Edition. New York: Irwin.

- KIRBY, P., 1993. Flexibility and quality are the keys. *Journal of Engineering News Clues*, circle 205:85, August 13

- KUEHN, S.E., 1992. Reliability-centred Maintenance trims plant costs. Power Engineering, 96(8):23-28, August.

- KUEHN, S.E., 1992. Reliability-centred Maintenance trims plant costs. Power Engineering, 96(11):30-31, November.

- KRAJEWSKI, L.J. and Ritzman, L.P. 1987. Operations management - Strategy and analysis. London: Addison-Wesley.

- MENIPEZ, E. 1984. Essentials of production and operations management. London: Prentice-Hall.

- MONKS, J.G. 1987. Operations management, 3rd Edition. London: McGraw-Hill.

- MOUBRAY, J.M. 1993. Reliability-centered maintenance. London: Clays Ltd.

- MOUBRAY, J.M. 1997. Reliability-centered maintenance. London: Clays Ltd.

- NOWLAN, F.S. & HOWARD, F.H. 1978. Reliability-centered maintenance. San Francisco, California: United Airlines.

- PHILLIPS, L.B. 1992. Reliability-centered maintenance. Benefits identification and cost reduction.

- PRADHAM, S. 1993. Apply RCM to seamless pump management. *Hydrocarbon Processing*, Jan., Houston

- SAFRIPOL Limited, 1995. The market pioneer, 46p.

- SAFRIPOL Limited, 1998 (Jan-June). Production reports

- SANDTORV, H., 1991. RCM-Closing the loop between design reliability and operational reliability. Maintenance, 6(1):13-21, January.

- SMITH, A.M., 1992. Preventive maintenance impact on plant availability. Proceedings of the 1992 Annual Reliability and Maintainability Symposium, NJ. 177-180p.

GLOSSARY OF TERMS

- **Maintenance:** Ensuring that physical assets continue to fulfil their intended functions.
- **Reliability-Centered Maintenance (RCM):** A process used to determine the requirements of any physical asset in its operating context.
- **Functional failure:** The inability of an asset to meet a desired standard of performance.
- **Failure mode:** A cause of loss of asset function.
- **Failure effects:** The consequence of loss of asset function.
- **Potential failure:** Identifiable physical conditions that indicate that a functional failure is about to occur or is in the process of occurring.
- **Hidden function:** A function whose failure will not be evident to an operator under normal conditions if it occurs on its own.
- **Availability:** A measure of the amount of time the equipment is capable of operating at all time.
- **PM:** Planned Maintenance.
- **TPM:** Total Planned Maintenance.

APPENDIX A

FUNCTIONS

FUNCTIONAL FAILURES

FAILURE MODES

AND

FAILURE EFFECTS

System:	**PP 25 kg Packaging**	**Compiled by:** S Hadebe	**Date: June 1998**	
Sub system:	**Bagging off system**	**Reviewed by:** S Hadebe	**Date: July 1998**	

	Function		**Functional failure**		**Failure mode (cause of failure)**	**Failure effect (what happens when it fails)**
1.	To automatically fill and seal 25 kg plastic bags with PP and Developing Products (DP grades) at a cumulative rate of 25 to 32 tons per hour.	A	Unable to fill bags at all.	1.	Higher level switch on the hopper stays on (indicating "product present" while in fact there is no product).	Indicates to the PLC that the hopper is full of product, which prevents further loading of product into the hopper. Indicates full on the SCADA in the control room. No bags can be filled until the high level switch is repaired (15 minutes to clean, 2 hours to replace).
				2.	Low level switch on the hopper stays on (indicating "product present" while in fact there is no product).	Indicates to the PLC that there is still product in the hopper, thus preventing further loading of product into the hopper. After a system reset, the system will start until product is detected, where after this low level is latched. No production until the low level is repaired (15 minutes to clean, 2 hours to replace).
				3.	"No product" switch fails to detect product when there is product present.	Indicates to the scale controller that there is no product, which will light up a "no product" indication. Will not weigh product at all. To replace the level switch takes up to 8 hours as it requires a scaffold to be built to reach it. However, the level switch contact can be manually overridden, which is done to prevent shutting down the producing plant. Any shutdown longer than 6 hours could loose Safripol > R500 000.
				4.	Hand valve above scale left in closed position by maintenance or operations.	No product will flow. To trace the problem can take about 30 minutes. Operator must open the valve. Can result in a backlog that will take about 5 hours to catch up.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
				5.	Vent (air strainer) on top of feed hopper blocked.	Unable to reach high level on feed hopper. Pneumatic transport system will slow down, eventually tripping on high pressure, indicating on SCADA in control room. To fault find this can take an hour or more as the operator may call the fitter, the instrumentation and the electrician before the fault is traced as the first assumption is that the line is probably blocked.
				6.	Feed hopper outlet blocked with fines.	Low level in the hopper will indicate that there is product. "No product" will indicate that no product is present. Can see if granules are moving through the sight glass.
				7.	Relief valve on the blower opens on high pressure due to the pressure switch failed and that the motor overload set too high (or fails).	If pressure switch does not close the slide valve on the blender at 0.6 bar then the relief valve will open at 0.7 bar, which will slow and eventually stop the filling rate. The relief valve cannot be heard as it is in a loud environment. Eventually the blower motor will trip on overload, which is indicated on the SCADA, by an audible alarm. Pipes will probably be blocked with product, which can be cleared by operations, and the electrician must reset the blower motor. Will take about 4 hours. See pneumatic transport system analysis.
		B	Unable to seal bags at all.	1.	Bottom sealer (sealer 1) does not seal due to temperature set too low.	Operator will notice that bags are not sealing on the same roll of film. Preheating set at too low current (must be less than 14 amps). Sealing must peak at 20 amps. Temperature must be readjusted by a skilled operator, which takes about 5 minutes to verify.

FUNCTION		**FUNCTIONAL FAILURE**		**FAILURE MODE (cause of failure)**		**FAILURE EFFECT (what happens when it fails)**
				2.	Bottom sealer (sealer 1) does not seal due to sealer timer set too low (timer 10 & 11).	Operator will notice that bags are not sealing on the same roll of film. Preheating and sealing current set at maximum, timer set too slow. Timer must be readjusted by a skilled operator, which takes about 5 minutes to verify.
				3.	Sealers do not seal due to incorrect specification of film (width tolerance exceeded).	Operator will notice that bags are not sealing on the same roll of film. Preheating and sealing current set at maximum, timer set to longer time. Film is supposed to be checked by laboratory prior to release to production. Operator will need to perform quality control test.
				4.	Sealers do not seal due to Teflon sheath worn.	Operator will notice that bags are not sealing on the same roll of film. Seal burns through. Operator pulls Teflon sheath across the sealer, which takes about 5 minutes. If the Teflon is ruptured then the instrument technician must refit Teflon (takes about 2 hours).
				5.	Sealers do not seal due to dirty sealers from burnt product on the heating elements.	Operator will notice that bags are not sealing on the same roll of film. Can see melted plastic along the seal. Operator must clean the Teflon (about 5 minutes). If the Teflon is damaged then it must be replaced (another 5 minutes). If the Teflon is finished, then a new roll of Teflon is fitted by the instrumentation technician.
				6.	Solenoids on the pistons fails due to poor quality pneumatic air (presence of coolant in oil).	Operator will notice that bags are not sealing. Alarm “sealer 1” or “sealer 2” will indicate on the PLC remote panel. Operator can manually override the solenoid to check piston operation.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
						The solenoid light comes on but solenoid does not switch. Solenoid must be replaced (about 1 hour if the spare is in main store).
				7.	Faulty limit switch on the piston (broken magnet in the piston).	Operator will notice that bags are not sealing. Alarm “pliers open” or “alarm pliers closed” will indicate on the PLC remote panel. No indication light on the limit switch. After adjusting the limit switch and this does not restore the function, then the magnet must be replaced (takes about 2 hours). After hours a considerable amount of time is spent waiting for the storeman.
				8.	Broken rod-end bearings (link) on any piston.	Operator will notice that bags are not sealing. The alarm that indicates will isolate piston affected. Operator can also see that the link is broken. Instrument fitter will repair the link (takes about an hour if the spare is in stock).
				9.	Loose blade or loose blade holder preventing the piston from full motion due to vibration.	Film will not be cut. Alarm “sealer 1” will indicate on the remote PLC. Blade must be fastened by instrument fitter (about 0.5 hours).
				10.	Top sealer (sealer 2) does not seal due to carriage not moving far enough forward.	Operator will notice that bags are not being sealed. For small errors in adjustment the limit switch will be made so no indications will be made at the PLC. Locknuts on the carriage arms will need to be adjusted.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
				11.	Clamps on sealer 1 not set to correct tension.	The bag will not seal on sealer 2. Can see that the logo on the bag has slipped a little. Or open the doors and tug on the bag. If it moves then the clamps must be tensioned.
				12.	Top sealer (sealer 2) does not seal due to timer 8 set too short.	If timer 8 is set too short then the clamps will not have time to clamp the bag before filling begins. Bags will spill. Instrument fitter or the operator must restore original time setting.
				13.	Bag blow-up does not blow up bag due to faulty solenoid.	Bags not sealed. Can switch the solenoid to manual to check if air is blowing through the ports. If not then the solenoid must be repaired (takes about 1 hour).
				14.	Bags blow up does not blow up bag due to restrictor valve adjusted incorrectly.	Bags not sealed. Can switch the solenoid to manual to check if air is blowing through the ports. If air does blow, then the restrictor can be adjusted to suit the requirements (takes 1 hours).
				15.	Sealer 2 damping on pistons incorrectly adjusted due to compensations made when pneumatic air pressure fluctuated.	Clamps close before the bag has time to get into position. Damper on the far right of the machine must be adjusted by the instrument fitter (takes about 0.5 hour to repair).
				16.	Either sealer 1 or sealer 2 alignment moves out due to normal operation.	Bad seal will result, sealing on the one side of the seal but not on the other. The instrument technician must then realign the sealer.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
				17.	Bags are cut too long or too short due to timer 2 set incorrectly.	If the bag is too short then product will not fit into the bag. The bag can slip from the pliers. If the bag is too long then the bag will seal skew, which will make stacking at the palletising difficult. Bag length must be adjusted with timer 2.
				18.	"O"-rings on the clamps worn.	Bags slips from the clamps during the shake down. Bags seal skew. Takes about 20 minutes to replace "O"-ring.
				19.	New roll of film installed out of alignment.	Corner of bag skew. Film snags on the gusset guides. Bags seal skew. The film roll must be realigned by the operator according to the marks on the spindle, which takes about 10 minutes.
		C	Unable to fill at greater 25 tons per hour.	1.	Machine times set too low by operator and instrumentation on the console.	The timer is set slow due to film quality and grade being bagged. The timer settings are checked on the panel according to the standard settings on the check sheet at the panel. The rate of filling is measured with a stop watch. Timer must be set to original settings by the operator, which takes about 5 minutes. Will affect production rate upstream.
				2.	Fine and coarse weighing settings set incorrectly in scale controlled (ideal: 80 % coarse, 20 % fine).	Alarm "awaiting discharge" on every bag. Although the scare does compensate for varying grades, when the grade change is from coarse to fine then the scale does not compensate quickly enough, and the instrument fitter will need to compensate, which takes about 30 minutes to adjust.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
				3.	Hopper outlet valve throttled by instrument technician (for coarse or fine feed) or operator (for different grades).	The valve is adjusted to compensate for different grades. Alarm “awaiting discharge” on the PLC remote panel. Sequence “coarse”, “fine”, “ready” on the weighing controller will be slower than normal. To adjust the valve takes 2 minutes.
				4.	Too thin film used (poor quality film).	Cooling times must be set longer to compensate for the thin film. If this is not done then seals are burnt through and product leaks from bottom seal. Cooling time longer than 2 seconds. One second delay is a loss of production of 3 tons per hour on both machines). Takes about 5 minutes to adjust cooling time.
				5.	Too thick film used.	Sealing times must be set longer. If this is not done then seals are not made and product leaks from bottom seal. Cooling time longer than 2 seconds. One second delay is a loss of production of 3 tons per hour on both machines). Takes about 5 minutes to adjust sealing time.
				6.	Trainee operator on the machine not competent to operate machine at full production rate on his own.	Timers are not set correctly. Film loading done incorrectly. Typical symptoms are granules lying around, filling will be slow and operations are only on one filling machine.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
				7.	No relief personnel for operators.	Bagging-off machine is stopped while operator is away for tea and toilet breaks. To manage this situation, the forklift driver has been used in the past to observe the machine. If he notices any exceptions he stops the machine. Any time the operator moves from the machine the downtime is about 40 minutes on average to restore full operation.
				8.	Short production runs (especially development and peroxide loaded grades).	Different properties of the product cause set up delays. Especially the peroxide loaded granules result in bags not stacking well. To cope it is necessary to switch to one machine only to ensure good packing at palletiser. Film of correct dimensions is very critical for these short production runs.
				9.	Artisans do not receive structured training on the machines.	Repair times are much longer, which is a particular problem after hours. Contributing factors is that there is no formal training program on these machines.
				10.	Hand valve on either scale pipeline indicates open, but valve closed due to sheared spindle.	Sequence on the weighing controller will be much slower than normal. Alarm “awaiting discharge” and alarm “slow cycle” will indicate on the scale controller. Before the valve is replaced the feed hopper must be emptied out. Takes about 1 hour to replace if there is one in stores, or 2 hours to repair the valve.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
2.	To contain up to 2 tons of product.	A	Fails to contain product at all.	1.	Manhole cover left open by operations or maintenance.	Spillage of granules on the floor. There is no indication that the manhole cover is open in the control room. The blower must be stopped by the control room operator. The level in the feed hopper must be reduced by bagging product through the bagging machine. This takes about half and hour and results in up to 5 ton spillage of granules. The spillage can be sold as sweepings.
3.	To control and indicate the level between a low level of 400 kg and a high level of 2 000 kg.	A	Fails to control the level between 400 kg (low) and 2 000 kg (high).	1.	Low level fails closed (no indication at all).	Alarm "no product", alarm "awaiting discharge" on PLC remote panel. Although the SCADA indicates product, there is no product, which means that the low level has failed. Clean probe, adjust sensitivity of probe and, if this does not work, replace probe.
				2.	High level fails closed (no indication at all).	Feed hopper can overfill, which will force product to build up in the pneumatic transport system. The high pressure switch will trip the blower. "Blower tripped" and "high pressure" will indicate on the SCADA. System will come to a stop. Will take about two hours to repair with another two hours to clean up.
		B	Unable to indicate a high or low level on SCADA screen (red or green).	1.	Input fuses on PLC.	Affected level switch flashes red. Due to fail safe design, system will react as if the feed hopper is full and will close the slide valve and stop the rotary feeder.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
						No transfer of material will take place, eventually causing the "no product" alarm to indicate". Takes up to 30 minutes to replace the fuse.
				2.	Communication card between the SCADA and the PLC faulty.	This has happened before, with a downtime of 8 hours (production loss of >R500 000, which increases to >R1 million when the producing plant is factored in). Selections made before communication is lost will be retained. Production can continue with the present run, but no adjustments can be made. Total control system failure. Control system may just need to rebooted, but if there is any further damage then finding the fault can take quite some time. A back up communications system is present, although its computer is currently failed; it can therefore be stripped for spares. This takes about one hour and happens about once every 2 months.
				3.	PLC on blending plant SCADA faulty.	Affected level switch flashes red. On the high level switch, due to fail safe design, system will react as if the feed hopper is full and will close the slide valve and stop the rotary feeder. No transfer of material will take place, eventually causing the "no product" alarm to indicate. On the low level switch no indication will be made, which means that it will not start the transport system to reload the feed hopper.

FUNCTION		**FUNCTIONAL FAILURE**		**FAILURE MODE (cause of failure)**		**FAILURE EFFECT (what happens when it fails)**
4.	To signal a "high pressure" symbol, to sound an audible warning and to indicate on the SCADA "high pressure" if the pressure exceeds 0.65 bar.	A	Unable to signal a "high pressure" symbol, to sound an audible warning and to indicate on the SCADA "high pressure" if the pressure exceeds 0.65 bar.	1.	Pressure switch sensing line blocked.	The pressure switch has been very reliable in practice. No indication on the local Pressure Indicator, yet the relief valve is open at 0.7 bar. Shortly thereafter the blower will trip on overload.
		B	Signals a "high pressure" symbol, sounds an audible warning and indicates on the SCADA "high pressure" while the pressure below 0.65 bar.	1.	Pressure switch incorrectly calibrated.	Local pressure indicator indicates a pressure below 0.65 bar, but bagging-off system is standing. Takes about half an hour to re-calibrate the pressure switch and the pressure indicator.
5.	To close the blender slide valve, stop the rotary feeder, indicate "slide valve closed" and indicate "rotary feeder stopped" within 60 seconds when the pressure drops below 0.35 bar.	A	Unable to close the blender slide valve, stop the rotary feeder, indicate "slide valve closed" and indicate "rotary feeder stopped" within 60 seconds when the pressure drops below 0.35 bar.	1.	Pressure switch contacts burnt closed.	This will result in a blocked pneumatic transport line. In the workshop when the pressure switch is repaired and tested it will become clear that the switch switches but the contacts do not open. To repair the switch takes about 1.5 hours and to clear the pneumatic transport line takes about 2 hours.

	FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)	FAILURE EFFECT (what happens when it fails)
6.	To control the flow of product from the hopper to the bagging scales.	A	Unable to control the flow of product.	1.	Hand valve set incorrectly due to change of product grade.	The valve is adjusted to compensate for different grades. Alarm "awaiting discharge" on the PLC remote panel. Sequence "coarse", "fine", "ready" on the weighing controller will be slower than normal. To adjust the valve takes 2 minutes.
7.	To weigh product accurately at 25 kg (tolerance + or – 0.02 kg).	A	Does not weigh product at all.	1.	Both load cells or controller not reading at all on either scale.	No weight reading on the scale controller. Alarm "low cycle" will indicate on scale controller. Product will overflow from scale bin. Load cells and the controller must be checked; 1 hour to replace the controller and then 2 hours to replace the load cells.
		B	Does not weigh product accurately.	1.	Load cells not calibrated.	The scale controller will indicate 25 kg, but the check scale measure a different mass. Scale must be re-calibrated, which takes about 1 hour.
				2.	Pneumatic air supply too low due to air regulator failure on scale.	Weight is indicated on the scale controller. Overweight or underweight alarm will indicate on the scale controller. Pistons operate too slowly. Scale will measure off and underweight or an overweight load, depending on which piston is slow. No alarm to say that the air supply is not good. Remove and service air regulator.
				3.	Pneumatic air supply fluctuating (as much as from 4 to 7 bar).	Will see the pressure fluctuations on the local pressure indicator. Scale will measure off inaccurate loads. The control of the air compressors must be investigated and restored.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
				4.	Faulty solenoids on the coarse or fine feed.	Scale will measure off inaccurate loads. Underweight or overweight alarms indicates on the scale controller. Hand valve must be closed, all the product must be drained from the system. Switch the coarse and fine feed solenoids to manual and detect which one of the solenoids is faulty.
				5.	Faulty pistons on the coarse or fine feed.	Scale will measure off inaccurate loads. Underweight or overweight alarm indicates on the scale controller. Hand valve must be closed, all the product must be drained form the system. Switch the coarse and fine feed solenoids to manual and detect which one of the pistons is faulty.
				6.	Fine feed does not switch at all.	Under fills. Alarm "underfill" on the scale controller will light on panel. Can be due to the output card of the controller, the solenoid switch is isolate the piston, solenoid or output card. If the controller is faulty then it takes about 1.5 hours to replace and calibrate the controller.
				7.	Scale controller fails to compensate for different grade sizes.	Scale controller will keep on indicating "overfill" or "underfill". Parameters on the scale need to be adjusted by instrument fitter. This typically happens whenever a product change is made from a normal grade to a "development" grade, which happens about twice or three times a month.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
				8.	Filling gate flaps, stops or linkages worn.	Scale controller will keep on indicating "overfill" or "underfill". These components are behind guards and are not easily accessible while the scale is operating. Can take upwards of 4 hours to repair and replace worn components.
				9.	Check scale not measuring mass accurately.	Would not know about this, since it means that both the bagging scale and the check scale are not measuring accurately. This can result in underweight or overweight bags being shipped, which may result in claims from customers, which can be hundreds of thousand of Rands.
8.	To signal a warning to the operator is overweighing (+0.3 kg) or underweighing (- 0.03 kg) is detected.	A	Incapable of signally any warning at all.	1.	Scale controller alarm function disabled or failed.	Will not know that this happens until the scale measures loads that are not within –0.03 kg to 0.03 kg and this is picked up by weighing bags on the check scale. To change the controller and to adjust parameters takes about an hour and 10 minutes.
9.	To load the machine with film. The film must be embossed on both sides and "corona" treated on the printed side to allow for ink to adhere.	A	Fails to feed film through automatically.	1.	Unwind motor switched off on panel.	When the operator tries to manually unwind, it won't. Machine will run automatically, but will not infeed the film. The operator must turn the unwinding switch to "on".
				2.	Unwind motor trips on overload due to snag in the film roll.	Alarm "thermic motor" indicates that one of the motors is overloading. The machine switches to manual. Instrument fitter is called to reset the motor. Takes about 0.5 \hours to restore and to remove the snag.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
				3.	Roll is misaligned.	Limit switch detects that roll is misaligned. Machine will not start. Alarm "film safety" appears on PLC remote panel. Operator readjusts roll.
				4.	Slippery film (poor quality film roll).	Rubber-lined unwind gears slip on the film, preventing unwinding. Sack length becomes longer or shorter than what was set up. In the palletiser bags stack with gaps. Must change the film roll to a better film roll and reject the substandard roll.
		B	Unable to wind film tightly.	1.	Limit switch on the ballerina arm fails.	Roll continues to unwind onto the floor. Operator checks the limit switch to see if it sticking and tries to release it. If not possible, will call instrument fitter to replace the limit switch, which takes about 1 hour.
				2.	Brake motor does not start due to brake assembly not releasing.	Alarm "thermic motor" appears on PLC remote panel. Instrument fitter must reset motor and, if the brake on the motor is faulty, usually replace the whole brake motor.
				3.	Brake motor does not start due to burnt out motor.	Alarm "thermic motor". Must replace the motor. Takes about 1 hour to replace the motor.
				4.	Brake motor does not start due to keyway on the shaft in the gearbox sheared due to mechanical overload.	Motor will continue running. The roller will not turn. The ballerina arm will pick up but not release downward again. Takes about 1 hour to replace the motor.
				5.	Brake motor does not start due to worn gearbox gears.	Alarm "thermic motor". Gearbox assembly must be replaced, which takes about 1 hour.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
				6.	Brake motor does not start due to bearings seized.	Alarm "thermic motor". Motor/gearbox must be replaced.
10.	To prepare an empty bag for filling according to the required settings on time 2.	A	Unable to prepare an empty bag for filling.	1.	Film not treated against static build up.	Suction cups cannot pull bag open. Alarm "bag opening" indicates on the PLC remote panel. Bagging-off system stops because the scale cannot discharge. Operators use "air gun" to blow air into bags to form a bubble before the film arrives for filling. If this does not help, then the film roll will need to be replaced, which takes about 10 minutes.
				2.	Suction cups worn.	Suction cups cannot pull bag open. Alarm "bag opening" indicates on the PLC remote panel. Bagging-off system stops because the scale cannot discharge. Suction cups must be replaced, which takes about 10 minutes.
				3.	Vacuum pump switched off.	Alarm "bag opening" indicates on the PLC remote panel. Operator can see and hear the vacuum pump is not running.
				4.	Vacuum pump filter blocked.	Alarm "bag opening" indicates on the PLC remote panel. Low vacuum indication on the vacuum indicator. Operator will confirm that pump is running and then call instrument fitter to clean filter. Takes about 0.5 hours.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
				5.	Granules in the suction cups.	Alarm "bag opening" . Operator can see that the problem is granules in the cups. He can clean the cups, which takes about 3 minutes. This problem occurs as a result of poor film quality or bag length too short.
				6.	Vacuum pipes damaged by abrasion (pipes move with the bagging mechanism).	Alarm "bag opening". Suction cups and pump are okay. Instrument fitter then verifies that the leak is in the line, and replaces the leaking line.
				7.	Three way vacuum valve leaking.	Alarm "bag opening" . Vacuum detector will not detect any vacuum and it is possible for the instrument fitter to feel on the valve if the leak is on the atmosphere side. To replace the valve takes about 1 hour.
				8.	Blow up system fails due to solenoid or restrictor failure.	Alarm "bag opening". Can see that while the bag is being prepared for filling that it does not blow, then adjust the restrictor. Otherwise the solenoid is faulty. This happens particularly when the air pressure varies. Takes about 5 minutes to adjust the restrictor and about 1.5 hours to replace the solenoid.
				9.	Cutting blades get too hot when the sealer temperature is set too high.	Pre-heater current greater than 14 amps. Alarm "bag opening". The blades seal the bag instead of just cutting it. Machine must be switched off to allow the blade to cool down (about 20 minutes). Operator must reset pre-heater amps to less than 14 amps.

FUNCTION		**FUNCTIONAL FAILURE**		**FAILURE MODE (cause of failure)**		**FAILURE EFFECT (what happens when it fails)**
				10.	Settings on the vacuum switch set too high or too low.	Gauge on the vacuum switch indicates the vacuum. Alarm "bag opening". A light lights up when vacuum setting is reached. Instrument fitter must readjust vacuum setting.
				11.	Piston travel to short due to mechanical failure.	This will prevent the suction cups from pulling the bag open. Alarm "bag opening". By visual inspection from the instrument fitter it will be clear that piston adjustment will be too short. To readjust is about 10 minutes, but if the piston must be replaced it takes about 1 hour.
				12.	Film alignment not correct or embossed strip on bag not located as per film specification.	The suction cup will try to suck onto the embossed section of the film and will be unable to pull bag open. Alarm "film safety" or alarm "bag opening". Film must be re-aligned by operator.
				13.	Timer 16 set too low.	The suction cups will not have enough time to seal against the film. Alarm "bag opening". This is the first thing that should be checked by the operator and corrected if found set too high.
				14.	Timer 16 too high.	Air will bleed through the sides of the suction cup. Alarm "bag opening". This is the first thing that should be checked by the operator and corrected if found set too low.
11.	To compact product into bags according to timer 3.	A	Fails to compact product.	1.	Mechanical settings are not adjusted to reach the bags.	The shaker does not reach the bag suspended overhead. The shaker table must be adjusted upward by operator.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
				2.	Shaft of the shaker motor is worn.	Motor turns but shaker is not shaking, which can be verified by the instrument fitter by changing to manual mode. Takes about 1 hour to replace the motor.
				3.	Timer 3 set too low.	Compacting of granules will not be good enough – a teat form is left on the surface of the granules. Operator will set time 3 according to specification. Sealer 2 may not seal.
				4.	Motor tripped due to overload from an empty bag which gets stuck in the mechanical components.	Alarm "thermic motor" on remote PLC panel. Can see that an empty bag is stuck in the mechanical components. It takes about 10 minutes to remove bag, reset motor and start up.
				5.	Brake motor does not start due to brake assembly not releasing.	Alarm "thermic motor" appears on PLC remote panel. Instrument fitter must reset motor and, if the brake on the motor is faulty, usually replace the whole brake motor.
				6.	Brake motor does not start due to motor burnt out.	Alarm "thermic motor". Must replace the motor. Takes about 1 hour to replace the motor.
				7.	Brake motor does not start due to keyway on the shaft in the gearbox shearing.	Motor will continue running. The roller will not turn. The ballerina arm will pick up but not release downward again. Takes about 1 hour to replace the motor.
				8.	Brake motor does not start due to worn gearbox gears.	Alarm "thermic motor". Gearbox assembly must be replaced, which takes about 1 hour.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
				9.	Brake motor does not start due to bearings seized.	Alarm "thermic motor". Motor / gearbox must be replaced.
12.	To push filled and sealed bags onto the idler rollers.	A	Unable to push filled and sealed bags onto the idler rollers.	1.	Incorrect table settings.	Shaker table stand level. Orange table (bag lifting table) must be set so that fingers miss the green table. If this is out of sync then the bag will end up lying skew on the green table. Tables must be adjusted, which can be done by the operator. No production while the operator adjusts (about 10 minutes).
				2.	Carriage motor tripped due to loose fingers which obstruct motion.	Alarm "thermic motor". Carriage will be stuck in transiting position and a finger that is out of place can be seen. This finger must be put back into place by the instrument fitter.
				3.	Carriage motor tripped due guides set too close together.	Carriage motor must work against a high resistance. Alarm "thermic motor" when motor trips. Can be seen that the guides are too close together. Guides must be readjusted by the instrument fitter, which takes about 10 minutes.
				4.	Bag lifter table are not lifted due to solenoid or piston failure.	Alarm "bag lifter up" or alarm "bag lifter down". Instrument fitter must check if it is the solenoid or the piston which has failed. To repair the solenoid about 0.5 hour, to repair piston, about 1 hour.
				5.	Carriage motor does not start due top brake assembly not releasing.	Alarm "thermic motor" appears on PLC remote panel. Instrument fitter must reset motor and, if the brake on the motor is faulty, usually replace the whole brake motor.

FUNCTION		**FUNCTIONAL FAILURE**		**FAILURE MODE (cause of failure)**		**FAILURE EFFECT (what happens when it fails)**
				6.	Carriage motor does not start due to motor burnt out.	Alarm "thermic motor". Must replace the motor. Takes about 1 hour to replace the motor.
				7.	Carriage motor does not start due to worn gearbox gears.	Alarm "thermic motor". Gearbox assembly must be replaced, which takes about 1 hour.
				8.	Carriage motor does not start due to bearings seized.	Alarm "thermic motor". Motor / gearbox must be replaced.
13.	To indicate "no air" if pressure drops below 5.5 bar on the pneumatic system.	A	Fails to indicate "no air' when pneumatic system's pressure drops below 5.5 bar.	1.	Adjustment on the pressure switch set too low.	When the pressure drops all pneumatic components will not operate normally. The local pressure indicator will indicate low pressure. Pressure switch must be adjusted back to 5.5 bar. Bags will not be sealed properly.
14.	To place the bagging system on hold if no product is present and to make a warning on the PLC panel "awaiting for discharge" and on the scale controller "no product".	A	Fails to place bagging system on hold in case of no product and incapable of indicating an "awaiting for discharge" warning on the PLC panel.	1.	Communication between the scale controller and the PLC fails.	While the machine is set to "fill bags" it makes empty bags because the bag filling machine "thinks" that the scale is filling bags. When this happens before it was a cable fault, but it could also be the interlocking relays which have failed. Will take about 0.5 hours to restore function.
		B	Incapable of indicating a "no product" warning on the scale controller.	1.	No product switch fails.	Alarm "slow cycle" on the scale controller, while "no product" warning light is off. Can also see that there is no product in the scale. The "no product" switch must be removed, cleaned, and if necessary replaced.

	FUNCTION		**FUNCTIONAL FAILURE**		**FAILURE MODE (cause of failure)**	**FAILURE EFFECT (what happens when it fails)**
15.	To signal a warning on the panel, "end of film reel" and to switch the system to manual if the end of the film roll is reached.	A	Fails to signal a warning when end of film.	1.	PLC and / or limit switch fails.	The machine will carry on filling until the film is completely finished. The alarm "bag opening" will eventually indicate on the PLC. Then the operator will see that there is no film left. The operator will check to see if the limit switch is just stuck. If it is failed, the instrument fitter will replace the limit switch.
		B	Fails to switch the system to manual when the end of the film roll is reached.	1.	PLC card error.	The machine will carry on filling until the film is completely finished. The alarm "bag opening" will eventually indicate on the PLC. Then the operator will see that there is no film left. The operator will check to see if the limit switch is stuck. If this is not the problem then the instrument technician will investigate the PLC card. Cannot restart the machine until the PLC output card is installed, which takes about 1 hour.
16.	To switch off the bagging system if any one of the four access doors to the machine are opened.	A	Fails to switch the bagging system off when any one of its door is opened.	1.	Faulty limit switches or PLC.	The chance that all four limits switches fail at the same time is unlikely. Will not know if the switches have failed until the door is opened. If found failed, the door limit switch and PLC must be repaired, which should take about 1 hour.
		B	Able to operate bagging machine with one or more of its doors opened.	1.	Limit switch left bridged out by maintenance.	Safripol does use bridging devices under running conditions. This may only be exercised by a suitably competent person with authority from the engineering manager. The door will not be able to close if the bridge is in place. Bridge must be removed.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
17.	To indicate "alarm sealer 1" or "alarm sealer 2" if the seal element is not operating at all or if it is drawing too much current.	A	Fails to indicate "alarm sealer 1" or "alarm sealer 2" if seal element is not operating or drawing too much current.	1.	Faulty sealer cards.	This alarm points protect the sealer card. Bags will not have any seal. There is no pre-heater current being drawn. There will be spillage as there are no seals. Sealer card must be replaced and calibrated for the correct temperature by the instrument technician.
				2.	Settings on the sealer card set incorrectly.	Bags will not have any seal. There is no pre-heater current being drawn. There will be spillage as there are no seals. Sealer card alarm point must be reset for the correct temperatures by the instrument technician.
18.	To indicate "pressor 1" on the PLC if the blade does not cut the film.	A	Does not give a "pressor 1" indication on the PLC when the blade does not cut the film.	1.	Faulty proximity switch or the PLC itself can be faulty.	The film will not be cut and the machine will keep on running. Can see that the blade did not cut the film. Bags cannot be filled. Instrument technician will adjust the limit switch. If this does not solve the problem, then the PLC output card could be faulty. Takes about 0.5 hours to repair if it is the proximity switch, and about 1 hour if is the PLC.
19.	To indicate "pliers open" or "pliers closed" if the carriage pliers do not respond correctly.	A	Incapable of indicating "pliers open" or "pliers closed" if the carriage pliers respond incorrectly.	1.	Faulty proximity switch or the PLC itself can be faulty.	The pliers will not clamp the bag. Bags will spill from top. Instrument technician will adjust the limit switch. If this does not solve the problem, then the PLC output card could be faulty. Takes about 0.5 hours to repair if it is the proximity switch, and about 1 hour if is the PLC.

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
20.	To indicate "hopper open" on the PLC if bags containing granules are not compacted.	A	Unable to indicate "hopper open" on the PLC when bags containing granules are not compacted.	1.	Faulty proximity switch or the PLC itself can be faulty.	The bag will not seal at sealer 2. Bags will spill from top. Instrumentation technician will adjust the limit switch. If this does not solve the problem, then the PLC output card could be faulty. Takes about 0.5 hours to repair if it is the proximity switch, and about 1 hour if is the PLC.
21.	To indicate "bag filter up" on the PLC if the bags are overfilled.	A	Fails to indicate " bag filter up" on the PLC in case of bag overfilling.	1.	Faulty proximity switch or the PLC itself can be faulty.	The bag filter will not lift the bag high enough. Carriage will take bag forward and the unsealed bag will spill. Instrument technician will adjust the limit switch. If this does not solve the problem, then the PLC output card could be faulty. Takes about 0.5 hours to repair if it is the proximity switch and about 1 our if is the PLC.
22.	To indicate "pressor 2" or "pressor 3" on the PLC if the set pressures are not met.	A	Fails to indicate "pressor 2" or "pressor 3" on the PLC if set pressures are not met.	1.	Faulty proximity switch or the PLC itself can be faulty.	Bags will not be sealed, resulting in spillage. Instrument technician will adjust the limit switch. If this does not solve the problem, then the PLC output card could be faulty. Takes about 0.5 hours to repair if it is the proximity switch, and about 1 hour if is the PLC.
23.	To prevent the bagging system from operating if the conveying system is not operating.	A	Does not prevent the system from operating if the conveying system is not operating.	1.	Interlock system fails.	The bagging-off system will continue to try and stack bags on the conveyor. Eventually the carriage will trip because it is obstructed by piled up bags. Alarm "thermic motor" will indicate. To reset the carriage motor about 10 minutes. The interlock must be restored.

SYSTEM:	PP 25 kg Packaging	COMPILED BY:	S HADEBE	DATE: JUNE 1998	
SUB SYSTEM:	Bagging off system	REVIEWED BY:	S HADEBE	DATE: JULY 1998	

FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE (cause of failure)		FAILURE EFFECT (what happens when it fails)
24.	To prevent the bagging system from operating if the palletising system is not operating.	A	Fails to stop bagging system if the palletising system is not operating.	1.	Interlock system fails.	The bagging-off system will continue to try and stack bags on the conveyor., Eventually the carriage will trip because it is obstructed by piled up bags. Alarm "thermic motor" will indicate. To reset the carriage motor about 120 minutes. The interlock must be restored.
25.	To stop each bagging machine with a local emergency stop on the control panel.	A	Unable to stop each bagging machine with a local emergency stop on the control panel.	1.	Emergency stop fails.	Bagging machine will not stop. This could mean that the elements are overheating, which could result in fire.
26.	To stop the palletiser, the bagging-off system and the conveyor from the curved conveyor.	A	Unable to stop the palletiser, the bagging-off system and the conveyor from the curved conveyor.	1.	Emergency stop fails(hip hit switch) at each BM machine, at the curved conveyors, the emergency ripcord at the incline conveyor, at the palletise paper sheer dispense, at the turntable station, at the palletiser control panel and at the palletiser local control station.	The palletiser, the bagging-off system and the conveyor will not stop. This is serious if somebody has fallen onto a conveyor.

APPENDIX B

THE SAFRIPOL EMPLOYEE DEVELOPMENT STRATEGY

POLICY STATEMENT

Derived from our mission statement where it is outlined as an objective to ensure a good return for all our stakeholders, we will ensure that:

- Safripol will pursue progressive policies and programmes in the human resources disciplines through its Apollo Programme, in the context of the needs of the South African society.
- All human potential is developed for the benefit of the individual, as well as the company.
- Employee development programmes will be established to improve the quality of life of all people and there will be definite progress towards a mix of competent and committed employees at all levels, to reflect more appropriately the diversity of the South African society.

The company opposed to all forms of discrimination on the basis of race, colour, sex or creed and will uphold the right of all individuals to progress purely on merit and ability in all aspects of work life. Within this context, the company will assist all employees to develop themselves to the maximum of their potential so that they may derive personal benefit from their employment.

It is, therefore, the company's intention to re-align the focus on those employees who, for whatever reason, have not received the same development opportunities as others. This is to be conducted in a nourishing environment of personal growth for all.

PURPOSE OF THE EMPLOYEE DEVELOPMENT STRATEGY

The purpose of the strategy is as follows:

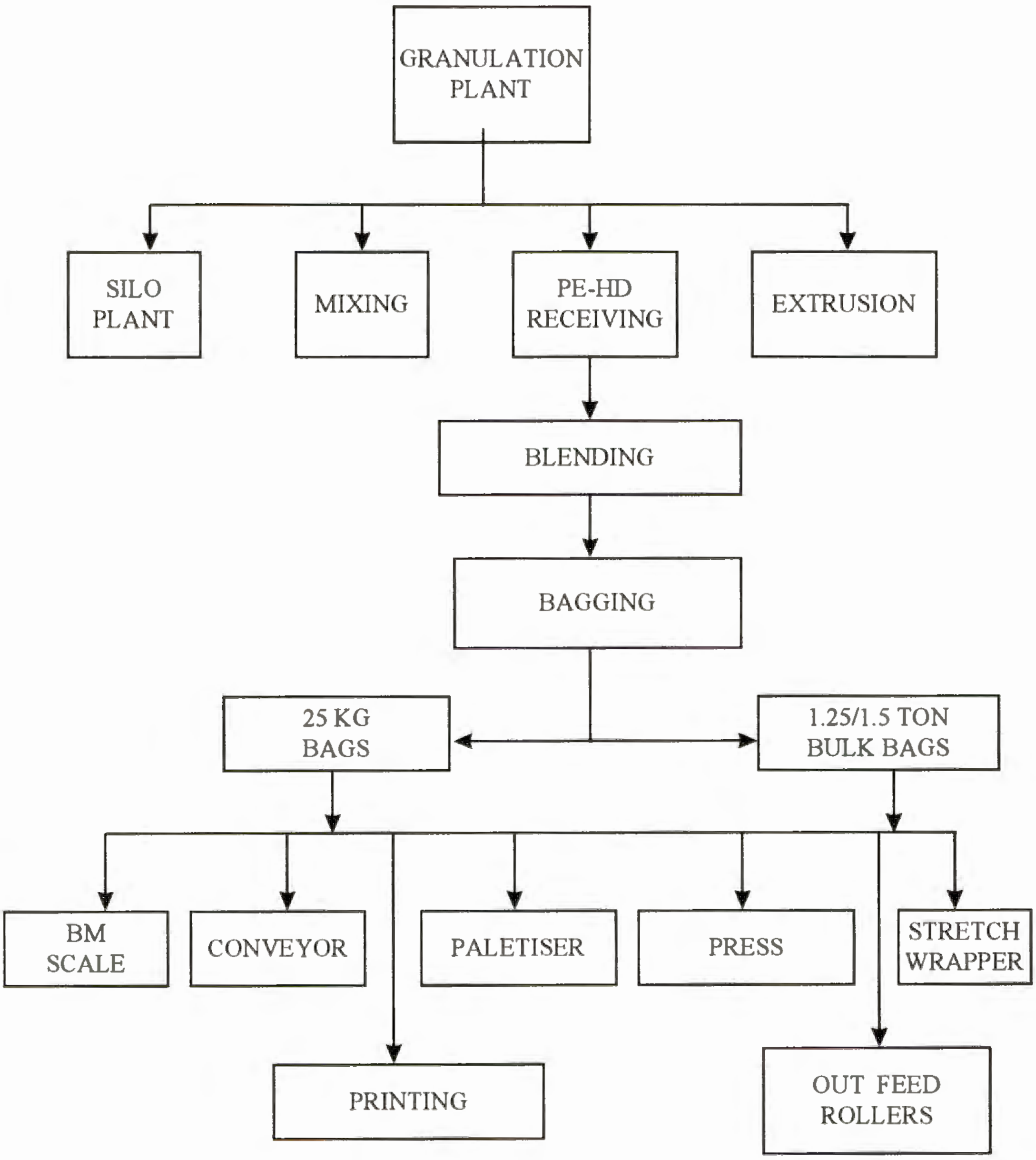
- To develop an organisational climate that will support as well as challenge employees with potential for development
- To provide appropriate techniques and opportunities for the identification of potential
- To provide systematic organisational integration opportunities to those employees who have difficulties in adjusting to the values of the company.
- To monitor the effectiveness of employee development programmes on a regular basis and to make necessary adjustments where necessary.

IMPERATIVES

- *Customers:* For obvious reasons, customers come first. They are the special stakeholders around which everything revolves. They are the reason we exist. It is vital that we understand this very clearly.
- *Costs:* Costs must be rigorously controlled so that revenue grows ahead of expenditure. There would be little point in creating wealth if it were all to be consumed by costs.
- *Safety:* It is fundamental to the industry in which we are that we recognise the fact that the process and plant, which have been entrusted to our safekeeping, can indeed be dangerous. A fundamental prerequisite is that we work safely and practise safe work procedures.
- *Co-operation:* Co-operation or teamwork is necessary because it creates synergy. It ensures that the whole is more than the sum of the constituent parts. The alternative is conflict-and it causes us all to lose our focus and our determination.
- *Communication:* Communication is the glue that holds everything together. Without communication nothing is possible

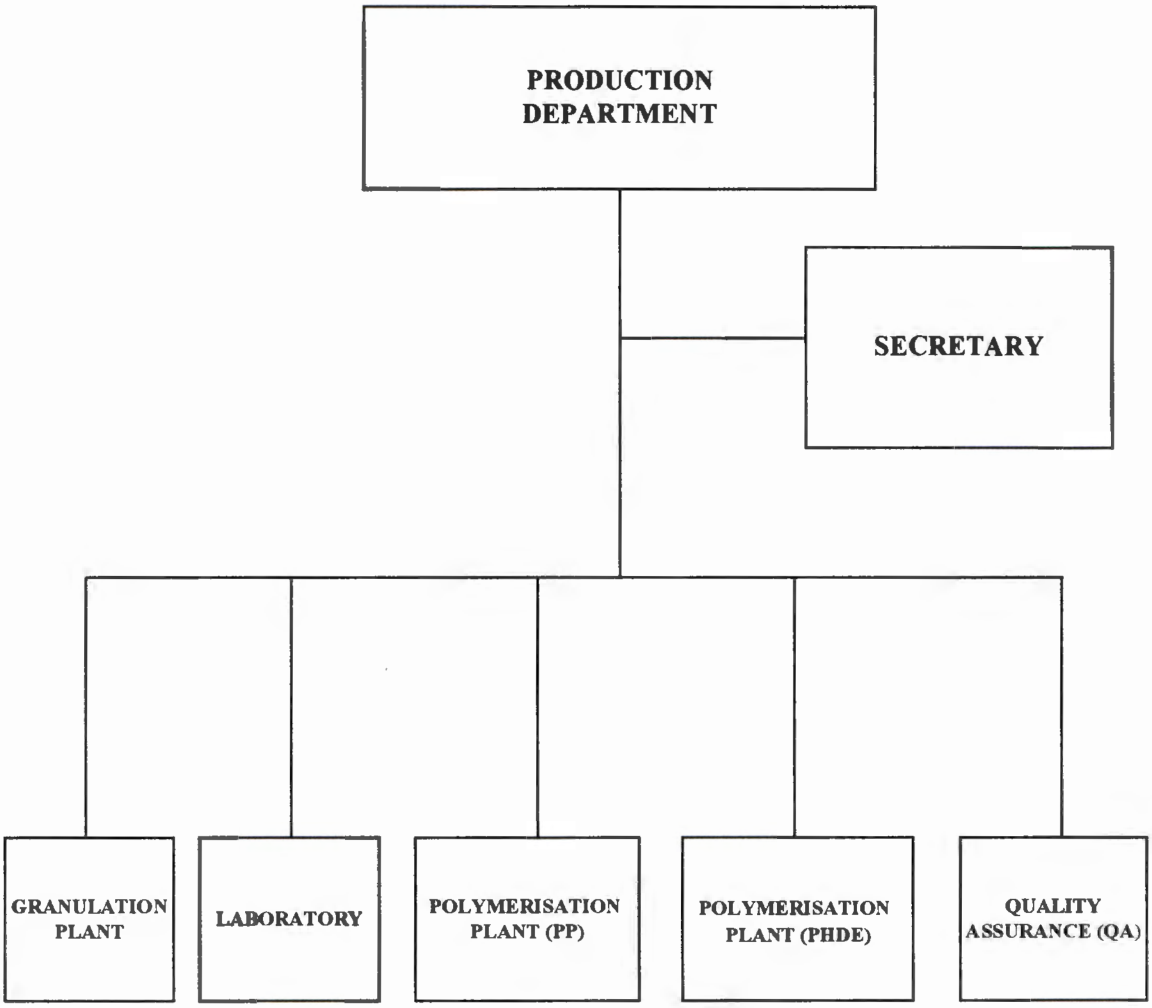
APPENDIX C

ASSET HIERARCHY



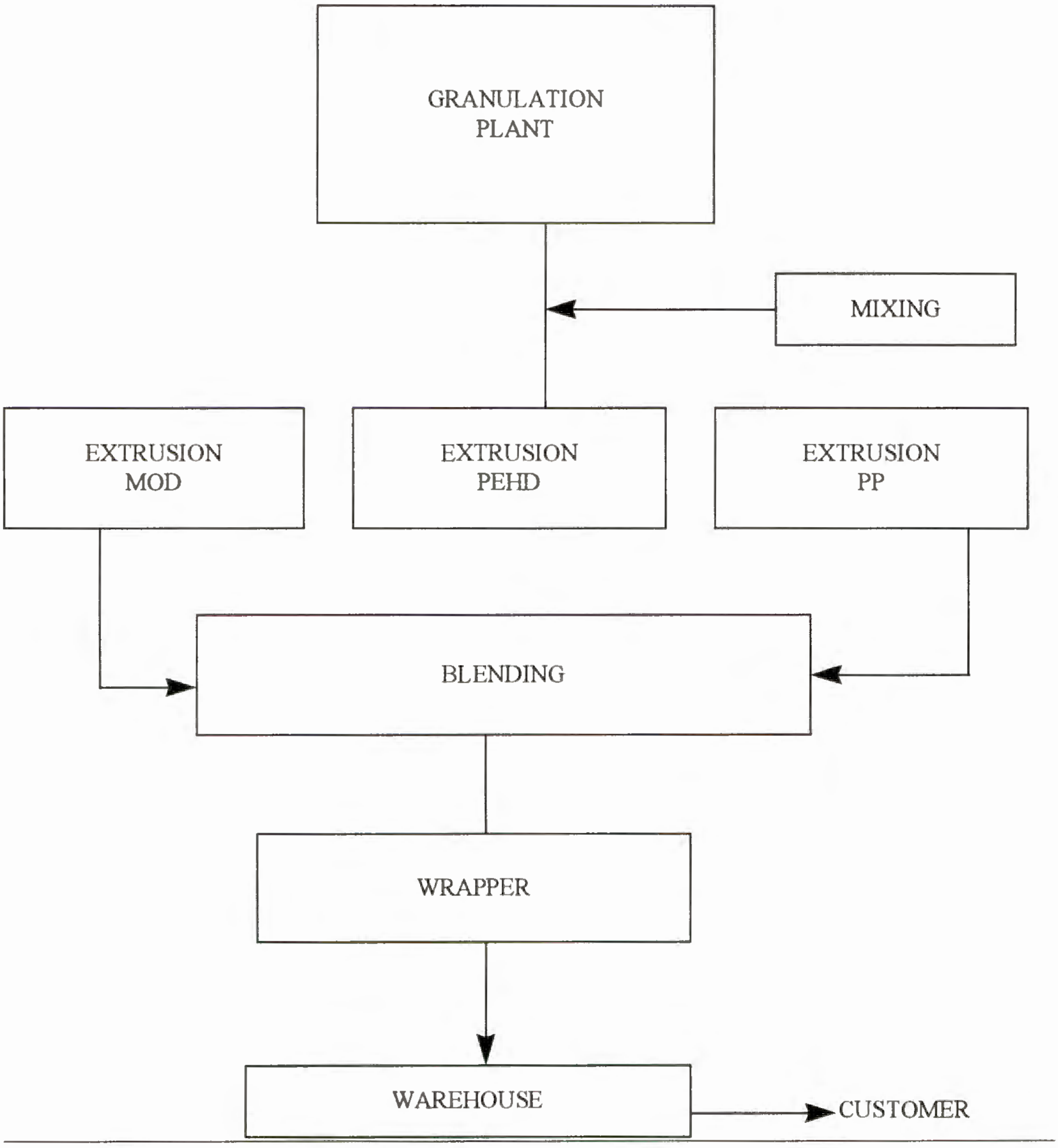
APPENDIX C

PRODUCTION FLOW DIAGRAM



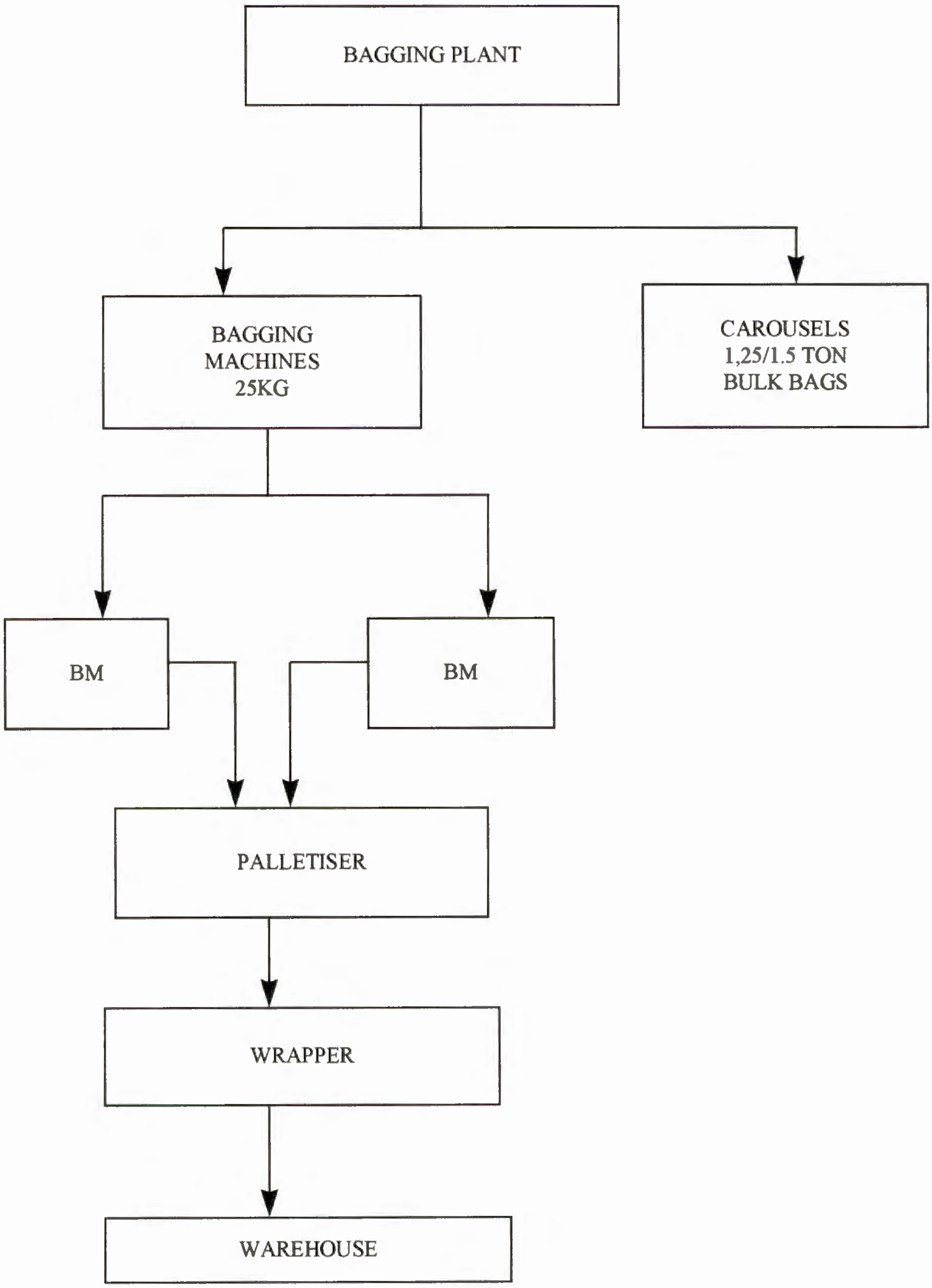
APPENDIX C

GRANULATION PLANT FLOW DIAGRAM



APPENDIX C

BAGGING PLANT FLOW DIAGRAM



The RCM Decision Diagram