A MODEL FOR MANAGING MAINTENANCE IN THE PREPARED FOODS INDUSTRY IN THE AREAS OF FROZEN VEGETABLES AND PREPARED FROZEN MEALS

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A project report submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

Heidelberg Transvaal, 1993

DECLARATION

I declare that this Project Report is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

(SIGNATURE OF CANDIDATE)

7 day of October 1993.

ABSTRACT

The objective of this research project is to propose a model by which maintenance may be managed in the Prepared Foods Industry. Various Companies in this industry have implemented modules of a maintenance administration system. Nowhere, for this industry, does a structured programme which will provide the Maintenance Manager with the elements of an administration system, their sequence of implementation and their interrelationships exist.

An extensive literature survey was undertaken to establish and assess the various elements of a maintenance administration system, their interrelationship and their applicability to the Prepared Foods Industry.

The results of the literature survey was compared to the programme being implemented at the company under investigation, culminating in a generic, theoretical model.

This project report concludes that if this proposed model, together with the aims and objectives of the specific organisation, is implemented, many of the claimed benefits will be achieved.

ACKNOWLEDGEMENTS

My sincere gratitude to my wife and my family for all their sacrifices, support and encouragement through my years of study

A special thank you to Mrs. L. Hoeben for typing this project report and to my employer Irvin and Johnson who's financial assistance made this report possible.

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1 INTRODUCTION

1.1 Objective and Scope of the Research Project

The objective of this research project is to provide a generalised model for managing maintenance in the prepared foods industry in the areas of Frozen Vegetables and Prepared Frozen Meals.

The model will contain sufficient information to allow it to be adapted for use in other industries.

It was decided to undertake the research project since the author is involved in maintenance management and in particular in the development and implementation of a planned maintenance programme. The process of development and implementation exposed many pitfalls awaiting any prospective maintenance engineer. There is ample information available on different aspects of maintenance but unfortunately most of it:

- is fragmented
- gives a brief description of what is required.
- promises large benefits for those who successfully implement such a programme
- provides few implementable, practical examples of what to do and how to do it
- seldom tells the reader or student of the pitfalls
- seldom tells the reader or student of the real effort required to design and successfully implement such a programme.

However, this project will put forward a model which will address many of the theoretical elements together with practical examples gained from experience in design and implementation of such a programme.

Factors which have a significant effect on the success of a company in this industry are :

- product quality
- product cost
- product availability
- product innovation.

The result is that equipment is often expected to be highly flexible in order to manufacture a wide range of products, have high availability so as to ensure high productivity of capital, and to manufacture quality products consistently while minimizing the adverse effects of waste, poor labour utilisation and high maintenance costs caused by substandard maintenance management and practices.

The research project will address the action of maintaining the equipment as well as the associated elements of planning, organisation, co-ordination and control of the work and workforce.

1.2 The Development and History of Maintenance Management

The evolution of maintenance management has taken place across three successive generations [1][2].

These may be summarised as follows :

1. First Generation of Maintenance Management

   With the advent of the twentieth century there was little need for any formal maintenance systems. Most production was performed by hand and the equipment which did exist was simple and easy to repair. Production output was more dependent on human skill than on machinery effectiveness in the conversion process. However, the industrial revolution impacted significantly on this status quo. Up to the beginning of the Second World War machinery was large, reasonably simple, over designed and inherently reliable. Industry was still very labour intensive and equipment breakdowns had less effect, resulting in less need of sophisticated maintenance systems with their associated higher skill requirements.

2. Second Generation

The advent of the Second World War changed all of this significantly. Increased quantities of goods and more equipment were required while there was a drop in the availability of effective manpower. The only alternative was automation and mechanisation. Rebuilding the world after the War ensured that the pressure was sustained. Industry became more reliant on machinery. Machines became lighter in construction, more complex, less reliable and required higher skill levels to maintain them. The maintenance concepts which evolved included the following :

- Scheduled maintenance based on the assumption that all components had a fixed life.
- Sophisticated administrative systems to plan, organise and control the resources required for maintenance.
- The collection and analysis of large masses of data to establish the operational lifespan of equipment or components.
- A new focus on work measurement in maintenance.

3. Third Generation

More changes occurred in the late 1960's. Automation and mechanisation escalated to levels where machinery outnumbered people in some industries. Industry became more dependent on machinery, electromechanical complexity increased and the direct pressure on maintenance became obvious.

4. Fourth Generation?

During the 1980's the concept of scheduled maintenance was fast being replaced by predictive or on- condition maintenance. Like so many other manufacturing concepts the concept of Total Productive Maintenance was brought to us from Japan. The "I operate - you fix" syndrome which seems to exist in most western manufacturing facilities is rapidly disappearing. TPM supports the new manufacturing technology of Just In Time (JIT). This new era is bringing about a change in the attitude of management whereby the person responsible for machine operation is also responsible for certain maintenance actions. This provides an avenue for really optimising the maintenance function [3][4][5].

1.3 Planned Maintenance in Perspective

In his opening address at the 1986 Maintenance Management Convention, D.B. Mostert[4] identified the following factors which could have significant influence on maintenance in South Africa in the future :

1. <u>Drop in Fixed Investment</u>

   Capital expenditure is at lower levels than depreciation charges resulting in a disinvestment in plant and machinery. The overall effect is that equipment is getting older and investment is being delayed. Although this is not necessarily true for all industries and companies, the arguments against cash outflow, depreciation charges and interest charges are strong, especially if one realises that with a little effort and some expenditure, the operational life of equipment can be extended for a good many years.

2. <u>Difficulty to Economically Justify Replacements</u>

   Due to the negative rate of exchange, price increases on imported equipment are phenomenal. Although equipment may bring significant productivity improvements, these are more than offset by the increases in prices of more modern equipment. The net effect is more rebuilding and modernisation of existing plant and equipment.

3. <u>Investment Funds in Short Supply</u>

With large foreign debts to redeem, it is likely that financing for domestic investment will be limited. We will in the short term also be unable to depend on large inflows of foreign capital.

4. <u>Short Staffed Maintenance Departments</u>

The skilled manpower shortage has always been felt in South African maintenance departments.

These comments were made a number of years ago and although the country's internal situation has changed somewhat, most of them are still applicable. Amongst these changes are the following :

1. Lower corporate tax rates with taxes on dividends are clearly a means to promote job creation and free funds for expansion. These expansions will probably not occur in highly automated and mechanised plants.

2. The probability of a new government in the very near future. To live up to the expectations of the majority of South Africans the new government will probably clamp down on automation in an attempt to increase employment. We will be under pressure to keep the present equipment running for longer.

3. The current national and international recessionary climate will sustain pressure on companies to reduce costs and maintain or increase profits in static markets. Cash outflow, depreciation and interest charges will remain under pressure.

4. Due to the large number of retrenchments the number

of skilled and capable tradesmen in the unemployment ranks has increased and we are able to select good calibre employees for maintenance and operations. In line with reducing maintenance costs we need to identify all tasks which may be performed by employees on lower levels and mount an aggressive campaign of training semi-skilled workers and multi-skilling others among our capable employees.

1.4 The Objectives of Planned Maintenance

Marcus[7] defined maintenance management simply as enabling an asset to continue to fulfil the function for which it was designed. Although this, in fact, is what maintenance management must achieve, the cost at which this is achieved must form part of the decision to maintain. Park[8] quotes a writer on the subject of maintenance, who suggests the following :

"The goal of any well run maintenance organisation is to have the lowest cost of the sum of two quantities, i.e.

- maintenance labour and material, and
- production loss cost resulting from an inadequate maintenance program."

In summary:

<u>The objective of Maintenance Management is to ensure that equipment and plant facilities remain operational at the design output levels for the duration of their economic life</u>

Planned Maintenance contributes to the achievement of this objective by :

- Ensuring that equipment and plant facilities are available for production when required.

- Ensuring that this is achieved cost-effectively i.e. wi.h the least resources.

- Ensuring that short-term effort (Planned maintenance actions now) achieves long-term availability.

- Ensuring that the safety of operating and maintenance personnel is never compromised by poor maintenance management decisions or maintenance actions.

Most often the maintenance department is viewed as an evil resulting from less than perfectly engineered equipment. All facilities require some form of maintenance action at one time or another, even that of our competitors. With this thought in mind and since we cannot wish maintenance requirements away, good maintenance management should be viewed as a strategic advantage. If designed and implemented correctly, it will:

- Reduce the cost of maintenance per manufactured item.

- Assist in maintaining the quality of a product.

- Ensure that both plant availability and safety are maximised.

- Ensure that all maintenance resources are managed correctly.

- Ensure that the effective life of equipment is increased.

IT WILL CONTRIBUTE TO COMPANY PROFITS

1.5 Definitions

The following definitions are not intended to prescribe to any person how the terms should be used, but rather to indicate how they are generally perceived and will be used throughout this text.

Administration

The management of public or private enterprises or operations.

Planned Maintenance

All those activities which must be executed to ensure that a specific plant item or component achieves a predetermined level of availability and effectiveness to ensure that the objectives of the organisation are achieved.

Scheduled Maintenance

Routine maintenance carried out with components replaced, regardless of actual conditions, on the basis of an assumed or proven hard life.

Preventive Maintenance

Periodic inspection of existing facilities and equipment to uncover conditions that may lead to equipment break down, as well as to correct these conditions while they are still minor and include lubrication, inspection, cleaning tasks and the replacement of parts showing imminent failure or for which a hard life has been established.

Breakdown Failure

Repairing items as they fail.

Productive Maintenance

The examination of the plant condition to determine when a potential failure condition has arisen and initiate action before this deteriorates to total failure.

Condition Monitoring

The continuous evaluation of the health of plant and equipment throughout their serviceable life which includes monitoring of performance parameters, noise and vibration analysis, wear particle analysis and NDT techniques.

The following diagram has been adapted from one proposed by Patton[7] and depicts how the above maintenance strategies are related :

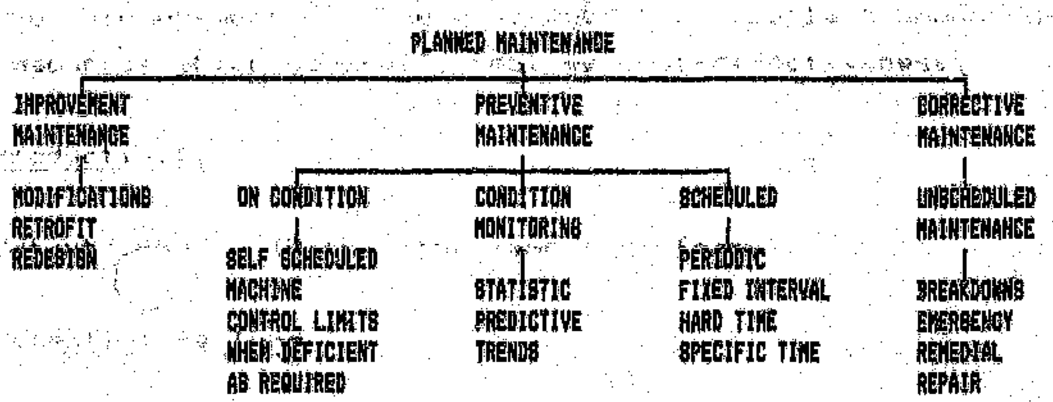


Figure I.1 Relationship Between Maintenance Strategies

Equipment Function

The purpose for which the equipment was designed and built.

Functional Failure

Inability of a system to meet a specified performance standard.

Failure Mode

The manner in which the failure occurred, e.g. a broken or worn component.

Failure Mechanism

The mechanistic detail by which the failure occurred, e.g. fatigue, overload, wear, misalignment.

Root Cause Analysis

The vital element which caused the failure.

Effectiveness

The achievement of objectives.

Efficiency

The achievement of the ends with the smallest amount of resources which generally implies cost-effectiveness.

Productivity

Output/input. (Within the same time-frame).

Potential Failure

Identifiable physical condition indicating that a functional failure is imminent.

Reliability

The probability that a system (subsystem or component) will function in the desired manner under specified conditions for a given time.

Failure

The termination of an item's ability to perform the required function.

Significant Item

One whose failure could affect operating safety or have major economic consequences.

2 THE INDUSTRY AND THE PROCESSING FACILITY

2.1 The Industry

2.1.1 Background

The industry in which the investigation was conducted is the Manufacturing Industry and in particular Food in the areas of Frozen Vegetables and Prepared Frozen Meals.

Generally the companies in this industr do not own any agricultural land but make use of producers who deliver the product to the factory or a depot and are paid for the quantity and quality of the product delivered. Factory involvement in the farming operation varies from actually preparing the fields, fertilizing them, the application of pesticides and herbicides to their eventual harvesting. Generally, however, company involvement is only geared to providing the producer with technical information.

Agricultural officers will submit daily forecasts to the factory operations manager to allow him to plan his facility utilization. Taking into account the nature of the product, unscheduled machine outages are unacceptable and some form of planned maintenance is of the utmost importance. Machine inspections/ maintenance must be slotted into production "windows", which are periods of low or no production. Incorrect forecasting or unplanned raw material intake could affect maintenance and will result in increased unplanned machine outages.

Research undertaken by the National Productivity Institute [16] shows that the average plant availability in the food, tobacco and beverages industry is quite low at 84%. Of the companies surveyed, the availability ranges from 54% - 96%. The survey also showed that 73% of manufacturing companies did have some form of preventive maintenance program, which was high, but the results achieved from the implementation of such programmes did not show that the envisaged results were being achieved.

Of all the industries surveyed the food industry seemed to gain the most benefit from increasing maintenance expenditure in the area of preventive maintenance. The difference between spending nil on preventive maintenance to spending 80% of maintenance costs on preventive maintenance constituted a 14% increase in plant availability.

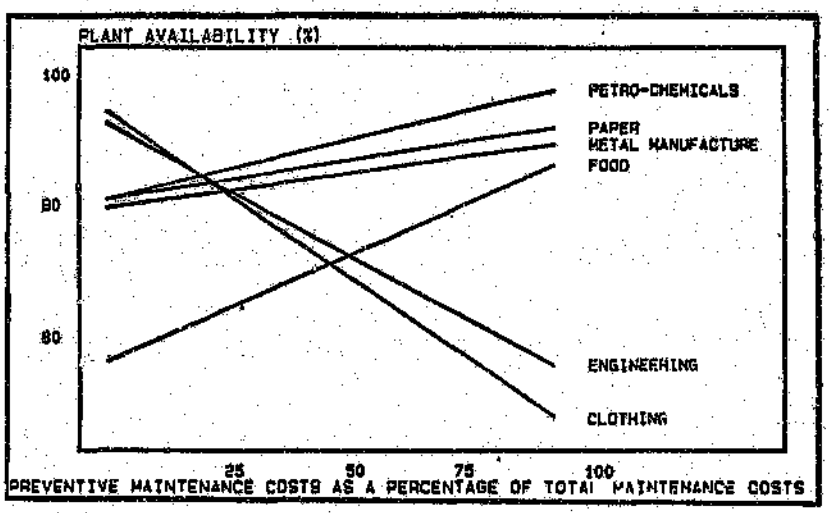


Figure 2.1 Influence of Preventive Maintenance Costs on Plant Availability.

A survey undertaken of the three major competitors in the frozen vegetable and prepared frozen meals arena showed that only one was measuring and recording plant availability on a regular basis. Another was recording actual production tons compared to required production tons and using it as a basis for line efficiency without actually recording the effect of different factors on poor throughput. One company had a formalised planned maintenance system installed while the other two, both belonging to the same holding company, had maintenance schedules in place. Both were in the process of reviewing their schedules following the RCM principles and were investigating computerising the maintenance administration system.

The industry is faced with certain unique challenges

- The production process is a flow process characterised by all items of equipment being interconnected. This makes it virtually impossible to stop any major item of equipment without shutting down the entire process. The plant does not continue operating uninterruptedly but is required to operate in this manner for at least a full shift.
- The intake of raw material is seasonal with the result that the annual sales requirements for a particular product is harvested and processed within a relatively short time.
- The raw material cannot be stored for longer than approximately 24 hours without the quality and grade being adversely affected.
- The processed product is stored in bulk and repacked into the required retail packaging when market demand calls for the product.
- In calculating the cost of lost production it is normal to ignore potential lost sales since the product is processed into stock and an out of stock situation resulting from equipment breakdown is highly unlikely. The cost of lost production is usually limited to the cost of direct labour which would be required to work additional hours to complete the throughput. Quality would only be affected after 24 hours if no alternative exists for processing the raw material.

- Different products require processing through purpose built machines and due to the seasonal nature of the products certain complex equipment stands idle for periods of the year. The result is that equipment is available for maintenance when it does not require maintenance. When the equipment is operational the maintenance requirements are high and it needs careful planning to ensure that the correct strategies are followed, the maintenance actions performed and availability achieved.

- Most of the processing equipment is imported and the adverse S.A. Rand/foreign currency exchange rates make equipment expensive. This, together with the low capital productivity of certain items of equipment due to the seasonal nature of the product, has ensured that all processing lines are engineered to maximize utilisation. This is achieved by change overs. Equipment life must be maximised through proper maintenance procedures.

- Since the products are destined for human consumption all activity, including that of maintenance, must be geared toward ensuring that the product is not directly contaminated. Nor that it will become contaminated after processing through product defrosting or product handling which may allow the growth of harmful micro-organisms.

- Due to the nature of the product, the use of direct labour is high, the typical ratio of direct to indirect being 70:30. Water consumption is high, typically 30 - 50 tons water per ton product. Electricity consumption is high, typically 3000 - 5000 kVA maximum demand per month and energy consumption of 1 500 000 kWhr per month.

- The product acidity levels are high and effluent water pH readings vary from 3,2 - 6. Equipment structures have historically been manufactured from a combination of low carbon steel and stainless steel. The high deterioration rate of carbon steels and the accompanying hygiene and maintenance related problems together with the availability of lower grades of stainless steel at prices which compare favourably with that of carbon steels have resulted in plant modernisation programmes to improve the life of equipment.

2.1.2 The Income Statement

Appendix 2.1A shows a generalised income statement which indicates what is typically taking place together with a revised income statement showing how an improvement in planned maintenance may directly and indirectly contribute to improved company profits.

The notes to the income statement ...w the assumptions made in drawing up the revised income statement.

2.1.3 Economic Indicators

To highlight the dilemma of the maintenance engineer it is important to investigate a few of the economic indicators which have a profound impact on our decision to repair or replace plant and equipment.

Foreign Exchange

Since most of our equipment is imported it will be prudent to investigate firstly the effect of the exchange rate on our buying power. The exchange rate with our most important suppliers are as follows :

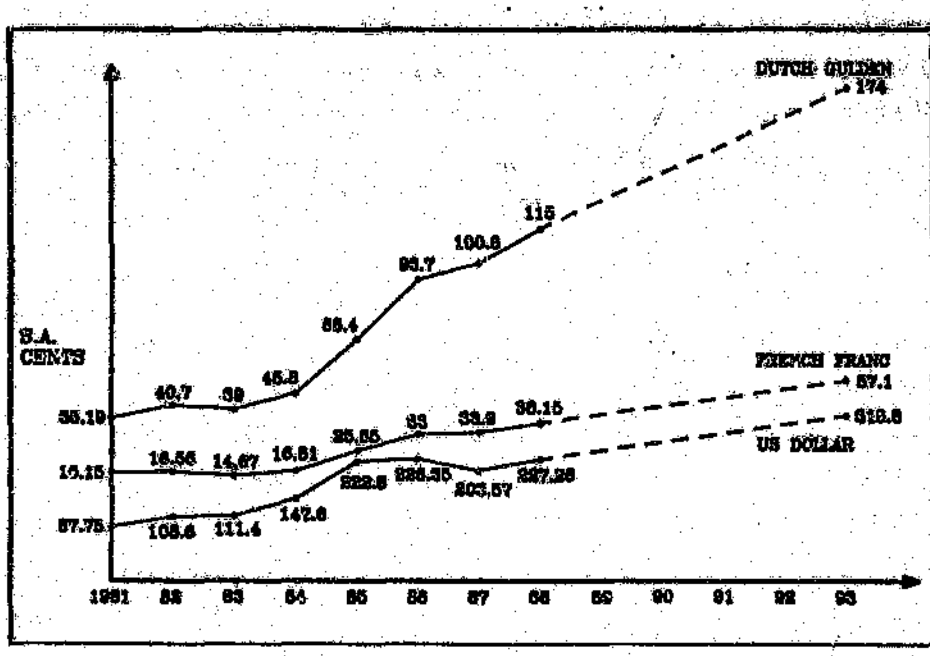


Figure 2.2 Foreign Exchange Rates [11]

Considering the poor exchange rate, the deterioration in the exchange rate may be compared to a compounded inflation rate of 11,3% per annum.

Fixed Investment

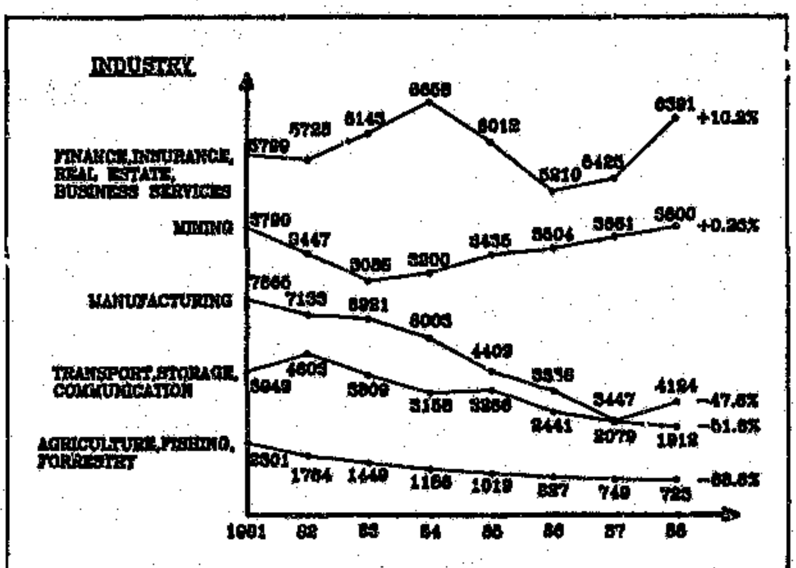


Figure 2.3 Fixed Investments in Selected Industries [11]
(As Constant 1985 prices)

The general trend indicates that in all industries there is a tendency to maximize the life of equipment and defer capital replacement. In the manufacturing industry real output started declining after 1981 [39] and the requirements for additional capacity would follow suit.

Production Prices

If a company is not replacing equipment, while it hopes to remain in business, it must repair the existing equipment. The production price index is an indication of what the maintenance engineer can expect to pay for replacement parts and other goods year on year.

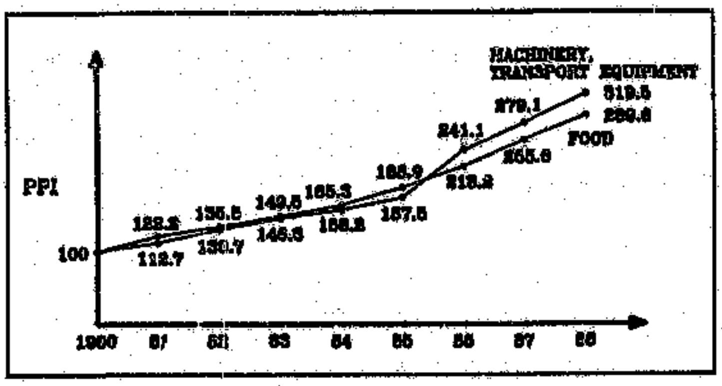


Figure 2.4 Production Prices [11]
(Indices: 1980 = 100)

Percentage Utilisation of Production Capacity

From the following it is clear that there is excess capacity in the industry which will make it extremely difficult to replace the existing equipment with new, more modern and higher capacity machines. It is obvious that capital productivity is lower and new investments will only be undertaken if they provide the accepted returns.

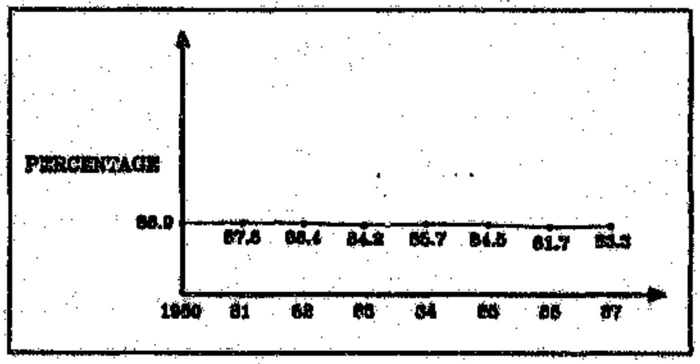


Figure 2.5 Percentage Utilisation of Production Capacity for Non-Durable Goods[11]
(At Constant 1980 Prices)

<u>Private Consumption Expenditure – Food, Beverages, Tobacco</u>

The trend since 1982 has been downward with slight improvements in 1984 and 1986. The market is still very static and in certain areas of the food business the market is contracting. The only means of improving sales would be to offer the customer a superior quality product at a better price than competitors.

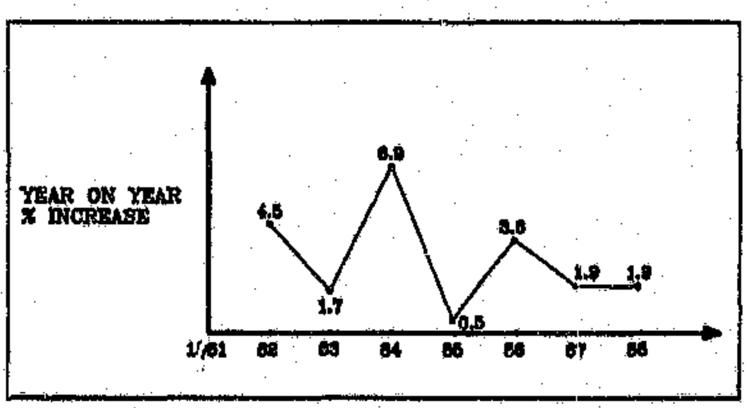


Figure 2.6 Private Consumption Expenditure Food, Beverages, Tobacco[11]
(At Constant 1985 Prices)

There are few if any real bright prospects for the industry. It is clear that we must :

- reduce the cost per item manufactured;
- supply a product of superior quality;
- use these to gain market share;
- ensure that maintenance becomes a strategic advantage since our competitors are facing the same odds.

2.2 The Processing Facility

The facility under investigation is the frozen vegetable and prepared frozen meals facility of the Prepared Foods Division of a R1,8 Billion turnover per annum company listed on the Johannesburg Stock Exchange. This facility is situated on the Reef, approximately 200 kilometres from the Loskop Irrigation Scheme in the Groblersdal and Marble Hall districts where approximately 40% of the vegetables for processing are grown. The remainder of the vegetables are procured from the North Eastern Transvaal (32%) and the Transvaal Highveld (28%).

This processing facility started as a vegetable canning facility, expanding into frozen vegetables and eventually discontinuing the canning of vegetables altogether. The result of this expansion, due to consumer demands, necessitated the procurement of larger volumes and varieties of raw materials. Due to the seasonal nature of the product there is limited time for processing the large volumes of material, e.g. Peas: 4000 - 6000 tons in 12 weeks. Moreover, the variety of products and the limited capacity of the expensive freezing equipment necessitated seeking additional procurement areas to expand the processing season of a particular product thereby permitting the intake of lower tonnages of product per shift worked while still maintaining or even expanding the variety of products.

2.2.1 Operating Units

The frozen vegetable and prepared frozen meals division consists of the following:

i) Agriculture

- Responsible for procuring raw material.
- Provides technical assistance to producers.
- In the case of crucial raw materials undertakes the ground preparation, planting and harvesting with the company's own equipment.
- Manages the depots where the product is delivered, grades the product, cleans and chills the product in preparation for transport, and dispatches the product to the main processing facility.

ii) Vegetable Main Processing Facility

- Receives the product in bulk, then washes and cleans the product.
- Trims the product to remove defects and foliage using labour on continuous trimming lines.
- Cuts, blanches, freezes and sorts the product, then feeds it into bulk storage to await final packaging as required by the trade.
- All lines are of continuous process with very little, if any, in process storage, should any machine become defective.

iii) Mixing Room

- Receives product from bulk cold storage daily.

- Mixes individual products on a continuous line in the proportions required by the various mixes.
- Feeds the mixes back into bulk cold storage to await final packaging as required by the trade.

iv) Repacking

- Receives the product from bulk cold storage daily.
- Feeds product through automatic checkweighers or volumetric fillers into forming, filling and sealing machines which package the product.
- Packs individual packaged products into outer cartons and palletises these for dispatch.
- Stores pallet loads into Mixing Warehouses.

v) Mixing Warehouses

- Stores all packaged products in cold rooms prior to dispatching them to distribution warehouses. All warehouses are refrigerated rooms to ensure maintenance of the cold chain.
- Assembles packaged product into the required mix prior to dispatching it to one of the distribution warehouses. All distribution by road transport.

vi) Prepared Frozen Meals

- Receives raw material from bulk cold storage or bulk dry goods stores.
- Mixes raw materials according to a recipe, then rolls or forms, freezes,

packages, and palletises these for dispatch.

- Stores pallet loads into Mixing Warehouses.

2.2.2 Typical Production Line Layouts

Appendix 2.2A shows general production line layouts for Bulk Quick Freezing (Figure 1), Repacking (Figure 2) and Prepared Frozen Meals (Figure 3).

2.2.3 Facility Operating Capacity

For the Vegetable Processing Facility, as shown in Appendix 2.2A, the bulk of the product passes through the four freezing tunnels. These tunnels can freeze an average of twelve (12) tons of product per hour for the four (4) units. However, before the product is frozen, it passes through the other processes which reduces the actual mass of the product requiring freezing through yield loss. The mass of the product requiring freezing is known as Nett Production, the volume of product sold, and is calculated from :

Nett Production = Gross Material Intake x Standard Yield

The capacity planning is based on an average standard yield of 70%. All calculations are based on :

- 7,75 hours effective production per shift so as to take into account the processing time lost to product run through at the start and end of a shift and lunchtimes. A full shift comprises 9,33 hours.
- Double shifts are worked.
- A five day week.
- A pattern of 4,4,5 weeks per month.
  4 week - hours available = 7,75 x 2 x 5 x 4 = 310
  5 week - hours available = 7,75 x 2 x 5 x 5 = 388

Figure 2.7 represents the required versus the available capacity of the freezing tunnels.

MONTH	GROSS PRODUCT INTAKE A	NETT PRODUCTION B = A X 0,7	HOURS AVAILABLE	(2) HOURS REQUIRED	% UTILISATION
July	2 666	1 866	310	156	50,2
August	3 645	2 551	310	213	68,6
September	4 590	3 213	388	268	69,0
October	2 040	1 428	310	119	38,4
November	1 850	1 295	310	108	34,8
Dec (1)	1 377	964	233	80	34,5
January	2 499	1 749	233	146	62,7
February	2 768	1 937	310	161	52,1
March	1 605	1 123	388	94	24,1
April	1 646	1 512	310	126	40,5
May	2 074	1 452	310	121	39,0
June	1 795	1 257	388	105	27,0
TOTAL	28 555	20 347	3 800	1 697	44,7

FIGURE 2.7 Vegetable Processing Facility Capacity Utilisation

<u>Notes:</u> 1) December has a planned shutdown during which the complete facility is off line for 3 weeks. This shutdown extends into January for 1 week. Thus the time available for production in December is 233 and in January 233 hours.

2) Hours required = Nett Production ÷ Standard capacity of the freezing tunnels/hour = Nett Production ÷ 12.

From Figure 2.7 it is clear that at no stage is the plant available capacity realised. The average utilisation of the complete processing facility is given by the following:

$$\frac{1697}{3800} \times 100\% = \underline{\underline{44,7\%}} \quad \text{-----} \quad (1)$$

For this figure to be meaningful it would be necessary to look at detailed capacity planning, but is still indicative of the available capacity.

Further, the calculated figures are based on an engineering availability of 100%. The following efficiencies are used :

- Operating Efficiency (LE) = 80%
- Line Utilisation (LU) = 80%
- Line Availability (LA) = 90% ——— (2)
- Line Effective Utilisation (LEU)

  = 0,8 x 0,8 = 0,64 or 64% ——— (3)

The average facility utilisation is improved to :

$$(1) \div (2) = \frac{\text{Theoretical Utilisation}}{\text{Line Availability}}$$

$$= \frac{0,447}{0,9} = 0,497$$

The LU is considered in the 7,75 effective working hours per shift.

$$= \underline{\underline{49,7\%}}$$

From Figure 2.7 the highest utilisation is 69%. Considering an LA of 90% the actual % utilisation is:

$$\frac{0,69}{0,9} \times 100\% = \underline{\underline{76,7\%}}$$

From this it is clear that there is no immediate danger of realising facility capacity.

If, however, the LA should reduce to 80%, the highest % utilisation would <u>increase</u> to :

$$\frac{0,69}{0,8} \times 100\% = \underline{\underline{83,3\%}}$$

$$\text{an increase of } \frac{(86,3 - 76,7)}{76,7} \times 100\% = \underline{\underline{12,5\%}}$$

3 LITERATURE REVIEW AND THEORETICAL MODEL

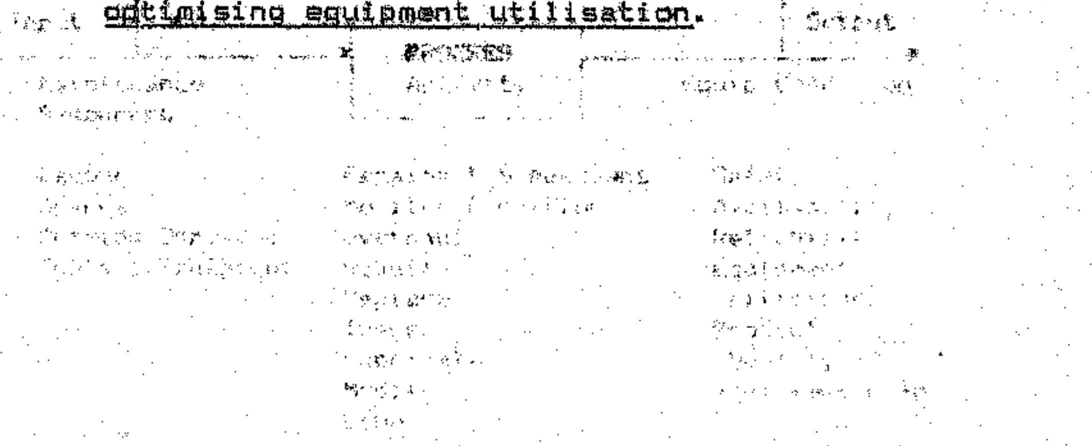
In order to manage maintenance in the Frozen Foods Industry, the following elements are perceived to be important and applicable. The elements were researched and will be discussed extensively in the context of a theoretical model to effect maintenance management.

- The Maintenance Plan
- The Maintenance Organisation
- The Plant Enhancement Programme
- The Maintenance Budget and Cost Control
- Maintenance Quality
- Equipment Replacement Policy

3.1 The Maintenance Plan

3.1.1 The Maintenance Function

Dobson depicts the Maintenance Function as follows:



the highest % utilisation would be reduced to :

$$\frac{0,69}{0,95} \times 100\% = 72,6\%$$

a reduction of $\frac{(76,7 - 72,6)}{76,7} \times 100\% = \underline{5,3\%}$

From this it is clear that plant capacity can be increased not only by purchasing additional capital equipment, but simply by improving the performance of maintenance!

These figures act as a guideline only since it is not always possible to process the full range of products on all the freezing tunnels since their methods of operation differ. This has the effect that at certain times of the year the plant flexibility is low, resulting in certain equipment operating at or near full capacity. <u>It is also clear that improvements in plant utilisation and resulting throughput is not the responsibility of one department only. Every department which interacts with the equipment has the responsibility of optimising equipment utilisation.</u>

3 LITERATURE SURVEY AND THE THEORETICAL MODEL

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- The Maintenance Plan
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3.1 The Maintenance Plan

3.1.1 The Maintenance Function

Dobson [12] depicts the Maintenance Function as follows:

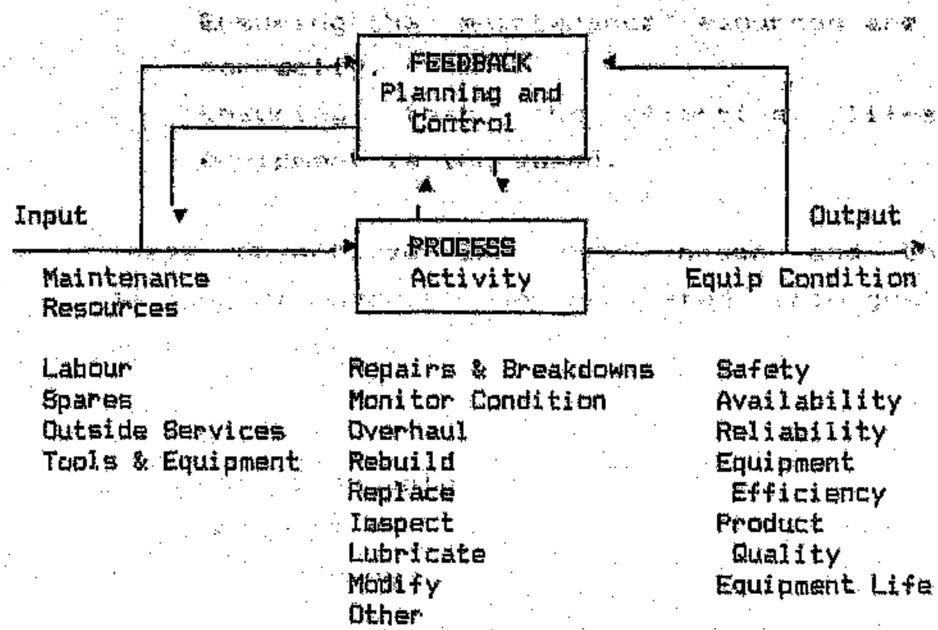


Figure 3.1 The Maintenance Function [12]

Where:

- The output of the maintenance function is some measure of equipment condition. There are a number of parameters which may be measured to establish the effectiveness of maintenance.

- The input to the maintenance function comprise the maintenance resources.
- The process of maintenance could be viewed as the maintenance activities which are carried out to convert the resources into the required output.

3.1.2 The Maintenance Objective

The primary objectives of maintenance have been identified to include :

- Reducing the cost of maintenance per manufactured item.
- Assisting in maintaining product quality.
- Ensuring that plant availability and safety are maximised.
- Ensuring that maintenance resources are managed correctly.
- Ensuring that the effective lifespan of equipment is increased.

These objectives are very broad and to become meaningful need to be translated into goals which are:

- written
- understandable
- measurable
- challenging
- achievable.

These goals must never be established without considering the overall company objectives and the objectives of the departments which make use of the maintenance function. Typical goals may include :

- Limiting annual maintenance expenses to 6% of sales.
- Achieving a plant availability of 90% within one or two financial years.
- Limiting overtime worked to 27% of normal hours worked.
- Achieving an overall artisan utilisation of 80% within one financial year.

This step identifies the expected savings and where they are likely to be achieved. It provides the goals to direct effort and is a measure of whether the goals are being achieved.

3.1.3 Maintenance Strategy

Du Preez[13] gives a definition of strategy that seems to explain appropriately how the solution to maintenance related problems should be approached:
"The process of deciding on the objectives of the organisation (maintenance department), on changes in these objectives, on the resources used to attain these objectives and on the policies that are to govern the acquisition, use and disposition of resources."

Strategy is by definition a means to an end an. may graphically be depicted as follows :

Where we are $\xrightarrow{\text{STRATEGY}}$ Where we want to be

How we are going to get there

Maintenance strategy finds application in two distinct areas in maintenance. Firstly it is a macro strategy which looks at the maintenance function as a whole and considers the elements of maintenance administration:

- Equipment Register/Plant Inventory
- Maintenance Organisation
- Plant Enhancement Programme
- Jobcard System
- Maintenance Information System
- Maintenance Spares Control
- Management of Plant Utilities
- Maintenance Budget and Cost Control
- Reliability Theory
- Maintenance Quality.

Secondly it is a micro strategy in the context of maintenance action, i.e. performing the work. This comes to fruition during the Plant Enhancement Programme when Maintenance Policy is established :

- What must be maintained,
- When must it be maintained,
- Why must it be maintained, and
- How must it be maintained.

The strategy to be followed may be either one or a combination of the following :

- Fixed time interval maintenance
- Condition based maintenance
- On-condition maintenance
- Operate to failure
- Redesign or project maintenance

In setting up the maintenance plan, the elements of the maintenance administration system must be addressed individually to establish how each may be achieved in the context of the overall strategy.

The maintenance actions will be addressed when considering the Plant Enhancement Programme.

3.1.4 Controlling and Enhancing the Maintenance Function

"In order to be in a position to enhance maintenance in any way, we must ensure that the maintenance function is under control. For this reason we must examine the two concepts of Managerial Control and Managerial Enhancement as they involve distinctly different strategies."[12]

Management Control

The managerial function of control is the measurement and correction of performance in order to make sure that the objectives and the plans devised to attain them are accomplished. The basic control process involves three steps :

- Establishing standards
- Measuring performance against these standards
- Correcting variations from standards and plans.

To effect corrections in a continuous manner requires the development and implementation of a control programme.

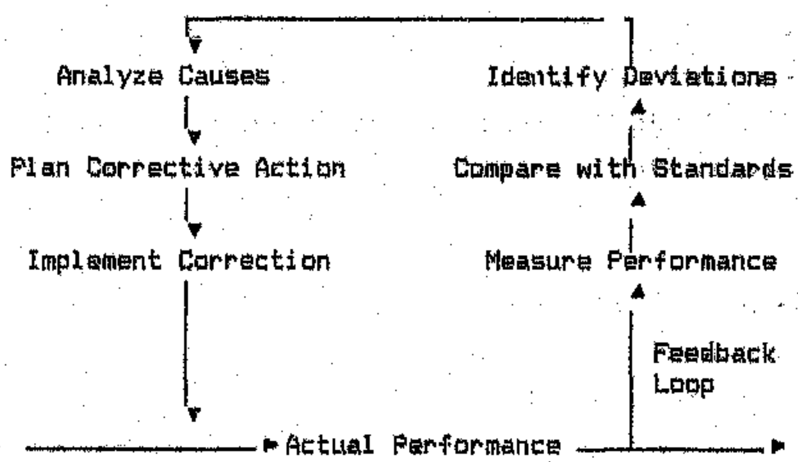


Figure 3.2 The Management Control Loop[13]

"One of the most important ways of tailoring controls to needs for effectiveness and efficiency, is to make sure they are designed to highlight exceptions. In other words, by concentrating on exceptions from planned performance, managers can use controls, based on the time honoured exception principle, to detect those places where their attention is required." [12] It is impossible to focus attention on everything, so it is important to set meaningful standards and react to deviations from those standards.

Management Enhancement

A Plant Enhancement Programme has as its underlying principle the achievement of maintenance objectives i.e. improved maintenance effectiveness measured in terms of plant and equipment condition and maintenance efficiency measured in terms of an improved utilisation of the maintenance resources. This brings us to the concept of Maintenance Productivity.

The effectiveness of maintenance is related to output while efficiency is related to input. The maintenance manager has control over the input and the conversion process while the output is a result of the input and the process. The maintenance strategy is directed at enabling the maintenance engineer or manager to manipulate both the input and process to achieve the desired output (objectives of the maintenance function).

Figure 3.3 below depicts the relationship between managerial control and managerial breakthrough and their individual effect on the achievement of objectives.

"Managerial breakthrough differs from managerial control as an "attack" strategy differs from a "defence" strategy. Where managerial control consists of keeping the actual performance close to the target or standard, managerial breakthrough questions the standard itself." [12] Most enhancement programmes suffer from lack of breakthrough in that the set objectives are not attained. The control system will only detect deviations from the standard and bring about actions which will bring actual performance back to standard.

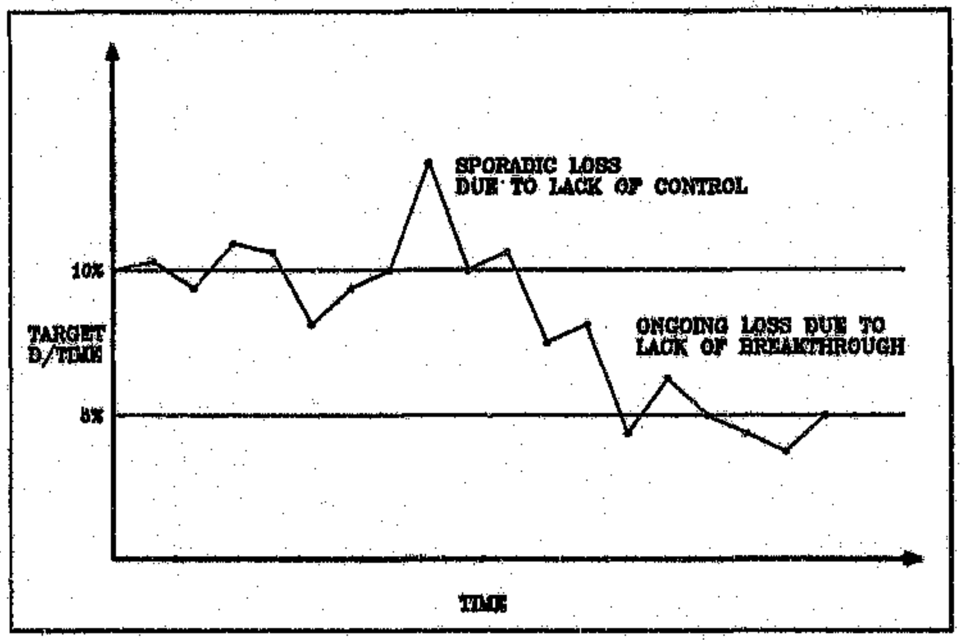


Figure 3.3 Management Breakthrough [12]

The maintenance department in itself will not achieve the improvements required to achieve the company objectives set for maintenance improvement. At best it may achieve 50% of the goal. Managerial breakthrough therefore requires communication across departmental boundaries. The enhancement project necessitates representation from all departments concerned. Managerial breakthrough most often requires a significant change in organisational culture. All too often the implementation of systems only is viewed as all the change required to achieve the objectives.

Systems only may not have the desired result when an enhancement programme is embarked upon. The stumbling block is human resistance to change while the underlying problem is fear of the unknown. To address this problem requires the following:

- good communication - to inform all involved, of what needs to be achieved and how this may be achieved.
- training - to ensure that everyone concerned is familiar with the objectives and aware of any new concepts involved.
- active involvement from all who will work with and interface with the new system and procedures. A sense of ownership must evolve since people will more readily accept things they have helped create.

3.2 The Maintenance Organisation

3.2.1 Basic Concepts

Some of the basic concepts of good organisation are[14]:

1. Establish reasonably clear division of authority with little or no overlap. The division of authority can be functional, geographic, based on expediency, or a combination of all three.

2. Keep vertical lines of authority and responsibility as short as possible. "Stacking", or the use of assistants, should be minimized unless a clear division of duties can be made between the assistant and the assisted.

3. Maintain optimum number of people reporting to one individual. The most effective organisations limit the number of people reporting to one supervisory individual to between three and six. Where the amount of supervision needed is small, or the work supervised follows a general pattern, one man can supervise ten to twelve people.

4. Fit the organisation to the personalities of those involved. Generally, smooth functioning of the maintenance department requires consideration of the personalities making up the organisation. Maintenance is a service organisation and a means to an end, not an end in itself. It serves customers and customer satisfaction must be an objective of each individual in the organisation. To this end maintenance personnel must be carefully selected and trained so that all will work toward achieving the objectives of maintenance.

Local problems which affect maintenance organisation[4]

1. Type of operation:-
   The type of maintenance will affect the type and amount of supervision.

2. Continuity of operations:-
   Using 5-day, one shift operations vs. round-the-clock, 7-day operations affects the size of the maintenance force and the structure of the supervisory organisation.

3. Geographical situation:-
   Maintenance which is effective in a compact plant must be modified to handle a dispersed plant. A plant spread over a large location must be decentralised, which may result in several parallel organisations performing the same type of work at different locations.

4. Size of plant:-
   The size of a plant, as it affects the number of maintenance employees involved, must be considered, primarily to determine the number

of supervisory employees needed. In a small plant it may be necessary to double up on responsibility, using fewer but more versatile people.

5. Scope of the Plant Maintenance Department:-
This is determined by management policy. When many secondary functions are added the number of supervisory personnel will increase accordingly.

6. State of Training and Reliability of Work Force:-
Generally, where the machine-tool industry predominates, skilled craftsmen will be available, and fewer supervisors will be needed. Where lower skilled craftsmen and semi-skilled workers are present the supervision density may be higher.

3.2.2 Maintenance Organisation

Matteis[15] states that although different types of expertise are required, it is essential that the responsibility should rest with one individual. The main services required are mechanical, electrical, refrigeration and instrumentation. In general the bulk of the work is mechanical. Historical figures yield the information on the maintenance time spent by the various disciplines and are shown in Appendix 3.2A.

For this reason a mechanically orientated Plant Eng.neer/Maintenance Manager uhould be the responsible person for the co-ordination and planning of overall maintenance action, while the heads of electrical, refrigeration, instrumentation services, etc., are responsible for technical expertise, work quality and planning as well as the organising of their individual disciplines.

Services such as electrical, refrigeration, civils, boilermaking, vehicle maintenance and machining are normally centralised for the whole site. Since the site is geographically spread out, the plant fitters are decentralised and allocated to area workshops. The advantages of decentralisation in this respect are described by Matteis[15] and include:

- Proximity to plant reduces walking time, which not only improves labour utilisation but also allows for more prompt action as well as being less tiring.

- Small crews, up to 12 artisans, are easier to motivate and control.

- The same people handling the same machinery leads to more intimate knowledge of the equipment and associated problems. A man/machine relationship is developed.

- The same artisans relating to the same operators improve job relations and reduce conflict.

- The engineering supervisor has a better opportunity to implement planning, improvements and quality control.

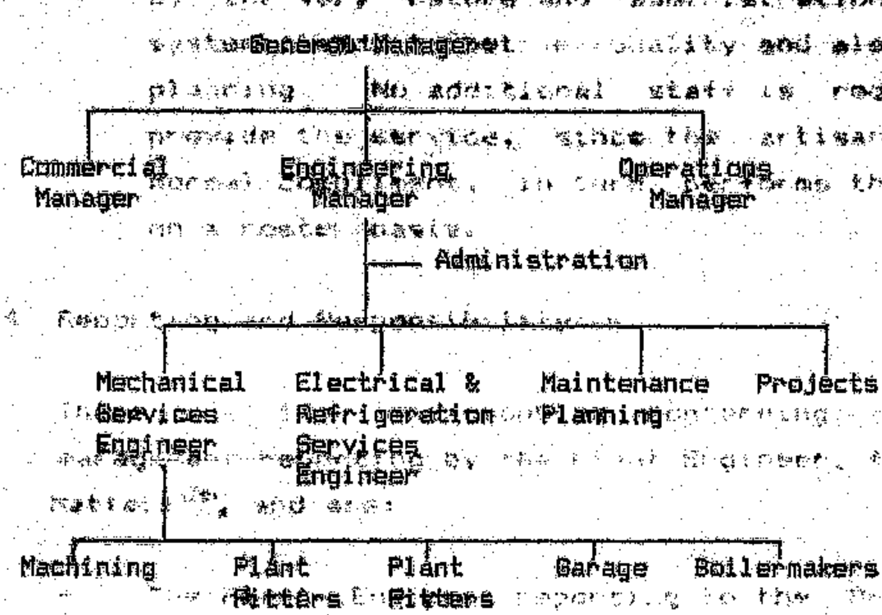


Figure 3.4 The Reporting Structure

3.2.3 After Hours Service

Two alternatives to providing this service exist :

1. **Shift Artisans**

The artisan is readily available on site. This has the disadvantage that the operator does not plan since there is someone to attend to the problems. The quality of work is often poor because of a lack of supervision and interest in the artisan since he is not allocated permanently to one area. Records of night work are often non-existent, because the artisan is invariably instructed verbally, or inadequately. Additional staff is required for providing this service.

2. **Stand-by Artisans**

Where stand-by artisans are used for after hours service, the control, which is enforced by the very nature and administration of the system, leads to better quality and gives better planning. No additional staff is required to provide the services since the artisan of the normal compliment, in turn performs this duty on a roster basis.

3.2.4 Reporting and Responsibility

There are two philosophies concerning the line management reporting by the Plant Engineer, following Matteis[illegible], and are:

- The Plant Engineer reporting to the Production Manager of the relevant section, who has full authority over this particular engineer.
- The Plant Engineer reporting to the Engineering Manager.

1. Reporting to Production Manager

Since the engineers in charge of services will report to an Engineering Manager, this system creates the anomaly that the Plant Engineer will have two bosses, giving rise to conflicting situations. Other disadvantages are that each section operates in isolation and even on technical matters the Engineering Manager has a limited authority. This often leads to problems being solved by compromises in order not to upset the other department. The advantage claimed is that the Production Manager can best decide on priority while communication is direct. Since communication is a matter of personality, if there is a problem in this field it will not be solved by authority and, as far as priorities go, these are in any case always ruled by production requirements. This system creates a situation where responsibility and authority are divided, which is incompatible with sound management.

2. Reporting to Engineering Manager

This system is more consistent and allows for better administration from a technical and disciplinary point of view. The system is much more conducive to the creation of a team spirit amongst the various engineers who can draw from one another's facilities and expertise. The Engineerirn Manager is in a better position to reallocate facilities and labour according to circumstances and priorities. Conflicts are minimised. Interchangeability of staff for leave or sickness relief, stand-by and emergency services are much easier to arrange. The exchange of material and spares is also facilitated and an overall uniform policy is implemented throughout the organisation. This type of organisation naturally does not exclude the direct communication, on the shop floor, between the operating and engineering personnel. The reporting to a single authority is always essential for a more professional execution of any service.

3.2.5 Workshops

The plant fitters should be equipped to perform all the operations which are part of a daily routine maintenance requirement, including a certain amount of welding and rigging. The machine shop, boilermakers, riggers and civil trades will have equipment and labour adequate to handle all work of such size and nature which is not part of a daily routine. A list of equipment and tooling which is basic to the different trades and workshops is in Appendix 3.2B.

3.2.6 Maintenance Planning

Of the key points which can have a profound effect on successful maintenance management, one of the most important is the role of the maintenance planner. His main function is to carry out all the administrative and planning work associated with planned maintenance but realising that the action remains the responsibility of Engineering Management.

- Having a maintenance planning department does not imply a planned maintenance system. The responsibility for successful planned maintenance rests with Engineering Management. The maintenance planner "keeps the score".

- Foremen must not receive orders from planners but from the engineer.

The size of the Maintenance Planning Department

Its size depends upon :

- Level of Planned Maintenance
- Size and Complexity of the Plant
- Number of items of inventory
- Geographic spread of the plant
- Level of Computerisation
- Level of Condition Monitoring.

A general guideline as to the size of this department is provided by PE Corporate Services[44];

- One full-time planner and one clerk for a plant employing 20 maintenance artisans.
- Two full-time planners and two clerks for 50 maintenance artisans.
- Three full-time planners and three clerks for 90 artisans, and so on.

These numbers relate to the staff requirements for operating a planned maintenance system. To develop and implement a system will require more people. The additional number of people is based on how quickly the planned maintenance system must be developed and implemented.

The duties of the Maintenance Planning Department

- Maintaining an up-to-date inventory, which includes:
    - Ensuring that all items of equipment are physically numbered.
    - Incorporating new plant items into inventory.
    - Ensuring that the plant inventory and the asset register contain the same information.
- Preparing maintenance schedules together with the maintenance foremen and the engineers.
- Planning and issuing of maintenance schedules and discussion with the foremen and the engineers.
- Keeping track of outstanding workload.
- Planning periodic shutdowns.
- Maintaining accurate and relevant machine history records.
- Ensuring that systems and procedures are being followed correctly; revising and updating them when necessary.
- Preparing management information about the performance of the maintenance department.
- Training of new employees in the use of the planned maintenance system.

The qualification of a Maintenance Planner

- Should be a qualified tradesman.
- Approach to all people should be tactfu' and diplomatic.
- Should have respect of engineering personnel.
- Should want the job.
- Should be able to work methodically and systematically.
- Should be appointed at outset of a new programme.
- Should be paid according to responsibilities.
- Should be properly trained in the principles of planned maintenance.

3.3 The Plant Enhancement Prog

No maintenance departmen. ist without maintenance personnel. Any y operating equipment will have some form of maintenance organisation. This does not mean that a planned maintenance system or work administration system is in place. Maintenance administration is made up of the following elements :

MAINTENANCE ADMINISTRATION SYSTEM

MAINTENANCE ORGANISATION

WORK ADMINISTRATION SYSTEM

- Jobcard and Job Administration System
- Job Time Estimating
- Setting of Priorities
- Equipment Register/Plant Inventory
- Maintenance Management Information System

PLANNED MAINTENANCE SYSTEM

- Equipment Selection
- Equipment Analysis
- Failure Mode, Effect, Criticality Analysis
- Maintenance Policy/Strategy
- Task and Frequency Analyses
- Legal Tasks, Services and Lubrication
- Task Grouping

MAINTENANCE QUALITY

MAINTENANCE BUDGET AND COST CONTROL

EQUIPMENT REPLACEMENT POLICY

The maintenance organisation has been discussed in detail. The Plant Enhancement Programme (PEP) will focus on the system required to Plan, Measure and Control maintenance resources and the maintenance activity. The PEP has as its objective :

"The cost effective performance improvement of existing plant and equipment." [17]

It covers the following elements :

- Jobcard and job administration system
- Equipment Register/Plant Inventory
- Maintenance Management Information System
- Planned maintenance programme and administration

3.3.1 Jobcard and Job Administration System

"The maintenance manager or plant engineer begins to obtain the control necessary to genuinely manage maintenance when a work order system is put into effect." [18][19]

"The key to effective work administration is a first rate Job Card System." [12]

"An important module in the Maintenance Management Information System is concerned with the active, inactive and completed work orders." [20]

Nolden [19] states that :

"Work order control is the basis of the total maintenance information system, which includes interface with inventory, purchasing, and payroll." This interface is shown in Figure 3.5 below.

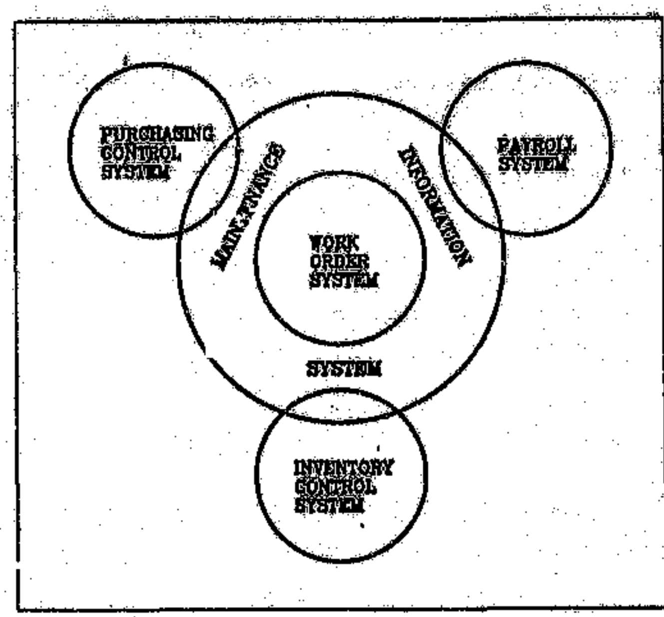


Figure 3.5 Interface of Work Order System with Other Functions[18]

It is clear that no Planning and no Control in the maintenance environment can be successful without a Work Order System. It provides quantifiable feedback on overall maintenance performance, labour and equipment cost, and equipment history. A properly structured Work Order System should do the following:

- Provide a written request for maintenance work.
- Provide a written record of what was done, by whom and how long it took.
- Define and scope each job whether it is breakdown, PM, Project or other work.
- Authorise work to be done.
- Assign job priorities so that the most important work gets done first.
- Make it possible to plan and schedule work.
- Capture labour cost on each job.

- Record use of special tools and materials.

- Provide a written instruction to the artisan.

- Measure performance and efficiency of labour force.

- Provide data to analyze maintenance cost and maintenance history by job, equipment and cost centre.

- Enable the calculation of the outstanding workload per trade and operating section.

There are four basic rules which are essential to the success of the jobcard system [14]:

- One document should be used for all types of maintenance work. Using different documents for different work only confuses the staff by making it more difficult to get the system working properly.

- Heavy paper should be used for the copy of the jobcard which reaches the artisan.

- Only one man should ever work on one jobcard. This makes planning simpler and allows for accurate costing.

- All jobs done by every artisan must be covered by job cards. This is essential for history records, workshop planning and costing.

Designing the Jobcard

Smaller, pocket-sized forms are the most convenient to carry and use; therefore the most likely to be used properly by supervisors and craftsmen. The jobcards are usually bound in books of fifty. There are three (3) copies of each jobcard, the first two are flimsy copies and self carboning. The last copy is of heavy paper.

Nolden[illegible] summarises the basic information to be collected as follows:

Purpose		Information Requested
To define the job	-	A unique job number
	-	Equipment number, description, and location
	-	Account number
	-	Budget/Project number
	-	Priority code
	-	Type of work code
	-	Work requested
Planning, Scheduling, Control	-	Labour estimate
	-	Material estimate
	-	Job plan
	-	Total estimated cost
	-	Approvals
Control, History	-	Actual labour cost
	-	Actual material cost
	-	Actual work done
	-	Failure codes

The information required above is all encompassing and its use will depend on the type of organisation. Most often the organisation runs a costing system in parallel to the work administration system and it becomes unnecessary to capture material and spares cost on the jobcard.

Jobcard Format

Appendix 3.3A Figure 1 shows the front and Appendix 3.3A Figure 2 the back of a jobcard together with the general layout and information required effectively to perform work administration.

<u>The Jobcard Procedure</u>

1. The originator, any person requesting work, fills in the work request. During normal working hours when the maintenance foreman is on site, or when requesting work other than the repair of a breakdown, the jobcard book is forwarded to the maintenance foreman who will sign the jobcard book, enter the time received and detach the perforated copies. When there is no maintenance supervision, or in the case of a breakdown, the jobcard book may be forwarded directly to the artisan on shift.

If required, the maintenance foreman will write out the job instruction and post it either the Foreman's Control Cabinet, shown in Appendix 3.3B Figure 1, or directly to the Artisan Loading Board, shown in Appendix 3.3B Figure 2. The second flimsy is retained by the foreman as a control to ensure that issued jobcards have been returned and consolidated with the retained flimsy.

3. The artisan collects the jobcard and will request the foreman to write out and sign any requisitions for spares and material required.

4. On completion of the job the artisan enters a short description of the work done and important spares used. With ease of use in mind the information supplied must be to the point to allow the maintenance planner to capture the essence of the work done on a history summary card or in a computerised database. The artisan also fills in the time spent and signs the jobcard.

5. The jobcard is returned to the foreman who will satisfy himself that the job was completed

satisfactorily before signing it off. The jobcard is returned to the originator for final approval.

6. Once per week the maintenance planner will collect all jobcards and record the data required.

Currently we are faced with a powerful new philosophy, namely World Class Manufacturing (WCM). Of the three cornerstones of WCM, two are related to the maintenance function namely Total Preventative Maintenance (TPM) and Total Quality Control (TQC). Since we should continually be striving to eliminate poor quality and ensure customer satisfaction, we have a quality assurance document in maintenance, the jobcard, which goes a long way toward assisting us in achieving this objective.

If we ensure that instructions are issued clearly, artisan feedback on the job report is done correctly and that the interested parties sign the jobcard when the job has been completed to the satisfaction of all, we ensure that the feedback loop is complete and we are provided with timeous information to allow adjustment of our own system if negative deviations exist or occur.

This jobcard procedure is graphically depicted in Appendix 3.38 Figure 3. The outlined procedure is a general one and my be adapted to suit the particular factory or maintenance policy.

Job Time Estimating

To Plan and Control maintenance work it is essential to have an idea of how long each task is going to take to complete. It is therefore necessary to estimate job times for :

- Maintenance schedules and checklists

- All work requests not attended to immediately.

This enables planning to estimate the outstanding workload for each workshop and eventually to provide the engineer with the information necessary to effect longterm planning of manpower requirements.

The two methods most often used are :

- Analytical Estimating, where :
  - the job is broken down into elements
  - the time to complete each element is estimated
  - element times are added together to give the overall job time
  - allowances are made for rest, preparation, etc.

- Comparative Estimating, where :
  - a range of similar jobs are analyzed to determine the time for completion
  - these jobs are used as "benchmark" jobs and any jobs requiring estimating are compared to these "benchmark" jobs.

Job Priorities

To ensure that the "most important" jobs get done first requires an objective priority rating system for the planning and scheduling of maintenance work.

It is possible to develop one's own system but Nolden[18] discusses systems which may be applied with relative ease and little or no adjustment. The setting of priorities may be done using multiplier systems or straight numeric systems. The systems considered below fall into the category of multiplier systems :

1. Relative Importance of Maintenance Expenditures (RIME)

   - Uses two scales. One to rate machinery, buildings or equipment and the other to rate categories of maintenance work.
   - For machinery and equipment on a scale of 1 to 10, 10 being the highest rating.
   - For category of work on a scale of 1 to 10, safety and breakdowns are rated as a 10.
   - The priority index is obtained from the product of the two ratings. The highest rating is always given to work most important to production and will be the job to complete first.

2. Need Urgency x Customer Rank x Equipment Criticality (NUCREC)

   - Three scales are used each ranging from 1 to 4, 1 considered the highest rank:

     1 = Emergency,
     2 = Downtime,
     3 = Routine Work,
     4 = Convenience.

   - Need urgency scale:

     1 = Emergency,
     2 = Downtime,
     3 = Routine Work,
     4 = Convenience.

   - Customer Ranking scale:

     1 = Top management,
     2 = Production with direct revenue implications,
     3 = Middle Management, R+D,
     4 = Others.

   - Equipment Criticality:

     1 = Utilities and Safety Systems,
     2 = Key equipment with no backup,
     3 = Impact on morale or productivity,

Little use or reflection output

The most important job is one with the highest rating.

A job might require a change in priority and the Need Urgency rating may be changed to reflect this.

3.3.2 Equipment Register/Plant Inventory

Maintenance departments have to look after many items of plant and equipment. It is essential to know how many items there are and what they are. For this purpose it is essential to develop the Equipment Register, which is a list of all items of plant that are the responsibility of the maintenance department. This differs from the Asset Register which is a list of all the company assets and is designed and used for accounting purposes. To make equipment easily identifiable and allow the work administration to function properly, requires the development of a comprehensive and logically constructed plant numbering system[14]. The choice of a numbering system ultimately determines the power and flexibility of the Maintenance Management Information System[12].

A number of departments have an interest in the equipment namely :

- Maintenance
- Operations
- Accounting
- Stores (Spares and material)

The key link between the departments is the equipment itself. The equipment register or plant inventory forms the basis of the management system and the link between departments.

Careful attention should be paid to the following points when deciding upon a plant numbering system[14]:

- Wherever possible, it is wise to develop a hierarchical numbering system based preferably on the location of the equipment. A simple and effective numbering system commences with the production cost centre number as an indication of plant location.

- The plant numbering system should be used only to indicate the plant number and should be as short as possible. Seven digits is usually considered to be a reasonable maximum.

- Obtain the input of all users of the eventual information. The numbering system must provide all the requirements of maintenance management and fit easily into existing procedures.

- In the control of expenses it is often important to control at equipment level, a higher level of similar pieces of equipment or equipment logically grouped or a higher level still of equipment grouped by manufacturing or processing department or unit. The plant number must provide for this by simply allowing for summarizing by a different field within the number.

3.3.3 Maintenance Management Information System (MMIS)

<u>Identifying the MMI requirements</u>

Versteeg [23] states :

"Recorded and processed data can be used for a lot of reasons. The most essential uses, however are in the areas of planning and controlling.", and summarises the interaction of the MMIS and the control loop as follows :

The measurement of performance and comparison to standards only indicates that a problem does exist.

Analysis of the problem requires a much lower level of information. To perform an analysis with ease depends to a large extent on

- accessibility of source information
- summarised data at various levels
- format of the data and information.

To attempt to analyze the deviation is an attempt to analyze the symptom of the problem. The first step of the analysis is to determine the root cause of the problem. This will probably require further analysis of information as well as in-depth investigations. Unless the manager has time or the assistance to carry out this analysis, the final step to control (corrective action) does not take place. It is in the area of analysis and corrective action where the control cycle normally breaks down.

Maintenance management information is taken from the following sources:

- operational downtime log sheets
- outstanding job cards
- completed jobcards
- stores transactions
- time sheets

From this it is clear that to have a clear and accurate picture of how well the system is performing requires an analysis of :

- resources
- work (activity)
- equipment performance

In this section I will deal with the resource conversion process and the equipment performance while the resources will be covered extensively in the section on Budget and Cost Control although it forms an integral part of the MMIS.

"The amount of work accomplished y the maintenance function is no guide to the worth of the maintenance staff, or to the effectiveness of the service the function performs." [22]

Operational and cost objectives define the two main performance areas that must be assessed to determine the effectiveness of the maintenance function. To achieve its ob.ectives the maintenance function needs to emba.k on the Plant Enhancement Programme while the effects of good maintenance and the results of the PEP are determined from an assessment of the improvement in the objectives.

The elements that require assessment and the parameters that need to be monitored are depicted in Appendix 3.3C and follow the guidelines provided by Stapelberg[22], Wakefield[25] and Carroll [48].

Performance Parameters

Each of the parameters to be measured will be discussed with, wherever applicable, a possible explanation on root causes for poor performance.

1. Maintenance Function Operating Efficiently

Time Re overy (Manpower utilisation)

$$= \frac{\text{Total Hours Booked to Jobs}}{\text{Total Hours on Site}}$$

This is calculated for the artisans in each workshop. It is possible to achieve a time recovery of 90-95% for mechanical workers, 78-85% for electrical workers. When implementing the maintenance syutem these figures may be lower. Recoveries below these figures may be due to:

- Jobcards lost. Importance of work feedback should be continually brought to the attention of the workforce.

- Inadequate workshop planning. Artisans stand around waiting for work. Use the planning boards.

- Shift artisans not expected to do anything but repair breakdowns. This depends on management policy.

- Incorrect booking of time to jobs. Often done to impress the foreman.

- Incomplete jobs. Incomplete jobcards are carried over from one control period to the next.

- Outstanding work not fully documented. Artisans stand around idle because no-one is aware of outstanding work.

- Private jobs.

- Stealing time. The artisan slips away without clocking out. Same as theft.

- Insufficient work. Too many artisans.

Time recovery must be approached cautiously and we must ensure that root causes are analyzed properly before any decisions are taken. Foremen may feel obliged to start booking excess time on jobcards to compensate.

Outstanding workload (work order turnover). This parameter may be calculated in two ways. If job time estimating is done:

$$= \frac{\text{Total Hours Outstanding Work}}{\text{Total Manhours Available/week}}$$

Common practice is to establish an average target of two weeks per workshop.

Another measure is the ratio of work order turnover:

$$= \frac{\text{Number of Jobs Completed}}{\text{Total Number of Jobs on Request}}$$

Reasons for consistently low workload:

- Outstanding jobs not recorded on jobcards
- Outstanding jobs not being estimated
- Estimates not recorded
- Workshop overstaffed

Consistently high workload:

- Workshop productivity low
- Completed jobs not recorded
- Workshop understaffed

<u>Plant/Equipment Performance</u>

Frequency of breakdowns is a measure of equipment reliability (Mean Time Between Failures MTBF):

$$= \frac{\text{Total Shift Hours Less Planned Stoppages}}{\text{Number of Breakdowns}}$$

Proportion of time (Non-availability of equipment) lost through breakdowns:

$$= \frac{\text{Total Actual Time for Breakdowns/Defect Stoppages}}{\text{Total Shift Hours Less Production Stoppages}}$$

Equipment availability:

$$= \frac{\text{Total Shift Time Less Total Downtime}}{\text{Total Shift Time}}$$

Equipment utilisation:

$$= \frac{\text{Total Operational Time}}{\text{Total Shift Time}}$$

Equipment capitalisation:

$$= \frac{\text{Total Equipment Utilisation}}{\text{Total Equipment Availability}}$$

Equipment Availability is one of the indicators that probably attract the most attention since everybody is immediately notified when a machine goes down and becomes unavailable for production. Following Collacott[23] and Bradley[24] availability provides a measure of how available assets are by incorporating both the time-in-use and the time-off for equipment in the following way:

$$\text{Availability} = \frac{\text{Time in use}}{\text{Total Time Required For Production}}$$

$$= \frac{\text{Time in use}}{\text{Time in use + Time to Repair}}$$

$$= \frac{\text{MTTF}}{\text{MTTF + MTTR}}$$

Where MTTF = Mean Time to Failure

MTTR = Mean Time to Repair

This may be used as a measure of the <u>total maintenance activity</u>:

- Diagnostic time
- Strip down time
- Replacement time
- Re-assembly time
- Commissioning time

thus allowing optimisation of each of these elements to increase equipment up-time, or as a measure of management effectiveness:

- Spares availability
- Training
- Manning levels.

It is difficult to generalise about equipment availability but it has been suggested that most modern equipment should be able to sustain at least 95%. For single items of plant as used in manufacturing or with facilities with high equipment redundancy this figure is also a measure of plant availability. In the production or process industry where plant availability is a function of the availability of a line of several items of equipment each with its own availability, the plant availability is calculated from the product of individual availabilities or series availability. Series availability states that the line is down if any item is down. With an individual availability of 95% each, and four items series connected, the plant availability changes to:

$$0,95 \times 0,95 \times 0,95 \times 0,95 = \underline{0,81}$$

This is a true reflection of what can be expected and must be borne in mind when budgeting throughput. Contributors to low plant availability will include the following:

- Undermaintenance
- Overmaintenance
- Inadequately trained maintenance or operating personnel
- Machines inadequately specified, designed, built, installed
- Machines overloaded
- Lack of availability of spares
- Sabotage

2. <u>Assessing Management Proficiency of the Maintenance Function</u>

<u>Maintenance Planning</u>

Routine maintenance completion:

$$= \frac{\text{Total Hours on Scheduled Maintenance Jobs}}{\text{Total Hours Planned for Scheduled Maintenance Jobs}}$$

or

$$= \frac{\text{Total Number of Schedules Completed}}{\text{Total Number of Schedules Issued}}$$

The target should be 100% and not lower than 95%. Reasons for lower returns :

- Too many breakdowns. The artisan is too busy repairing breakdowns to carry out the schedules
- Modifications done at the expense of maintenance jobs
- Production staff not making machines available for scheduled maintenance
- Too many schedules
- Bad schedules
- Lost schedules
- Inadequate workshop planning
- Lack of interest from engineering personnel
- Shortage of staff

Care must be taken to ensure that schedules are not just ticked off in the office; this requires the engineer or foreman to do checks to ensure that schedules have been completed correctly.

Work by category :

Measures the percentage/proportion of the total time spent on different categories of engineering work.

- Breakdowns
- Maintenance
- Modifications
- Capital Work
- Safety

The NPI[18] provides the following target for the maintenance mix:

Preventive	58%
Repairs	21%
Projects	21%

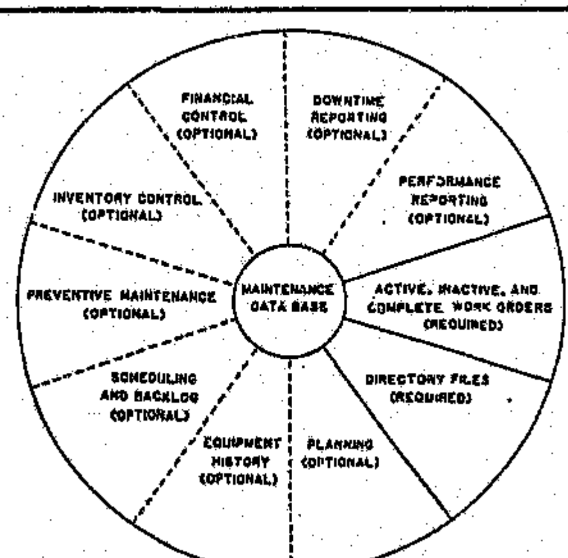
while general targets are 15-20% on scheduled maintenance and 15-20% on breakdowns.

To be truly effective these indices should :

- be easy to read and understand
- be concise and relevant
- be completed regularly
- show trends and highlight variances
- show initial and target performance while their impact can be heightened by preparing the information graphically.

Computerised Data Capturing

Maun et al[20] writes that recent studies have shown that there are in excess of 102 software packages to perform various aspects of plant maintenance. The application of Computer Aided Maintenance Management (CAMM) ranges from simple microcomputer-based systems to comprehensive mainframe-based systems. There are a number of hardware suppliers who are interested in marketing software and a number of software packages which will only run on certain hardware. Do not get off the beaten track. It is a very expensive exercise to purchase a sophisticated, matched hardware/software system which is totally inflexible and more often than not ends up not getting used. Many programmes initially driven by huge mainframe systems have been replaced by PC driven systems[24].
The MMIS consists of all the information required by each level of management. The information may be grouped into specific modules and at the outset it is not necessary to purchase or develop a computerised system capable of addressing all the modules. The all encompassing maintenance data base is depicted in Figure 3.6 showing the modules which are required and those which are optional and may be added in time.



All encompassing maintenance data base.

Figure 3.6 Computer Aided Maintenance Management[20]

Benjamin et al[25] writes that a survey among companies interested in CAMM, showed that general applications software packages for microcomputers were very popular due to their relatively low cost. These packages are readily available and the maintenance manager must consider the option of developing a collection of these packages to suit his needs. Another alternative in the development of CAMM is the adaption of general application software (Lotus 1-2-3), which most often includes features for:

- word processing
- spreadsheet analysis
- graphics
- database management.

Bought, comprehensive systems are expensive to acquire and install and often require further modification to give the user what he wants. The system is often inflexible and serious consideration must be given to developing a unique system suited to company needs.

3.3.4 Planned Maintenance Programme and Administration

Versteeg[26], Moubray[1], Fogel[27] and Pratt[28,29] all indicate that, until recently, it was assumed that the best form of maintenance was systematic plant overhauls with equipment or components replaced on the basis of an assumed or proven hard life. All that was required was to accumulate sufficient data and replace the component before the calculated average life was reached. This approach is, however, only applicable to simple items of equipment or equipment with a dominant failure mode.

The move is away from a simple Scheduled Maintenance Programme to a Planned Maintenance Programme. The implementation of a Planned Maintenance Programme requires a structured approach as depicted in

Appendix 3.3D. This model has been adapted from one provided by PE Corporate Services.[36]

Equipment Selection Analysis

The cost of a project, depending upon the plant size, will be high whether utilising own personnel or outside consultants. The decision to follow this route is an economical one and the cost of the project must be offset against the benefits of less downtime, lower maintenance expenses and better utilisation of equipment and labour. In plants operating with high levels of downtime the benefits of a maintenance programme are self evident and management will easily be convinced of the need to spend the money. In plants operating at lower levels of downtime and in the current economic recession, management is hard pressed to reduce cash outflow. The maintenance engineer or maintenance manager is already faced with reduced manpower, pressure to reduce expenses, improve productivity and further reduce plant downtime. To ensure that any programme is successful requires of the engineer to :

- identify the areas requiring attention
- prioritise these areas or items of equipment
- proceed with the programme, focusing on the most significant plant or equipment.

The Pareto principle must be applied since, in general, it has been found that approximately 20% of all the maintenance problems in an organisation generate about 80% of the losses.

At some plants records are limited to daily operational logs or shift reports while elsewhere detailed reports and maintenance records are kept. This information may be supplemented by plant tours, discussion with operations personnel and maintenance personnel. The analysis is primarily concerned with the main factors affecting plant performance:

- Availability/Utilisation
- Production Rate
- Product Yield
- Cost.

Gibson[17] gives an example of an analysis on a power station and is graphically depicted in Figure 3.7.

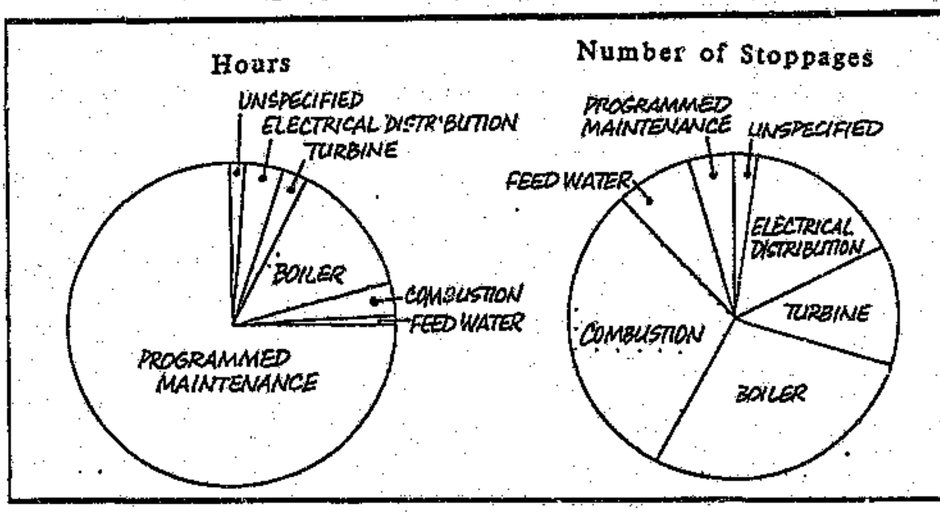


Figure 3.7 Downtime Analysis[17]

The downtime analysis shows that apart from scheduled maintenance, the boiler seems troublesome. However, further analysis in terms of the number of stoppages shows that combustion problems are disruptive. Attention can be focused where it will have greatest impact.

Equipment Analysis

Plant and equipment exist to perform a certain job, i.e. they have a specific function. Maintenance has the responsibility of ensuring that the equipment carries out the function and plant output is a measure of the success with which the plant carries out its function. Versteeg[26] indicates that the obvious place to start considering the maintenance requirements of an item of equipment is by defining its functions. The inability of an item of a plant to perform its intended function is termed a Functional Failure. To fully define the overall failure of an item of equipment requires:

- identifying the significant components of the item. This requires a logical breakdown of the item into significant components. This breakdown may follow the product flow through the equipment or be in terms of assemblies or sub-assemblies of the equipment. The identification of significant components may be done following a modified Fault Tree Analysis (FTA)[24][47] or Equipment Assembly Tree (EAT)[30]. These two methods are graphically depicted in Appendix 3.3E.

- identifying all of the functions of each significant component separately. It is only in these functions that the functional failures can be identified.

The following is an example of such an analysis:

Equipment	:	Conveyer System
Functional Components	:	1. Conveyer Drive 2. Tensioning Device 3. Belting 4. Pulleys (head & tail) 5. Idlers 6. Feed hopper
Functions	:	1.1 Drive Belt 1.2 Move Load 1.3 Return Load when Stopped | | 6.1 Channel Flow to Slide Gate 6.2 Contains Material
Functional Failure	:	1A Belt Stops 1B Conveyer cannot take load 1C Conveyer runs back | | 6A No product flow 6B Material spillage occurs

Reliability Centred Maintenance (RCM)

In 1978 F. Stanley Nowlan and Howard F. Heap[31] published a book, "Reliability Centred Maintenance" which was the result of experience gained in the maintenance of civil transport aircraft over more than twenty years. RCM is a maintenance concept which combines several well established principles and presents a logical and structured manner to analyze equipment and develop applicable maintenance programmes. It answers the following questions :

- what must be maintained?
- why must it be maintained?
- how must it be maintained?

Moubray[4] indicates that in the management of maintenance we are striving to integrate the classical theories of maintenance with issues relating to safety, operating economics, plant design, spares management, reliability theory, equipment criticality and condition monitoring. A technique for integrating all of this lies in RCM.

Failure Mode Effect and Criticality Analysis (FMECA)

The concept of Function and Functional Failure has been defined and discussed in the context of significant components. The ability to identify a functional failure or potential failure depends on :

- clear definitions of the functions of items as they relate to the equipment or the operating context in which the items are to be used

- a clear definition of the conditions that constitute a functional failure in such a case

- a clear definition of the conditions that indicate the iminence of this failure.

Failure Modes

A functional failure may be due to a number of different reasons, designated failure modes. It is the manner in which the functional failure occurred. An example is the conveyer feed hopper which fails when material spillage occurs. This failure may be the result of the flange bolts failing, the casing corroded or the casing worn. The most likely failure modes must be identified for maintenance purposes.

Failure Effects

A short summary of the effect of the failure is added to assist when making a decision about an applicable maintenance task. The questions generally considered are:

- will the operating personnel know that a failure has occurred or is the failure hidden?

- how will be failure become evident?

- are there any safety consequences resulting from the failure?

- what maintenance action will be required and how long will it take?

- what possible secondary damage may result from the failure?

- what precautionary measures may be taken if repair cannot be effected immediately?

- what is the probability of such an event occurring?

The aspects of Function, Functional Failure, Failure Mode and Failure Affect are addressed using the Information Worksheet shown in Appendix 3.3F.

Maintenance Strategy

Equipment Failure Patterns

One of the underlying assumptions of maintenance has always been that there is a direct link between the amount of scheduled maintenance and operating reliability. This assumption was based on the belief that because mechanical parts wear out, the reliability of any equipment is directly related to operating age. It followed that to reduce the likelihood of failure, an increase in the frequency of overhauls was required. Studies based on the analysis of failure data suggested that maintenance based on hard-time policies were, apart from their expense, ineffective in controlling failure rates. The reason was not because intervals were too long or that inspections were not thorough, but rather because, contrary to expectations, for many items the likelihood of failure did not, in fact, increase with operating age.[24] Nowlan[31] found that only 11% of items, in fact, benefited from scheduled maintenance while 89% followed different failure patters, none of which showed wearout with operating age. Age-Reliability Patterns are shown in Appendix 3.3G.

The differences in failure patterns hold the key to maintenance strategy. This aspect has led the move away from trying to find often non-existent fixed time intervals for Scheduled Maintenance to the concept of Planned Maintenance where the most appropriate maintenance task is identified. Since it is the objective of maintenance to ensure that equipment is available when required by the operating personnel, there is an increasing trend toward <u>inspection procedures</u> designed to identify potential failures, and to initiate action before a functional failure occurs. The concept of "P-F" time is depicted in Figure 3.8 below.

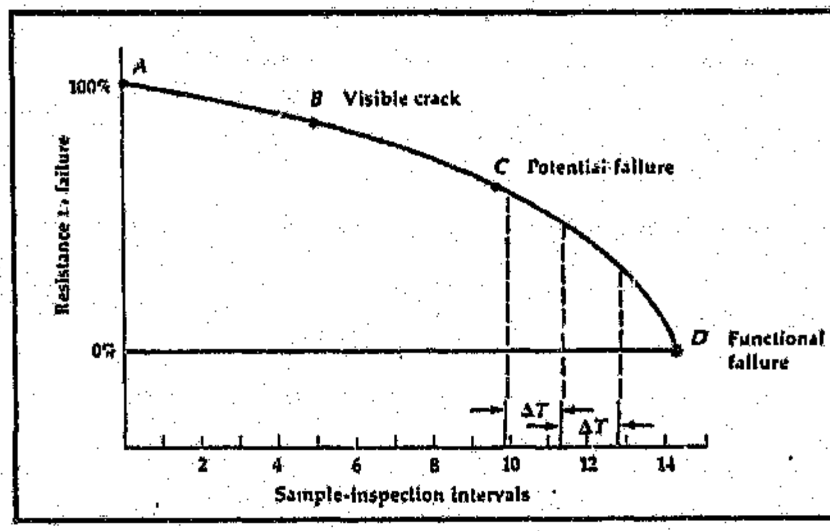


Figure 3.8 "P-F"-Time Plot

The interval between a potential failure and a functional failure is denoted as the "P-F" time.

Reliability Engineering

To be able to establish a failure pattern for an item requires an understanding of Reliability Engineering and the associated definitions and concepts which govern the acquisition and analysis of data. The theory discussed below has been taken from the works of Bradley[24], Churchley[32], Beasley[33] and Britz[34]. Since the nomenclature of reliability engineering is not yet standardised the symbols will be defined as and when they are used and generally follow the guidelines provided by Bradley[24].

Reliability, expressed graphically, is a plot of the relative frequency of survival to operating time. Relative frequency being the ratio of the no. of items surviving to the total no. of items which started the test, at a specific operating time.

$$\text{Reliability at time t} = R(t) = \frac{\text{Number surviving at time t}}{\text{Number of items when time} = 0}$$

or R(t) = Probability of the item working at time t.

In contrast to Reliability we have <u>Unreliability</u>.

Unreliability: F(t) = Probability than an item will fail before time t.

The number of surviving items plus the number of failed items constitute the total number of items which started the test. Thus, relative to the total number of items, the proportion of surviving items plus the proportion of failed items constitute the whole, and since R(t) and F(t) are both defined as proportions, then:

$R(t) + F(t) = 1$

Graphically, the concepts of Reliability and Unreliability are shown in Figure 3.9 below :

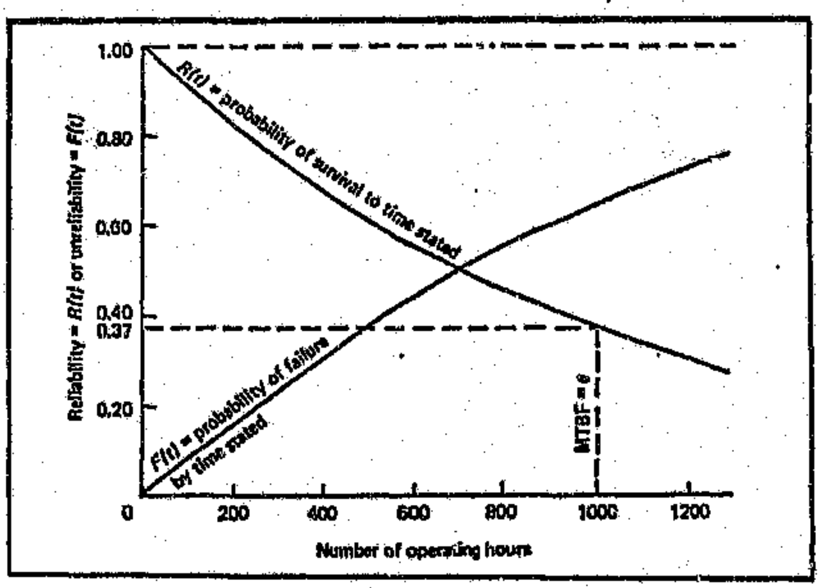


Figure 3.9 Plot of R(t) and F(t) vs Time [24]

The probability of failure in a given time interval t1 to t2. Can be expressed as R(t1) - R(t2). The <u>failure rate</u>, Ø(t), is the rate at which failures occur in the interval t1 to t2.

$$Ø(t) = \frac{R(t1) - R(t2)}{(t2 - t1)R(t1)}$$

The instantaneous failure rate, or hazard rate, z(t) is defined as the limit of the failure as the interval length approaches zero. A constant failure rate, which corresponds to Ø(t), is often called lambda (λ). A constant failure rate simplifies the mathematics of reliability engineering. Often z(t) is not constant all over t but is constant within certain limits of t.

The <u>Failure Probability Density Function</u>, f(t) may be defined as follows :

$$\int_{t=0}^{t=\infty} f(t)dt = 1,0$$

The area under the f(t) curve is unity or 100% since all items will fail eventually. The f(t) curve can be divided into regions of F(t) and R(t):

$$\int_{0}^{t} f(t)dt = F(t) \qquad \int_{t}^{\infty} f(t)dt = R(t) \qquad F(t) + R(t) = 1$$

This is depicted graphically in Figure 3.10 below:

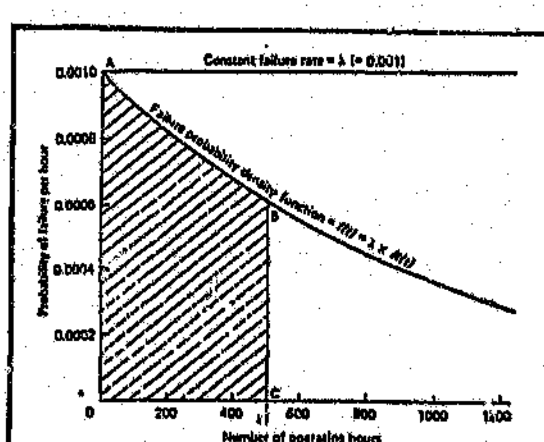


Figure 3.10 Failure Probability Density Function

The different sections of the classical "Bath Tub Curve", Figure 3.11, can now be analyzed in terms of the above theory.

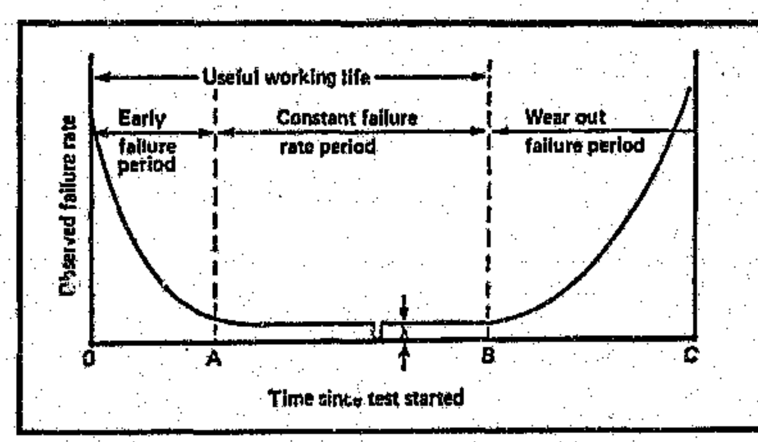


Figure 3.11 "Bath Tub Curve" of Hazard Rate z(t) [24]

Failures in the first region are due to manufacturing and design faults. In the second region failures occur at a low rate, at random and from causes such as accidents. In the final period, failures occur mainly from components wearing out. Although components within an item may show wear, the item generally follows a constant failure rate.

If it is assumed that the time to failure is described by an exponential density function, then

$$f(t) = \frac{1}{\theta} e^{-t/\theta}$$

where: θ = Mean Life
t = Time period of interest

Now Reliability at time t can be expressed as:

$$R(t) = \int_t^{\infty} \frac{1}{\theta} e^{-t/\theta} dt$$

$$= e^{-t/\theta}$$

Mean life = arithmetic average of the lifetimes of all items considered and for the exponential function the mean life is equivalent to the mean time between failures.

Then: $R(t) = e^{-t/M}$
$= e^{-\lambda t}$

Where: $\lambda = \dfrac{\text{Number of failures}}{\text{Total operating hours}}$

M = Mean time between failures (MTBF) $= \dfrac{1}{\lambda}$

Failure Consequences

The evaluation of failure consequences and maintenance strategies are facilitated by a decision diagram technique. This involves a specific sequence of decision questions requiring a "yes/no" answer in each case. Where the information to make a specific decision is not clear, a default answer specifies the action that will best protect the equipment until there is a basis for a better decision. The RCM Decision Diagram is given in Appendix 3.3H. The answers to the decision diagram are documented in the RCM Decision Worksheet as shown in Appendix 3.3I.

The consequences of a failure will dictate the maintenance requirements. These may vary from the cost of replacing a failed component to the destruction of expensive equipment or the loss of life. All failure consequences are grouped into four categories defined as follows :

- Safety, involving danger to personnel
- Operational, involving economic loss and the cost of repair
- Non-operational, involving only the cost of repair
- Hidden Failure, which has no direct impact, but increases the likelihood of multiple failure.

The importance of identifying the consequences of failure is given by Versteeg[26]:

- it determines the significance of items for preventive maintenance
- it establishes the preventive task objective
- it determines the default strategy when no applicable and effective task can be found.

The decision process involving the identification of the consequences of failure is depicted in Figure 3.12 below:

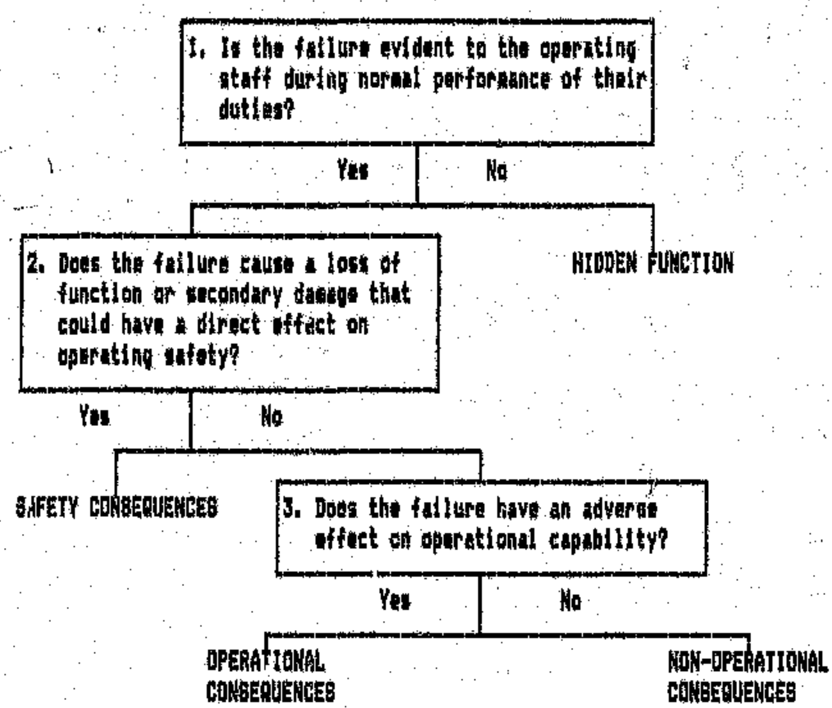


Figure 3.12 Failure Consequences[12]

Maintenance Strategy

An effective maintenance program will realise the inherent reliability of the equipment but no amount of maintenance will improve its reliability. If the reliability is inadequate the only recourse is redesign.

RCM identifies five categories of planned maintenance tasks:

On-condition Tasks. Scheduled inspections to detect potential failures are commonly termed on-condition tasks, since they call for the removal or repair of individual components of an item "on the condition" that they do not meet the required standa'J.

Scheduled Maintenance which includes Rework and Discard tasks. Many simple and single-celled items display wearout characteristics. That is, the probability of failure increases significantly after a certain operating age. If this wear-out age is identifiable, the overall failure rate may be reduced by imposing a hard time limit to prevent operation at the ages of higher failure frequency. Rework or Discard and Replacement of parts refers to the maintenance actions required to restore the items' original resistance to failure.

Redesign. When the reliability of an item is unacceptable and no maintenance can be found which is applicable and effective, the reliability must be improved by redesign.

Failure-finding Tasks for Hidden Failures. These are scheduled inspections for hidden failures.

No-Scheduled Maintenance. If no tasks are found which are both applicable and effective, the item is left in service until a functional failure occurs. This permits the item to realise its maximum useful life. It is important to ensure that such an item has no hidden failures and that a failure has no safety consequences.

The development of a maintenance programme consists of determining which of the maintenance tasks are both applicable and effective :

- applicability depends on the failure characteristics of the item. An inspection for potential failures can be applicable only if the item has characteristics that make it possible to define a potential failure condition.

- effectiveness is a measure of the results of the task. If the failure does not involve safety, then the effectiveness is measured in economic terms, i.e. the task is effective if it is cost-effective. In the case of operational consequences the cost of finding and correcting potential failures must be less than the combined cost of the operational consequences plus the cost of repairing the failed units. Dobson[12] provides a standardised economic trade off study which is included in Appendix 3.3J.

Services and Lubrication. Most equipment requires scheduled servicing and lubrication to maintain satisfactory operation. Lubrication constitutes a discard task while servicing constitutes an on-condition task. There is usually no question about whether they are applicable and effective and are automatically included in the Maintenance Programme.

Tasks and Frequency Analysis

Once the applicable Maintenance Strategy has been identified and providing that it involves some form of maintenance, a task is identified to achieve the objective of identifying or eliminating a failure. In the absence of sufficient operating data a conservative initial interval for the task is selected. With the acquisition of operating data the factual information required to revise initial decisions will be available. An example of maintenance tasks and frequencies are presented in Figure 3.13 below.

2. Servicing

Mode	2.1 Task	2.2 Purpose	2.3 Frequency
1	Check coolant level in overflow reservoir		Once weekly
2	Flush radiator per MP-1077	Remove solid particles & gelled matter	Once yearly
3	None		

3. Condition-monitoring

Mode	3.1 Parameter	3.2 Frequency	3.3 Criteria
1	Coolant temperature (gage on dash)	15-minute intervals	>180F
2	(same as for Mode 1)	(same as for Mode 1)	(same as for Mode 1)
3	(same as for Mode 1)	5 minutes after each c[illegible]d start	<155F

4. Scheduled inspections for condition assessment

Mode	4.1 Condition	4.2 Frequency	4.3 Criteria
1	Puddling beneath vehicle	Daily	Presence of puddle
2	Rate of draining during flushing	Once yearly (while flushing)	Abnormally slow
3	None		

Figure 3.13 Task and Frequency Identification[38]

Following Moss[38], RCM maximises the effectiveness and efficiency of preventive maintenance by directing tasks to defer or prevent the occurrence of a specific failure. The tasks must be organised into a schedule that imposes the least burden on the product user and minimizes the time that the item must be removed from service to perform preventive maintenance. The maintenance action must, as far as practicable, be performed when the item is not required by operations personnel. Tasks must be fitted into a modularly structured schedule using calender time or operating hours as the trigger for maintenance action.

An example of a Maintenance Schedule from the work of De-Weerdt[2] is provided in Appendix 3.3K.

3.4 The Maintenance Budget and Cost Control

"The quality of the service provided by the Maintenance Department has become a cornerstone of profitability in many industries. However, the growth in the demand for this service has led to a corresponding growth in the relative cost of maintenance."[14]

Hence the maintenance function faces a twofold problem, i.e. one of quality of service and one of the cost associated with providing the service. Maintenance cost can be reduced in a number of ways, among which are the following :

- effectively utilising artisans, thereby reducing the number of staff required

- identifying those items of plant making the biggest contribution to maintenance cost and focusing managerial effort to ensure that breakdowns are reduced while eliminating over-maintenance

- Improving the standard of workmanship; eliminating unnecessary re-work

- critical and consumable spares analyses to ensure a high enough service level and simultaneously reducing the high cost associated with keeping expensive spares

- ensuring that those who are spending the money have access to information which will timeously inform them of expenditure to date and relative to budget

- ensuring that a reliable method is used to accumulate, allocate and report costs in a way that is simple to understand and meaningful to those who must use the information

- establishing an efficient equipment replacement policy.

Sanctions have ensured that equipment and spare parts inflation greatly exceeds the consumer price index (CPI). To ensure that the cost of maintenance influence on the CPI is minimized, maintenance cost control is very real and equipment replacement policies have disappeared along with the capital required for the investment. This aspect is not as negative as it appears at first. In line with World Class Manufacturing 60% of Japanese spending is devoted to upgrading the capabilities of existing equipment and processes whereas the US spends 75% on additional capacity and replacement of old equipment. Maintenance cost control strategies and maintenance policies must ensure availability in the short and in the long term.

Maintenance cost may be divided into two main categories, i.e. labour cost and material cost.

3.4.1 Material Cost

Maintenance materials are the items required to ensure that plant and equipment are kept operating safely and reliably. These materials can be divided into a number of different categories, see Dobson[1] and Hipkin[33], but may generally be classified as usage spares and insurance spares.

Usage spares are used on a regular basis and are subject to normal stock control systems which include minimum stock levels, re-order levels and most economic re-order quantities based on historical usage. See Appendix 3.4A Figure 1. Items are classified using the ABC distribution, Appendix 3.4A Figure 2. ABC analysis has as its basis stringent control of costly materials and relaxed control of cheap materials. An example of an ABC analysis is provided in Appendix 3.4B and is taken from the work of Schonberger et al[34].

Insurance spares

Dobson[12] states that if all maintenance spares were managed using an ABC analysis most of them would end up as B or C class items and managed accordingly since usage spares make up a small portion of total spares. The results would be :

- many items being eliminated from the stock list due to low usage

- lower customer service levels being set, while certain items require 100% service levels

- relatively unsophisticated techniques will be selected to manage important spares.

Following Petrarolo et al[37] critical spares will halt production and therefore require a service level of at least 95%, whereas non-critical items require a service level of 90%. Insurance spares are purchased and kept in stock to avert major economic disaster. They are usually expensive, have low usage and follow very irregular demand patterns.

The decision for keeping inventory is an economic one. It compares the risk of not having the spares available in case of a breakdown to the cost required for the investment.

<u>Accumulating Material Cost</u>

<u>Maintenance Spares</u>

When a spare is issued from the store, the value of the spare is debited to the cost centre to which the spare is issued. The following illustration shows how the cost of the spare is allocated :

Transaction 1:	Supplier		Stores	
		Spares XXX	Spares XXX	

Transaction 2:	Stores		Cost Centre	
		Spares XXX	Spares XXX	

The main document in this case is the Stores Requisition, Appendix 3.4C Figure 1.

It is possible to bypass the store and purchase directly for a specific machine. The allocation of the cost of the spares is as follows :

Transaction 1:	Supplier	Cost Centre
	Spares XXX	Spares XXX

The main document in this case is the Purchase Requisition, Appendix 3.4C Figure 2.

The central accounting system will capture the stores, purchase requisitions and provide monthly feedback in the form of a summarised General Ledger Account together with other cost elements such as salaries, overtime, benefits, etc. An example of such a General Ledger Account is provided in Appendix 3.4D. This information is useful in that it provides an indication of the performance of a department and eventually the business but does little to provide information timeously and permit an analysis for identification of the equipment contributing most to maintenance expense.

3.4.2 Maintenance Labour Cost

Maintenance labour is analogous to maintenance spares in that a cost centre must pay for the labour hours (spares) purchased from the maintenance workshop (store). The maintenance workshop means any group of maintenance artisans working for a single foreman.

Spares (Material)	Labour (Time)
Supplier	Man
Store	Workshop

Cost Centre

Allocating the cost of spares is reasonably simple. Allocating or issuing maintenance labour to cost centres may be problematic. The biggest problem arises from the way in which this time is managed, the way in which the cost of this time is calculated and the accurate and honest recording of the time spent in the various departments.

Cost per Hour Worked

Maintenance labour time may be divided into two separate classes.

- Time spent on site - The overtime and normal time for which the artisan is booked, is the time captured from the clockcard.

- Time booked to jobs - The time actually booked to specific jobs by the artisan and is acquired from the jobcards.

Some of the artisan's time is taken up by waiting for the next job and in contrast to looking for spares, walking to the job, or discussing the job, which all forms part of the job, cannot be allocated to any specific job. This introduces the concept of Time Recovery.

$$\text{Time Recovery} = \frac{\text{Time booked to jobs}}{\text{Time spent on site}} \times 100\%$$

The time in both cases must be for the same period. General values for time recovery for different industries and different engineering disciplines are obtainable and may be used to evaluate the specific industry.

In calculating the charge out rate it is necessary to establish the total cost of an engineering workshop. The cost is made up of the following elements :

- Salaries - artisans, supervisory staff, maintenance management
- Wages - artisans' assistants

- Staff benefits
- Consumables - protective clothing, cleaning materials, tea & coffee
- Tools
- Workshop spares and materials
- Telephone, water, electricity, transport associated with the workshop.

The Charge Out Rate is the cost of an artisan hour and if multiplied by the actual number of hours spent in a department will provide the proportion of maintenance cost to be allocated to a cost centre :

$$\text{Charge Out Rate} = \frac{\text{Total Cost of Maintenance}}{\text{Total actual hours booked to jobs}}$$

This method of allocating maintenance cost is simple to understand, provides a true cost of an artisan hour and provides a basis of comparison with similar companies in industry. An example of such a calculation is shown in Appendix 3.4E and is taken from the work of Brand[38].

Time sheets versus Job Cards

To book time to jobs many companies make use of a time sheet. This sheet is filled out at the end of the shift and the artisan is expected to reflect where he spent his time. The disadvantages associated with this means of allocating time are as follows :

- Time booked is inaccurate since the artisan attempts to allocate every minute of his time

- Since the sheet is completed at the end of the day, the artisan invariably will not be able to recall accurately where he was at a particular time and will be in a hurry to get home

- Since most companies also operate a job card system it will be expected of the artisan to book the same information twice on two separate sheets.

This form of collecting data and allocating time must be eliminated and use should only be made of the job card as discussed earlier. To ensure that accurate data is provided every job should be done with a job card and only one person should work on a job card. The job cards provides us with :

- a record of what was done
- the artisan who did the job - identified by a unique number making a summary simple
- the time spent
- where the time was spent - unique plant number
- the workshop that did the job - unique engineering discipline number.

A summary of the hours off the job cards will provide us with the actual hours booked to jobs.

Time Spent on Site

The time spent on site may easily be acquired from clock cards. It is important to note that clock cards are usually returned to the commercial department on a weekly basis and if the time is not captured before this, it will be very difficult to determine it later on. To provide a continuous record of artisan and labourer time performance it may be worthwhile for the foreman to open a register on a monthly basis to record overtime worked, sick hours, leave, time off, etc. This register is sent to the maintenance planning department weekly to permit capture of hours on site and will then also serve as a backup in the event of clock cards getting lost and no other means of acquiring this information exists.

Time recovery in conjunction with plant availability provides another measurement for management :

- If availability is high and recovery low it shows that artisans are free to be utilised otherwise, i.e. project work.

- If availability is low and recovery low it would seem that jobs are not being done and jobs are being done without jobcards.

3.4.3 Allocating Maintenance Cost

Maintenance costs must be allocated to the departments which use the service. To allocate costs at this level only will not provide the maintenance manager with meaningful information on which to base decisions. The cost of maintenance must be allocated to individual machines for the following reasons[14] :

- allows for pinpointing the causes of sustained high costs

- provides meaningful information for decision making

- cost performance of different machines can be compared

- budgeting becomes more accurate

- cost-effectiveness of different maintenance routines and policies can be evaluated.

If the plant numbering system has been designed correctly the allocation of maintenance costs is greatly simplified. PE Corporate Services[14] proposes that maintenance costs be reported in great detail. This is the ideal situation but will probably only be implemented with great difficulty in companies where the Accounting Management Information System has not been designed specifically with this reporting structure in mind.

The cost must at least be allocated to items of equipment while further analysis will require scrutiny of detailed General Ledger Accounts.

3.4.4 Maintenance Budget

Maintenance budgeting may be done using a Zero Based Budget or Historical Costs.

<u>Zero Based Budgets</u>

It is a time consuming practice of having the engineer justify all activities and costs as if they were being undertaken for the first time. It yields benefits but requires much time and effort.

<u>Historical Cost Budgets</u>

This seems to be the generally accepted method of budgeting for maintenance. Much work has been done on providing indices for the level of maintenance required in various industries. Some of the methods used for budgeting include:

<u>Capital Replacement Value</u>. De Matteis[15] states that this is the most significant and reliable index and suggests a figure of 4% for the chemical industry. For the Food industry this figure lies between 3% and 6%.

<u>Sales Value</u> is often used as a basis for establishing maintenance costs. In the Food Industry this figure is between 4% and 6% of NSV and is low when compared with certain other industries.

<u>Standard Cost</u> is based on historical costs versus production volumes. This assumes that all maintenance cost is variable and is a function only of production volumes. The actual monthly costs are compared to budgeted

Standard Costs and variances are explained in relation to production volumes. This is an over simplification of the function. Certain costs will be incurred regardless of production volumes while other costs are directly related to production volumes, level of planned maintenance, level of maintenance related plant improvements and production process improvements involving equipment redesign or line layouts.

Escalation of Previous Year's Budget

A third method for budgeting maintenance cost is simply to increase the previous year's budget by an inflationary amount with total disregard for reductions in maintenance expenditure, comparisons with similar companies in the same industry, or generally accepted norms for the level of costs.

Cost Standards and Budgets

The general categories of maintenance expense are :

1. Additions to capital, which include

   - New equipment
   - Improvements
   - Replacements

2. Repair and maintenance expense, including

   - Breakdown repair to equipment
   - Preventive maintenance
   - Housekeeping, i.e. painting
   - Repair to buildings

3. Cost of producing and distributing utilities, including steam, electricity, water, compressed air and refrigeration.

The maintenance budget is set up using a combination of the different budgeting methods :

- Machinery Repair Budget - a variable budget is developed and is expressed in cost per unit of production.

- Plant Facility - most repairs are of a predictable nature. All facilities are surveyed and anticipated repairs forecast for the next budget.

- Vehicle Repair Budget - a variable budget is developed and is expressed in cost per unit of production.

- Labour Budget - this budget consists of a fixed and a variable portion. The variable portion is expressed in terms of manhours per unit of production.

It is clear that the standards are established from historical costs. These standards are modified to include any cost escalations, proposed productivity improvements and cost reduction goals and objectives of the organisation.

Marketing provides the projected sales volumes for the next budget period and the total repairs and maintenance costs are calculated. These costs are compared to those of previous periods to establish whether the overall escalation is within the objectives of the organisation. Further it is compared to the Plant Capital Replacement Value and the Nett Sales Value to establish whether these ratios are within the industry norms.

Appendix 3.4F gives an example of a maintenance budget.

3.5 Maintenance Quality

An exact definition for Quality hardly exists but generally relates to the degree in which the product or service conforms to the design specifications. A popular concept of quality is doing things right the first time and every time. Following Schonberger et al [36] and Adam et al [39] the key to managing for quality lies first in the awareness of the need to improve, and then selecting improvement techniques with a good chance of success. There are several significant steps in effectively managing for quality products and services and is diagrammatically depicted in Appendix 3.5A Figure 1[39].

For any organisation there are key elements that affect quality. These typically include people, facilities and material and we must understand how they interact with the company. Products are manufactured, parts are made, services are generated and customers are served. Adam et al [39] states that in this conversion process we must establish whether we are conforming to plan. The questions we must ask and answer are:

- are we seeking the continual quality improvement desired?

- are quality processes under control?

- are quality costs in line with expectations?

Once again it is necessary briefly to consider productivity. Following Faull [40] there are three main themes in productivity : effectiveness, conversion (utilisation) and efficiency (cost-effectiveness), and, put simply, it measures the ratio of "value of outputs" to "cost of inputs". The "value" is defined by the customer (operations management) and this is where "effectiveness" or doing the right things (QUALITY OUTPUT) finds its application. The maintenance department is being effective insomuch as it correctly defines the customer's needs and begins to satisfy them. The inputs are physical units and generally include LABOUR + CAPITAL + MATERIALS + ENERGY. These inputs are converted to outputs by maintenance actions; hence productivity is negatively affected if we do not meet the customer defined outputs or if we allocate more than the required resource inputs to achieve the outputs.

In the maintenance plan we convert customer requirements and overall business objectives into maintenance objectives. It is in the achievement of these objectives that we find Maintenance Quality or Maintenance Productivity. In the absence of products manufactured we measure results and report them for successive periods and compare them with similar organisations. Following Brand[39] typical parameters and indices include:

- actual cost of one hour of maintenance work
- ratio of labour cost to material cost
- ratio of maintenance cost to Nett Sales, Capital Replacement Value
- Total Maintenance Down-time
- Maintenance staff to total employees.

The sole purpose of the organisation is to make a profit. In our highly competitive markets the pressure is on reducing costs and providing lower priced products to remain competitive and to survive.

Faull[40] states that every CEO needs to create a "questioning culture". This culture will welcome and nurture attempts to find better ways of doing things, eliminate wasteful use of resources, etc. This is at the heart of the productive organisation, and

Productivity Improvement is synonymous with Quality Improvement.

All of the aspects discussed thus far

- The Maintenance Plan
- The Maintenance Organisation
- The Plant Enhancement Programme
- The Maintenance Budget and Cost Control

are in effect Quality Control and Quality Improvement techniques. They do, however, relate mostly to the Systems required to establish control but fail to address the most important element, that of the People who operate within the system. Brown[41] states that standards are only part of the picture and that managers must try to focus their people on causing process improvement if they are to avoid the "Garbage-in, Garbage-out" syndrome. This is the only way to avoid the negative chain of rework, checking, sorting and pacifying customers. We need to focus on the concept of Total Quality Management since it applies equally to Production and Services in the organisation.

Brown[41] provides four distinct steps to follow in our pursuance of the Total Quality Management goal:

- All individuals must agree on a definition of quality as conformance to requirements. Management must take the setting of requirements seriously and insist they be met at all times.

- To achieve quality, management must use prevention and not appraisal after the event. Everyone must be taught to eliminate the problems that cause non-conformance.

- The performance standard must be set at zero defects. Giving people standards that encourage them to believe that errors are a normal part of business life is counterproductive. All individuals must be expected to carry out their jobs correctly the first time- every time.

- Quality (or the lack of it) must be measured in terms of money. The people must know what it costs to do things wrong.

Faull[48] provides a framework for improving Productivity but it may be applied to improving Quality equally successfully since the two concepts are synonymous. The framework compliments the four steps outlined above in that it demonstrates how they might be attained in practice.

1. Create a questioning culture. Never stop asking the question. "How can we improve productivity/quality?"

2. Create a cause-effect vision for the organisation.

3. Characterise initiative with these factors :
   - Goals
   - Feedback
   - Participation
   - Experimentation
   - Pressure
   - Perseverance

Each of these concepts will be discussed briefly.

- <u>The Cause-Effect Vision</u>

  The individual needs to know why the function exists and how his/her job relates to the overall objectives of the department and the overall purpose of the organisation and what happens for them if the organisation succeeds. Individuals will understand how their jobs relate to the organisation's survival, effectiveness and competitiveness. An obsession with responsiveness to customers, externally and internally needs to exist.

- <u>Goals</u>

Goals give direction to effort but must be measurable and realistic. Furthermore, specific and challenging goals lead to higher performance than easy goals. Job goals must be clear.

- <u>Feedback</u>

Feedback is the return of information to an individual so that at least some of the information is a reflection of his performance. The objective being that he/she may self-correct his/her performance.

- <u>Participation</u>

This includes participation in decision making, goal setting, evaluating feedback, and participation in the results (rewards and disbenefits). South African research has shown high correlations between successful sections and the degree to which managers are visible and involved in the day-to-day affairs of their areas on an unstructured basis in addition to scheduled meetings.

- <u>Experimentation</u>

To search consciously for answers to questions, trying different approaches. Inherent in the concept is action, questioning and risk. The outcome is not predictable with certainty and the organisation must be tolerant of error and "failed" experiments if it wishes to encourage the questioning culture and experimentation.

- <u>Pressure</u>

  Pressure is seen here to drive out complacency, to demand attention and compel action. The pressure should be stable and not erratic or of a crisis nature. Research has shown that bosses in successful areas are both more demanding (raising pressure) and more patient (reducing pressure) than their counterparts in lesser areas.

- <u>Perseverance</u>

  The act or fact of sticking to a purpose or an aim. The pursuit of productivity or quality must not be a flash-in-the-pan. Evidence shows that results are cumulative and are evident over a period of time. In this area we find the learning curve theory where repetition over time breeds competence leading to improvement. Realistic time frames must be set for achieving results or failure and disillusionment are sure to follow.

Appendix 3.5A Figure 2 is a dynamic representation of the improvement process for Productivity or Quality. Management, in the context of maintenance will include foremen and engineers.

3.6 Equipment Replacement Policy

3.6.1 Introduction

Hsu[42] states that the expansion and improvement of production facilities are critical items which affect the well being of any firm. An effective equipment replacement policy means a rapid increase in production capital formation and affects the operations of the business for years to come. Historically business firms have had difficulty in developing sound and effective measurement methods for equipment replacement. The physical life of equipment can be extended indefinitely by proper maintenance and the replacement of parts. This statement is supported by Brand[39] who states, in the light of the astronomical costs associated with equipment replacement and the tremendous pressures on profits and cash flow, that "Replacement Policies" have disappeared along with the capital required for the investment.

It is necessary to be realistic and realise that an organisation must remain profitable and in doing so needs to evaluate all investment opportunities. To this end the replacement of equipment to reduce expenses or improve operations may be a sound investment. Because equipment replacement represents the long-term commitment of financial resources, the financial evaluation methods are based on the "time concept of money". These include:

- Discounted Rate of Return (DRR) or Internal Rate of Return (IRR) where the discount rate which makes future inflows of cash equal to the cost of the project must be equal to or greater than the organisation's cost of capital or also commonly named Hurdle Rate.

- Net Present Value (NPV) where the present value of the future cash inflows, discounted at the organisation's cost of capital, must be equal to or greater than the cost of the project. Following Wacht[43] NPV has been acknowledged as the best criterion for analysing capital investments while Hsu[49] states that DRR is the most widely used.

- Discounted Payback Period (DPP). Based on the discounted cash flow technique it considers the time required to recover the initial investment. This addresses liquidity since, generally, the shorter the payback period the smaller the liquidity risk and vice versa.

3.6.2 Economic Life

The total cost of owning, maintaining and operating an item of equipment is obtained by adding the capital cost and current expenses. These two cost functions and their effect on the total cost is depicted in Figure 3.14 below.

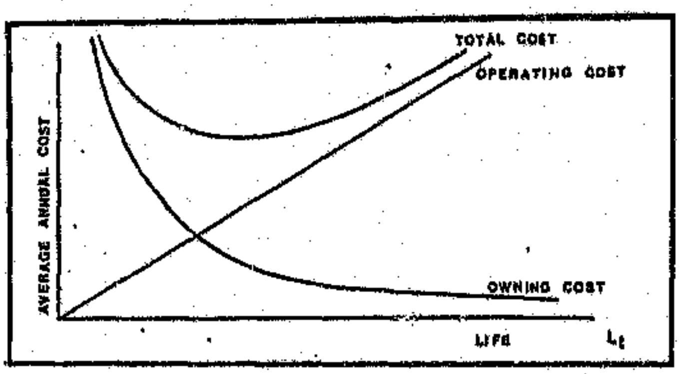


Figure 3.14 Basic Average Cost Model[16].

From this model it can be seen that :

- Operating costs increase with age due to a greater input of spares and labour for maintenance and repair

- Owning costs decrease with age because the capital cost (purchase price minus residual value) can be spread over a longer period of time

- The total cost curve has a minimum value as it is first pushed up by high capital costs, then by high operating costs.

Following PE Corporate Services[14] the economic life is the period which ends when the average annual cost of owning and operating a machine reaches a minimum.

3.6.3 Replacement Decision

There are two approaches which may be used to decide on equipment replacement. Both use the concept of economic life and are :

- Minimum Average Annual Cost where the investment is accepted if the machine under investigation has surpassed its economic life.

- The Challenger and Defender Concept where the machine under investigation is retained beyond its minimum cost point on the condition that it remains cheaper than the minimum average annual cost which could be expected from an equivalent machine.

The time value of money and the impact of taxes and equipment depreciation must be considered. An example of the economic life calculation is shown in Appendix 3.6A.

The above discussion considers only the quantitative judgement techniques. The decision to replace will also consider qualitative aspects like :

- the organisation's replacement policy
- marketing requirements
- improved product quality or mechanical quality
- executive judgement
- liquidity of the organisation.

4 IMPLEMENTATION

Implementation will consider those elements of the theoretical model which require further discussion through application of the aforementioned theory and will include :

- The Maintenance Organisation
- The Jobcard
- The Equipment Register/Plant Inventory
- Maintenance Management Information (MMI)
- Planned Maintenance
- Cost Control

4.1 The Maintenance Organisation

4.1.1 Facilities

The plant under consideration is geographically spread out and covers approximately 90 000 square metres. It is distinctly divided into ten areas each covering a unique process or operation. Appendix 4.1A shows a plan view of the complete facility with approximate location of the various processes and operations.

4.1.2 Skill Requirements

The various maintenance disciplines may be organisationally central or area structured and geographically central or area located. Services such as electrical, boilermaking, civils, machining, steam generation effluent plant management, refrigeration and vehicle maintenance are centrally located for the whole site. Due to the area skill requirements and geographical dispersion plant fitters are decentralised and allocated to area workshops. Almost all of the disciplines have a skill orientated foreman. The disciplines are grouped as either mechanical or electrical and refrigeration and resort under engineers with the appropriate technical expertise.

4.1.3 Labour Requirements

The breakdown of labour hours with the size of the disciplines required is shown in Appendix 3.2A. The maintenance organisation with the relevant supervision and number of employees per discipline is shown in Appendix 4.1B.

4.1.4 Maintenance Service

The processing plants work on a two shift basis of 9,33 hours per shift. Time is required between shifts for cleaning of equipment and servicing of machines. Plant Fitters, Electricians and Refrigeration Operators are required to work shifts. These are normal shifts, a night shift and a day shift of one week duration each. The day and the night shifts are each of 12 hour duration and ensure that the plant is covered 24 hours. Shift artisans are required to remain on site to be readily available for any emergencies. A machinist and a mechanic are placed on standby for after hours service. All other personnel will work a basic 10 hour normal dayshift. With regard to supervision a mechanical and an electrical or a refrigeration foreman will be placed on standby for one week and will supervise all work undertaken on a weekend or public holiday. Appendix 4.1C is an example of a duty roster.

4.1.5 Reporting and Responsibility

The reporting structure together with the lines of authority is shown in Appendix 4.1B. This type of organisation does not exclude the direct communication on the shop floor.

4.2 The Jobcard

The jobcard shown in Appendix 3.3A is a copy of the original jobcard. It was subsequently established that the jobcard book was too large to fit into a person's pocket. This had the effect that the book lay in an office and when work was required this was verbally requested of the artisan with the promise that a jobcard would follow. This very seldom happened and work was being done without a jobcard. The jobcard book has been redesigned and streamlined. It fits comfortably into the pocket of a jacket or coat. A copy of this revised jobcard is shown in Appendix 4.2A Figure 1 and Figure 2.

The foreman is supplied with a list of Job Card Codes which covers the identified Functional Components, Failure Modes and Causes of Failure. Following the principle that the system must be simple and easy to use it was decided to issue a list of general components and modes. The RCM codes are only filled in in the event of a breakdown. An example of such a list is shown in Appendix 4.2B.

The jobcard does not make any provision for material cost data. All information regarding material costs is taken from the Stores and Purchase requisitions. Equipment is prioritised according to cost and breakdown history. Any ad hoc investigations require the analysis of the jobcards and requisitions to determine the main contributors to cost and downtime. This method has proved to be quite sufficient.

The jobcard procedure, format and basic information has been adequately covered in Section 3.3.1.

The artisan loading board has been revised. The loading board only makes provision for Jobs Allocated and Jobs Completed. When a job is held up due to waiting for spares the jobcard is completed by the artisan and returned to the foreman. The reason being that quite often the delivery of spares takes place in the month following that in which the machine was stripped or the artisan is on leave or busy with another job. The foreman has the responsibility of allocating jobs and setting priorities and will in all probability have to reallocate the job of equipment assembling to the same or another artisan.

4.3 The Equipment Register/Plant Inventory

4.3.1 Plant Numbering System

The numbering system must provide all the requirements of maintenance management and fit easily into existing procedures. It must provide for :

- simplicity
- flexibility
- the summarizing of information to various levels
- easy identification of equipment location
- sort codes for data processing.

It is imperative to ensure that limitations are not created in the long term purely because the equipment number was not correctly organised and structured. It was established that three (3) fields would satisfy the requirements of cost and history summary at the different levels. The three fields contain a total of seven digits which is about the recommended maximum number of digits. The original numbering system was changed to suit the requirements of simplicity, etc, and appears on the example in Appendix 4.3A.

The first three digits represent the cost centre or manufacturing department. The original financial cost centre codes were retained since they allowed for easy identification of the area of location. The next two digits represent a unit or line number (similar equipment or equipment grouped logically). Since the accounting structure requires the summarising of maintenance costs separately for buildings, vehicles and fixed plant it was decided to differentiate as follows :

Cost Centre		Line/Unit Number		Item Number
x x x	-	1 0	-	Fixed Plant
	-	6 9	-	
x x x	-	7 0	-	Buildings
	-	7 9	-	
x x x	-	8 0	-	Vehicles
	-	9 9	-	

The final two digits represent individual items within a unit or line. The numbering system is hierarchical following the cost centre where :

-	1 0	-	0 1	Item

represents the first machine in the first line in a department. Appendix 4.3A is an example of the Equipment Numbering System while Appendix 4.3B is an example of the Plant Inventory.

In the case of equipment which may be moved or equipment which may be used on more than one line it should be grouped separately under a unit number independent of any specific line. Vehicles such as forklifts should be grouped under one unit number with all individual machines marked consecutively with an item number commencing with 01. If the machine is moved to another cost centre it will only require changing of the cost centre number.

4.3.2 Engineering Department Responsibility Codes

When maintenance information is presented, a requirement may be an analysis of the time (cost) spent per engineering discipline per unit, line or department. For this reason it would be necessary to provide each discipline with a unique identification number or sort code for summarizing and ease of data processing. The method used in developing and allocating these numbers must still fulfil the requirements set for the development of the plant numbering system. Appendix 4.3C is an example of such a numbering system.

4.4 Maintenance Management Information (MMI)

4.4.1 Productivity

Manpower Utilisation

This is calculated for each discipline and for the maintenance department as a whole. An objective of 80% has been set for all disciplines and will be evaluated for a more appropriate objective when the maintenance programme has been in operation for a sufficient length of time. An example of the time recovery for all disciplines is shown in Appendix 4.4A Figure 1 while Appendix 4.4A Figure 2 shows the trend for a specific discipline.

The low levels of time recovery show that jobs are being done without jobcards. In the case of the electrical discipline, the nightshift electrician is repairing breakdowns only and since there is always 25% of that department on nightshift it will impact significantly on time recovery.

Appendix 4.4B shows an example of the attendance register for a department and identifies the employee/employees who have poor attendance and poor time recoveries.

Mean Time To Repair (MTTR)

The MTTR is calculated over all Breakdown actions since it is only these actions which affect the equipment availability.

$$\text{MTTR} = \frac{\text{Total time spent on breakdown actions}}{\text{Number of breakdown actions}}$$

4.4.2 Planning

<u>Preventive Maintenance (PM)</u>

Percentage of total time spent on PM tasks :

$$\% \text{ PM} = \frac{\text{Hours spent on PM}}{\text{Total hours all types of work}}$$

Percentage of PM tasks completed and consists of condition monitoring, on-condition tasks and scheduled tasks with regard to:

- Lubrication
- Vehicles
- Plant and Machinery

$$\% \text{ Completed} = \frac{\text{Number of PM actions completed}}{\text{Total number of PM actions required}}$$

This figure should be 100%. An example of a PM scheduling document and the percentage completed is shown in Appendix 4.4C Figure 1.

<u>Other Categories of Maintenance</u>

This calculates the percentage of actual hours spent on Maintenance, Breakdowns, Safety and Modifications. Appendix 4.4C Figure 2 shows an example of the breakdown of actual hours between the categories and includes PM time in the category of Maintenance. Modifications includes redesign projects and projects of a capital nature.

4.4.3 Work Order Programme

Work Order Turnover

Since job time estimating is not done, the work order turnover is measured as follows :

$$\text{Work Order Turnover} = \frac{\text{Number of Jobs Completed}}{\text{Total Number of Jobs on Request}}$$

Since certain jobcards are carried over from one period to the next awaiting attendance it is necessary to determine :

- Jobcards Completed
- Backlog (Number of outstanding jobcards)
- Jobcards Received
  = (Backlog Previous Period - Backlog Present Period) + Jobcards Completed
  ∴ Jobson Request = Backlog Previous Period + Jobcards Received

4.4.4 Maintenance Effectiveness

Plant Availability

$$\text{Availability} = \frac{\text{Total Shift Time} - \text{Total Downtime}}{\text{Total Shift Time}}$$

The production index of utilisation is calculated using 7,75 effective hours per shift. This accounts for processing time lost to product run through at the start and end of the shift. The Shift Time, however, is 9,33 hours since the equipment runs for the full shift and is oblivious of the presence or absence of product.

Total Shift Time is acc.ired from the Production Log since the processing lines do not operate continuously. The total hours required for production is entered into a Log and accumulated for the period under investigation.

Appendix 4.4D shows the availability trend of a processing line over a number of consecutive quarters. The objective is an overall availability of 92%.

Mean Time Between Failures (MTBF)

The frequency of breakdowns is a measure of equipment reliability.

Equipment Capitalization

This is not a measure of equipment performance but rather of managerial effectiveness and measures how effectively equipment is utilised after being made available.

4.4.5 Cost

Costs are accumulated according to :

- Labour costs
- Material costs
- Company Benefits
- Miscellaneous

Labour/Material

The ratio of Labour to Material is calculated

$$= \frac{\text{Total Labour Cost}}{\text{Total Material Cost}}$$

Cost per Maintenance Hour

$$= \frac{\text{Total Cost of Engineering Department}}{\text{Actual Number of Hours Recorded}}$$

All of the above performance parameters are assembled into the summarised Maintenance Report which is shown in Appendix 4.4E.

4.5 Planned Maintenance

4.5.1 Equipment Selection

In the plant to be analysed the availabilities are generally high with two exceptions as shown in Appendix 4.5A. Of the two, the "Burger line" is approximately 10 points off the objective of 92%. This line has the most machines operating in series and also the most complex machines. It was decided to focus attention on this ... the assistance of a consultant an ana... the line with prioritising of the machines ... stigated was made.

A Top Ten analysis of the machines, prioritised in order of contribution to overall downtime, throughout the plant was made and is shown in Appendix 4.5B. All machines in the "Burger line" carry the line or unit number "21-" and contribute $\frac{83}{130} = 63,8\%$ to overall plant downtime. It can also be seen that the "Formaxes" or forming machines feature three times in the Top Ten and, although not all three are in the same area, it was decided to further analyse these machines. Their contribution to downtime being $\frac{44}{130} = 33,8\%$.

Since downtime alone is not a criterium for prioritising equipment, a cost analysis in terms of maintenance expenses by line and machine was done. This cost analysis is shown in Appendix 4.5C. The cost analysis supports the maintenance history analysis.

4.5.2 Equipment Analysis

The forming machines may be logically broken down into systems directly associated with the product flow through the machine, with the services required and with the support structure. It was decided to analyse the machines following a modified Equipment Assembly Tree. The breakdown of the machine into its systems and subsystems is shown in Appendix 4.5D. Appendix 4.5E shows an analysis of the components into subsystems and into piece parts. The analysis of the piece parts will provide for Failure Mode analysis or the ways in which each assembly and final component will contribute to overall Functional Failure.

4.5.3 Failure Mode Effect and Criticality Analysis

An analysis of one Functional Component of the forming machine, the Knockout System, is shown in Appendix 4.5F.

4.5.4 Maintenance Strategy

Applying the Decision Diagram logic to each of the aforementioned Failure Modes of the equipment knockout System, yields the Decision Worksheet shown in Appendix 4.5G. Of the eight Failure Modes only two require a Preventive Maintenance task.

This process was completed for all Functional Components and Failure Modes.

To facilitate the process of identifying components, functional failures, failure modes and effects and eventually the applicable maintenance task computerised spreadsheets were developed. The analysis is performed on the computer and at the end of each session the worksheets are printed ready for filing and use.

4.5.5 Maintenance Schedules

An RCM analysis of the forming machine has shown that most tasks fall into the categories of On-Condition and Condition Monitoring. Since the machines run a different product almost daily many change-overs are required. To ensure that the equipment operates correctly after each change-over it must be cycled or run "dry". During this "dry run" a daily checklist is completed which includes both On-Condition and Condition Monitoring tasks. An example of such a Daily Checklist is shown in Appendix 4.5H Figure 1 and Figure 2. It is required of the Fitter to enter a code for his maintenance action and not merely tick off in answer to a Yes or No question. He signs the checklist and presents it to the foreman. The checklist will gather information for one month on both shifts worked.

4.6 Cost Control

It is impossible to control a monthly budget on month end figures alone. If the central accounting system cannot provide information more regularly with relative ease it may be necessary to run a manual or computerised off line programme. This will permit the capture of labour and material data as it is generated and immediately allocate it to the relevant equipment and cost centre. This is done using the plant number which can accumulate costs at different levels from equipment level to department level. The information must be updated at least weekly and must be made available to those who "spend" the money, i.e. those who fill out and authorise stores and purchase requisitions. This will enable all levels of maintenance management to know how actual expenses compare to budgeted expenses and will highlight those areas requiring careful attention.

Attempting to manage by month end figures alone will result in the maintenance manager attending monthly review meetings in a completely defensive mode. He will be unsure of where and how expenses were incurred. He will not be in a position to present plans of how expenses were or will be brought under control. This will have the effect that monthly expenses will oscillate wildly about the budget values.

A system for controlling expenses may be structured as follows :

4.6.1 Labour Expenses

Within maintenance the number of employees should remain constant and with the exception of special bonuses or increases the cost of indirect salaries and wages should not change. Contractor labour is often viewed as material cost and does not form part of the labour bill.

Arguably the most important aspect to monitor and control is overtime. All overtime is entered onto the attendance register and once per week a departmental summary of overtime is made. The cumulative value is compared to the monthly budget and the variances indicate the "value" of overtime left to month end. An example of such an analysis is shown in Figure 4.1 below.

SUMMARY DEPARTMENT 151

BUDGET	40540
ACTUAL(MTD)	36650
VARIANCE	3890

SUMMARY DEPARTMENT 355

BUDGET	1772
ACTUAL(MTD)	5519
VARIANCE	-3747

Figure 4.1 Overtime Summary

4.6.2 Material Expenses

Material expenses are accumulated from Purchase and Stores requisitions. The purchase requisition is filled out in triplicate. One copy is forwarded to the buyer, one to maintenance planning and one is retained by the foreman. The stores requisition is filled out in duplicate. One copy is retained by engineering stores while the other is forwarded to data processing. Once per week a summary of all stores' issues with values is forwarded to maintenance planning. The purchase requisition and stores' issues are accumulated for the week and for the month to date. These are compared to the budget and the variance once again shows the balance to month's end. This information is presented to all foremen and engineers to assist them in decision making with regard to expenses. An example of such a monthly control sheet is shown in Appendix 4.6A.

Before the expense statements are accumulated in the Income Statement, copies are sent to responsible departmental heads. The figures are scrutinised and corrections made where necessary. These statements must include provision for expenses incurred but for which no invoices have been received. Quite often all purchase requisitions have not reached the accounts department by the time the expense statement is generated and major expenses may not have been provided for. If the maintenance manager has accumulated expenses throughout the month, he will be in a position to include the necessary provisions and will not be misled by the often huge "favourable" variances on the expense statements. This not being the case, he will authorise purchases while no money is available and consequently overspend his budget.

5 CONCLUSION

5.1 Summary and Conclusion

There is not a single article in any magazine or newspaper today which deals with Income Statements, Financial Reports or Operations Management and does not emphasise the importance of reducing operating costs. If designed, implemented and managed correctly, maintenance engineering will assist in reducing costs and improving profits. In a study conducted by the Forbes [44] business magazine in America they concluded that $1 in every $3 spent on maintenance is wasted and a major portion of that $1 is from over-maintaining or incorrectly maintaining a plant.

Other studies[44] conducted have yielded the following results:

- British Department of Industry: The 2000 factories in the study could save £400-million (>RM2000) by incorporating predictive maintenance strategies.

- Du Pont: Reported a saving of £261-million in 1983 through the incorporation of predictive maintenance strategies.

- Electric Power Research Institute: Findings state that preventive maintenance will reduce costs over corrective maintenance by 25% to 30%. Predictive maintenance will reduce costs over corrective by 50% to 61%.

- Iscor: An Internal Rate of Return of 33% can be achieved from setting up a predictive maintenance programme.

Although none of these studies pertain directly to the food industry it is clear that the potential for increasing profits is so enormous that a formal

Planned Maintenance Programme must benefit this industry as well. There are a number of fundamental differences between the various industries but the enormous advantage of the maintenance techniques available are their flexibility. With little effort and ingenuity they can be adapted to suit any environment.

The extensive research into the available literature has yielded a theoretical maintenance model which is generic and may, with adaptation, be used in any industry. Much emphasis has been placed on developing the physical system while the human impact was considered in as much detail as permitted by the text. If not accepted and used by the maintenance personnel, the system has little chance of success. On the other hand, it is of no use having a well qualified and motivated group of employees but no way of controlling or recording their activities. It is in the recording of the maintenance action that we can measure our successes or failures and decide upon alternative courses of action. Neither the organisation nor the work administration system can operate in isolation; they are interdependent.

The overall system will not be self sustaining. There are numerous internal and external influences which impact on the system and it is the maintenance manager or engineer's responsibility to monitor the system continuously. This monitoring will reveal positive or negative reaction to these influences and call for modification. The system must be seen as dynamic and adaptable as the organisation changes.

The model will yield the promised results if it is implemented and used correctly.

5.2 Further Investigations

The next step is Total Productive Maintenance. This subject is beyond the scope of this project but warrants mention as it may be the Fourth Generation of maintenance. Since our goal must be to maximize profits, we are defeating our objective if we let part of the workforce stand around idle while the other part is working[45][46]. The amount of maintenance is dictated by tl user of the machine and it is only correct that he/she be made accountable for the condition eof. We develop predictive maintenance strategies and buy sophisticated monitoring equipment to check the machine while we have a highly flexible and very sophisticated monitoring device standing right next to it - the operator. It is estimated that by making the operator accountable for his equipment and providi-- him with the required backup, skills training an. ols, machine breakdowns may be reduced by up to ‹ω%. TPM shows us that cost-effective maintenance is a shared responsibility.

APPENDIX 2.1A

	Generalised Income Statement R'000	%	Revised Income Statement R'000	%
Sales Volume (Tons)	25 000		25 000	
Nett Sales (N.S.V.) (5)+(6)	135 000	100	135 000	100
Less: Standard Variable Cost (S.V.C.) (2)	51 300	38	49 950	37
Standard Margin	83 700	62	85 050	63
Less: Cost Variance	1 350	1	1 350	1
Gross Margin	82 350	61	83 700	62
Less: Cost of Distribution	18 900	14	18 900	14
Nett Margin	63 450	47	64 800	48
Less: Fixed Costs	56 700	42	55 796	41,33
Production Costs	29 700	22	28 796	21,33
(1) Salaries	4 050	3	4 050	3
(1) Wages - Indirect	2 700	2	2 700	2
(1)+(9) Wages - Direct	7 425	5,5	6 683	4,95
(7) Services	4 050	3	3 888	2,88
Repairs & Maintenance	5 400	4	5 400	4
Sundry	6 075	4,5	6 075	4,5
Other	27 000	20	27 000	20
Trading Profit	6 750	5	9 000	6,67
Less: Interest	2 000	1,5	2 000	1,50
Profit before Tax (P.B.T.)	4 750	3,5	7 000	5,2

47,4% Increase in P.B.T.

Notes:

1. Salaries and Wages-Indirect include salaries and wages of maintenance personnel.
2. S.V.C. includes Raw Material, Transport and Harvesting.
3. Repairs and Maintenance are for material only and does not increase.
4. Assume a 7% increase in availability with 3,5% increase in capacity utili ation.
5. Net Sales Value remains constant. This is what may be expected in the present static markets.
6. Assume 1% reduction in S.V.C. due to improved functioning of equipment which improves yield and reduces raw material requirements for equal Sales Volume.
7. Cost of Services (water, steam, gas, electricity) reduced by 4%.
8. Depreciation charges remain constant even though a reduction may be experienced if it is possible to inc ease equipment's economic life through improved maintenance practices.
9. Di ect labour utilisation improved by 10% due to fewer stoppages which impact on the work rhythm.

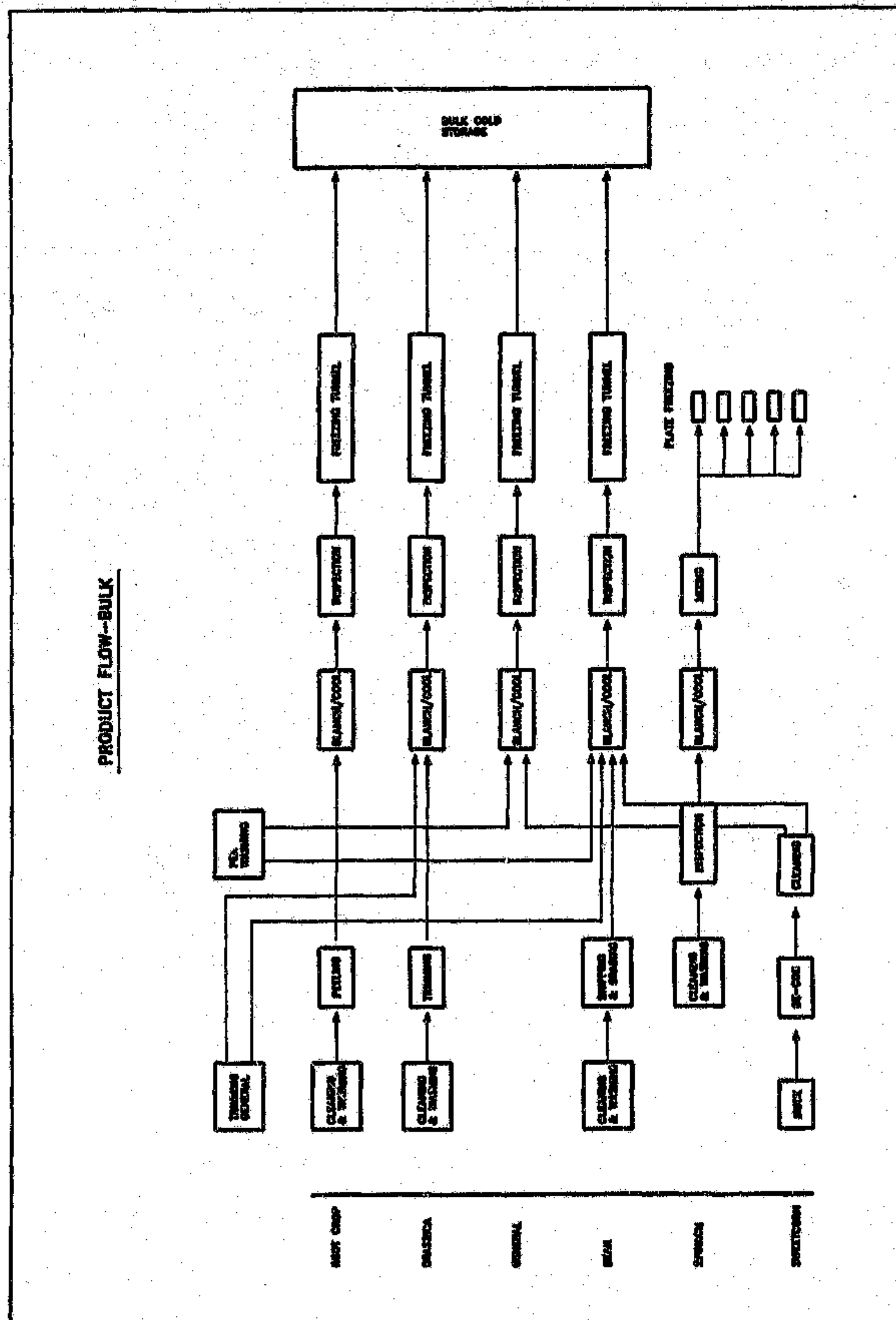

PRODUCT FLOW-BULK

Figure 2

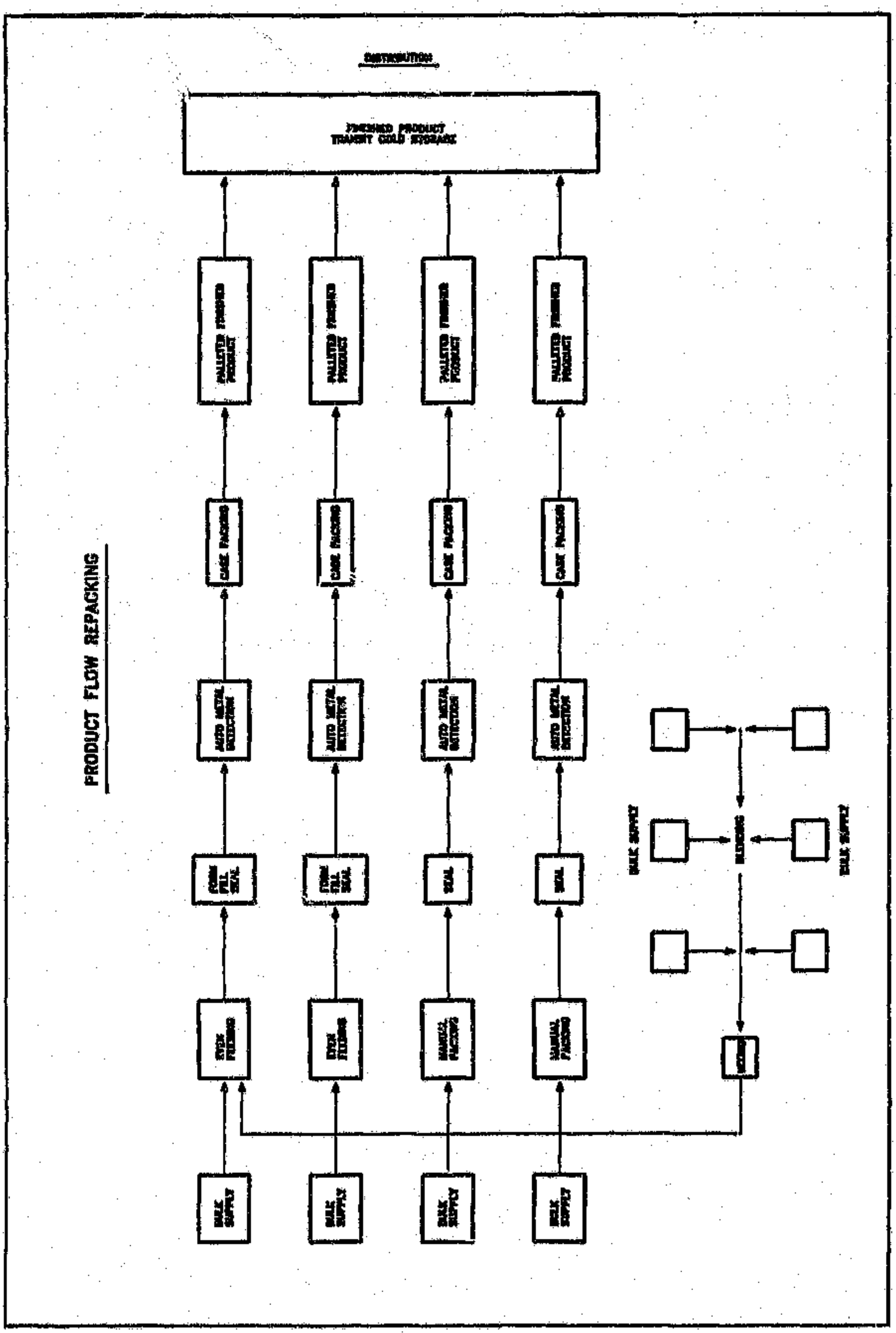
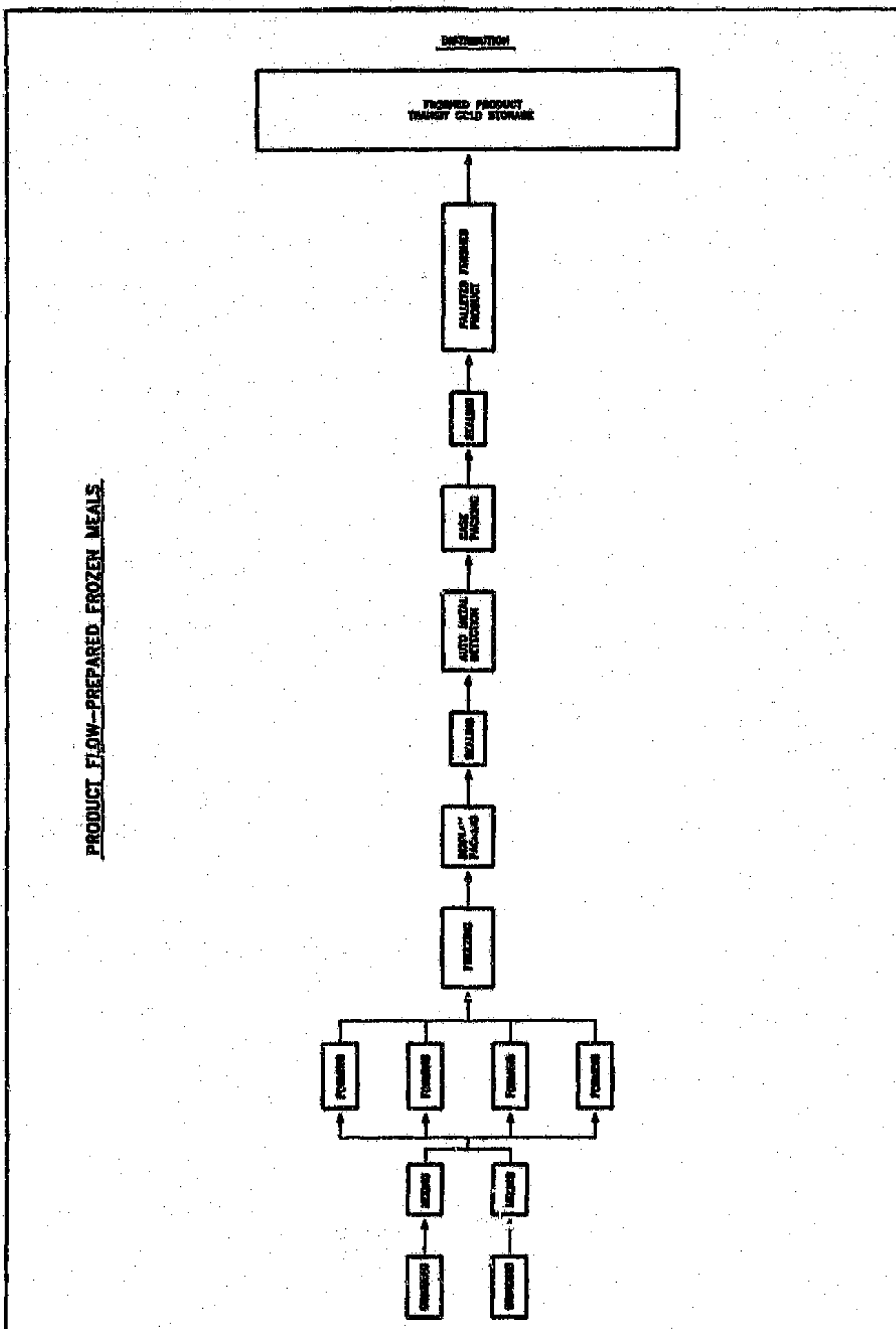


Figure 3



APPENDIX 3.2A

Maintenance Time Spent by Trade

DEPARTMENT	CODE	HOURS	%
BRICKLAYER	151-10	1001.30	2.24
WORKSHOP	151-20	6792.86	15.17
BOILERMAKER	151-30	605.55	1.35
QF MECHANICAL	151-40	11685.59	26.10
GARAGE	151-50	4992.18	11.15
QF ELECTRICAL	151-60	3952.30	8.83
REFRIGERATION	151-70	7628.66	17.04
RM MECHANICAL	355-11	6907.68	15.43
RM ELECTRICAL	355-30	1209.35	2.70
TOTALS		44775.46	100.00

Size of Disciplines

1. Mechanical:

Recorded hours pa = 11 686 + 6 907	=	18 593
Plus: Time Recovery @ 65%		10 112
Clocked Hours	=	28 605
Less: Overtime Hours @ 20%	-	(5 721)
Normal Hours	=	22 884
Plus: Absenteeism @ 5%		1 144
Total Hours Required	=	24 088

Artisan Hours average 200 per month

$\therefore$ No. of fitters required = $\dfrac{24\ 088}{200 \times 12}$ = 10,1

Each month 1 fitter will be on leave

$\therefore$ No. of fitters = 1,09 x 11 = 12

The fitters work in two areas and each group requires a foreman with the necessary technical expertise $\therefore$ number of mechanical foremen required = 2.

This exercise is repeated for each discipline. In the absence of historical data an estimate will be required of either the workforce of similarly sized organisations or the number of potential jobs must be estimated to establish the workforce size from first principles.

MONTHLY HAND TOOL CHECK (FITTER)

DEPARTMENT .... NAME: .... CO. NO. ....

NO	DESCRIPTION	SIZE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Set Flat Ring Spanners	6mm – 32mm												
		+10; 13; 17; 19; 22												
2	Set Flat Ring Spanners Imperial	3/16" – 1 1/4"												
3	Set Metric Allen Keys													
4	Set Imperial Allen Keys													
5	Socket Set	6 – 25mm + 27mm, 32mm												
6	Set Screw Drivers	3x75, 5x150, 6x40, 6x100, 9x150												
		Star 6x40, 5x80, 6x100, 8x150												
7	Pipe Wrench	12"												
8	Shifting Spanner	8"												
9	Shifting Spanner	12"												
10	Ball Hammer Pein	2 lb												
11	Hammer	4 lb												
12	Mallet													
13	Side Cutter	6"												
14	Combination Plier	200mm												
15	Water Pump Plier	[illegible]0mm												
16	Vice Grip	200mm												
17	Tinsnips	200mm												
18	Inside Straight Circlip + 90 degree Pliers	40mm – 100mm Shaft												
19	Outside Straight Circlip + 90 degree Pliers	40mm – 100mm Shaft												
20	Set Drills	5mm – 13mm												
21	Hacksaw													
22	Chisel	25mm												
23	Tommy Bar	400mm												
24	Centre Punch													
25	Brass Punch													
26	Set Pin Punches (Mitco)	2mm – 10mm												
27	2 Round Second Cut files	Small & Large												
28	2 Flat Second Cut Files	Small & Large												
29	2 Half Round Second Cut Files	Small & Large												
30	2 Triangle Second Cut Files	Small & Large												
31	Tape	5 Meter												
32	Rule	300mm												
33	Combination Square													
34	Combination Metric & Imperial	150mm												
35	Long Nosed Plier	150mm												
36	Divider	300mm												
37														
38														
39														
40														
41														
42														
43														
44														
45														
46														
47														
48														
49														
50														
	INSPECTED BY	SIGNATURE												

APPENDIX 3.2B

MONTHLY HAND TOOL CHECK (TURNER)

DEPARTMENT .... NAME: .... CO. NO. ....

NO	DESCRIPTION	SIZE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Set Flat Ring Spanners	6mm – 32mm												
		+10, 13, 17, 19, 22												
2	Set Flat Ring Spanners Imperial	3/16" – 1 1/4"												
3	Set Metric Allen Keys													
4	Set Imperial Allen Keys													
5	Socket Set	6 – 25mm + 27mm, 32mm												
6	Set Screw Drivers	3x75, 5x150, 6x40, 6x100, 9x150												
		Star 6x40, 5x80, 6x100, 8x150												
7	Pipe Wrench	12"												
8	Shifting Spanner	8"												
9	Shifting Spanner	12"												
10	Ball Hammer Pein	2 lb												
11	Hammer	4 lb												
12	Mallet													
13	Side Cutter	8"												
14	Combination Plier	200mm												
15	Water Pump Plier	300mm												
16	Vice Grip	200mm												
17	Tinsnips	200mm												
18	Inside Straight Circlip + 90 degree Pliers	40mm – 100mm Shaft												
19	Outside Straight Circlip + 90 degree Pliers	40mm – 100mm Shaft												
20	Set Drills	1,5mm – 13mm												
21	Hacksaw													
22	Chisel	25mm												
23	Tommy Bar	400mm												
24	Centre Punch													
25	Brass Punch													
26	Set Pin Punches (Mitco)	2mm – 10mm												
27	2 Round Second Cut files	Small & Large												
28	2 Flat Second Cut Files	Small & Large												
29	2 Half Round Second Cut Files	Small & Large												
30	2 Triangle Second Cut Files	Small & Large												
31	Tape	5 Meter												
32	Rule	300mm												
33	Combination Square													
34	Combination Metric & Imperial	150mm												
35	Long Nosed Plier	150mm												
36	Divider	300mm												
37	Divider	150mm												
38	Internal Caliper	300mm												
39	External Caliper	300mm												
40	Level (Machine)	200mm												
41	Machine Square	200mm												
42	Telescopic Gage	6 Piece												
43	Micrometers (Metric)	0–25, 25–50, 50–75, 75–100												
44	Vernier	200mm												
45	Gage Plate	Metric & Imperial												
46	Thread Gage													
47	Thread File													
48	Scriber	200mm												
49	Set Easy Outs													
50														
	INSPECTED BY	SIGNATURE												

APPENDIX 3.3A

Figure 1 Jobcard Front

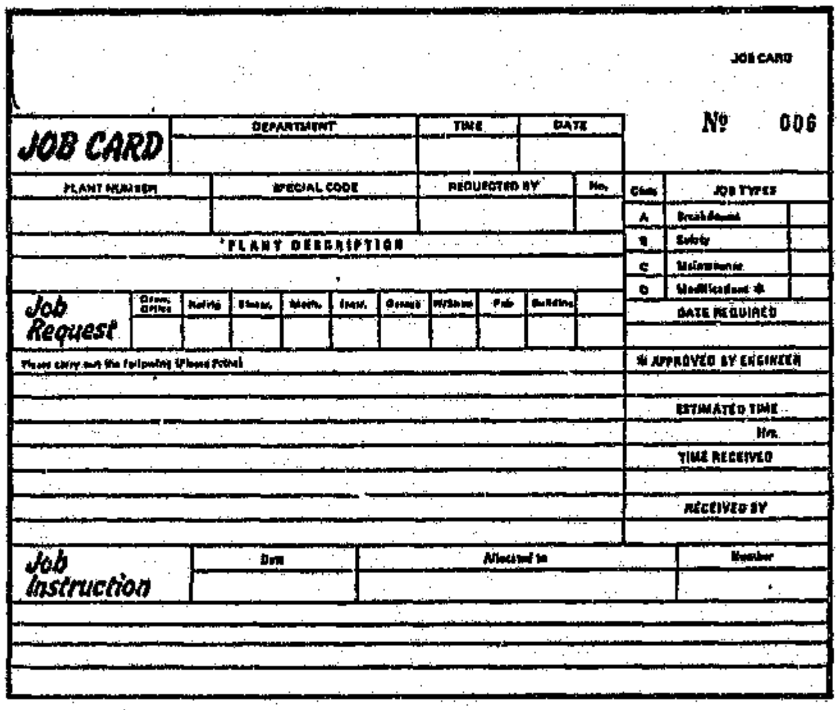


Figure 2 Jobcard Back

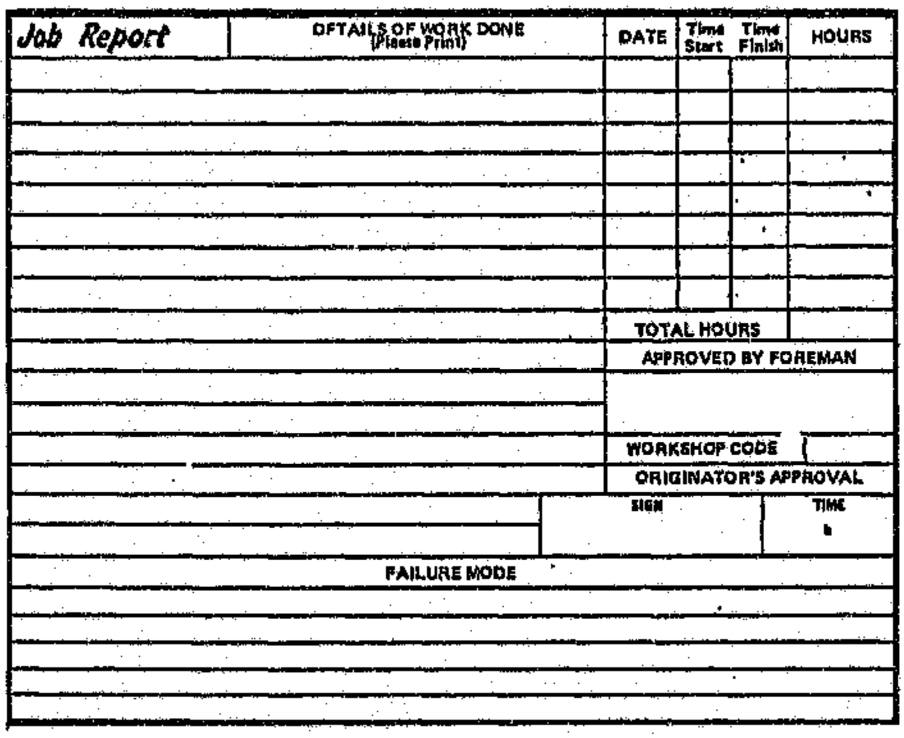


Figure 1 Foreman Control Cabinet

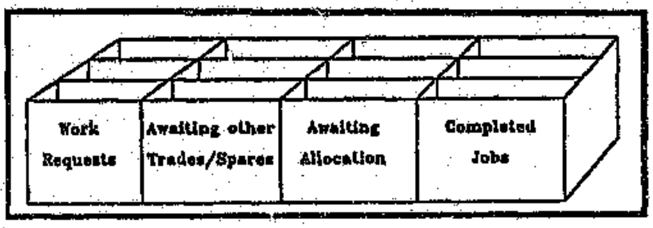
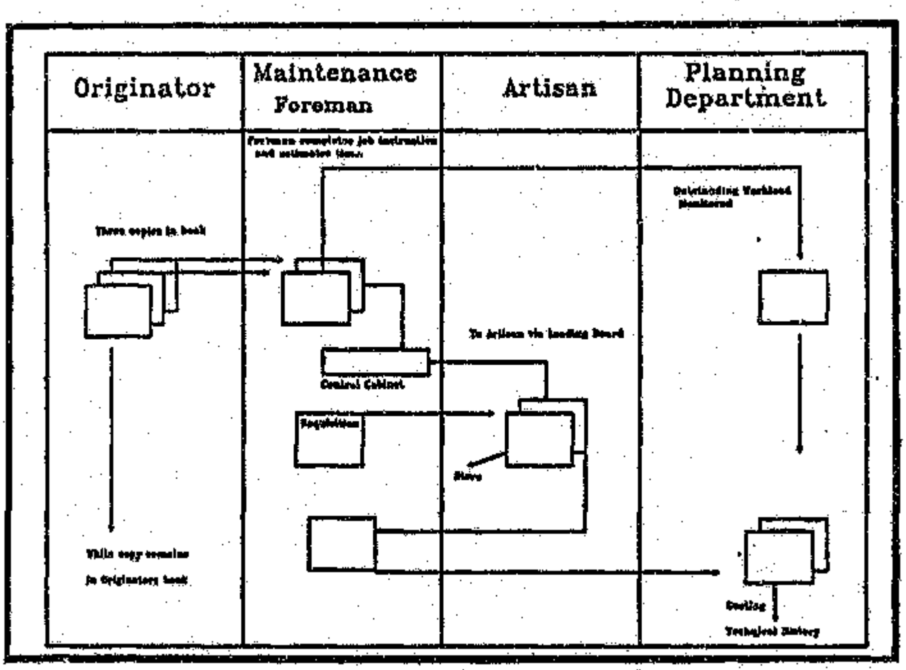


Figure 2 Artisan Loading Board

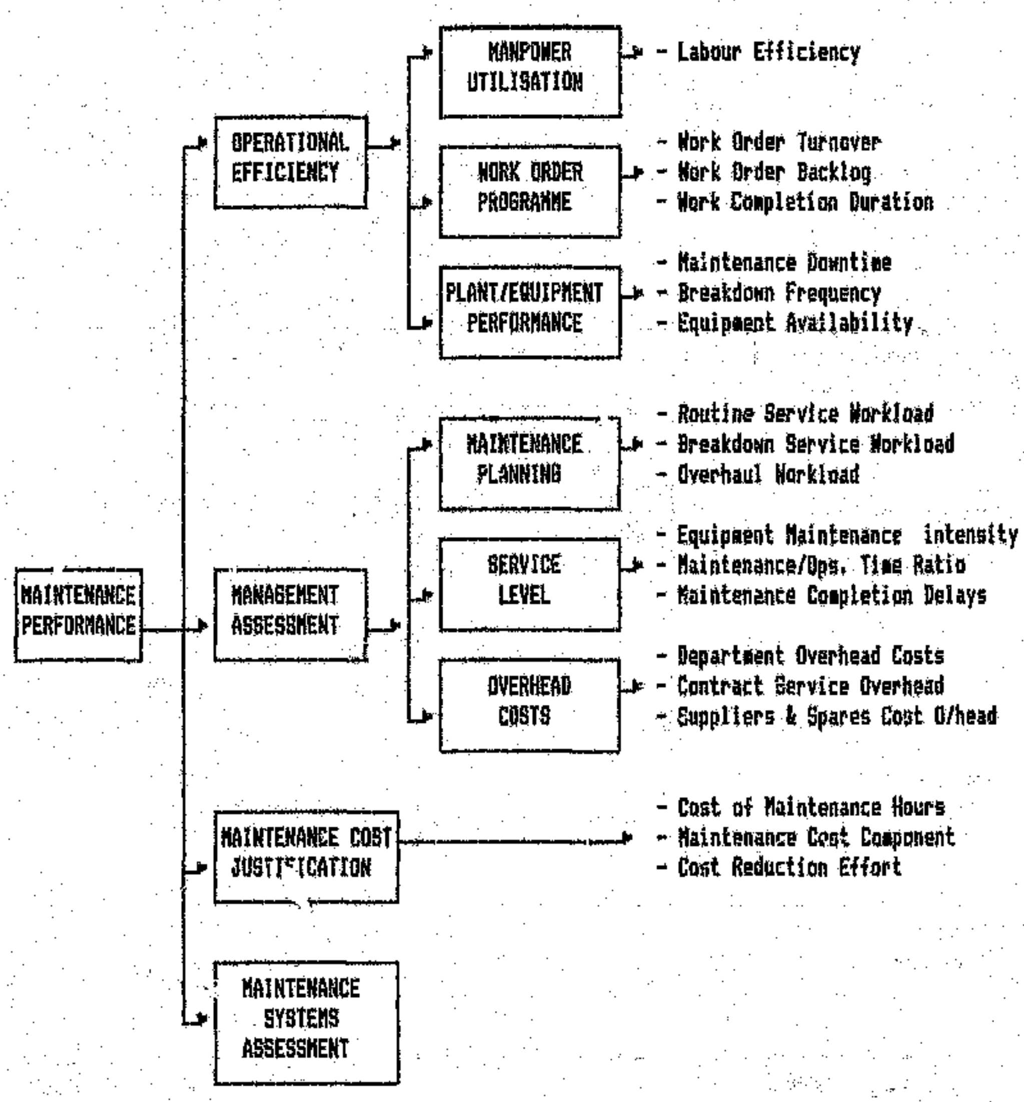
ARTISAN LOADING BOARD	Dave Shaw	Jan Alberts	Thomas Jones	John Smith	Dave Reyneke	Andrew Williams	Frans Smit
Jobs Allocated							
Jobs Held up							
Current Job							
Completed Jobs							

Figure 3 The Jobcard Procedure



APPENDIX 3.3C

Evaluating Maintenance Performance



APPENDIX 3.3D

Planned Maintenance Programme

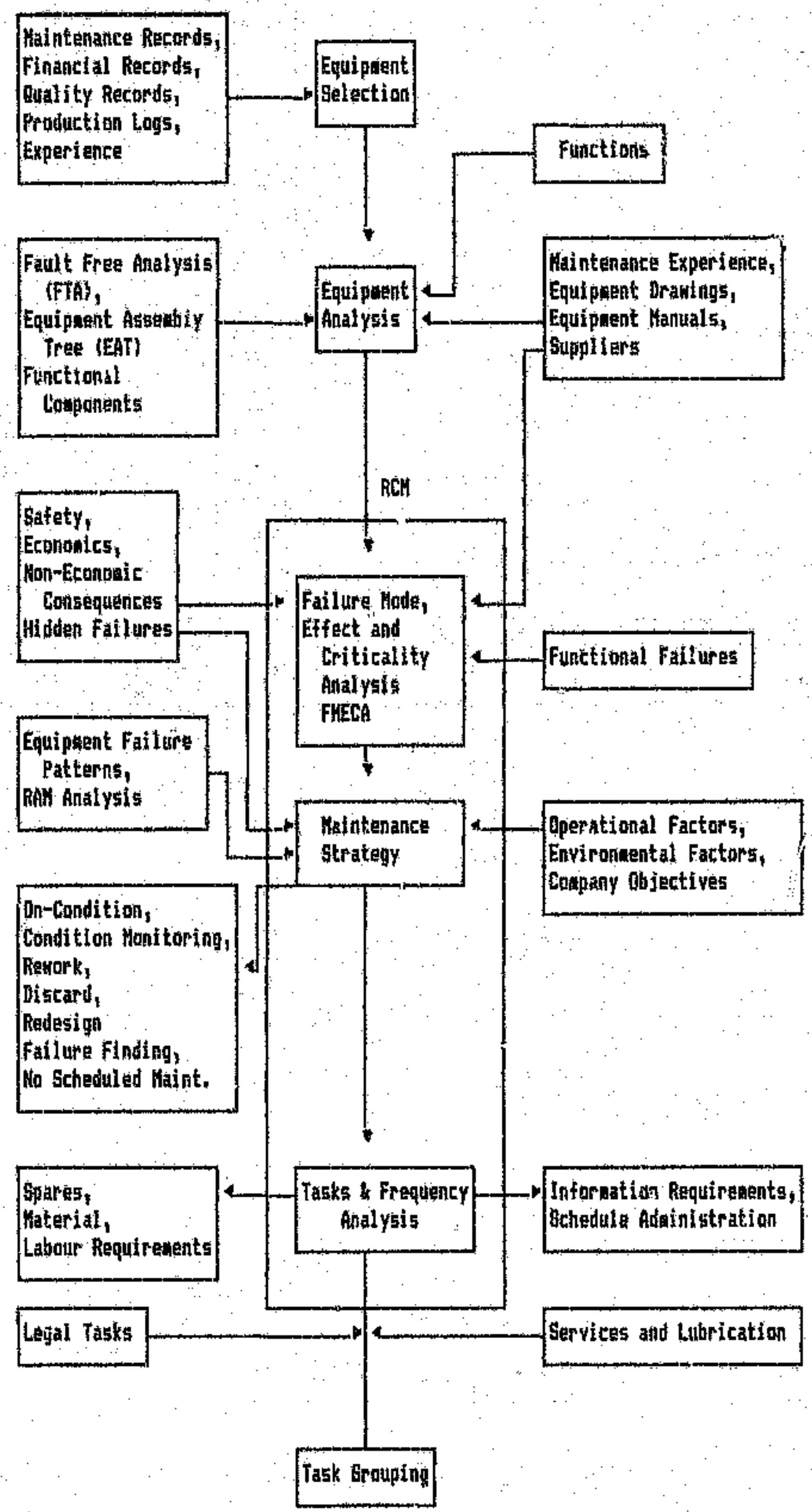


Figure 1 Fault Tree Analysis

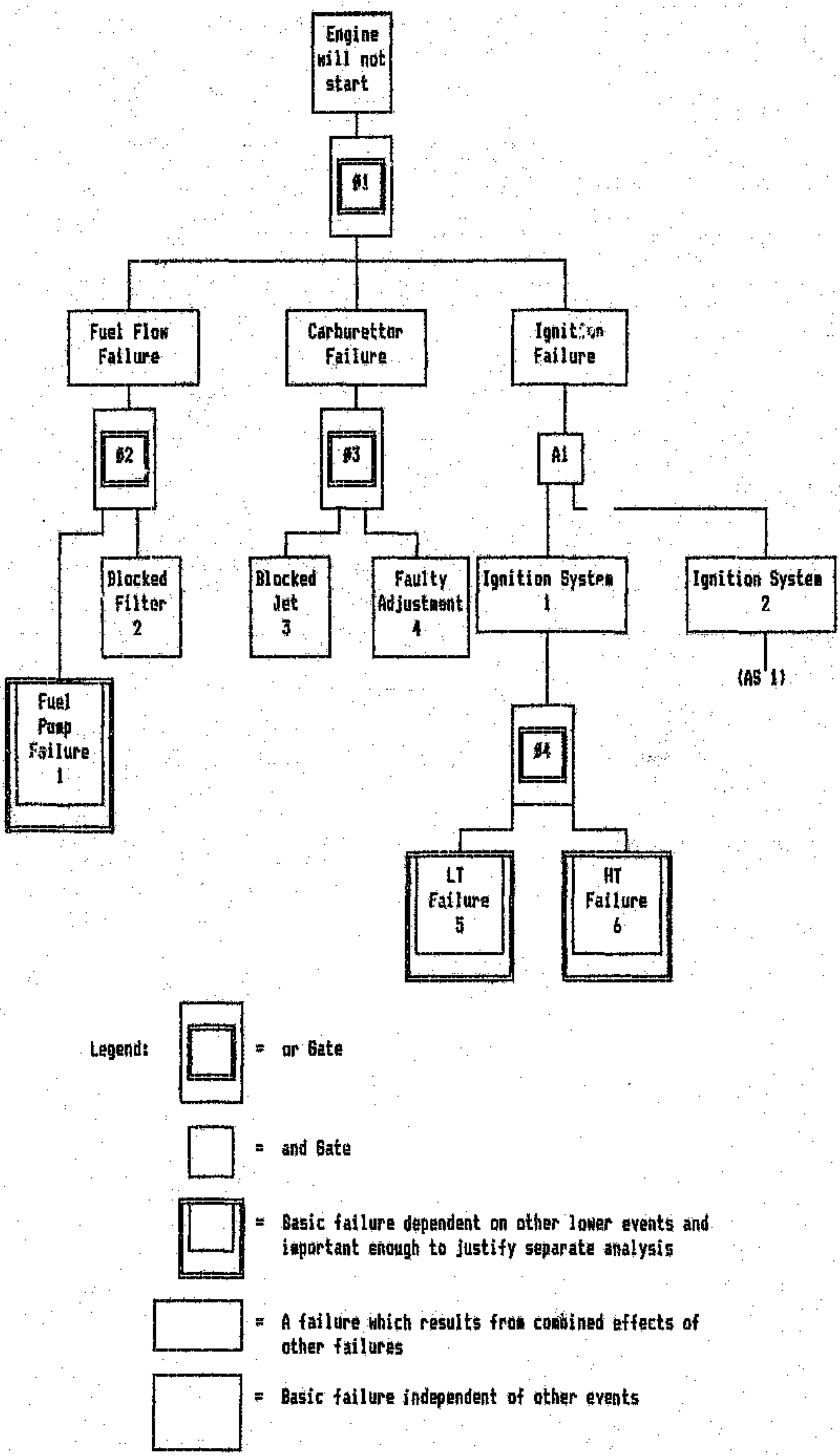
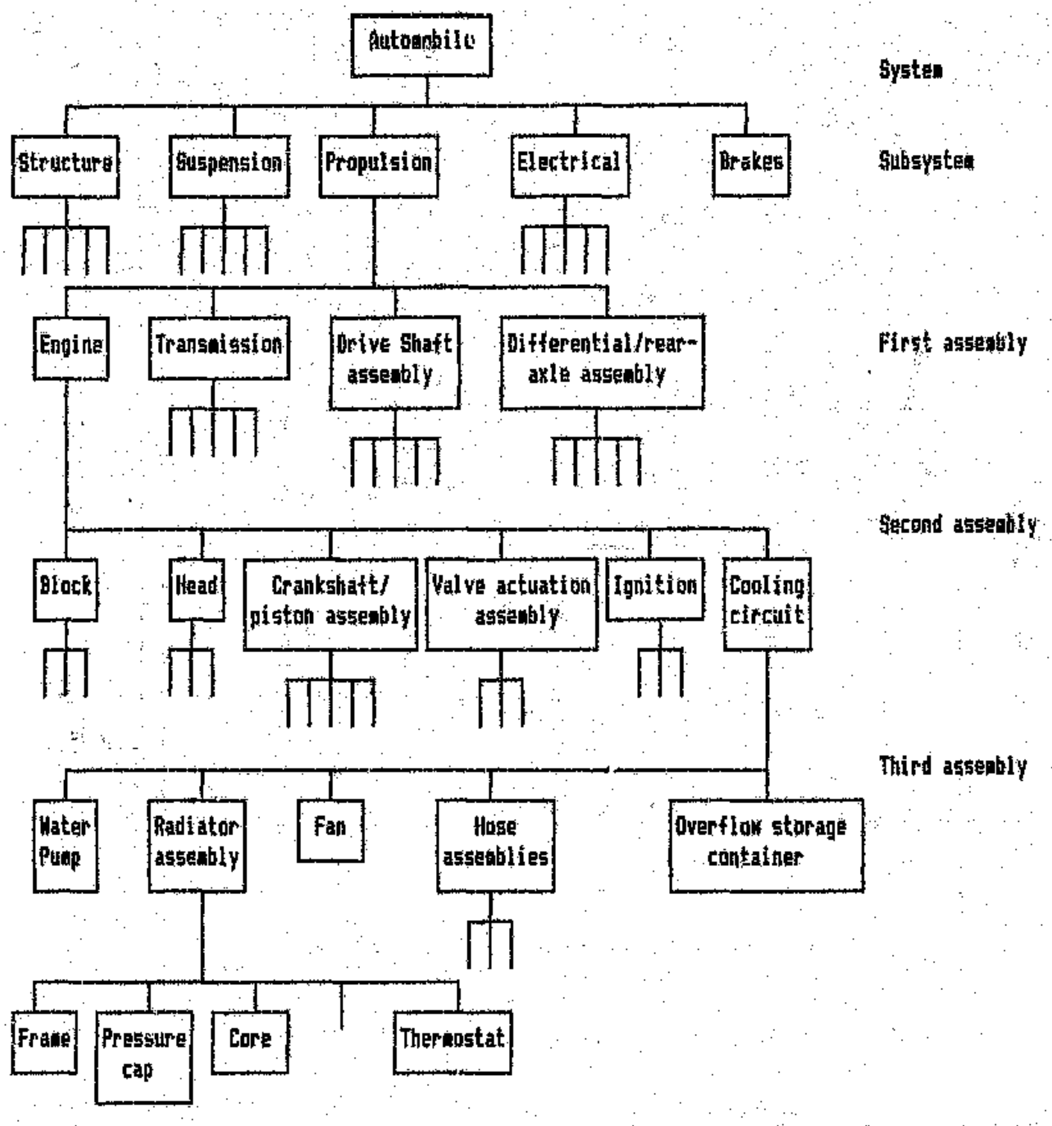


Figure 2 Equipment Assembly Tree



INFORMATION WORKSHEET

PAGE 1 OF

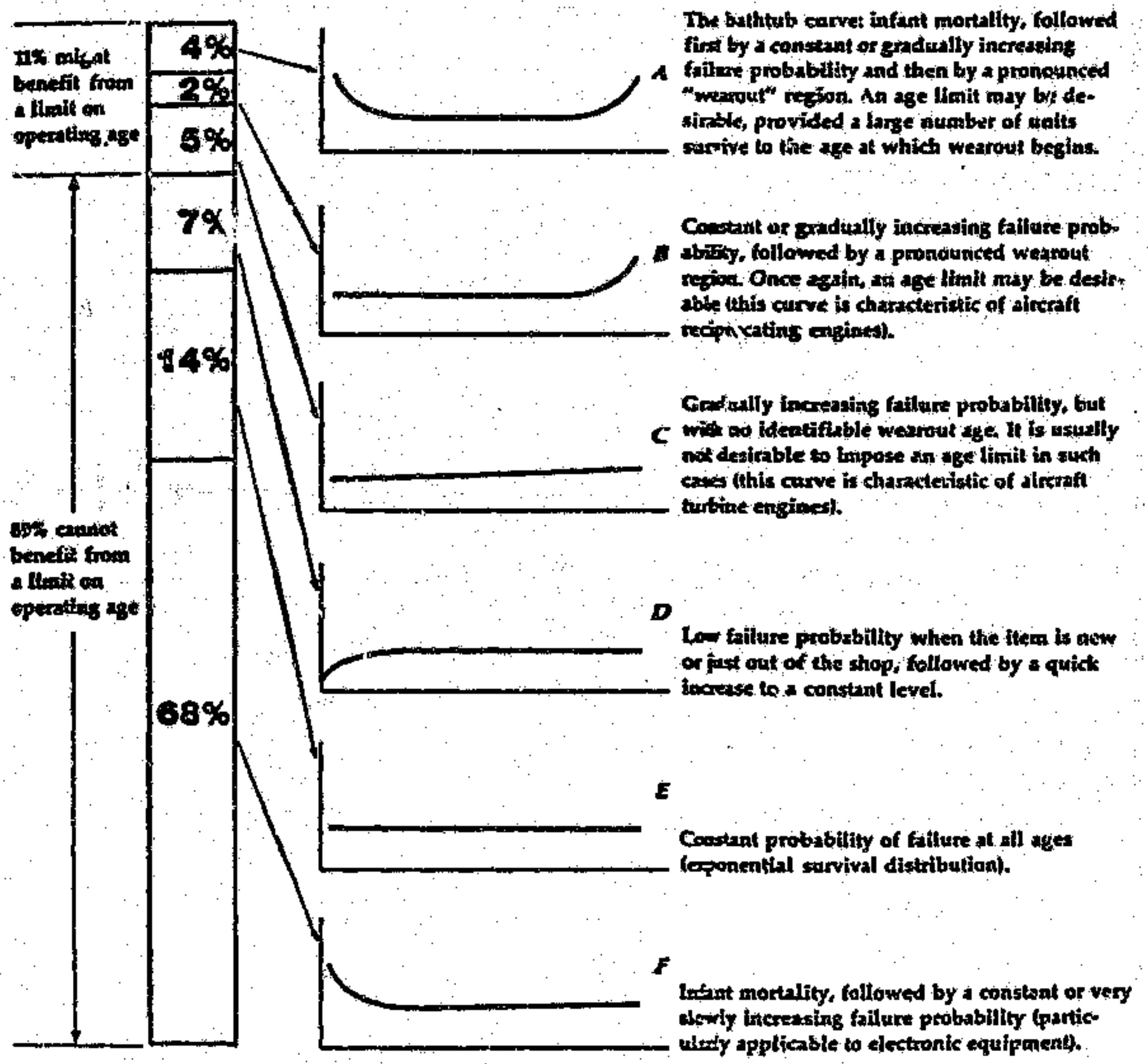
EQUIPMENT: CONVEYOR SYSTEM NO.: COMPILED BY: DATE:

COMPONENT: FEED HOPPER REVIEWED BY: DATE:

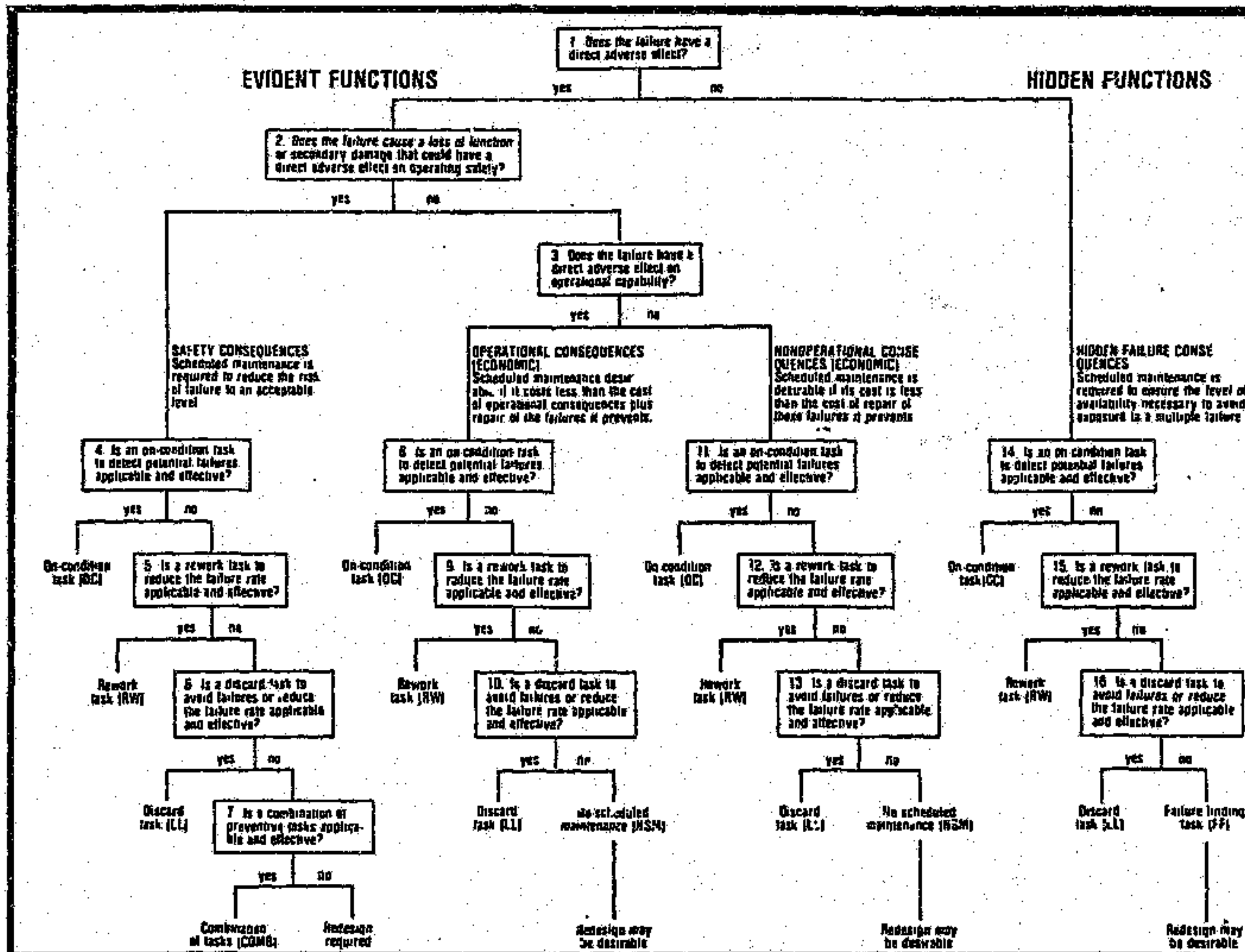
FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECTS
1. Channel flow to slide gate.	A. No flow.	1. Liner came loose and obstructing outlet.	Operating crew will notice no material flow and notify maintenance crew - diagnosis and removal of obstruction through inspection port will cause approximately 3 hours downtime. Casing will be exposed to wear (unless there is a general failure of liners - probability low).
2. Contain material in hopper.	A. Material spillage occurs.	1. Flange bolts failing.	Potential for complete failure of bin.
		2. Casing corroded.	Spillage will be evident long before hopper fails completely. Hopper will be patched until replacement can be arranged.
		3. Casing worn.	Localised wear areas will be noticed and patched. If wear is of general nature the hopper might fail completely by "bursting" but this would be highlighted by the number of patches on the hopper casing.

Age Reliability Patterns

Age-reliability patterns. In each case the vertical axis represents the conditional probability of failure and the horizontal axis represents operating age since manufacture, overhaul, or repair. These six curves are derived from reliability analyses conducted over a number of years, during which all the items analyzed were found to be characterized by one or another of the age-reliability relationships shown. The percentages indicate the percentage of items studied that fell into each of the basic patterns (United Airlines)



RCM Decision Diagram



DECISION WORKSHEET

PAGE 1 OF

EQUIPMENT: CONVEYOR SYSTEM NO.: COMPILED BY: DATE:

COMPONENT: FEED HOPPER REVIEWED BY: DATE:

Information Reference			RESPONSE TO DECISION - DIAGRAM QUESTIONS																	
			Conse-quences			TASK SELECTION														
f	ff	fm	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	PROPOSED TASK	INITIAL INTERVAL
1	A	1	Y	N	Y					Y	-	-							(Inspecting for missing liner bolts is applicable but not effective because it would require removal of stockpile to correct potential failure of blockage and eventual wear of hopper. This would be patched until shutdown is arranged). - Inspect for broken liner bolts.	During shutdown.
2	A	1	Y	N	N								N	N	N				(Because of very low probability and the fact that temporary arrangements can be made - NSM)	
2	A	2	Y	N	N								N	N	N				(If corrosion proves to be a problem, then an on-condition task can be applied).	
2	A	3	Y	N	N								Y	-	-				Check number of patches on hopper.	3 Monthly.

Economic-Tradeoff Study

PREVENTIVE STRATEGY	CORRECTIVE STRATEGY
Cost of Preventive Action:	Cost of Preventive Action:
Duration of preventive task: ______	NOT APPLICABLE
Cost per manhour: x ______	
Frequency per annum: x ______	
Annual Preventive Cost =	Annual Preventive Cost = R0.00
Cost of Planning a Job:	Cost of Planning a Job:
Total cost of planning: ______	NOT APPLICABLE
Number of jobs planned: ______	
Annual Planning Cost =	Annual Planning Cost = R0.00
Cost of Corrective Action:	Cost of Corrective Action:
Repair time: ______	Repair time: ______
Labour cost per hour: ______	Labour cost per hour: ______
Repair costs: ______	Repair costs: ______
Frequency per year: ______	Frequency: ______
Total Corrective Costs =	Total Corrective Costs =
Cost of Downtime:	Cost of Downtime:
Downtime (hours): ______	Downtime (hours): ______
Cost of hour down: ______	Cost of hour down: ______
Frequency: ______	Frequency: ______
Total Downtime Costs =	Total Downtime Costs = ______
TOTAL ANNUAL COSTS	TOTAL ANNUAL COSTS

MAINTENANCE SCHEDULE
LINE

BODYMAKER

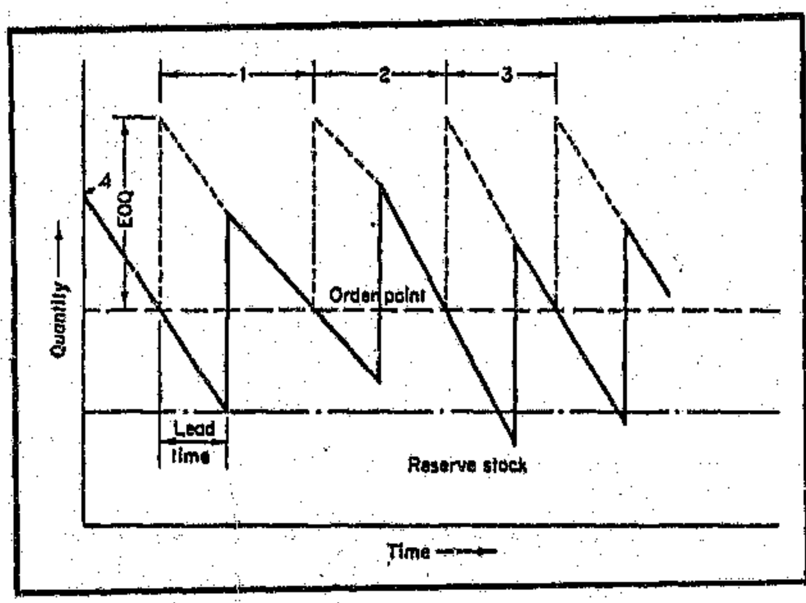
INV. N°.

DATE

DESIGNATION	DESCRIPTION	SPEC.	ACTUAL	COMMENTS
Feed hopper	Using a blank, check for good fit. Check separators for wear and chips.			
Vacuum sucker	Check for max vertical play of 1,5m, max horizontal play of 0,15mm and vacuum release 20,0mm ± 2,0mm above tinline.	1,5 0,15 20 ± 2		
Cross feed ass.	Check for excess blade wear and mz 0,25mm slide wear. Check timing, blade must be 9,5mm ± 1,5mm clear before start of forward stroke.	0,25 9,5 ± 1,5		
Spline and end blocks	Check condition. Check depth according to Standards Manual.			
Form horn insert	Check for tight fit and condition.			
Bumper steel	Check bead height for max wear of 10mm. Check condition.1	10		
Expander ass.	Check screws for wear and rolls for flat spots.			
Outside hook steels	Check 1st and 2nd form for nicks and wear. 1st fold for excess grooving and 1mm step, 2nd fold for excess wear.	1		
Inside hook steels	Check 1st form for nicks and wear, 2nd form for max radius of 5mm and no nicks. Check qst fold for excess grooving and 1mm step, 2nd fold for excess wear.	5 1		
Guide steels	Check inside and outside hook for excess damage.			
Rolling unit	Check clearance between rolls of 0,05 to 0,1mm. Check rolls are parallel to within 0,02mm. Check front brake, lower wear steel, chain and sprockets for excess wear.	0,05 0,1 0,02		
Notching station	Check bolt surface to gauge face right and left hand 28,57 - 41,27 ± 0,01mm. Check for vertical play, slit side 0,007mm max, notch side 0,18mm max.	28,57 41,27 0,007 0,18		
Finger bar	With bar fully forward check for max reciprocal play of 0,64mm finger spacing max of 0,1mm free and uniform finger action and max out-of-square between fingers of 0,05.	0,64 0,1 0,05		
Stop bars	Check for excess grooving and max out-of-square of 0,05mm	0,05		

APPENDIX 3.4A

Order Point and Order Quantity



ABC Analysis

The following table gives a list of parts, their unit costs, and annual requirements[34]:

Part Number	Unit Cost	Annual Demand
M2	20.00	120
A5	2.00	155 000
A7	8 000.00	13
L8	950.00	6
L4	0.30	7 000
A6	10.00	9 400
M9	6 000.00	70
Q2	400.00	240
Z1	0.50	200

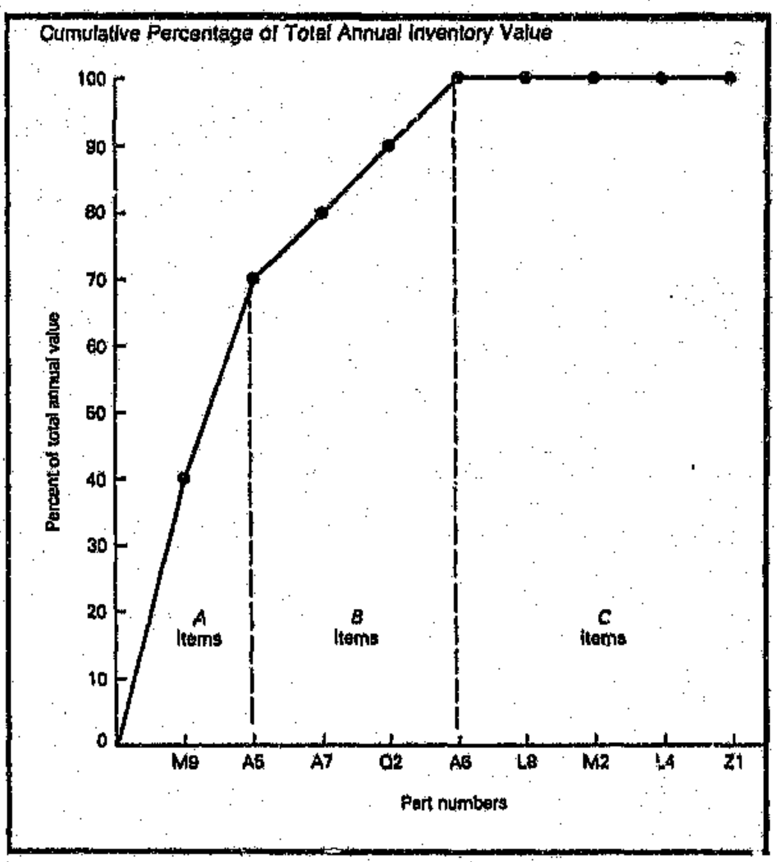
1. Annual Value and Percentage of Total

Part Number	Annual Value	Percentage of Total	Cumulative Percentage
M9	420 000	40.61%	40.61%
A5	310 000	29.97	70.58
A7	104 000	10.06	80.64
Q2	96 000	9.28	89.92
A6	94 000	9.09	99.01
L8	5 700	0.55	99.56
M2	2 400	0.23	99.79
L4	2 100	0.20	99.99
Z1	100	0.01	100.00
	1 034 300		

Two parts, M9 and A5, account for over 70% of the total annual materials value.

2. ABC Categories

Category	Part Number	Percentage of Total
A	M9	
	A5	70.58%
B	A7	
	Q2	
	A6	28.43%
C	L8	
	M2	
	L4	
	Z1	0.99%



APPENDIX 3.4C

Figure 1 Stores Requisition

STORES REQUISITION FOR MISCELLANEOUS ISSUES SR № 38202

COST/C CODE

DATE
Data Capture

QTY REQUES. Units	Dec	DESCRIPTION	U.O.M.		ITEM NUMBER	ISSUE Whs	Loc	QTY ISSUED Units	Dec	Item Contract
				1		0 0				
				2		0 0				
				3		0 0				
				4		0 0				
				5		0 0				
				6		0 0				

REQUEST AUTHORISED BY: ____________________ ITEMS ISSUED BY: ____________________

ITEMS RECEIVED BY: ____________________

Copies: Pink — Requesting Party / White — In Book
Yellow — Data Processing

R & M 1005

Figure 2 Purchase Requisition

A/c. Code
Code
M/C No.

PURCHASING REQUISITION

Dept. ____________________
Date ____________________

№ 62412

Quantity	Description and Reference	Purpose	Usage last 4 weeks	Stock	Min.

R & M

Supplier .... Signed ....
Price ....
Delivery .... Agreed ....
Order No. ....

CURRENT PERIOD APR 91 ORIGINAL BUDGET	ACTUAL	VARIANCE	ENGINEERING GENERAL EXPENSE STATEMENT	YEAR TO DATE JUL 90 TO APR 91 ORIGINAL BUDGET	ACTUAL	VARIANCE	%	Y.T.D TO APR PREVIOUS YEAR
			SALARIES					
129265	135219	5976 U	SALARIES - INDIRECT	1292430	1281824	10606	.8	612916
37117	31942	5175	SALARIES - OVERTIME	371173	335013	36157	9.7	119520
166380	167161	801 U	TOTAL - SALARIES	1663603	1616837	46763	2.8	732436
			WAGES					
35588	40510	5022 U	WAGES - NORMAL INDIRECT	355883	329995	25885	7.3	223786
10725	8203	2522	WAGES - OVERTIME INDIRECT	107250	93967	13283	12.4	46048
46313	48813	2510 U	TOTAL - WAGES	463130	423962	39168	8.5	266834
			CO CONTRIBUTIONS					
12567	14194	1627 U	MEDICAL AID	125670	130660	4990 U	4.0	61085
13263	13119	144	PENSION FUND	132630	132917	287 U	.2	59179
1286	1235	51	U.I.F.	12860	11457	1403	10.9	6212
1056	1336		WORKMANS COMP	10560	10560			5350
28172	29504	1432 U	TOTAL - CO CONTRIBUTIONS	281720	285593	3873 U	1.4	131926
			STAFF BENEFITS					
			BONUSES	96695	90385	6310	6.5	48334
2935	4632	1797 U	LEAVE PAY	29250	39527	10277 U	35.1	31299
1596	660	936	SICK-LEAVE PAY	15960	12711	3249	20.4	9876
4521	5292	771 U	TOTAL - STAFF BENEFITS	141905	142623	718 U	.5	89509
245386	250871	5535 U	TOTAL MANPOWER COSTS	2550355	2469015	81340	3.2	1220605
			VEHICLES					
240	394	154 U	VEHICLES - FUEL	2400	5280	2880 U	120.0	3907
			VEHICLES - INS & LICENCE	86	158	72 U	83.7	66
			VEHICLES - MAINTENANCE	1808	1356	452	25.0	317
			VEHICLES - TYRES & TUBES	728	826	98 U	13.5	
240	394	154 U	TOTAL - VEHICLES	5022	7620	2598 U	51.7	4290
			SERVICES					
	483	483 U	FUEL LP GAS		7617	7617 U		
	483	483 U	TOTAL - SERVICES		7617	7617 U		
			REPAIRS & MAINTENANCE					
	16237	16237 U	R & M BUILDINGS	43647	7365	36282	83.1	466887
336	1337	337 U	R&M FORKLIFTS	25800	22113	3687	14.3	1020
1330	3513	2313 U	R&M PLANT	44299	38301	5399	13.3	471539

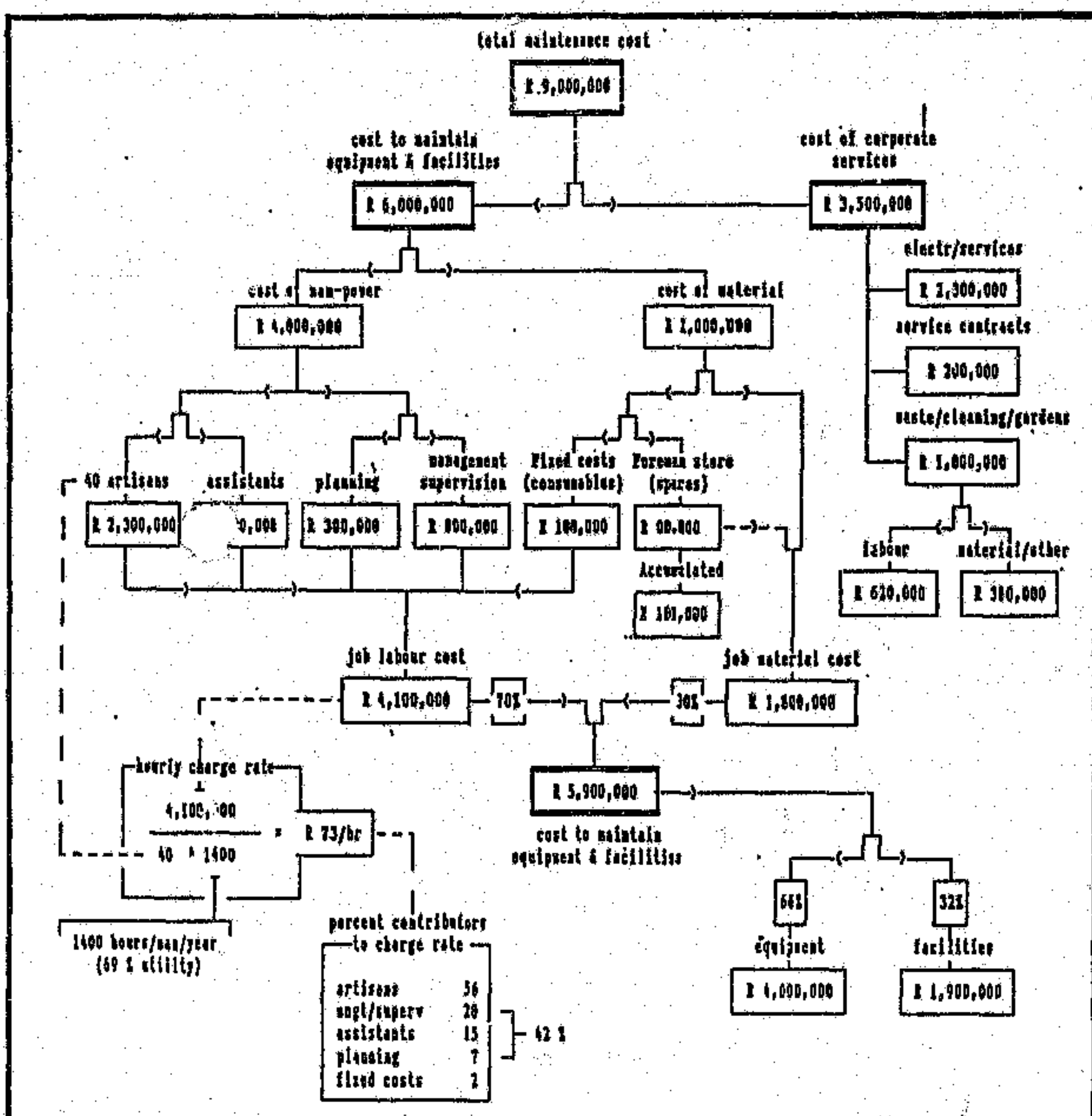
General Ledger Account

Page 138

APPENDIX 3.4D

APPENDIX 3.4E

Functional Breakdown of Total Maintenance Expenditure



APPENDIX 3.4F

The Maintenance Budget

Maintenance Cost Standards

Material Costs :	Total Maintenance Expenses		= 7 000 000
	Labour/Material		= 56,5/43,5
	∴ Total Material Cost = 0,435 x 7 000 000		= 3 045 000
	Maintenance	87%	= 2 649 150
	Modifications	13%	= 395 850
	Total Maintenance Cost		= 2 649 150
	Machinery Repairs	77,5%	= 2 053 091
	Forklift Repairs	10,5%	= 278 161
	Plant Facilities	12,0%	= 317 898
	Total Production Tons (Y-1)		= 17 000

Actual cost per ton:

- Machinery $= \frac{2\ 053\ 091}{17\ 000}$ = 121
- Forklifts $= \frac{278\ 161}{17\ 000}$ = 16

Cost of Equipment and Forklift maintenance is expected to rise by 5%:

New Standard:

- Machinery = 1,05 x 121 = 127
- Forklifts = 1,05 x 16 = 17

Labour Cost :	Total actual hours for all maintenance		= 35 000
	Maintenance	87,25%	= 30 538
	Modifications	12,75%	= 4 462

Hours per ton $= \frac{30\ 538}{17\ 000}$ = 1,80

Total labour cost = 0,565 x 7 000 000		= 3 955 000
Maintenance	87,25%	= 3 450 738
Modifications	12,75%	= 504 262

Labour Tariff = $\frac{3\ 450\ 738}{30\ 538}$ = 113

Labour cost per ton = 1,8 x 113 = 203

Maintenance labour is expected to rise by 8%

New Standard = 1,08 x 203 = 220

Total cost per ton of production = 127 + 17 + 220 = 364

Budget

The following information is provided regarding the new budget :

- Annual production volume 19 000 tons
- Material cost per ton = 127 + 17 = 144
  Labour cost per ton = 220

Material Budget:	Machinery Repairs = 19 000 x 127	=	2 413 000
	Modifications: a reduction of 10% in the material requirements of modifications is expected : 395 850 x 0,9	=	356 265
	Forklifts = 19 000 x 17	=	323 000
	Plant Facilities:	=	300 000
	Painting of roofs	=	50 000
	Painting of structures	=	100 000
	Repairs to roads	=	50 000
	Replacement of floors	=	100 000
	Total material budget	=	3 392 265
Labour Budget :	Maintenance = 19 000 x 220	=	4 180 000
	Modifications: the reduction in modifications will lead to a reduction in labour requirements of 13%: 504 262 x 0,87	=	438 708
	Total labour budget		4 618 708
	Labour hours required	=	38 082
	Maintenance = 19 000 x 1,8	=	34 200
	Modifications = 4 462 x 0,87	=	3 882

Artisan utility = 65%

.'. Labour hours required = $\frac{38\ 082}{0,65}$ = 58 588

Average absenteeism = 4%

.'. Labour hours required = $\frac{58\ 588}{0,96}$ = 61 029

Of the total hours worked
20% is overtime:
∴ Clocked artisan hours
= 0,8 x 61 029 = 48 823

Artisans work 200 hours per
month excluding overtime
∴ Number of artisans required

$$= \frac{48\ 823}{200 \times 12} = 20,3$$

21

The labour budget is set out
as follows :

1.	Supervisory Personnel	17,4%	=	803 655
2.	Artisans	57,5%	=	2 655 757
3.	Assistants	21,6%	=	997 641
4.	Planning	1,3%	=	60 043
5.	Workshop overhead	2,2%	=	101 612
			=	4 618 708

Total maintenance budget = 3 392 265 + 4 618 708 = 8 010 973

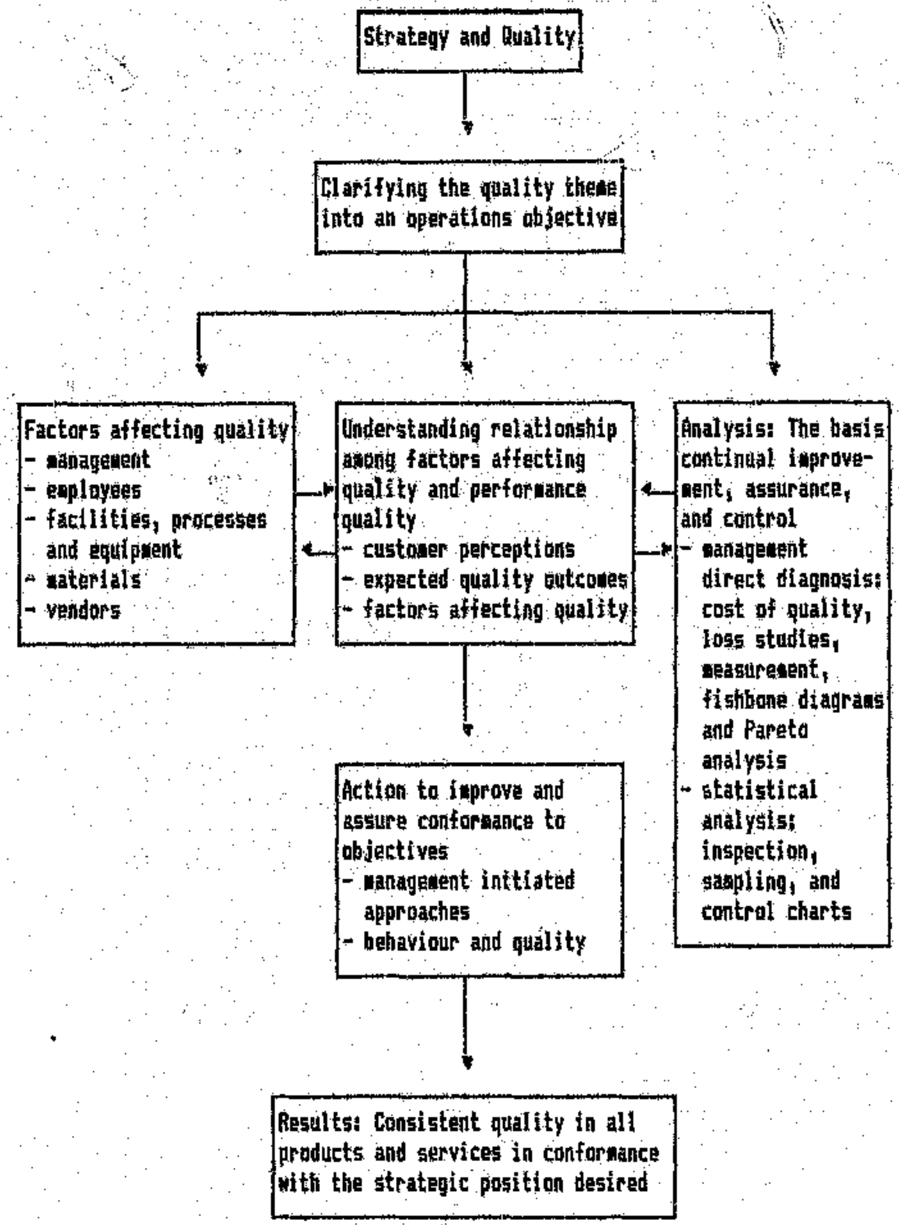
Increase in maintenance budget = 14,4%

Projected Nett Sales Value = RM130
Maintenance/NSV = 6,2%

Capital Replacement Value = RM120
Maintenance/CRV = 6,7%

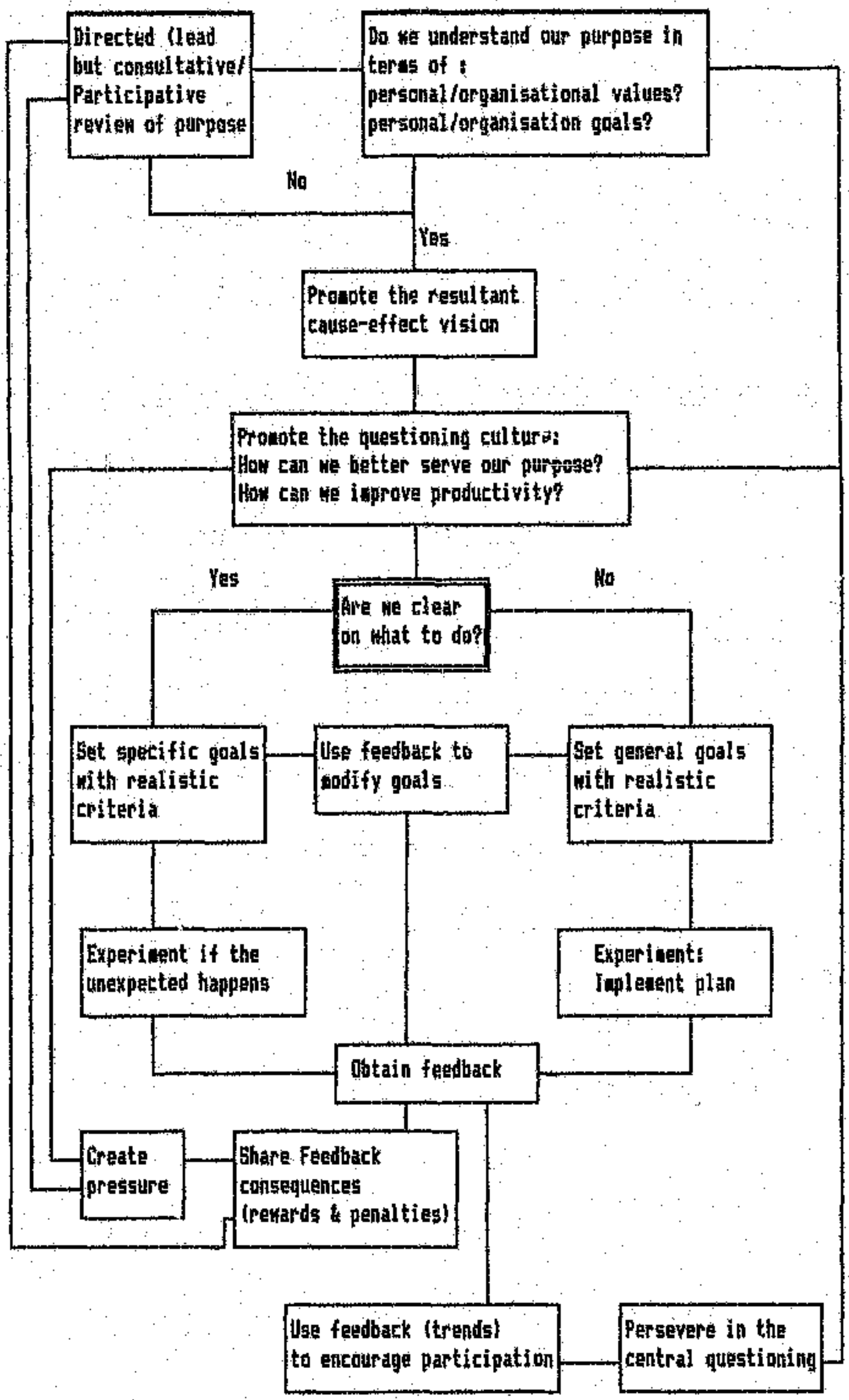
APPENDIX 3.5A

Figure 1 Managing for Quality Products and Services



APPENDIX 3.5A

Figure 2 A Framework for Improving Productivity/Quality



APPENDIX 3.6A

Economic Life Calculation

The optimum life of machinery is based on the operating cost of the machinery only

Cost of Capital 18%			Book Value	PV Factor	PV
Cost of Plant	yr 0		37 500		
Initial allowance & depreciation	yr 1	15 000	22 500	0,847	19 056
Depreciation	yr 2	4 500	18 000	0,718	12 924
	yr 3	3 600	14 400	0,609	8 770
	yr 4	2 880	11 520	0,516	5 944
	yr 5	2 304	9 216	0,437	4 027
	yr 6	1 843	7 373	0,37	2 728
	yr 7	1 475	5 898	0,314	1 852
	yr 8	1 180	4 718	0,266	1 255

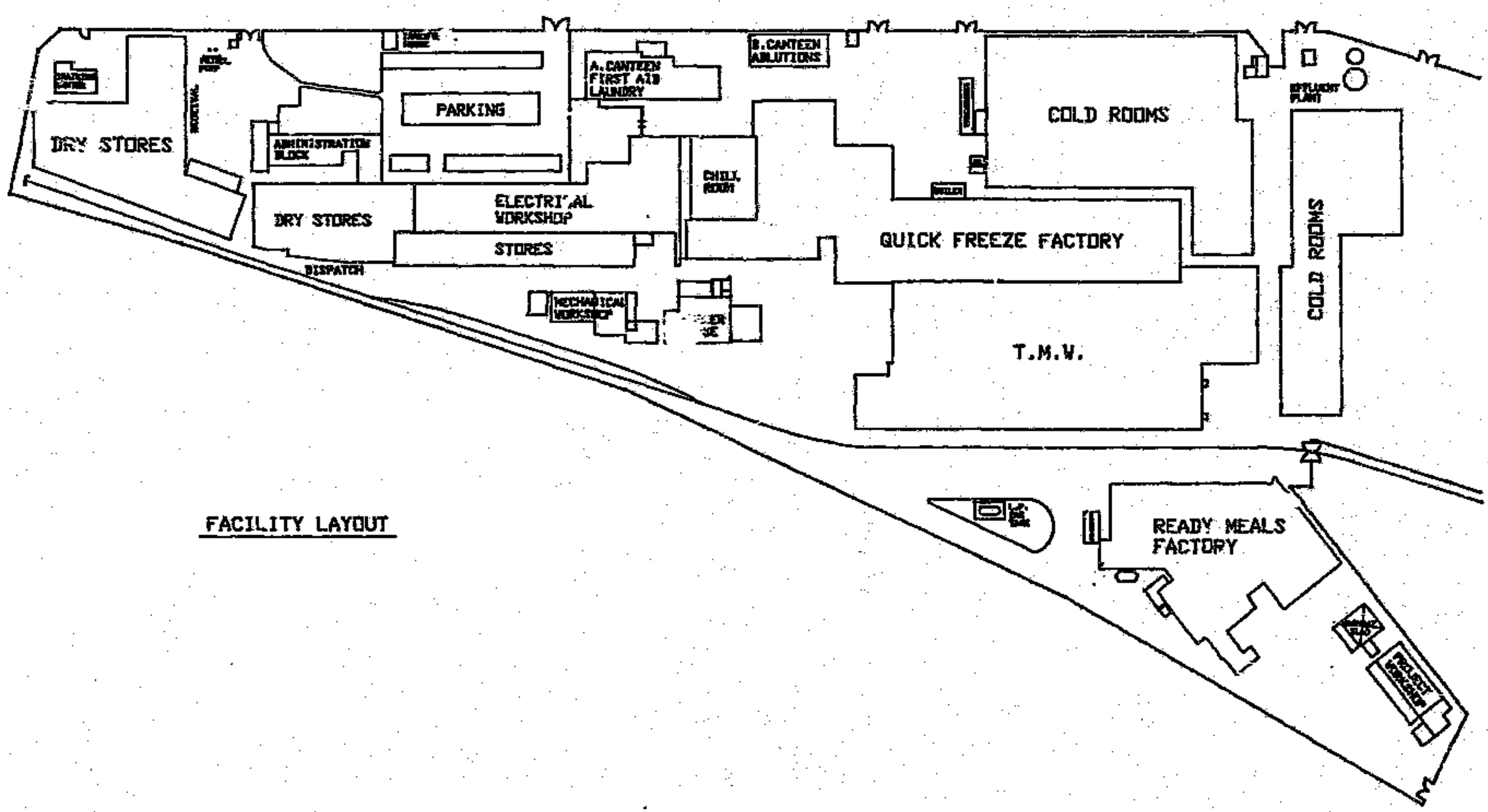
Ignore sales, operating costs and all costs that stay unchanged over the machine life

		3	4	5	6	7
Maintenance cost after tax	11667 x 0,6	7000				
	15000 x 0,6		9000			
	18333 x 0,6			11000		
	21667 x 0,6				13000	
	25000 x 0,6					15000
PVF		0,609	0,516	0,437	0,37	0,314
PV		4263	4644	4807	4810	4710
Depreciation		3600	2880	2304	1843	1475
Depreciation Tax shield = Depr x 0,4		1440	1152	922	737	590
PV		877	594	403	273	185

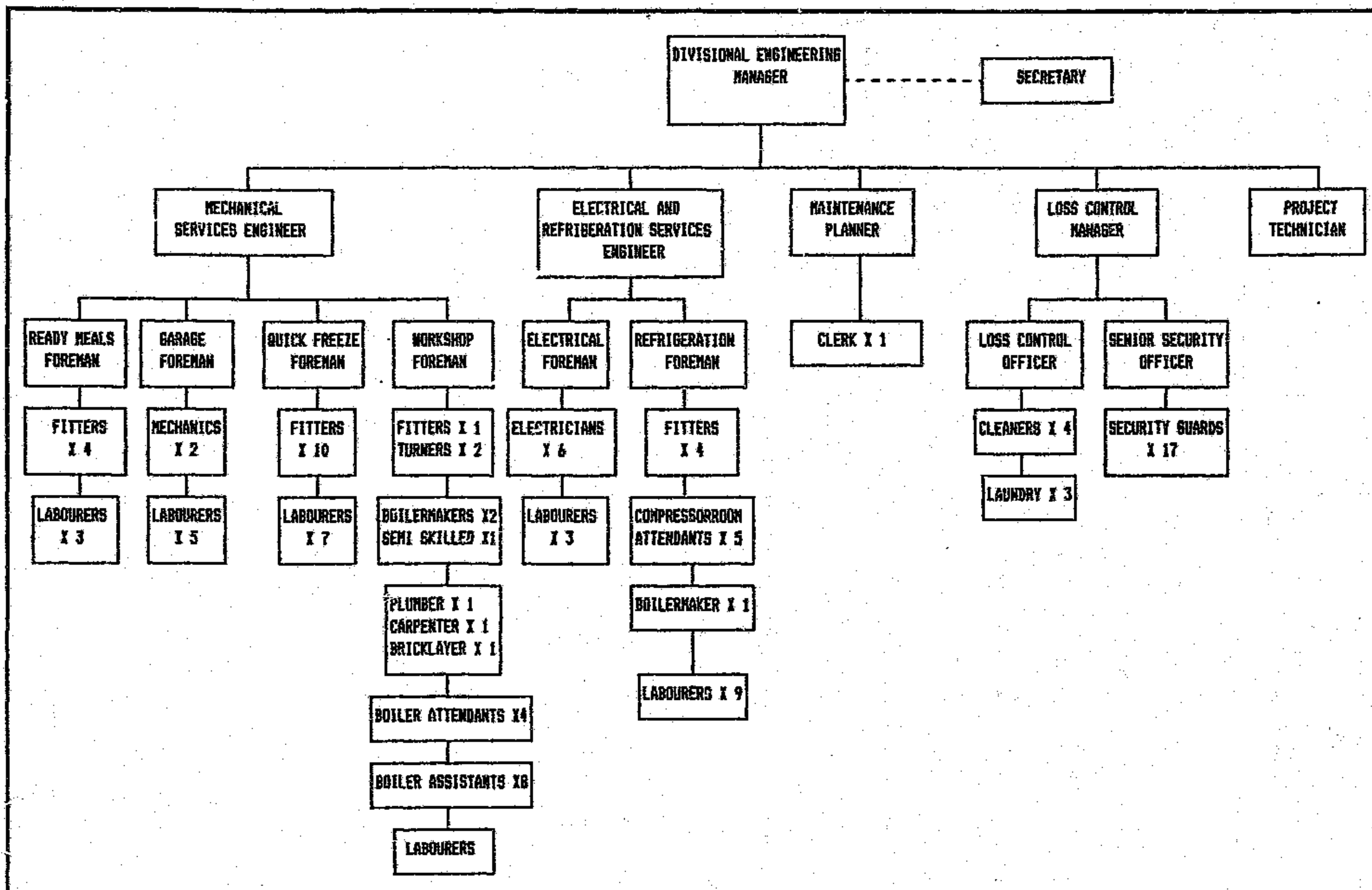
	3	4	5	6	7
	37500	37500	37500	37500	37500
3 Maint - Depr. Shield	3386	3386	3386	3386	3386
4		4050	4050	4050	4050
5			4404	4404	4404
6				4537	4537
7					4527
	40886	44936	49340	53877	58404
Less: PV Scrap Val.	-8526	-5378	-3853	-2580	-1726
Less: PV Scrapping all	-97	-83	-70	-59	-50
	32263	39502	45417	51238	56628
PVA factor	2,174	2,690	3,127	3,498	3,812
	14840	14685	14524	14648	14855

Most economic life 5 years

APPENDIX 4.1A



FACILITY LAYOUT



APPENDIX 4.1B

APPENDIX 4.1C

DUTY ROSTER

WEEK ENDING

ENGINEERING MAINTENANCE TEAM

DATE:

	SATURDAY	SUNDAY
TEAM LEADERS		
SHIFT ELECTRICIAN		
SHIFT FITTER		
SHIFT FITTER		
STANDBY FITTER (REFR)		
STANDBY MECHANIC		
ADDITIONAL STAFF		
ARTISANS		
ASSISTANTS		

APPENDIX 4.2A

Figure 1 Jobcard Front

JOB CARD NO.:

DEPARTMENT	TIME	DATE		CODE	JOB TYPES
				A	BREAKDOWN
PLANT NUMBER			SPECIAL CODE	B	SAFETY
- -				C	MAINT.
REQUESTED BY:				D	MODS. *
JOB REQUEST:				DATE REQUIRED	
				ESTIMATED TIME	
ALLOCATED TO		DATE	NUMBER		
				* APPROVED BY ENGINEER	
TIME RECEIVED	RECEIVED BY				

Figure 2 Jobcard Back

DETAILS OF WORK DONE			DATE	TIME START	TIME FINISH	HOURS
			TOTAL HOURS			
			APPROVED BY FOREMAN			
			WORKSHOP CODE			
			ORIGINATOR'S APPROVAL			
			SIGN		TIME	
FC	FN	CAUSE			h	

APPENDIX 4.2B

JOB CARD CODES

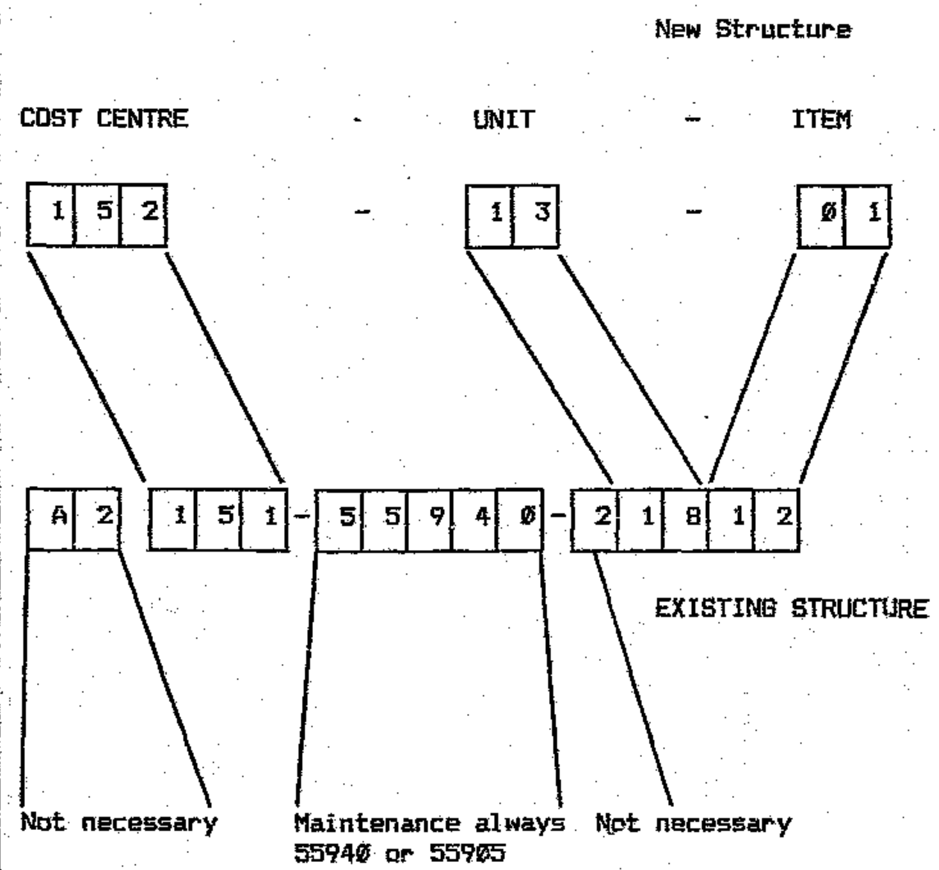
CODE	FUNCTIONAL COMPONENT (FC)
A	Cooling System (air and liquid)
B	Drive
C	Electrical System
D	Filtration System
E	Fuel System
F	Heating System
G	Hydraulic System
H	Lubrication System
I	Pneumatic System
J	Refrigeration System
K	Structure
L	Product Forming / Cutting System
M	Product Feed System
N	Sealing System

CODE	FAILURE MODES (FM)
01	Bearing /Bush Failure
02	Filter Blocked / Failed
03	Pipe Blocked / Broken
04	Brake Failure
05	Broken / ked / Damaged
06	Chain Failure
07	Clutch Failure
08	Conveyor Belt Failure
09	Coupling Failure
10	Cylinder Failure
11	Drive Belt Failure
12	Electric Control Circuit Failure
13	Electric Main Circuit Failure
14	Electric Motor Failure
15	Electric Wiring Failure
16	Gear Failure
17	Gearbox Failure
18	Heating Elements Failure
19	Instrumentation Failure
20	Low Level (Gas, Diesel, Coal)
21	Low Level (Refrigerant, Water, Steam, Air)
22	Pump Failure
23	Regulator Failure
24	Roller Failure
25	Scheduled Inspection
26	Seal Failure
27	Shaft / Pulley Failure
28	Sprocket Failure
29	Valve Failure
30	Wear
31	Hydraulic Motor Failure
32	Jammed / Blocked
33	Low Pressure
34	Incorrect Adjustment / Assembly
35	Faulty Packaging / Product

CODE	CAUSE OF FAILURE
A1	Wrong Alignment
A2	Abnormal Working Cond
A3	Overloading
A4	Overheating
A5	Mech Wear/Limited Life
A6	Setting/Operator's Fault
A7	Vibration
A8	Operator's Neglect/Misuse
A9	Bad Maint./Lack of PM
A10	Ingress of dirt/ Foreign Material
A11	Spikes / Resonance
A12	Unknown or no failure
A13	Damage by forklift/Neglect

Equipment Numbering System

FIXED PLANT NUMBER STRUCTURE



MOBILE EQUIPMENT NUMBER STRUCTURE

COST CENTRE - UNIT - ITEM

1 5 2 - 9 0 - 1 3

TYPES

00 Buildings
01 Plant and Equipment
to
69 Plant and Equipment
70 Free for expansion
80 Forklifts
90 Vehicles

APPENDIX 4.3A

Plant Inventory

COST CENTRE

140 Cold Stores
151 Engineering
152 Quick Freeze
170 Dry Stores
171 Engineering Stores
177 Marble Hall
179 Ohrigstad
180 Letsitele
182 Thabazimbi
355 Prepared Foods
655 Carmel
901 Staff Shop
914 Security
916 Training
918 Laundry
919 Surgery
935 Admin

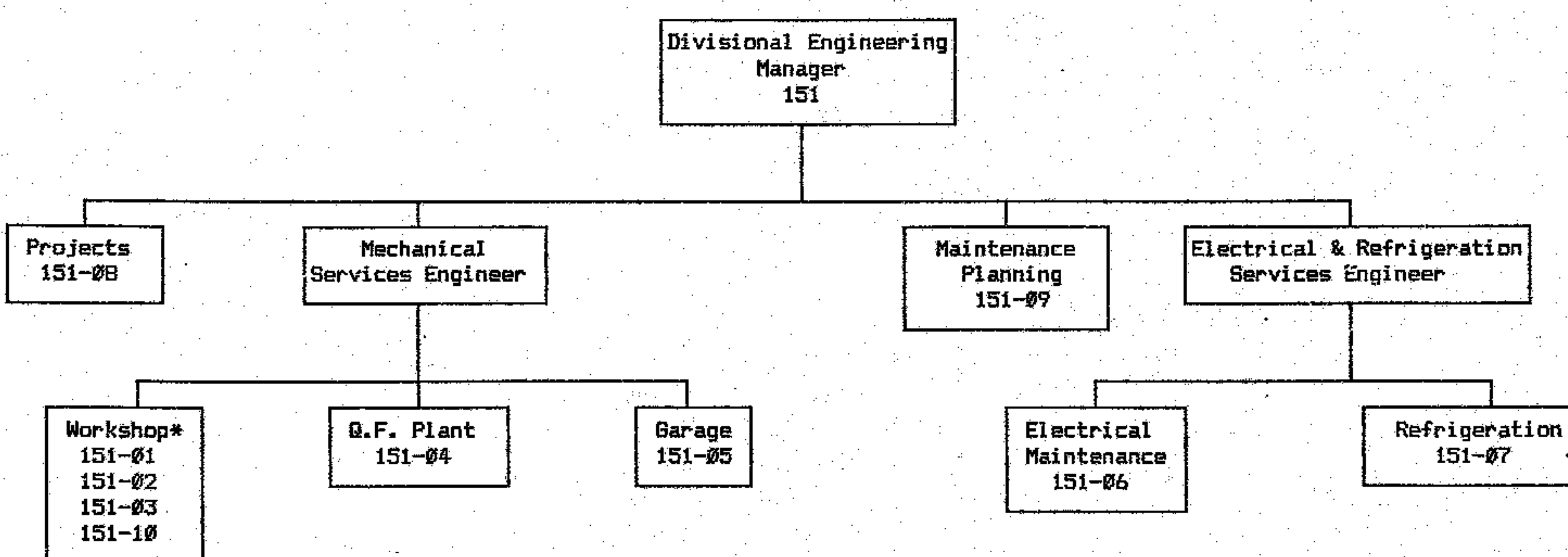
UNIT

00 General
11 Line No. 1
12 Line No. 2
13 Line No. 3
14 Line No. 4
15 Spinach Line
16 Corn Line
17 Bean Infeed Line
18 Thermal Oil Heating System
19 High Pressure Boiler
20 Chlorine Dosing System
21 Plate Freezers
22 Ammonia Supply Unit
23 Effluent Handling System
24 ...
25 ...
26 ...
.. ...
.. ...
70 Buildings
80 Internal Combustion Fork Trucks
90 Vehicles

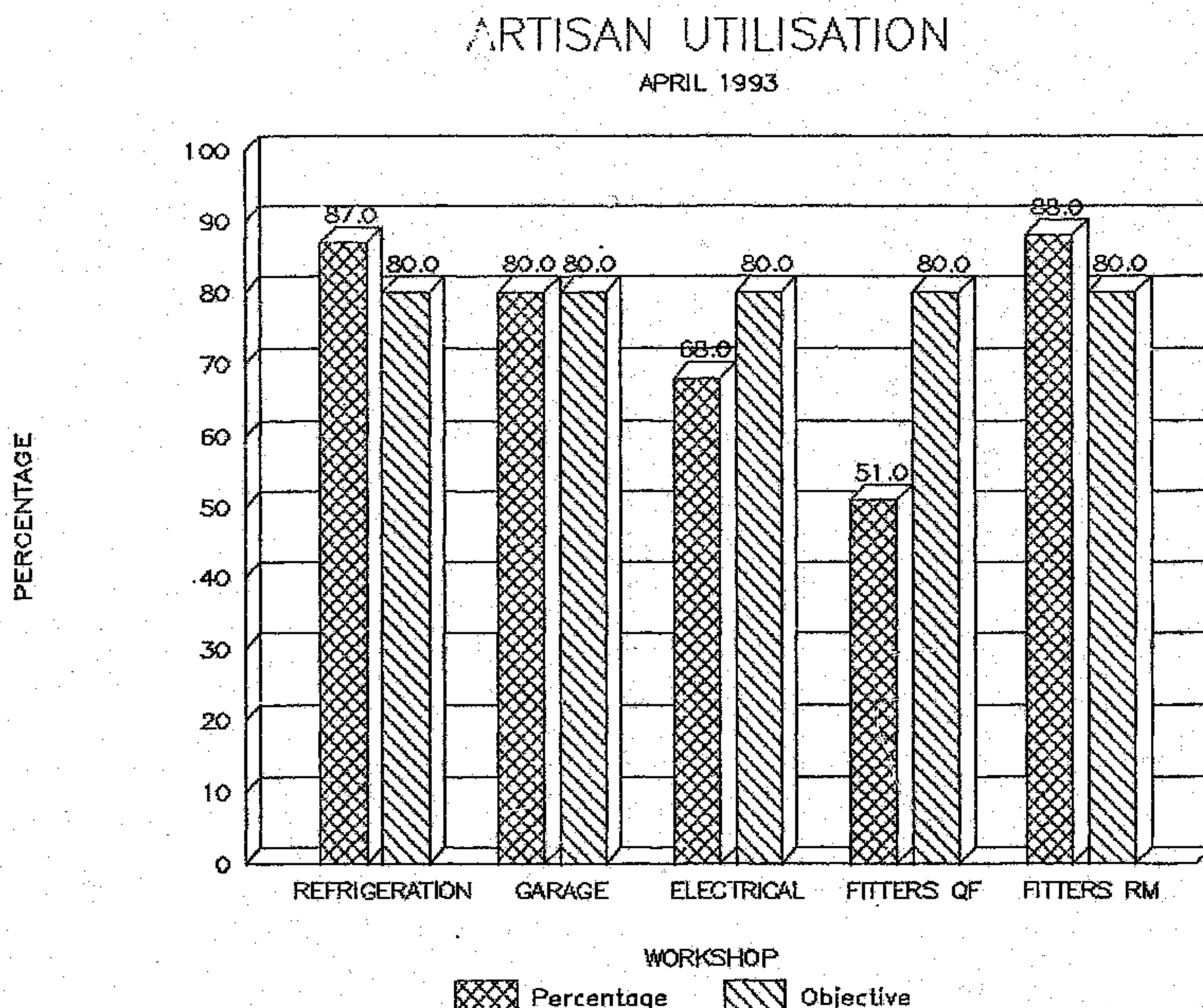
ITEM

00 ...
01 Bulk Bin Tipper
02 Heath Hopper
03 Cross Conveyor
04 Sand Remover
05 Dry & Wet Washer
06 Slatted Conveyor Elevator
07 Vertical Slatted Elevator
08 Steam Peeler
09 Scrubber
10 Slatted Elevator
11 Sorting & Trimming Belt
12 Re-peel Conveyor
13 Slatted Elevator
14 Holding Tank
15 Screw Elevator
16 Shaker
17 Cross Conveyor
18 Scraper Elevator
19 Blancher No. 1
20 S'iver Remover
21 Shaker Grader
22 Blancher No. 2
23 De-watering Shaker
24 Fryer
25 Defatting Shaker
26 Wire Mesh Elevator
27 Cooler Blower
28 Wire Mesh Elevator
.. ...

Engineering Department Responsibility Codes



151-Ø1 Plumbing
* 151-Ø2 Bricklaying
151-Ø3 Carpentry
151-1Ø Machining


ARTISAN UTILISATION
APRIL 1993
PERCENTAGE
100
90
80
70
60
50
40
30
20
10
0
87.0
80.0
80.0
80.0
68.0
80.0
51.0
80.0
88.0
80.0
REFRIGERATION
GARAGE
ELECTRICAL
FITTERS QF
FITTERS RM
WORKSHOP
Percentage
Objective

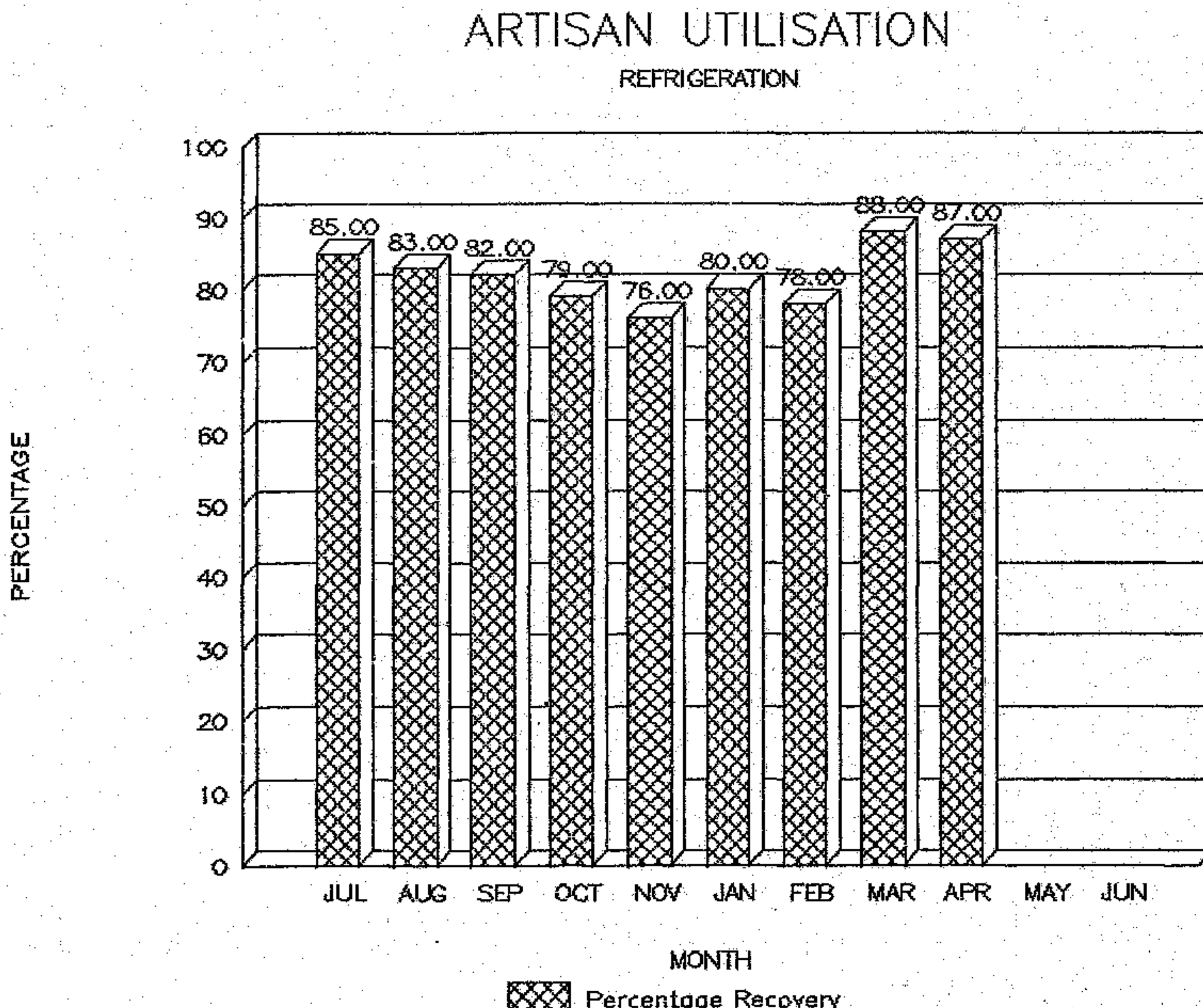


Figure 2

APPENDIX 4.4A

<u>Attendance Register</u>

PREPARED FOODS MONTH: ____________

WORKSHOP		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
J.H.C. VENTER	1001																															
L.C. SMIT	1567																															
P.J.A. JONES	1593																															
J.J. KOEKEMOER	1068																															
W. LEKGEU	1612496																															
E. LELOSA	1617415																															
W. KULA	1642826																															

<u>LEGEND</u> A – LATE B – SICK C – LEAVE D – OVERTIME E – MEI [illegible] F – ABSENT G – ABSENT WITH PERMISSION H – CALL OUT

APPENDIX 4.4B

Figure 1 PM Scheduling

SCHEDULE PLANNER
FOR THE MONTH OF/MAY 1993

EQUIPMENT NUMBER	EQUIPMENT DESCRIPTION	SCHEDULE TYPE AND FREQUENCY	SCHEDULE FILE NUMBER	DATE REQUIRED	COMPLETED Y/N	DATE COMPLETED	JOBCARD NUMBER
152-12-36	TUNNEL 2	MECH, 6 WEEKLY REFR, 6 WEEKLY	F6-003 RF6-003	14-MAY-93			43956 43957
152-14-17	TUNNEL 4	MECH, 6 WEEKLY REFR, 6 WEEKLY	F6-004 RF6-004	07-MAY-93	Y Y	08-MAY-93 09-MAY-93	43952 49953
152-12-26	BLANCHER 2	MECH, 24 WEEKLY ELECT, 24 WEEKLY	F24-005 E24-003	09-MAY-93	N Y	 09-MAY-93	97644 97645
	EARTH LEAKAGE REGISTER	ELECT, ONCE MONTHLY		24-MAY-93			
152-57-01	GOODS HOIST # 1	MECH, 12 WEEKLY ELECT, 12 WEEKLY	F12-029 E12-008	21-MAY-93			
152-57-02	GOODS HOIST # 2	MECH, 12 WEEKLY ELECT, 12 WEEKLY	F12-028 E12-008	21-MAY-93			
152-20-27	STITCHER	MECH, 12 WEEKLY ELECT, 12 WEEKLY	F12-019 E12-005	28-MAY-93			

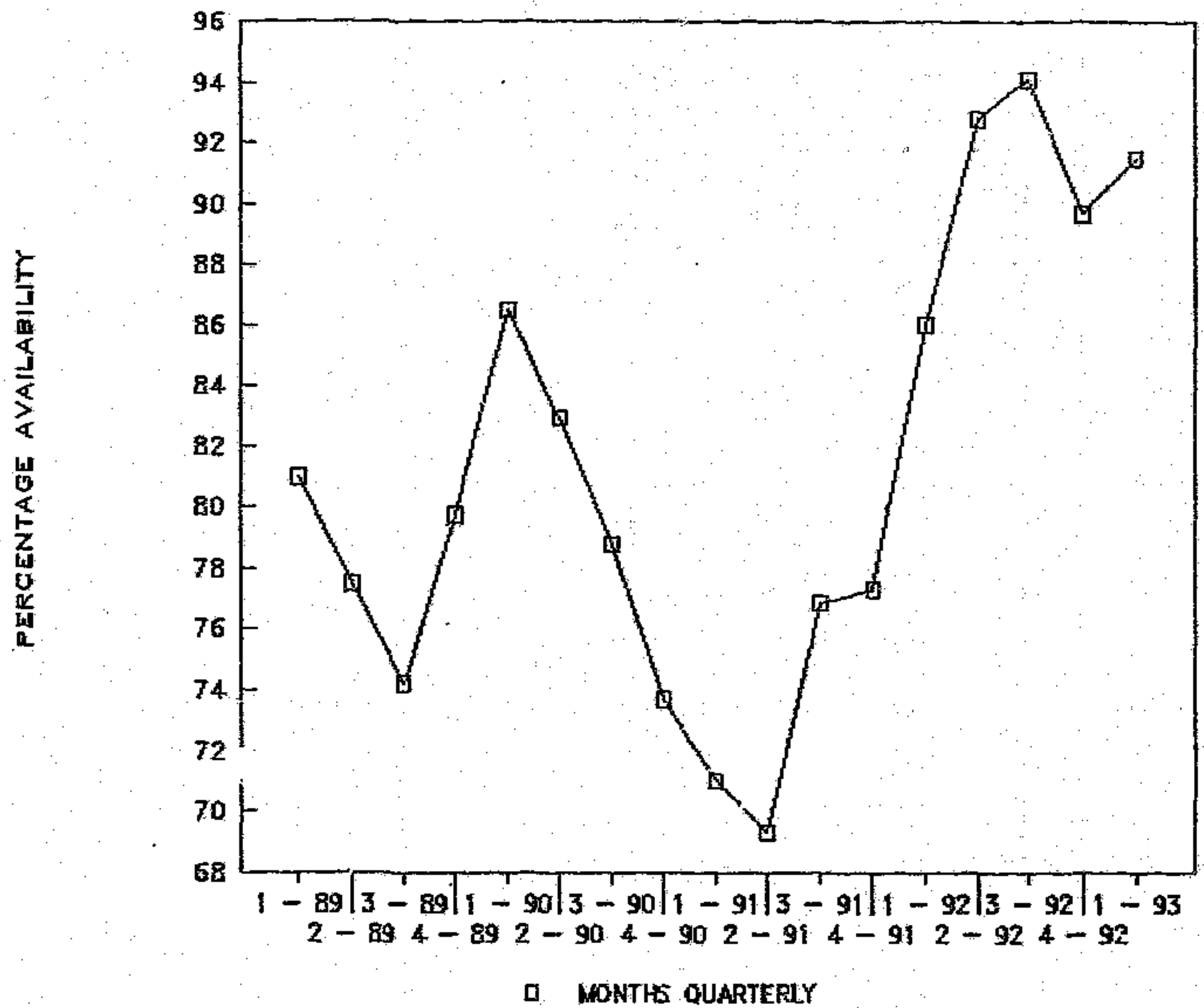
PERCENTAGE COMPLETE: 21

Figure 2 Time Spent in Categories of Maintenance

DEPARTMENT	B/DOWNS	SAFETY	MAINT	MODS	TOTAL	%
100	388,81	0	471,07	0	859,88	1,74
140	1 031,97	159,74	2 059,59	148,50	3 399,80	6,89
151	170,33	186,32	1 745,86	197,66	2 300,17	4,66
152	3 484,77	627,31	17 884,25	4 542,72	26 539,05	53,79
170	126,00	4,00	158,33	[illegible]2,75	301,08	0,61
355	3 362,20	371,63	[illegible] 300,70	[illegible],61	13 273,14	26,90
903	699,96	103,75	1 715,87	14[illegible],38	2 662,96	5,39
TOTAL	9 264,04	1 452,75	32 335,67	6 283,62	49 336,08	100,00
%	18,77	2,94	65,54	12,73	100,00	
NPI	21	-	58	21	100,00	

LINE AVAILABILITY CONTROL CHART

LINE 111 QF



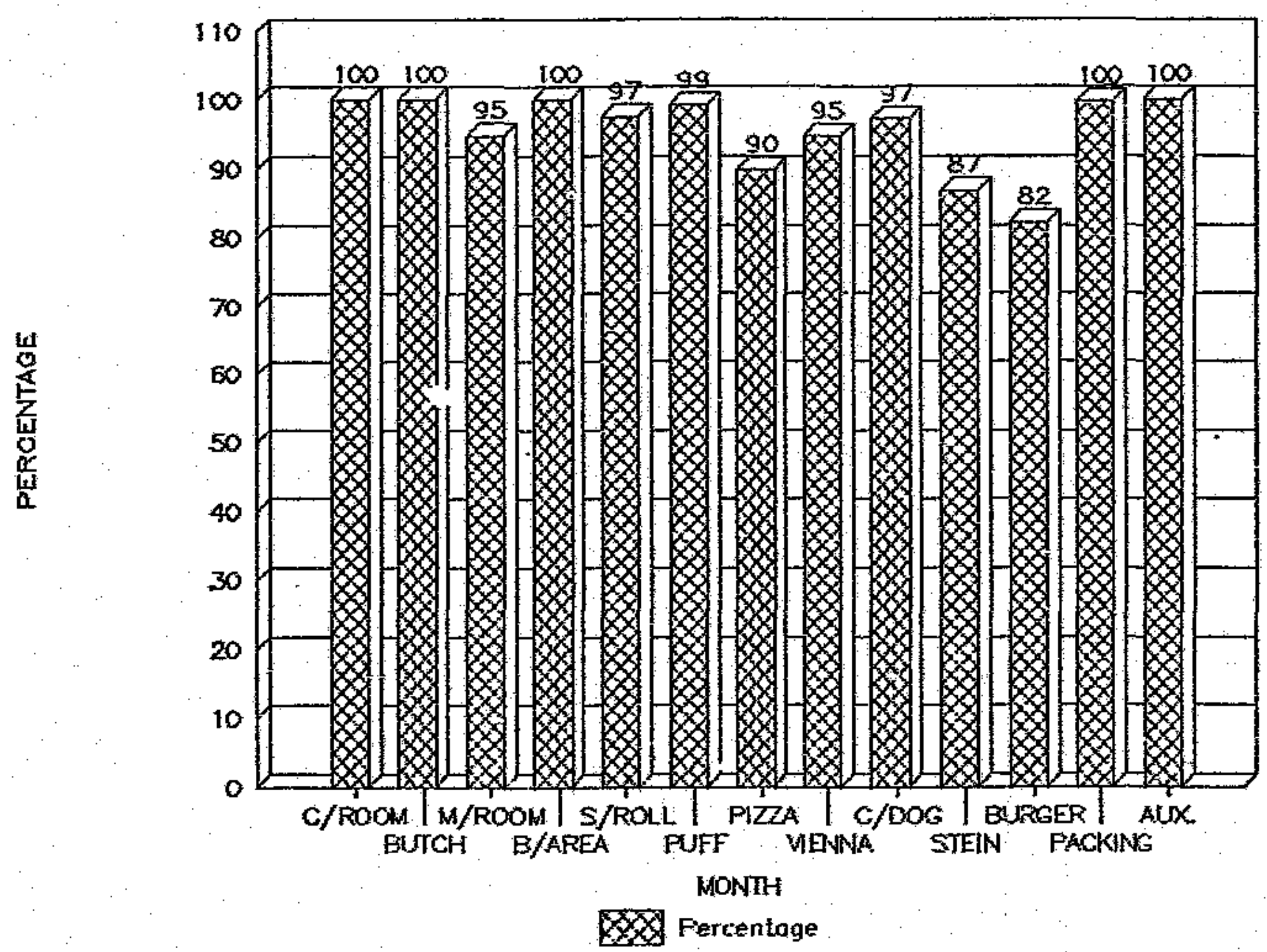
APPENDIX 4.4D

APPENDIX 4.4E

MONTH		JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	CUM
	LAB													
	MAT													
	LAB/MAT													
MAINT	ACT M/HRS													
COST	MAINT TARIFF													
	TOT ACTUAL													
	TOT BUDGET													
	VARIANCE													
WORK	JOBS REC													
ORDER	JOBS COMP													
PROG	BACK LOG													
	PERF INDEX													
MAINT	MTTR P&M													
PROD	MTTR VEH													
	OT/NT HOURS													
	SAFETY													
	B/DOWNS													
PLANNED	MAINT													
MAINT	MODS													
PROG	PM RATIO													
	MTBF P&M													
	MTBF VEH													

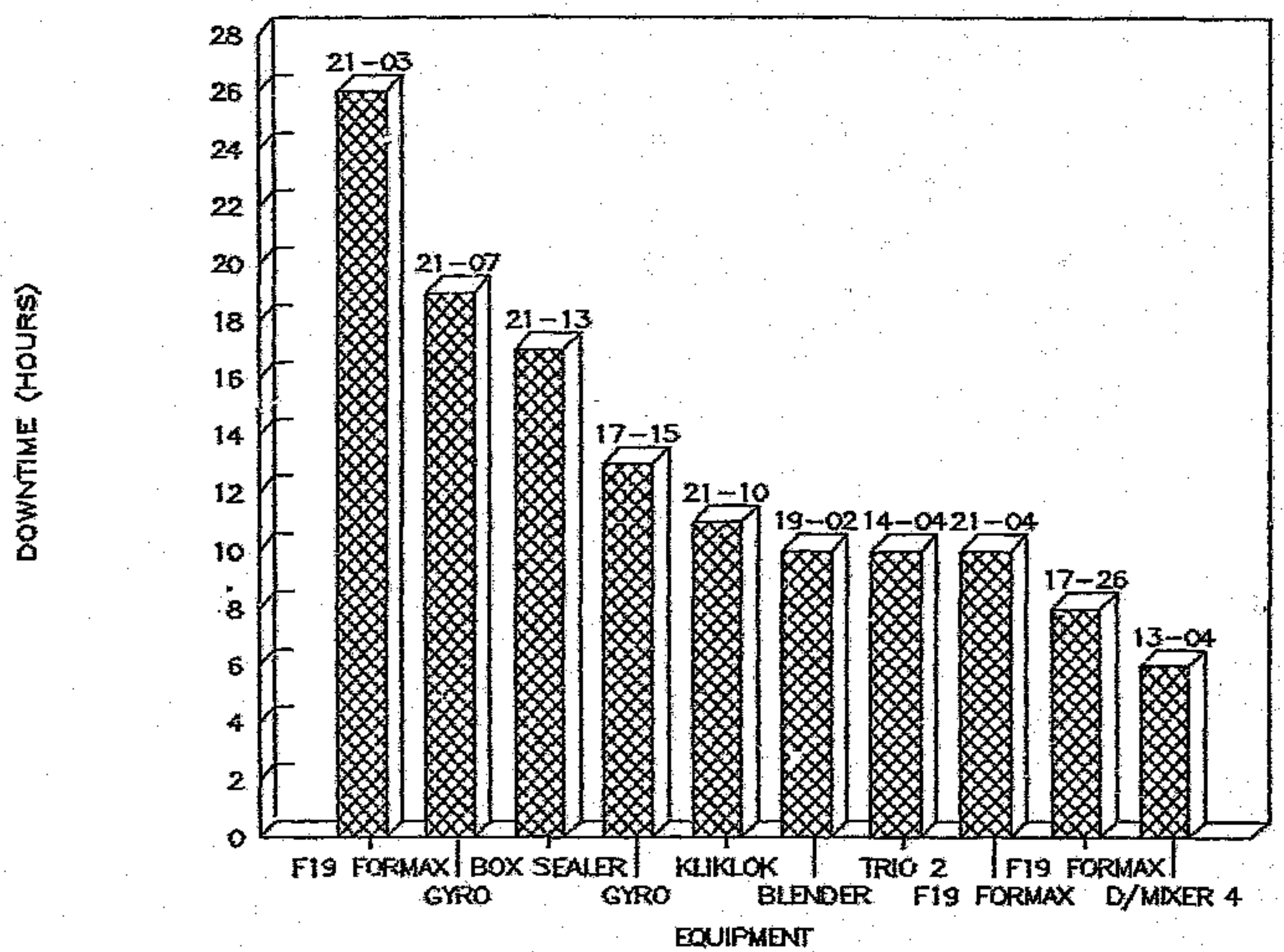
LINE AVAILABILITY R.M.

APRIL 1993



TOP TEN

PREPARED FOODS (355) - APRIL 1993

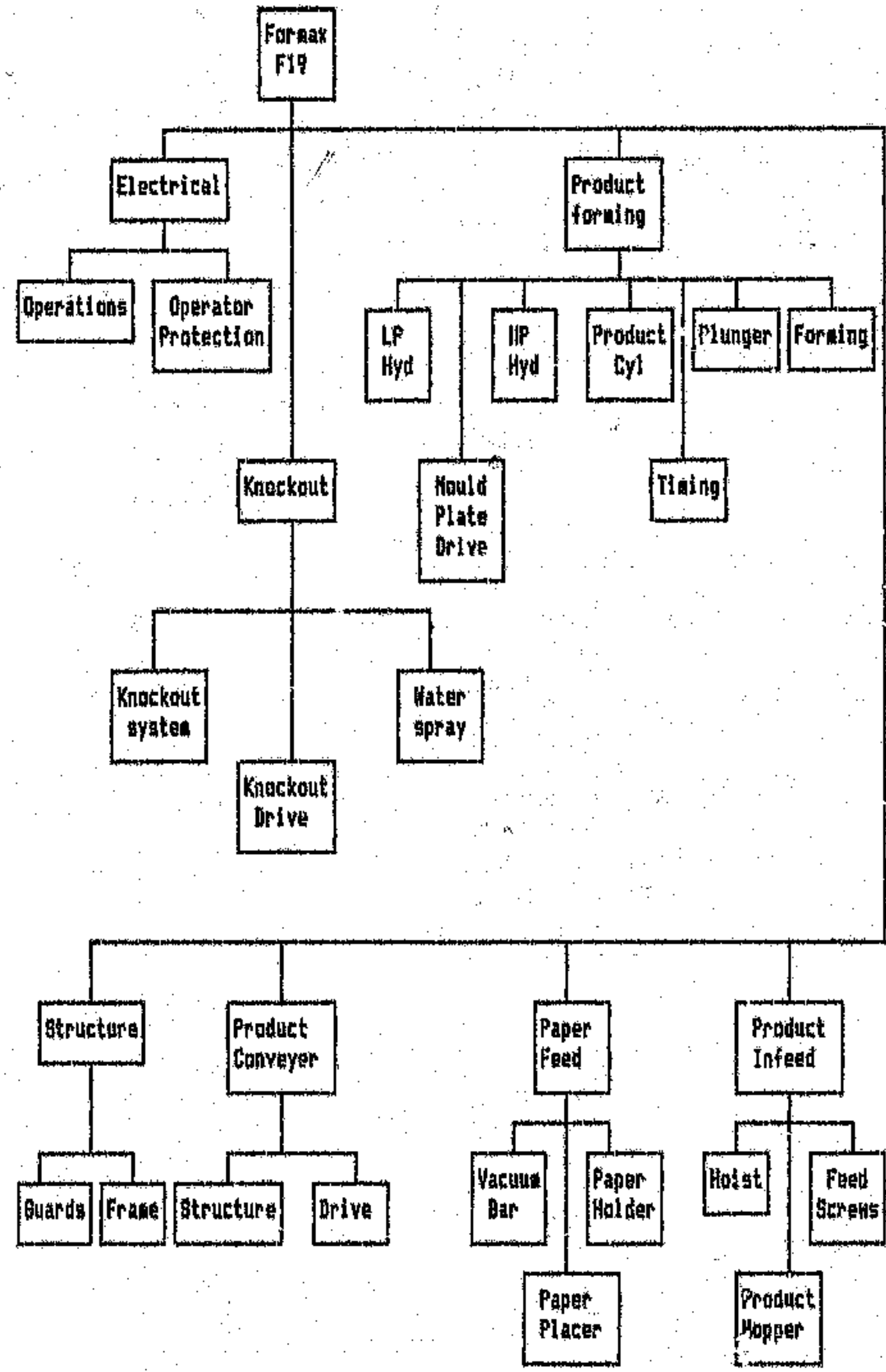


APPENDIX 4.5B

PREPARED FROZEN MEALS

LINE NUMBER	LINE DESCRIPTION	TOTAL MATERIAL COST 01/07/92 – 19/05/93
355–10–00	COMPRESSOR ROOM	33180.23
355–12–00	BUTCHERY	2043.11
355–13–00	MIXING ROOM	5103.34
355–14–00	BOOKING AREA	6631.95
355–15–00	SAUSAGE ROLL LINE	26566.64
355–16–00	PUFF LINE	23181.19
355–17–00	PIZZA LINE	63664.58
355–18–00	VIENNA LINE	65250.73
355–19–00	CORN DOG LINE	1044.17
355–20–00	STEIN LINE	74638.31
355–21–00	BURGER LINE *	202042.20
355–22–00	PACKING LINE	6774.47
355–26–00	AUXILIARIES	10316.36
	* BURGER LINE	
UNIT NUMBER	EQUIPMENT DESCRIPTION	
355–21–01	Grinder	2325.25
355–21–02	Mincer & Mixer	11537.80
355–21–03	F19 Formax Machine 1	45930.59
355–21–04	F19 Formax Machine 2	37431.60
355–21–05	F12 Formax Machine	7529.07
355–21–07	Gyro	9203.54
355–21–08	Outfeed Conveyor	740.00
355–21–09	Delivery Conveyor	1405.39
355–21–10	Klikklok box former	6161.71
355–21–11	Packing Conveyor	12097.65
355–21–12	Box Conveyor	5174.47
355–21–13	Box Sealer	5074.63
355–21–15	Outfeed Roller Conveyor	431.50
355–21–24	Cooking Pot 1	915.03
355–21–25	Cooking Pot 2	143.95
355–21–26	Cooking Pot 3	1284.55
355–21–30	Vemag Melts Machine	13027.40
		202042.20

Equipment Assembly Tree



I&J Springs ** Assembly Tree Analysis ** Page 1

PLANT: READY MEALS
EQUIPMENT: F19 FORMAX MACHINE

Compiled by: Date:
Reviewed by: Date:

FUNCTIONAL COMPONENT	ASSEMBLY	SUB ASSEMBLIES / PIECE PARTS
ELECTRICAL	OPERATIONS	SUPPLY CABLE
		ELECTRICAL CONTROL PANEL & STOP/START BUTTONS
		INTERNAL CONTROL WIRING
		LIMIT SWITCHES & PROXIMITY SWITCHES
	OPERATOR PROTECTION	LIMIT SWITCHES
		EMERGENCY STOPS
KNOCKOUT	KNOCKOUT SYSTEM	KNOCKOUT BAR
		KNOCKOUT CUPS
		KNOCKOUT RODS
		KNOCKOUT ARM RETAINERS
		KNOCKOUT ARMS & BEARINGS
		KNOCKOUT ROD LINK TO ARM
		KNOCKOUT SPRINGS
		KNOCKOUT STOP BASE AND PADS
		KNOCKOUT ARM SHOULDER BOLTS
	KO DRIVE	KNOCKOUT DRIVE SPROCKET FROM MOULD PLATE DRIVE REDUCER
		CHAIN TENSIONER & MOUNTING GASKET
		KNOCKOUT CAM SHAFT DRIVE SPROCKET
		KNOCKOUT CAM SHAFT
		LH AND RH KNOCKOUT CAMS AND MOUNTING BLOCKS
		KNOCKOUT CAM SHAFT LH AND RH BEARINGS
	WATER SPRAYS	
PRODUCT FORMING	LP HD SYSTEM	INLET STRAINER
		INLET PIPING
		LP HYD PUMP
		PUMP/MOTOR COUPLING
		DELIVERY PIPING
		NON RETURN VALVE
		PRESSURE RELIEF VALVE & PRESSURE GAUGE
		DIRECTIONAL CONTROL VALVE
		DRIVE MOTOR
		RESERVOIR
	HP HYD SYSTEM	INLET STRAINER
		INLET PIPING
		HP HYD PUMP
		PUMP/MOTOR COUPLING
		DELIVERY PIPING
		NON RETURN VALVE
		HYDRAULIC ACCUMULATOR
		ACCUMULATOR DUMP VALVE
		PRODUCT PRESSURE GAUGE
		HP DIRECTIONAL CONTROL VALVE
		DRIVE MOTOR
		RESERVOIR

I&J Springs ** RCM Information Worksheet ** Page 1

PLANT: READY MEALS
EQUIPMENT: F19 FORMAX MACHINE

Compiled by: Date:
Reviewed by: Date:

FUNCTIONAL COMPONENT	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECTS
1 KNOCKOUT SYSTEM.	A PATTIES ARE NOT EJECTED OR ARE DAMAGED.	1 KNOCKOUT CUPS MISSING OR DAMAGED.	EVIDENT TO OPERATOR NO SAFETY CONSEQUENCES REPLACE CUP +/- 0.5 HOURS PRODUCTION LOSS POSSIBLE WARNING NOT AGE-RELATED
		2 KNOCKOUT BAR BENT UPWARD.	EVIDENT TO OPERATOR NO SAFETY CONSEQUENCES REPLACE/REPLACE +/- 1 HOUR PRODUCTION LOSS NO WARNING NOT AGE-RELATED
		3 KNOCKOUT ROD LINK SHOULDER BOLTS MISSING OR BROKEN.	EVIDENT TO OPERATOR NO SAFETY CONSEQUENCES REPLACE +/- 1 HOUR PRODUCTION LOSS NO WARNING NOT AGE-RELATED
		4 KNOCKOUT ARM SHOULDER BOLT MISSING OR BROKEN.	EVIDENT TO OPERATOR NO SAFETY CONSEQUENCES REPLACE +/- 0.5 HOUR PRODUCTION LOSS NO WARNING NOT AGE-RELATED
		5 KNOCKOUT SPRINGS BROKEN.	EVIDENT TO OPERATOR NO SAFETY CONSEQUENCES REPLACE +/- 2 HOURS NO WARNING NOT AGE-RELATED
		6 KNOCKOUT ARMS BROKEN.	EVIDENT TO OPERATOR NO SAFETY CONSEQUENCES REPLACE +/- 5 HOURS NO WARNING NOT AGE-RELATED
		7 KNOCKOUT SHAFT DRIVE SPROCKETS AND CHAIN BROKEN.	EVIDENT TO OPERATOR NO SAFETY CONSEQUENCES REPLACE +/-0.5 HOURS POSSIBLE WARNING NOT AGE-RELATED
		8 CHAIN TENSIONER WORN OR BROKEN.	EVIDENT TO OPERATOR NO SAFETY CONSEQUENCES REPLACE +/-0.5 HOURS POSSIBLE WARNING NOT AGE-RELATED

I&J Springs ** RCM Decision Worksheet ** Page 1

PLANT: I&J Springs Compiled by: Date:
EQUIPMENT:F19 Formax machine Reviewed by:

Date :

REF.			CONSEQ.			TASK SELECTION.																
FC	FF	FN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	PROPOSED TASK	FREQ	COMMENTS	TR
1	A	1	Y	N	Y					Y									ENSURE CUPS SECURE	DAILY	DAILY CHECK LIST	F
1	A	2	Y	N	Y					Y									CHECK THAT BAR IS STRAIGHT	DAILY	DAILY CHECK LIST	F
1	A	3	Y	N	Y					N	N	N							NSM		REPAIR WHEN BROKEN	F
1	A	4	Y	N	Y					N	N	N							NSM		REPLACE WHEN BROKEN	F
1	A	5	Y	N	Y					N	N	N							NSM		REPLACE WHEN BROKEN	F
1	A	6	Y	N	Y					N	N	N							NSM		REPLACE WHEN BROKEN	F
1	A	7	Y	N	Y					N	N	N							NSM		REPLACE WHEN BROKEN	F
1	A	8	Y	N	Y					N	N	N							NSM		REPLACE WHEN BROKEN	F

DAILY CHECK - FORMAX MACHINES

BEFORE INITIAL DAILY START UP INSPECT PUMP BOX AND HOPPER FOR ANY FOREIGN OBJECTS WHICH MAY HAVE FOUND ITS WAY INTO THESE AREAS.

ACTIONS TO BE PERFORMED:

1)ENSURE CAM FOLLOWER IN POSITION AND SECURE.
2)INSPECT ALL CHAINS AND SPROCKETS FOR CORRECT TENSION AND EXCESSIVE WEAR.
3)ENSURE WATER PRESSURE SET CORRECTLY FOR HYDRAULIC COOLER.
4)ENSURE ALL WATER SPRAY NOZZLES IN POSITION AND SECURE.
5)ENSURE KNOCKOUT CUP ASSEMBLY IN POSITION AND SECURE.
6)ENSURE VACUUM CUP BAR IN POSITION AND SECURE.
7)ENSURE VACUUM BAR IN POSITION AND SECURE.
8)START UP VACUUM PUMPS AND ENSURE SOLENOIDS OPERATIONAL.
9)RECORD VACUUM READING FOR PAPER PICKUP PUMP.
10)RECORD VACUUM READING FOR VACUUM BAR PUMP.
NOTE:ENSURE VACUUM RANGE MARKED ON GLASS OF METER.
11)ENSURE ALL GUARDS IN POSITION AND SECURE.
12)ENSURE PAPER HOPPER IN POSITION AND SECURE.
13)START HYDRAULIC SYSTEM AND MACHINE.
14)ENSURE PLUNGER CYCLING.
15)ENSURE FEED SCREWS TURNING.
16)ENSURE MOULD PLATE RUNNING FREE.
17)ENSURE KNOCKOUT CUPS ARE DROPPING AND AREN'T HITTING ANYTHING.
18)ENSURE PAPER FEED OPERATING CORRECTLY.
19)ENSURE OUTFEED CONVEYOR OPERATING CORRECTLY.
20)RECORD HP. HYDRAULIC PRESSURE.
21)RECORD LP. HYDRAULIC PRESSURE.
22)ENSURE HOIST OPERATING CORRECTLY.
23)ENSURE ALL SAFETY SWITCHES OPERATIONAL.
24)INSPECT MAIN DRIVE BELT AND ENSURE VARI-SPEED PULLEY OPERATIONAL.
25)RECORD HYDRAULIC PRESSURE ON HOIST POWER PACK.
26)ENSURE CORRECT MOULD PLATE AND SPACER PLATES FITTED FOR PRODUCT TYPE.

APPENDIX 4.6A

IRVIN & JOHNSON
BUDGET CONTROL
140 - 55940

FOR THE MONTH OF January 1993

(4)

WEEK ENDING	PURCHASE REQUISITIONS CUMULATIVE	STORES REQUISITIONS CUMULATIVE	TOTAL REQUISITIONS CUMULATIVE
08-01-93			
15-01-93	906,80	435,74	1342,54
22-01-93	-	1121,12	2027,92
29-01-93	-	2749,80	3656,60
ACT. MONTH / TOTALS	906,80	2749,80	3656,60
MONTHLY BUDGET			17808,39
MONTHLY VARIANCE			14151,79

IRVIN & JOHNSON Actual (4) 104950,34
BUDGET CONTROL
140 - 55940

FOR THE MONTH OF February 1993

(5)

WEEK ENDING	PURCHASE REQUISITIONS CUMULATIVE	STORES REQUISITIONS CUMULATIVE	TOTAL REQUISITIONS CUMULATIVE
05-02-93	7000	1169,05	8169,05
12-02-93	-	1821,88	8821,88
19-02-93	-	1961,46	
26-02-93	2341	3783,34	13124,34
ACT. MONTHLY TOTALS	9341	3783,34	13124,34
MONTHLY BUDGET			20638,74
MONTHLY VARIANCE			7514,40

IRVIN & JOHNSON Actual (5) 103173,74
BUDGET CONTROL
140 - 55940

FOR THE MONTH OF March 1993

(4)

WEEK ENDING	PURCHASE REQUISITIONS CUMULATIVE	STORES REQUISITIONS CUMULATIVE	TOTAL REQUISITIONS CUMULATIVE
05-03-93	94,72	143,19	237,91
12-03-93	654,72	875,81	1530,53
19-03-93	969,72	885,33	1855,05
26-03-93	1019,70	885,33	1905,03
02-04-93	-		
ACT. MONTHLY TOTALS	1019,70	885,33	1905,03
MONTHLY BUDGET			22517,55
MONTHLY VARIANCE			20612,35

Actual (4) 900[illegible],40

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