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A PRACTICAL MAINTENANCE FRAMEWORK FOR PRODUCTION EQUIPMENT MANUFACTURES AND USERS

"An Analysis of Maintenance Strategies for SME's"

By

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ABSTRACT

The work presented here concerns a Practical Maintenance Framework (PMF) for Small and Medium size Enterprises (SME's) aimed, ultimately, at implementing Total Productive Maintenance (TPM). Typically, the successful implementation of TPM requires large financial and human resource commitments, which are usually unrealistic in SME's. So it is usually the larger companies that are more willing and able to dedicate resources for TPM development.

The PMF introduced in this work support SME's in four ways; the Model is simple and flexible for companies to implement, and typically it does not require a significant financial commitment during its implementation. Further improvements can be achieved shortly after implementation. Finally, the Model does not involve specialist TPM teams or committees; instead there is a single team to which every person in the company will be attached to.

PMF is a framework that operates in an iterative and interactive process of improvement, review and analysis. The PMF is mainly built on a quantitative measure of performance based on data collection and subsequent analysis of Overall Equipment Efficiency (OEE) originally introduced by Nakajima (1988).

In addition, in this research, we show how a simplified version of this OEE measure can be usefully adopted in certain circumstances to calculate the efficiency of a production line.

To illustrate some of our work we present and discuss results from one of many case studies, which demonstrate the value of maintenance strategies such as PMF. Both PMF and the OEE measure are shown to be effective when used to improve equipment efficiency. Finally, the research suggests a way that can help both equipment manufactures and equipment users to cooperate with an aim to produce more efficient equipment and products.

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CHAPTER ONE

INTRODUCTION

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1.1 Introduction

The process of globalisation prevalent in today's manufacturing markets is one of the major forces impacting on a company's business. The mechanism of globalisation has changed a company's perspective and, in the last few decades, companies have changed their strategies; typically they can no longer only consider local markets but must now compete in a much more international marketplace. While it once meant a strong domestic market base, it has now assumed the meaning of open trade, where a company can be attacked anywhere, including its home markets. Protected domestic markets are rapidly disappearing.

Companies have become aware that opportunities for economies of scale and enhanced competitiveness are greater if they can manage to integrate and create marketing strategies on a global scale. This change has increased the importance of international marketing to many firms and made it into the broad and pervasive activity it is today. This market change has increased the importance of international marketing to many firms, and companies became involved in international markets.

The impact of globalisation puts more competitive pressure on companies in providing more product choice for customers, with different quality and price. Companies may concentrate on marketing to earn profits from the satisfaction of human wants and needs. For these companies to succeed in the international market they have to be aware of the many factors that have a strong affect on the way their production lines behave.

Once export marketing becomes an integral part of the company's marketing activity, it will begin to seek new directions for growth and expansion. This stage is called international marketing. To strengthen its competitive position, the international company begins to adapt products and promotion, if necessary, to meet the needs and wants of customers in different alternative ways. The company may allocate a certain portion of its manufacturing capacity to its export business. Because of transportation costs, tariffs and other regulations, and availability of human and capital resources in the foreign markets, the company may even begin manufacturing locally. The main feature of international marketing is with emphasis on product and promotional adaptation in foreign markets, whenever necessary.

Profitability of a company can increase when manufacturing costs can be controlled and reduced. In order to understand and influence the consumer's wants and needs, some companies might start thinking of reducing the number of staff working for them. Other companies might try to find alternative sources of raw material, which is cheaper in the global market. A more reasonable and strategic thinking in improving the quality, and reducing the cost, is to maximise the efficiency of their production process. This is done by renewing or reconditioning their machinery, modifying their production process (streamline), or contracting out parts of their product works.

One of the efficient processes in reducing cost is by planning and controlling their maintenance strategies. Maintenance can be simply defined as repairing equipment, or any effort intended to keep an asset in an acceptable working condition, this asset could be in the form of machines, facilities, etc. Maintenance systems are responsible for keeping equipment fit, safe to operate and well configured to perform its task.

The traditional way of managing maintenance was done by repairing the equipment when it broke down, which is a practice that is inherently wasteful and ineffective with disadvantages such as: unscheduled downtime of machinery, possibility of secondary damage, no warning of failure with possible safety risks, production loss or delay, and the need for standby machinery where necessary.

Equipment has to be reliable, efficient and cost effective. Maintenance plays a key role in the long-term profitability of an organisation in the manufacturing sector, where it has a major impact on delivery, quality and cost. The importance of maintenance has increased, as high productivity and quality can be achieved by means of well-developed and organised maintenance, this puts more emphasis on the role of maintenance in business. Maintenance must be controlled in a way that the equipment is stopped for maintenance, in a planned stoppage schedule, and not by an unplanned stop.

As Tsang (2000) states, market forces are demanding more emphasis on customisation, quick delivery and superb quality, and the success of these efforts relies on maintenance to optimise equipment capacity and availability.

In addition, Yamashina (1995), states that it is vital for the manufacturing company to provide customers with the right product, at the right time, at the right price, which incidentally needs essential support of good maintenance practice.

This pressure means that maintenance must be regarded as a critical factor in determining the availability and reliability of a production line. When maintenance in companies is handled as a core function, and planned as a strategic fundamental, then the market requirements are achieved and profitability will increase. This thesis is concerned with the study of maintenance strategies (or lack of them) adopted by manufacturing companies.

1.2 Research Aims and Objectives

The main aims of this research are to investigate typical maintenance strategies and attitudes toward maintenance, to develop a conceptual framework to improve a production line's efficiency and to reduce costs. Progress towards achieving these aims is through several objectives:

- One objective is to analyse the Total Productive Maintenance (TPM) method to identify and address challenges and difficulties that this method faces. This involves:

1. Considering possible ways by which the procedures of TPM can be simplified and developing a more practical framework by

which small and medium size enterprises can progress towards implementing TPM.

2. Developing simple quantitative measures for assessing production performance that are easy to apply.

- Another objective of the work is to analyse company data acquired through questionnaires and fact-finding visits made to different manufacturing companies. The motivation being to further identify the difficulties that TPM faces, to devise proposals for remedying these problems, taking into account the different types of companies and how this might influence maintenance strategies.

1.3 Research Methods

The empirical work of this research was conducted mainly on site visits and through questionnaires given to a selection of different manufacturing companies with different sizes and products. The on-site visits included giving presentations on various aspects of the research we were conducting, touring production and maintenance facilities as well as discussions with the maintenance and production managers. The focus of these visits was on maintenance and production strategies, training procedures and preventive maintenance that the host companies may have.

Among the areas explored with the management was the possibility of applying the concepts embodied in our Framework towards implementing Total Productive Maintenance (TPM), and the contribution of the maintenance practices to quality and productivity. In the research, a company, receptive to our proposals, agreed to implement our maintenance framework. The results obtained from this test case are analysed to illustrate the potential of the model's success.

A mixture of qualitative and quantitative techniques has been used throughout the case study process, these include documentary analysis and identifying problem causes. Company documents, including policy statements and general correspondences, were highly accessible, and these have provided a useful reference source for understanding the policies and culture that different companies adopt.

1.4 Outline of Research

The research presented here is mainly concerned with helping companies to recognise the profit loss that they are incurring due to maintenance procedures. A key part of this being the introduction of a simple and practical maintenance framework that can help enterprises implement Total Productive Maintenance (TPM). The layout of the thesis has been divided into four parts as follows:

- First part deals with policy issues:

    In Chapter Two we discuss the role of maintenance in business and the advantages that companies can accomplish in planning and implementing TPM in their companies. Then, in Chapter Three, we discuss the challenges that face the implementation of TPM in the manufacturing sector, and this will be introduced and discussed.

- The second part of the thesis deals with the development of quantitative measures and a maintenance framework for manufacturing companies to adopt:

    In Chapter Four, we introduce and illustrate the use of a quantitative method that can help companies recognise the profit losses due to the current maintenance situation, and help companies predict reductions in profit loss due to future target improvements. This Maintenance Framework is developed in Chapter Five and is aimed at improving equipment efficiency and reducing the maintenance cost. Then, in Chapter Six, this framework is assessed through its implementation in a company. We present results indicating efficiency improvements that this company achieved during the study.

- The third part of the thesis, presents results obtained from site visits and questionnaires. These illustrate what is actually happening in the manufacturing world and help to further refine the proposed maintenance framework:

  Visits were made to a wide variety of companies in different countries and their attitudes and strategies toward maintenance studied. These manufacturing companies have been classified into sectors and categories in Chapter Seven.

- The final part of the thesis concerns the integration of maintenance strategy with both business and manufacturing strategies specifically. A proposal is introduced in Chapter Eight suggesting how our framework could be implemented in the suggested categories and sectors.

In the next chapter we will discuss the role that maintenance plays in the business strategy of organisations, and introduce a Japanese maintenance method, which helps companies control their maintenance.

CHAPTER TWO
AN OVERVIEW OF TPM AND LITERATURE REVIEW

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2.1 Introduction

Many companies now participate in the international market, which offers huge opportunities for broadening the customer base, but where there is likely to be increased competition. Market research, which is to establish the extent of the demand for a product or service, is essential. To assure future success, organisations these days must be financially sound and customer orientated. This is possible only if their internal processes can provide a set of distinctive core competencies that will enable them to achieve their business objectives.

A company needs to deliver a reliable product, or service, on time and ensure that customer requirements are satisfied. Research and development is needed for the company to stay ahead of changing customer requirements. The price of the product, or service, must be kept low enough to be competitive, whilst providing a sufficient margin for the business to be profitable and capable of funding research and development. In particular, reduction and the eventual elimination of unnecessary costs associated with waste of time or materials should be one of a company's vital goals.

It follows that great attention should be placed on the reliability of the production lines in order to achieve the highest product quality and at a minimum cost. In a typical manufacturing scenario, the desirable productivity, cost, inventory and quality, all depend on the efficient functioning of the company's production facilities.

In most cases, it is true that only the manufacturing operations have been automated, and the maintenance activities still depend heavily on human input. This in turn, requires an appropriate maintenance organisation for its effective and efficient application.

In this chapter, we will start by discussing the role of maintenance in the manufacturing business. Then a maintenance method, which is called Total Productive

Maintenance (TPM), that could be the solution for many manufacturing companies in today's market, will be discussed with some examples of improvement. Finally, the role of TPM in the Business Excellence will be presented.

2.2 The Role of Maintenance in Business Strategy

As discussed in the previous section, today's international market conditions are characterised by greater emphasis on cost, delivery performance and quality, which represent the business strategy for many companies to be the best in the market in their field.

To respond to these requirements, manufacturers are using high-tech equipment. They are also adopting new material control methods such as the just-in-time philosophy, which calls for continuous production systems working without inventory. Set-up and adjustment times are also reduced to a minimum. All these factors are shifting the focus to maintenance, since unplanned unavailability of machines will result in serious problems (Hayes *et al.*, 1988).

As Blanchard (1997) stated, recent trends indicate that in general, systems are increasing in complexity with the introduction of new technologies, but are not meeting customer expectations in terms of performance and effectiveness, and are becoming more costly relative to their operation and support.

Therefore, it is not only the cost of the maintenance that makes it more important than before, even though the cost can be high, but it is also the necessity of controlling the equipment to serve the need of the production line to be competitive in the market. Tudor (1994) reported that rising maintenance costs typically account for 4-14% of total production costs, which is often greater than plant profit.

According to Walker (1994), industry in the UK spends 14 billion pounds on maintenance, one-fifth of the total value of all plant and equipment. To which must be added the cost of maintenance failures, usually downtime following breakdowns, and quality failures because equipment was not properly set up. According to a study reported by Mobley (1990), between 15-40% (with an average of 28%) of the total cost of finished goods can be attributed to maintenance activities in the factory.

The integration of maintenance activities into production is an efficient way of enhancing a company's capability to handle production losses and quality defects. This can improve competitiveness and extend the work content for production personnel.

Equipment maintenance and reliability management are important in the effective running of business enterprises today. With the growing dependence on technologies for most business operations, it is important to develop appropriate maintainability and reliability strategies to ensure that these organisations are able to deliver high quality and dependable services to their customers (Ahlman, 1993); (Madu, 2000).

Maintenance of equipment and machines is an essential part of the operation's function and an effective maintenance strategy can significantly contribute through adding value to the production activities.

Maintenance should be seen and considered as a world class principal for manufacturers. Manufacturing organizations striving for world-class performance have shown that the contribution of an effective maintenance strategy can be significant in providing a competitive advantage (Al-Najar, 1996); (Bamber *et al.*, 1999).

The primary output of production is the desired product, and its secondary output is demand for maintenance, which is in turn input for the maintenance function. Maintenance results in a secondary input to production in the form of production capacity. While production manufactures the product, maintenance produces the capacity for production. Therefore, maintenance affects production by increasing production capacity and controlling the quality and quantity of output. This relationship can be shown in Figure 2.1 (Ben-Daya & Duffuaa, 1995):

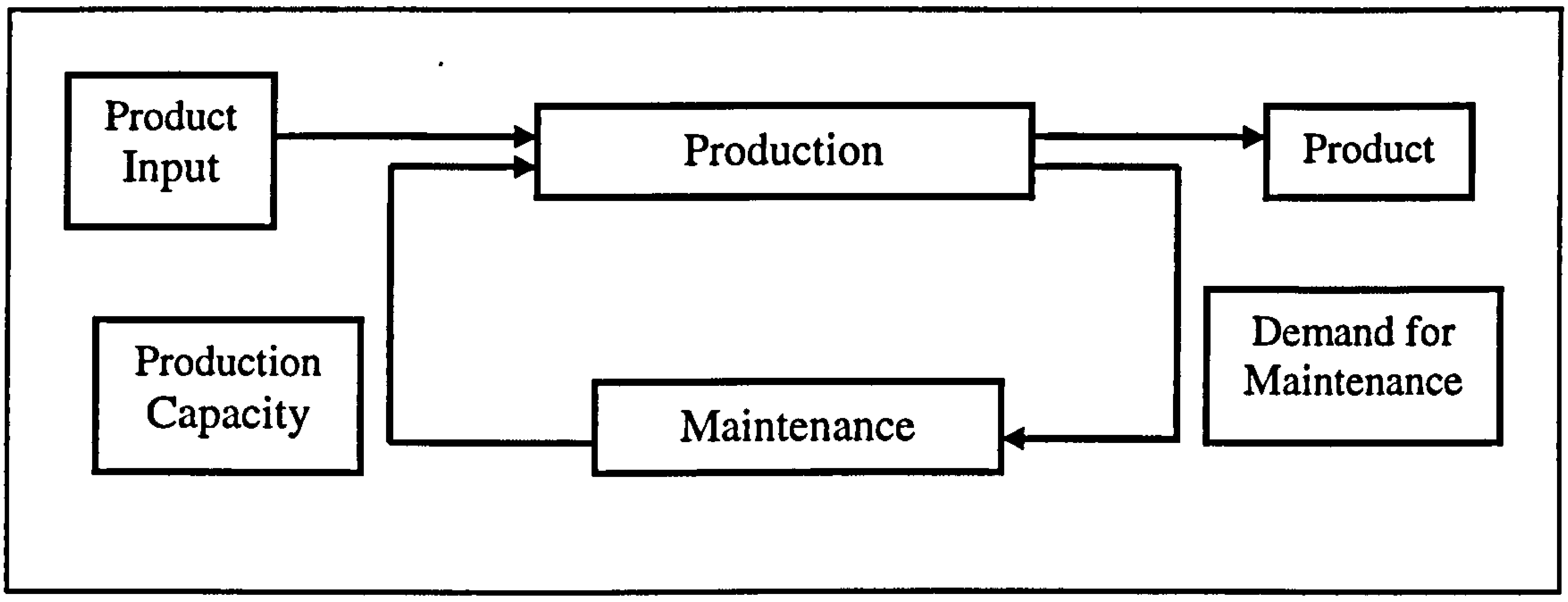

Figure 2.1: The Role of Maintenance in Production

Maintenance is a very important function in an organization that operates in conjunction with production to ensure the production flow. To receive a continuous production flow of equipment and machinery, manufacturers should consider maintenance as a core function that needs to be planned in a strategic way.

The competitive power of the manufacturing company increasingly depends on the creation of advanced production engineering to establish an appropriate production process, that demands excellent maintenance practice in such a way that machines, and processes are available whenever needed, and produce wanted products with a required quality level (Ollila and Malmipuro, 1999); (Yamashina, 2000).

The role of maintenance in the long-term should be seen as an essential function in an organisation's strategy. Maintenance should be planned carefully and realistically according to the organisation's ability and resources. The clear planning of maintenance and application will help improve equipment's reliability and availability by reducing unplanned breakdowns and defects, and this will help in providing the market with products that have high quality and lower cost.

When a company can provide the market with a product that is cheap, and meets the customer's expectations then this company can increase its market share, which will lead to a better chance of staying in business. This will give companies the chance to provide more jobs, as shown in Figure 2.2.

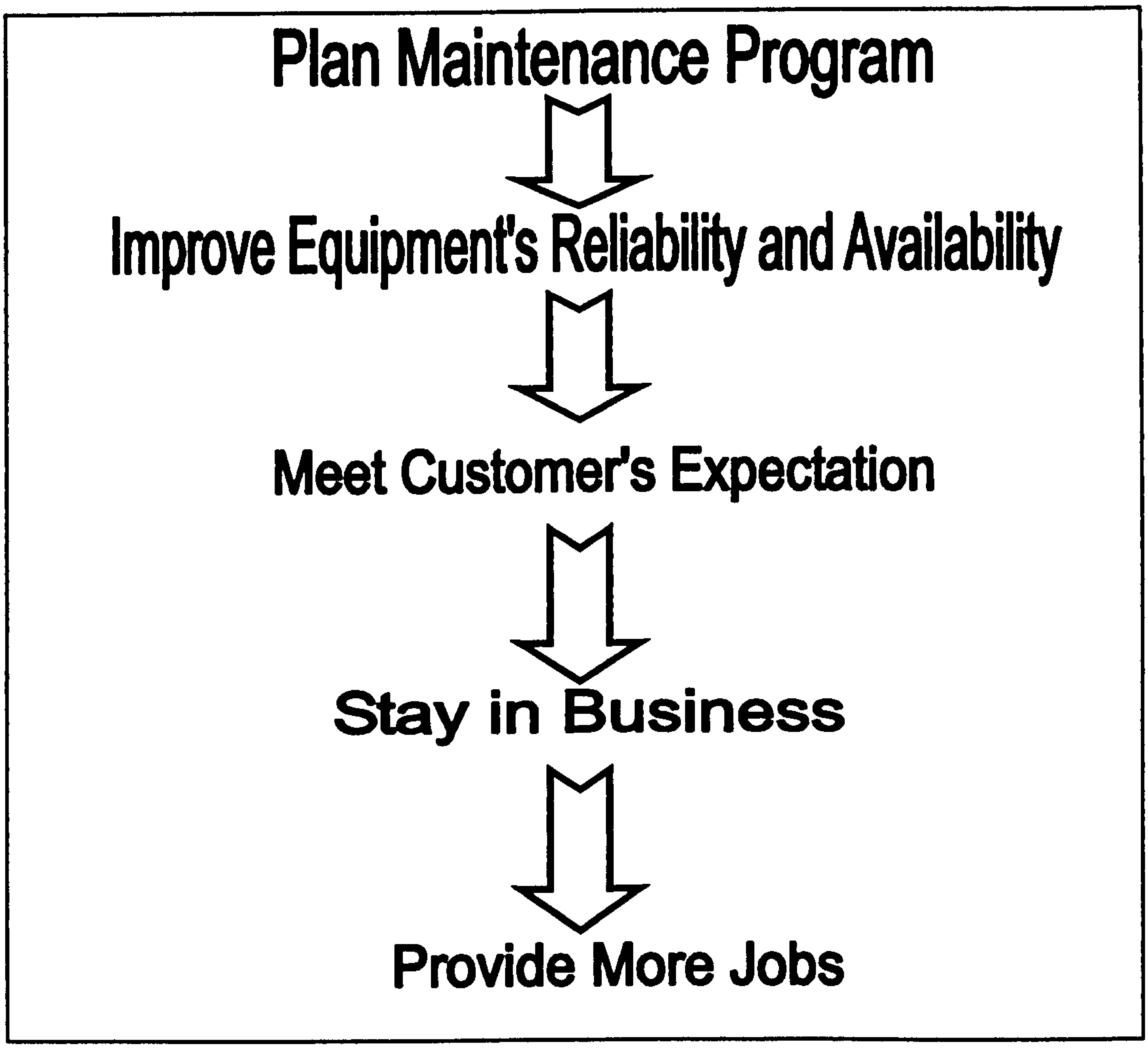

Figure 2.2:* *The Role of Maintenance in the Business Strategies

As Ben-Daya & Duffuaa (1995) mention, the role of maintenance in this endeavour cannot be neglected. In general terms, equipment, which is not well maintained and fails periodically, experiences speed losses and lack of precision and hence tends to produce defects. More often than not, such equipment drives manufacturing processes out of control.

A process that is out of control produces defective products and, therefore, increases the production cost, which amounts to less profitability and endangers the survival of the organization. If companies do not assess the costs of rework and waste then they can find it difficult to assess any savings made through reduced waste and rework.

As Patterson *et al.* (1995) states, many companies employ maintenance practices that result in reduced throughput, increased inventory, and poor due-date performance.

Typically, these firms view maintenance as an operating expense to be minimised. Accordingly, they avoid the expenditures for periodic and predictive maintenance, which could improve their process reliability. These companies do not achieve the benefits of maintenance, (Knezevic, 1995). Managers are increasingly recognizing the criticality of the maintenance function to organizational success.

As organizations have moved to reduce costs and improve quality and responsiveness, reductions in inventory and/or excess capacity have revealed serious weaknesses in traditional maintenance programs. One of the major trends in maintenance management today, in response to this situation, is a movement toward Total Productive Maintenance (TPM), Lawrence (1999), which will be presented in the next section.

2.3 Total Productive Maintenance (TPM)

As Jonsson (1997) illustrates, maintenance has become more important since firms have downsized their organizations, minimized inventory levels, and changed to flexible and time-based manufacturing systems. Improved quality of products and services increasingly depends on the features and conditions of an organization's equipment and facilities.

Because of this, the need for a maintenance approach is necessary to accomplish the necessary needs of organizations in today's business. Leading the way is the Japanese theory, Total Productive Maintenance (TPM), a proactive equipment maintenance strategy designed to improve overall equipment effectiveness. Robinson and Ginder, (1995) argue that in today's manufacturing world, maintenance costs represent a large percentage of total production costs, yet most companies have been slow to address the issue of reducing maintenance costs through equipment management. After successful implementation in hundreds of important companies in Japan, TPM started being applied in many organizations worldwide.

Reed *et al.,* (1994) discuses the fact that TPM is an approach that helps maximize equipment effectiveness, which leads to improved equipment operation rates, reduces cost, minimizes inventory and, in a way, increases labour productivity. By improving worker and equipment utilization it is therefore a program for fundamental improvement within a company.

TPM aims to build a robust enterprise by maximizing production system efficiency. When implemented fully, TPM dramatically improves productivity and quality and also reduces costs. It addresses the entire production system life cycle and builds a shop floor based system to prevent all losses. It aims to eliminate all accidents, defects and breakdowns. It involves the entire human resource; all departments and all personnel are involved and must be co-ordinated. It is fundamentally a team-based activity, Nakajima (1989); (Fujikoshi, 1990).

2.3.1 The History of TPM

Breakdown maintenance, as generally practiced by most organizations around the world, means that maintenance technicians fix equipment only after it has broken down. According to Shirose(1) (1992), the concept of preventive maintenance (PM) was introduced to Japan in 1951 from the United States. However, over the years the PM approach was gradually changed to meet the new demands placed on industry in the modern world. In the 1960's productive maintenance became well established. This consists of maintaining the overall optimal conditions for production including quality, yield and safety. The growth of TPM can be divided into the following four development stages, as Reed *et al.,* (1994) illustrate:

Stage 1: Breakdown Maintenance (BM): This means fixing equipment only after it has broken down (Nakajima, 1988).

Stage 2: Preventive Maintenance (PM): This is a program of planned inspections, replacement and repairs designed to prevent expensive catastrophic failures and control deterioration (Shirose(1), 1992).

Stage 3: Productive Maintenance: This approach aims toward maximising productivity, which means profitability. It includes three types of activities, which are preventive maintenance, improvement-related maintenance, and maintenance prevention. Improvement-related maintenance activities focus on improving the equipment to reduce future breakdowns or defects. In other words, it is an activity of making equipment easier to maintain and making improvements designed to eliminate a machine's weak points. Maintenance prevention is needed in the design stage. It is aimed at making equipment reliable, easy to care for, and user-friendly, so operators can easily retool, adjust and run (Shirose[1], 1992).

Stage 4: Total Productive Maintenance: The development of total productive maintenance began in the 1970's. In 1971, the Japanese Institute of Plant Maintenance (JIPM), defined TPM as a system of maintenance covering the entire life of the equipment in every division including planning, manufacturing and maintenance. In view of its aim of increasing the productivity yield of equipment, the term TPM is sometimes known as Total Productive Management.

2.3.2 TPM - Definition, Aims and Goals

The Japanese Institute of Plant Maintenance (JIPM) promotes the Japanese approach to TPM and Nakajima (1988) defines it in particular as:

> "*Total Productive Maintenance (TPM) is productive maintenance involving total participation of all employees through small group activity in addition to maximising equipment effectiveness and establishing a thorough system of a comprehensive planned maintenance system*".

He recognised that the full definition contains the following five points:

1. It aims at getting the most efficient use of equipment.
2. It establishes a total company-wide, Planned Maintenance (PM) system encompassing maintenance prevention, preventive maintenance, and improvement related maintenance.

3. It requires the participation of equipment designers, equipment operators, and maintenance department workers.
4. It involves every employee from top management down.
5. It promotes and implements PM based on autonomous, small group activities.

In TPM, the machine operator is totally responsible for the maintenance of the machine as well as its operation. The implementation of TPM can generate considerable cost savings through increased productivity of the machinery. The greater the degree of factory automation, the greater the cost reduction generated by TPM (Nakajima, 1988).

Nakajima (1989) stated that, TPM is a system so effective that it has been shown to reduce breakdowns to almost zero and increase worker productivity. According to Nakajima (1989), TPM is aimed at the improvement of enterprise through radical reforms in equipment and personnel, which could be described as:

TOTAL involvement of people:

- In all functional areas.
- At all levels.
- For increased efficiency in all spheres.

PRODUCTIVE in achieving:

- Maximum production efficiency.
- Zero defects.
- Zero breakdowns.
- Zero loss.

MAINTENANCE of:

- Plant and equipment.
- Related processes.

From a Western point of view, Willmott (1997) has acknowledged another definition of TPM:

> *"TPM seeks to engender a company-wide approach towards achieving a standard of performance in manufacturing, in terms of the overall effectiveness of equipment, machines and processes, which is truly world class."*

Similarly, Hartmann (1992), also provides a definition that is suggested as being more readily adopted by Western companies. He states:

> *"Total productive maintenance permanently improves the overall effectiveness of equipment with the active involvement of operators."*

Rhyne (1990) suggests that TPM can be considered as:

> *"A partnership between the maintenance and production organisations to improve product quality, reduces waste, reduce manufacturing cost, increase equipment availability, and improve the company's overall state of maintenance."*

The Western definition is more practical in the way it defines TPM as a way of doing the right job, involving different parts of the organization, to accomplish the goal. While the Japanese definition concentrates on showing that TPM is a philosophy of changing people's habits and attitudes suited to the new method to accomplish a purpose of reaching their goals. It could be the result of differences in the two cultures that created the two views that each represent.

As Nakajima (1988) explains, TPM has a double major goal: zero breakdowns and zero defects. When breakdowns and defects are eliminated, equipment operations rates improve, costs are reduced, inventory can be minimized and, as a consequence, labour productivity increases. Of course, such results cannot be achieved overnight. Typically three years are required from the introduction of TPM to achieve results (Nakajima, 1989).

Furthermore, in the early stages of TPM, the company must bear the additional expense of restoring equipment to its proper condition and educating personnel about the equipment. The actual cost depends on the initial quality of the equipment and the technical expertise and experience of maintenance staff. As productivity increases, however, these costs are quickly recouped. This is why TPM is often referred to as profitable Planned Maintenance, as mentioned by Nakajima (1988).

Equipment effectiveness is a measure of the value added to production through equipment. TPM maximizes equipment effectiveness through two types of activity:

Quantitative: Increasing the equipment's total availability and improving its productivity within a given period of operating time.

Qualitative: Reducing the number of defective products stabilizing and improving quality.

The goal of TPM is to increase equipment effectiveness so each piece of equipment can be operated to its full potential and maintained at that level. Human workers and machinery should both function steadily under optimal conditions with zero breakdowns and zero defects. Although approaching this ideal is difficult, believing that zero defects can be achieved is an important prerequisite for the success of TPM, Nakajima (1989).

The objective of TPM is to enhance equipment effectiveness and maximize equipment output. It strives to attain and maintain optimal equipment conditions in order to prevent unexpected breakdowns, speed losses and quality defects in process. Overall, by minimizing the cost of upkeep and maintaining optimal equipment conditions throughout the life of equipment achieves efficiency, including economic efficiency. In other words, by minimizing life cycle cost.

Equipment effectiveness is maximised, and life cycle cost minimised, through company-wide efforts to eliminate the following six big losses that reduce equipment effectiveness, Shirose[2] (1992):

Downtime

1. Breakdowns due to equipment failure.
2. Set-up and adjustment.

Speed losses

3. Idling and minor stoppages (abnormal operation of sensors, blockage of work on chutes, etc.).
4. Reduced speed (discrepancies between designed and actual speed of equipment).

Defects

5. Defects in process and rework (scrap and quality defects requiring repair).
6. Reduced yield between machine start-up and stable production.

Measuring the six big losses and their effect on the equipment requires a tool. This tool is Overall Equipment Effectiveness (OEE). This method of calculation requires accuracy if it is to provide a reliable figure for use in any factory to estimate their efficiency, (Nakajima, 1988); (Kotze, 1993): OEE is composed of 3 components

Availability = Loading time – Equipment downtime / loading time

Performance Efficiency = (Processed amount * ideal cycle time) / operation time

Rate of quality products = Good quality / processed amount

And the definition of OEE is then shown as:

$$OEE = Availability \times Performance\ efficiency \times Rate\ of\ quality\ products$$

This formula will be used and discussed in more detail in Chapter Four.

In general, the TPM method or philosophy has tremendous potential results for achieving an organization's goals in the way of increasing equipment efficiency, reduce waste, improve quality, guarantee delivery on time and smooth production flow. As to be discussed and shown in the next section it is a strategic way of dealing with an organization's operations in linking all departments to reach a goal, and an aim of being competitive, or perhaps the best, in their market.

2.3.3 The Need for TPM

As automation and labour-saving equipment take production tasks away from humans, the condition of production and office equipment increasingly affects output, quality, cost, delivery, health and safety, and employee morale. Neglected equipment can result in excessive losses and time wasted on finding and treating the cause. Both the operations and maintenance departments should accept responsibility for keeping equipment in good condition.

To eliminate the waste and losses hidden in a typical factory environment, the central role of workers in managing the production process must be acknowledged. No matter how thoroughly plants are automated, or how many robots are installed, people are ultimately responsible for equipment operation and maintenance. Every aspect of a machine's performance, whether good or bad, can be traced back to a human act. Therefore, no matter how advanced the technology is, people play a key role in maintaining the optimum performance of the equipment.

When company employees accept this point of view, they will see the advantage of building quality into equipment and building an environment that prevents equipment and tools from generating production or quality problems. This company-wide, team-based effort, is at the heart of TPM. It represents a dramatic change from the traditional attitude that so often divides workers. Through TPM, everyone co-operates to maintain the equipment with which the company depends on for survival and, ultimately, for profitability.

Examples of improvement

Some examples of different, well-known companies, are given to show how TPM has helped in improving their performance. Neff (1999) reports that Copeland Industries, for example, implemented a TPM program in 1989. Since that time, the company has recorded a 57 percent improvement in manufacturing cycle time, scrap and rework costs have declined by 72 percent, and manufacturing costs are down 60 percent. Plant operating costs declined by $2 million in just 18 months, and total downtime for maintenance was at an outstanding 1.9 percent.

Roberts (1998) stated that Kodak had reported that a $5 million investment resulted in a $16 million increase in profits, which could be traced, and directly attributable, to implementing a TPM program.

Ireland and Dale (2001), states that in one of the companies that they had studied for the latest two-year period for which data were available, the costs of TPM were estimated to be £400,000, with benefits of over £2m.

Patterson *et al.*, (1996) reported that at Asten Inc., since the start of their TPM program, the reject rate for finished goods had plunged 20%, and productivity had risen from 1.73 pounds per man-hour in 1989 to 1.91 pounds per man-hour at the end of 1995.

In addition, Teresko (1992) estimated that Eastman Co., Tennessee, saved $24 million and employees typically accepted the changes required of them after the implementation of TPM.

Important organizations like Dupont, Kodak, Motorola, Ford Motor Company, Boeing and also the U.S. Postal Service, started using this "best manufacturing practice" as the US Government has called it. Now there are several hundreds of companies under TPM, although only a small percentage of companies succeed at fully implementing this discipline, Steinbacher and Steinbacher (1993).

2.3.4 TPM Implementation

According to Nakajima (1989), there are three major requirements for fundamental improvement:

- Increasing Motivation (changing peoples' attitudes).
- Increasing Competency (increasing peoples' skills).
- Improving the work environment so that it supports the establishment of a program for implementing TPM.

Nakajima's development program explains the implementation procedure in twelve steps, which are:

Preparation Stage:

1. Announce top management decision to introduce TPM.
2. Launch education and campaign to introduce TPM.
3. Create organizations to promote TPM.
4. Establish basic TPM policies and goals.
5. Formulate master plan for TPM development.

Preliminary Implementation Stage:

6. Hold TPM kick-off.

TPM Implementation Stage:

7. Improve effectiveness of each piece of equipment.
8. Develop an autonomous maintenance program.
9. Develop a scheduled maintenance program for the maintenance department (periodic maintenance).
10. Conduct training to improve operation and maintenance skills.
11. Develop early equipment management program.

Stabilisation Stage:

12. Perfect TPM implementation and raise TPM levels (set higher scores).

Companies must select and implement activities that will achieve the goals of TPM effectively and efficiently. Even though different companies may choose slightly different activities, (Suzuki, 1994); (Jorge and Perez-Lafont, 1997). Suzuki (1994) describes eight fundamental development activities that support the implementation of TPM as:

1. ***Focused Improvement:*** This is an improvement activity performed by cross-functional project teams composed of people such as production engineers, maintenance personnel, and operators. These activities are designed to minimise targeted losses that have been carefully measured and evaluated.

2. ***Autonomous Maintenance:*** Teams of operators perform routine maintenance tasks and participate in improvement activities that halt accelerated deterioration, control contamination, and maintain optimal conditions. The operators:

   - Must consider how Autonomous Maintenance steps can be conducted most effectively on different types of equipment.
   - Investigate the relative importance of different equipment items and determine appropriate maintenance approaches.
   - Prioritise maintenance tasks.
   - Allocate responsibilities appropriately between production and specialized maintenance personnel.

   Autonomous Maintenance is more than merely cleaning equipment; in doing so it focuses the individual/team on identifying and treating problems found in the course of cleaning.

3. ***Planned Maintenance:*** Planned or scheduled maintenance embraces three forms of maintenance: breakdown, periodic and predictive. Planned maintenance activities emphasize monitoring mean times between failures (MTBF), and using that analysis to specify the intervals for tasks in annual,

monthly and weekly maintenance calendars. Like other TPM activities, building a planned maintenance system should be done systematically, one step at a time.

Unexpected failures actually help to improve the system by revealing inadequacies in the timing and content of maintenance plans. Shutdown maintenance is a classic example of where Planned Maintenance should be implemented. Reliable plans must be laid out before the shutdown by using the Work Breakdown Structure diagram (WBS). The WBS gauges staff and materials needed, and monitors budget and achievement of objectives.

4. ***Training and Education:*** Implementing TPM is also a continuous learning process. Operators and maintenance personnel in particular must receive training to upgrade their equipment-related skills and knowledge. Plant managers and corporate managers must educate themselves about TPM and may even participate in model equipment restorations.

   Process industry workers are becoming scarcer, and more multi-skilled, so training must be an integral part of the career development system. There must be effective interaction annually between workers and supervisors to tailor training to the individual's need. Also, a firm schedule must be set for achieving program targets.

5. ***Early Management:*** This activity includes both early product management and early equipment management. The purpose of these activities is to achieve quickly, and economically, products that are easy to make and equipment that is easy to maintain and use.

   Early equipment management concerns equipment users, engineering companies and equipment manufacturers, and addresses the following areas:

   - Equipment Investment Planning.
   - Process design.

- Equipment design, fabrication and construction.
- Test operation.
- Start-up management.

The plant and equipment's required function and performance levels, and their reliability and maintenance levels, should be assessed and then budgets and schedules are established to achieve them.

6. *Quality Maintenance:* This is a set of activities designed to build in quality and prevent quality defects through the process and through the equipment. The key is controlling variability in a product quality characteristic by controlling the condition of the equipment components that affect it. In process industries, the effect of equipment on quality characteristics is particularly important (other factors include materials, personal actions (skills) and methods used). To apply Quality Maintenance in equipment design, teams must begin by identifying the components that will affect the product quality characteristics and ascertain the precise process conditions required for producing a perfect product.

7. *TPM in Administrative and Support Departments:* Administration and support departments play an important role in backing up production activities. While production and maintenance are engaged in TPM activities on the shop floor, administrative functions should aim to create "information factories" and apply process analysis to streamline information flow. The quality and timeliness of the information supplied by the administrative and support departments have a major impact on production activities.

   Essentially, they are process plants too, whose principle tasks are to collect, process and distribute information, and must be treated in a similarly serious matter to the related engineering process. Autonomous Maintenance in administrative departments aims to reduce costs and boost efficiency by improving administrative processes and removes obstacles to effective work hidden in the physical and psychological environment. Focused improvement in the administrative departments aims to improve efficiency and speed through automation of office tasks and electronic data-processing systems.

8. *Safety and Environmental Management:* Assuring safety and preventing adverse environmental impacts are important priorities in any TPM effort. Accidents cause breakdowns and loss of quality, and occasionally, they have adverse environmental impacts, and so safety and environmental management play an important role in TPM. It is particularly important in a process industry to incorporate fail-safe mechanisms; to design equipment and systems that remain stable, even when procedures are not followed explicitly.

2.4 The Role of TPM in Business Excellence

In this section, we will introduce and discuss the role that TPM has in the business process in addition to the linkage that it has to the business excellence model.

2.4.1 TPM as Part of the Business Process

TPM has its roots in manufacturing industries, Mileham *et al.*, (1997); Suito (1998); Ben-Daya (2000), but it could be argued that TPM has been proved extremely valuable for the service sector including hotels, education and finance. The most obvious examples of its application can be found in the caring for equipment, such as computers, copiers, communication systems and presentation aids etc.

However, TPM can usefully be extended to transportation facilities, buildings and furniture, including ergonomic issues. The proper maintenance of details such as seats, lighting, and the general office environment, could well be an essential ingredient for business excellence.

TPM is concerned with methods of sustaining improvement through process enhancement, Tajiri and Gotoh, (1992); Mileham *et al.*, (1997), where it offers impact on equipment life cycle costs by the reduction of total maintenance effort and improved life.

The costs associated with maintenance could be mainly due to labour and materials, including the need for spare parts and the cost due to loss of production. Furthermore, these costs are likely to increase at a higher rate in the future, with the added complexities of factory equipment, through the introduction of new technologies, large-scale automation, the ever-increasing use of robotics, and so the list goes on.

The machine's efficiency usually starts to drop gradually, over time, with no proper program of maintenance. This leads to a decrease in the quality of the products produced by the machine, and more defected products are produced, which is a loss of money and time.

According to Rheaume (1997) most, but not all, manufacturing operations in the US are in a reactive role when it comes to manufacturing. When facilities are operating in this state, their main objective is to get the product out the door. Operations in this mode run the equipment until it breaks down, fix it as quickly as possible, and then run it until it breaks down again.

This method of operation is extremely unreliable and not the appropriate way to treat your assets to maximize their useful life span. From this method of managing equipment, you can never know how fast it will run, how long it will run, and the quality of the product it will be producing.

In view of all that has been mentioned above, the need for TPM arises to help to solve these problems. Nakajima (1989), states that TPM has a double goal of Zero Breakdowns and Zero Defects, which would help organisations deliver what they have promised. When breakdowns and defects are eliminated, equipment downtime will be greatly reduced together with its associated costs, and the work-in-progress inventory can then be minimised. As a consequence, productivity in general would increase, Nakajima (1988).

TPM is an innovative approach to maintenance, which optimises equipment effectiveness, eliminates breakdowns and promotes autonomous operator maintenance through day-to-day activities, which involve the total workforce. TPM is productive maintenance carried out by all employees and aims to maximise equipment effectiveness and prevent any unscheduled breakdowns, Shirose (1992). Roberts *et al.*, (1994) states, that all employees must be empowered to initiate corrective action. Conversely, empowerment makes equipment effectiveness the responsibility of all (Tsang and Chan, 2000).

2.4.2 The Contribution of TPM to Business

TPM promises to deliver a strategy for opposing restrictive macro and micro environmental forces that lowers business performance. Such forces may vary in strength but, even if they remain constant, they will impact a reduction in business performance unless resisted by the counterweight afforded by TPM, Carannante *et al.*, (1996).

It appears that each of TPM's fundamentals can play an important role in the business excellence factors. We have linked each fundamental with one of the factors, which either affects it directly or indirectly.

There is a strategic association between the eight fundamental development activities, Suzuki (1994), that characterise the implementation of TPM, and the business excellence model as described below:

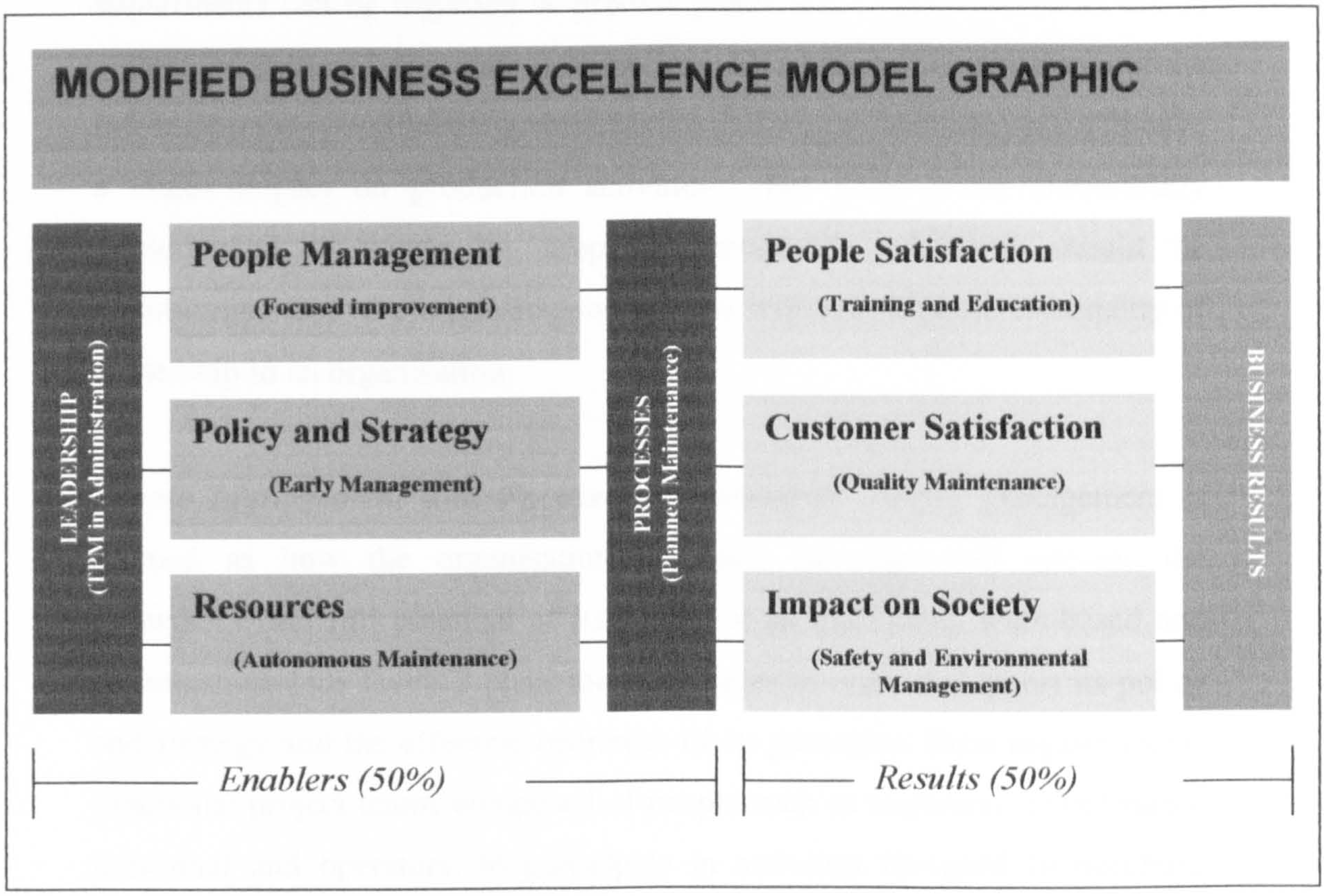

Figure 2.3: The Contribution of TPM to the Business Excellence Model

The modified business excellence model presented by EFQM (1999) in Figure 2.3 shows this linkage between TPM fundamentals and the Business Excellence Model factors. This will be discussed in detail as follows:

- ***Leadership and TPM in Administration***: Leadership is defined as how leaders develop and facilitate the achievement of the mission and vision, develop values required for long term success and implement these via appropriate actions and behaviours. In addition, they are personally involved in ensuring that the organisation's management system is developed and implemented.

  Support departments undertaking administrative functions should aim to create "information factories" and apply process analysis to streamline information flow, while the production and maintenance colleagues are engaged in TPM activities on the shop floor. Administrative and support departments can be regarded as process plants whose principal tasks are to collect, process and distribute information. The quality and timeliness of the information supplied by the administrative and support departments will have a major impact on production activities. For TPM to be successfully implemented it should be properly introduced and there should be commitment from the top management. This will help improve the quality of leadership in an organisation.

- ***People Management and Focused Improvement***: People management is defined as how the organisation manages, develops and releases the knowledge and full potential of its people at an individual, team-based and organisation-wide level. It plans these activities in order to support its policy and strategy and the effective operation of its processes. Both require cross-functional project teams composed of people such as engineers, maintenance personnel and operators, to participate in activities designed to minimise targeted losses. TPM, as a technique, helps in improving communication between the maintenance department and the production department.

  The production and maintenance people co-operate in order to eliminate defects and costs. Contrary to tradition for these departments, the maintenance training given to the production staff is carried out by their maintenance colleagues which, when successfully handled, will help improve their relationship. The maintenance staff will be removed from some of their more mundane responsibilities, and this will enable them to concentrate on other, perhaps more complicated and time consuming jobs, such as maintenance planning for ensuring equipment reliability.

- ***Policy & Strategy and Early Management***: Policy & Strategy could be defined as how the organisation implements its mission and vision based on the present and future needs and expectations of stakeholders. It is based on information from performance measurement, research, learning and creativity related activities, and these policies and strategies are developed, reviewed and updated. These activities include both early product management and early equipment management. The purpose of these activities is to achieve quickly, and economically, products that are easy to make and equipment that is easy to maintain and use. TPM is a good method in helping to plan the strategy of an organisation. A TPM practising company could have highly reliable equipment and, hence, would be in a position to give an accurate estimate of the time taken for production, and is able to use its equipment operating to maximum efficiency. This will help the company to formulate its plans and strategies to deliver the quantity of products needed at the right time.

- ***Resources and Autonomous Maintenance (AM):*** Resources are how the organisation plans and manages its external partnerships and internal resources, in order to support its policy and strategy, and the effective operation of its processes. Resources could cover a wide range of partnership, finance, buildings, equipment and materials (Daft, 1995). In TPM, teams of operators perform routine maintenance tasks and participate in improvement activities that halt accelerated deterioration, control contamination, and maintain optimal conditions.

  Autonomous maintenance is typically implemented in seven steps, which can cover all available resources, ranging from the buildings to the machines and all equipment used in the organisation, for the purpose of staying in their intended markets. In TPM, the AM function empowers the production operators to look after the conditions and effectiveness of equipment within their care, and so the chance of sudden breakdowns could be very much reduced, leading to the most efficient use of resources.

- ***Process and Planned Maintenance (PM):*** Process is defined as how the management designs, manages and improves its processes in order to support its policy and strategy. It is improved as needed, using innovation in order to fully satisfy and generate increasing value for its customers and other stakeholders. Products and services are designed and developed based on customer needs and expectations, and the customer relationships are managed and enhanced. Planned Maintenance (PM) embraces three forms of maintenance breakdown, preventive and predictive. Planned maintenance activities emphasise monitoring mean times between failures (MTBF), and using that analysis to specify the intervals for tasks in annual, monthly and weekly maintenance calendars. TPM requires a planned maintenance programme to be designed to look after the company's processes. This is, in fact, where TPM starts from and moves to other parts of the organisation. If "business process" were being taken in the widest context, TPM would thus be involved with all core activities, which a company will undertake.

- ***People Satisfaction and Training & Education:*** People satisfaction is what the organisation is achieving in relation to its people, in the form of perception measures and performance indicators. Implementing TPM is also a continuous learning process. Operators and maintenance personnel, in particular, must receive training to upgrade their equipment-related skills and knowledge. Plant managers and corporate managers must educate themselves about TPM, and may even participate in model equipment restorations.

  When TPM is implemented, the resulting increase of productivity and quality, the improvement of the condition of the machines and the factories, the reduction of costs and wastes, all these factors will have a strong influence on people's satisfaction and perception. The improvement of communication between departments, and between individuals seeking to achieve maximum equipment efficiency, will also have an indirect effect in increasing people's morale and satisfaction.

- ***Customer Satisfaction and Quality Maintenance:*** Customer satisfaction is what the organisation is achieving in relation to its external customer's needs and expectations. It is a set of activities designed to build in quality and prevent quality defects. In quality maintenance, the equipment components that affect variability in a product quality characteristic, will be identified and controlled. This, in turn, leads to products with high quality, low cost and delivered according to the planning target values, which would constitute the customers' main concern.

- ***Impact on Society and Safety & Environmental Management:*** Impact on society is what the organisation is achieving in relation to the local, national and international society as appropriate, by perception measures and performance indicators. Assuring safety, and preventing adverse environmental impacts, are important priorities in any TPM effort. The implementation of TPM helps in reducing waste, and improves health and safety conditions in the organisation, as well as on the production line. All these have benefits to offer to society.

2.4.3 TPM Implementation and its Association with Other Business Excellence Strategies

The implementation of Total Productive Maintenance is an organisation-wide undertaking, which demands commitment from senior management right through to equipment operators. No one knows the conditions of equipment better than the operators who are spending the whole of their working hours running it, and listening to the noises it makes under varying circumstances, (Rheaume, 1997), or office workers operating a word processor and other related office equipment.

TPM cannot be implemented in the same way in all organisations. This is because of the differences in their culture, environment and structure. Lawrence and Lorsch (1967), place the organisation in the context of its environment and recognise that an organisation must interact with its environment, obtain resources from it, and transform them into products in order to survive.

It is clear that not all organisations face the same environment; the environment of an organisation differs in its degree of complexity. Lawrence (1981) indicates, that a particular industry, at a specified point in time, can be characterised by its resource constraints and its strategic uncertainty. An organisation must adapt to its industry characteristics in order to be competitive in its environment. Similarly, the country in which an organisation operates can constrain or enable an organisation, through such things as the resources that it provides, and/or government support and restrictions of business. It will thus take some organisations more time than others to complete the implementation of TPM.

McKone *et al.* (1999) states, that the industry can also be an important factor in equipment maintenance, since the type of equipment, customer demands and strategic uncertainty can differ significantly from industry to industry.

Drazin (1995) discusses other factors that could effect the implementation of TPM, such as the company size and unionisation, which can impact the implementation of a maintenance program. In addition, McKone *et al.*, (1999) states that organisational size has been one of the predictors of organisational structure and managerial behaviour in the history of organisational design and behaviour research.

The implementation of TPM depends on the level of communication in the organisation, commitment from the management and the acceptance of the people in the organisation towards its implementation. It needs the co-operation of all people in the organisation from the top management to the shop floor worker. Without this co-operation the implementation will not succeed, even after a very long time, and much effort will have been wasted (Nakajima, 1989).

TPM is normally implemented in four phases: preparation, introduction, implementation and consolidation, which can be further organised into twelve steps (Nakajima, 1988).

In Figure 2.4, it is shown how TPM can be associated with other management methods and essential strategies, which could help bring about business excellence. Schonberger (1986) argues that JIT, TQM and TPM are critical components of world-class manufacturing. Therefore, it is believed that companies that have implemented other 'world class' manufacturing programs would be more likely to implement TPM, or vice versa. In line with system thinking, TPM is not isolated from these other programs and should be considered with respect to the other management practices.

Karlsson (1994) states, that TPM is a concept aimed at improving personnel, plant and corporate culture. Consequently, it is a global philosophy, a fundamental strategy, just like TQM, JIT and Lean Production. However, there is a difference: JIT focuses on material flow while TQM focuses on production quality. TPM, on the other hand, focuses on production and transport plant. Thus, TPM supports the other strategies. It is even possible to state that TPM is the more basic strategy, or even the key to the successful implementation of the other concepts.

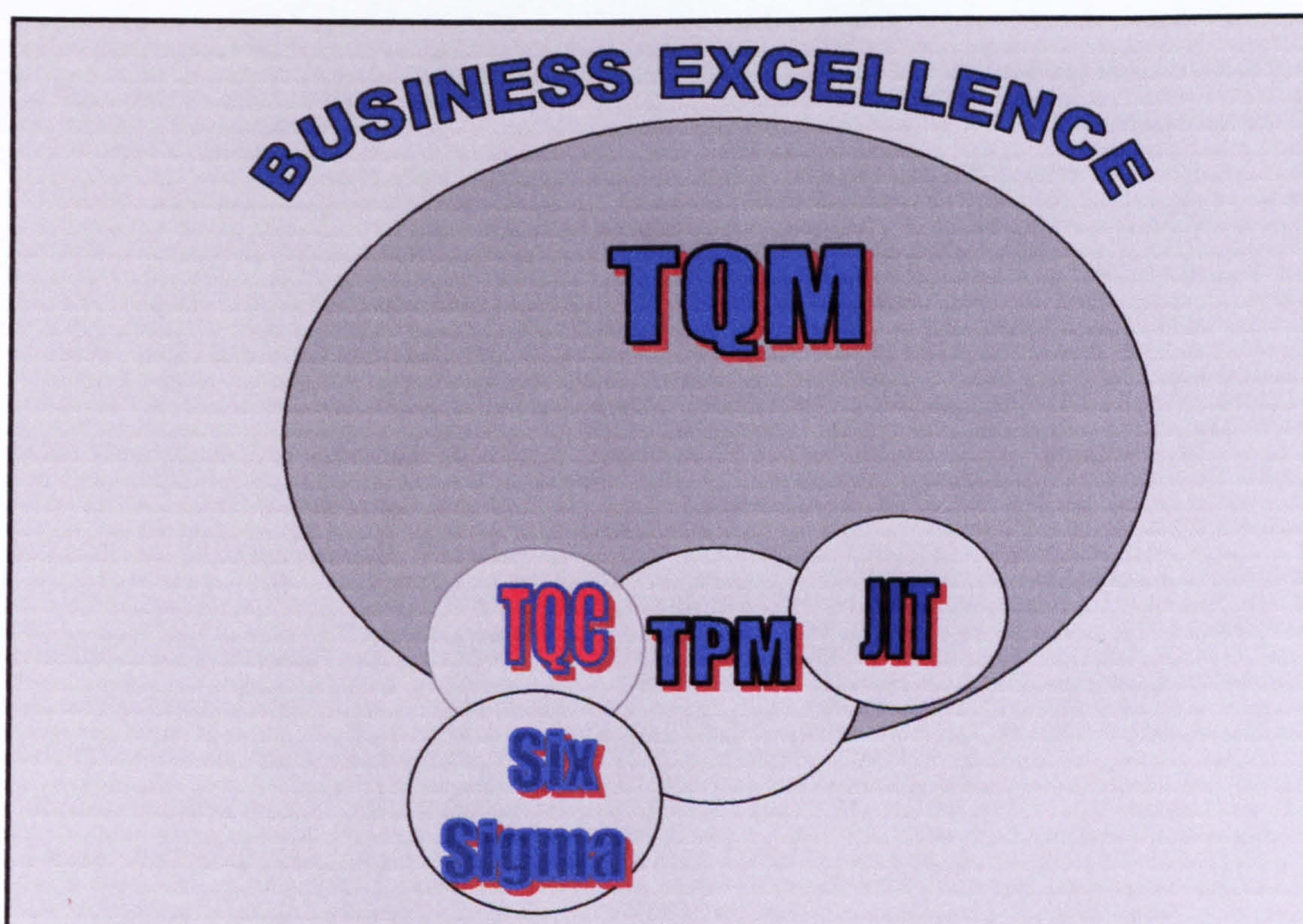

Figure 2.4: TPM and its Association with other Business Methods

Figure 2.4 illustrates the author's view of how TPM should be associated with other management methods to produce a well-known combination for organisation's seeking to reach the ultimate of business excellence. In the diagram shown, we can see that there are some similarities in the management methods and linkage between them. The overlap between them shows that the methods have some similarities and, together, they perform a complete method that will help improve the level of the organisation's competence in its market.

Now, each method is briefly discussed, highlighting the linkage with TPM, the similarities and how, together, they can perform.

TQM & TPM

Figure 2.4 shows overlap areas of Total Productive Maintenance (TPM) and Total Quality Management (TQM) such as commitment, good communication between all levels, employee empowerment and benchmarking, which could be shared with TPM. However, TPM concentrates initially on equipment effectiveness, whereas TQM practitioners may not pay too much attention to detailed planned maintenance programmes, which TPM demands.

McKone *et al.*, (2001) argues that the relationship between TPM and TQM is also important, where TQM aims to reduce variation in the product and eliminate defects. A strong maintenance program is needed to provide reliable equipment maintenance and reduce equipment process variation.

In some plants it is no longer acceptable to have a percentage of non-conforming products; quality performance is measured in defective parts per million. In order to consistently achieve the new goal of reduction toward zero defects, and to support TQM efforts, the equipment must be reliable and consistent. Production can no longer react to equipment failures, but must focus on reducing the variation in equipment performance. Therefore, we believe that companies with a strong TQM program are more likely to develop a TPM program, McKone *et al.*, (1999).

Nevertheless, it is very helpful for the implementation of TPM, if the organisations have already implemented TQM, because it will help in reducing the time and effort needed. In contrast, if TQM has not been implemented then it will take a great effort to change the culture of the organisation. It is likely that the use of TPM to improve equipment performance, and increase the skills of workers, could be an additional factor in supporting TQM.

JIT & TPM

Other techniques can also be associated with TPM, such as the well-established Just-in-Time (JIT). Many companies are trying to implement a JIT program to reduce inventories as an effort to respond to the changing demands in the marketplace. It is obvious that inventory reduction increases the costs associated with downtime. In reducing the inventory between work centres, the breakdown of one equipment or machine on the production line will quickly affect the entire production flow. In this case, the cost associated with failure may include the cost of production lost for the whole production line.

JIT's emphasis on waste reduction creates an environment where inventory is reduced, production processes are interdependent, and the plant operation is susceptible to breakdowns of any process. TPM provides dependable equipment, reduces the number of production disturbances, and increases plant capacity by providing effective equipment maintenance.

McKone *et al.*, (1999), states that JIT requires strong planned maintenance systems, so that maintenance is conducted as scheduled, rather than as a reaction to equipment problems. Therefore, we expect that strong JIT programs would be developed commensurate with strong TPM planned maintenance systems.

TQC & TPM

There is some linkage between Total Quality Control and Total Productive Maintenance in that both have strong links with the production and its quality. As TQC and TPM are becoming popular and widely used across many industries, the comparison of these two management methods has attracted increasing attention over the years. Miyake *et al.,* (1999), argue that it is still helpful in explaining how increasingly complex market requirements are.

They call for the complementary exploitation of the strengths featured by TQC and TPM, to nurture different organisational skills, rather than the deployment of a one-pattern approach based on a single performance improvement paradigm. It is evident that neither of them alone can nurture the development of the extended set of qualifications that well-balanced firms should possess nowadays.

Matsuzawa (1992) argues, that neither can be fulfilled alone, and the effective combination of these two programs is the key to accomplishing substantial and efficient progress in product quality, and linking this to the building of a company with a better constitution.

Six Sigma & TPM

It is interesting to reflect that some other, more modern techniques, which can bring about huge savings such as the much publicised procedure "Six Steps to Six Sigma" (Bendell, 2000), as practised by Motorola, which bring about huge savings, could be even further enhanced by TPM's support. The recent announcement by General Electric stated that it would save $500 million in 1997, and their actual savings of $1.2 billion by 1998, due to the application of “six sigma”, serve as a reminder of the effectiveness of this method.

The Six Sigma approach, when adopted as a long-term business strategy, looks after the quality assurance aspect of the company's business. It seeks to minimise variations of product quality from the traditional three sigma (2,700 parts per million) to the six sigma (0.002 parts per million or, more practically, a yield of 99.99966% if the process mean varies from the target by up to 1.5 sigma) limits.

It can, of course, be argued that no matter how well the design of the product, or how good the control and monitoring systems are, one would need a properly maintained production system to bring about the desirable performance level, which could promise such fantastic savings.

2.5 Summary and Conclusion

It has been shown in this chapter, that maintenance participates strongly in an organisation's strategy in the form of keeping conditions of an organisation's equipment and facilities well maintained, so as to provide improved quality of products and services. The business strategy of a company depends highly on the way their maintenance program is planned. When their maintenance is handled as a strategic function, and carefully planned, the condition of production and office equipment increasingly affects output, quality, cost delivery, health and safety, and employee morale.

In this chapter, we have given an overview of a maintenance method, TPM, together with its definition from both the Eastern and Western perspective. To successfully implement TPM, we have seen that it is important to create a flow of communication with operators, supervisors, managers etc. When they perceive the sincere purpose of providing them with better equipment, and an improved working environment, most of the barriers will be removed.

In addition, we have considered how TPM has a main role in the Business Excellence model, and how it could associate other methods to reach the purpose of improvement in the overall organisation process.

To conclude, we have indicated how TPM can provide specific tools that can be used to improve equipment performance, improve work areas around the equipment, and change the habits of the people who are responsible for buying, designing, installing, operating, and maintaining the equipment. The benefits that TPM carries to their organisations should be irresistible to managers. However, many companies do not implement TPM or even think about it. This could be the result of one or more of several factors that are to be discussed in detail in the next chapter.

CHAPTER THREE

CHALLENGES AND SME's

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3.1 Introduction

As already noted, planning equipment maintenance helps companies achieve their business strategies and goals. In addition, in the previous chapter, a detailed explanation of the Japanese maintenance method of TPM was discussed and its linkage to the business excellence model considered.

But the question that could be asked at this stage is why, if managers recognise the importance of applying TPM, don't they try to implement it? If managers claim that they have never heard about TPM, or any other new maintenance method, then these managers are facing a huge problem because the whole world is now seen as one small village, with the existence of the Internet and many manufacturing conferences. In addition, because of the strong competition in the global market these managers, who claim that they have never heard of TPM, cannot survive in today's market without maintenance strategies.

It could be that managers are concentrating on immediate results rather than long-term goals. Whatever the reason is, there are no excuses for managers not to try to plan and apply new maintenance methods to improve their production lines and realize their business goals and aims.

In this chapter we will look at environmental and human challenges to the successful implementation of TPM or any other maintenance method. In addition, in the second part of this chapter, we will talk about Small and Medium Enterprises (SME's) and their role in the world economy. As well as discussing the challenges that face small companies in business.

3.2 Challenges Facing TPM and Maintenance Methods

In this section we discuss some environmental and human factors that could affect the implementation of TPM or any new maintenance method. For a successful implementation of TPM these obstacles should be understood and studied carefully and possibly eliminated. Different authors illustrate these factors as follows:

Resistance to change: Any new maintenance method will require some adjustment and change to the way maintenance is handled on production lines. Also some people working on the production line could resist this change because it could alter their procedures. Lawrence (1999) illustrates that TPM faces the natural reaction that people develop against change. TPM represents a change and, even though it is mainly a positive one, employees do not always see it that way. For that reason, during the first stages of implementing TPM it may encounter resistance.

Misunderstanding TPM: Another challenge is the misunderstanding of TPM, where some feel it to be an attempt to increase the workload on operators. Lawrence (1999) states that another factor that contributes to employee scepticism about, and resistance to TPM, is the general movement on the part of business to try to do more with less. TPM can be interpreted as an attempt to make production employees do more work so the organisation can get by with fewer maintenance employees. Neither maintenance nor production will be very supportive of TPM if it is viewed in this light.

Heavy Workload: Sometimes, especially in mass production companies, due to the effect of implementing TPM, supervisors are unwilling to add further to the already heavy workload of their staff, as seen in some companies (Lawrence, 1999).

Lack of Trust: One of the problems that could face companies is that there could be a lack of trust between maintenance and production staff. The problem facing this relationship is that the production employees and managers are reluctant to accept responsibility for maintenance activities. This is due to concerns about whether or not production employees have sufficient skill or time to perform maintenance tasks. Maintenance workers, on the other hand, are reluctant to give maintenance responsibilities to production employees out of fear that production employees will not perform maintenance tasks appropriately. This could result in the maintenance department having to fix problems that production employees create, as stated by (Lawrence, 1999).

Bad Relationship Between Production and Maintenance Staff: A huge challenge that could face TPM, or any other maintenance method, is the relationship between the maintenance staff and operators.

If there is no co-operation between these two departments the production line will face severe problems. As Husband (1986) reports, traditionally, the relationship between maintenance and operation functions is notoriously delicate, where operators run the equipment until it breaks down and then call in the maintenance personnel to fix it.

Job Security in Companies: Job security is another challenge to the success of any maintenance method, where employees feel that their jobs are in jeopardy when a new method is introduced in their work. In some situations it is difficult to get the co-operation of the maintenance people to pass some of their knowledge onto the operators. They want to keep this knowledge to themselves feeling that this will keep the power in their hands and secure their jobs.

In addition, they could feel that if they pass some of their responsibility to the production people they could lose their jobs, as was seen in the case of 3M company, as reported by Taylor (1999). This will lead to a resulting lack of communication between the maintenance and production departments.

Bakerjan (1994) states the three major factors for unsuccessful implementation of TPM as:

- Lack of management support and understanding, which is attributed to management not completely understanding the true goal of the TPM program.

- Lack of sufficient training. Lack of training will inevitably lead to a decrease in overall equipment effectiveness and result in failure to adopt new and improved methods.

- Failure to allow sufficient time for the evolution, which is the time required to change from a reactive program to a proactive approach.

Production Overload: Overloading the production line is one of the challenges that face TPM and other maintenance methods. As Cooke (2000) mentioned, the operation function is often stretched to its limit to attain the necessary output, or to keep the plant running, yet must provide the maintenance department with access to its plant and equipment for maintenance work or safety inspection.

Similarly, the maintenance function may be frequently under pressure to meet its workload, but must find the resources to respond to yet another urgent call from the operation function. This does not give both departments the chance to participate in the early management part.

Implementing TPM on Too Many Machines: Misunderstanding the concept of TPM is a challenge and causes unsuccessful implementation of the method. In some companies time is a concern, and they start implementing TPM simultaneously on too many, or all, machines, as in Land Rover (Bohoris *et al.*, 1995); (Bamber, 1999).

This will cause a failure in the implementation of the method. Because, if it is to be applied on all the machines or most of the machines at the same time, the manpower in the organisation might not be sufficient to cover enough machines in the same time. In addition, the implementation of TPM on too many machines will affect the production line and cause delays on the production.

Davis (1997) states ten main reasons for TPM to fail within the UK manufacturing organisations:

- Inexperienced consultants or trainers are used to implement TPM.
- Lack of education and training for those expected to take it on board and provide support.
- The program of TPM is not serious about change.
- The program is too high a level run by managers for managers.
- There is a lack of structure and relationship to strategic needs.
- The program does not implement change on the shop floor and is not managed.
- Programs are initiated and run exclusively by engineering and seen by production as a project that does not involve them.
- Poor structure to support the TPM teams and their activities.
- TPM teams lack the necessary mix of skills and experience.
- Attempts to apply TPM in the same way it is implemented in Japan, using the standard approach found in Japanese publications.

3.3 Small and Medium Size Enterprises (SME's)

In this section we will discuss an important manufacturing sector, which is the Small and Medium Enterprises (SME's). We highlight the importance of SME's in the market as well as showing the challenges that this sector faces in the business market.

3.3.1 SME's Definition

In April 1996, the European Commission proposed a recommendation setting out a new common definition for SME's. The new definition states that an enterprise must fulfil the following criteria:

- Have no more than 250 employees.
- Not more than 25% owned, either singly or jointly, by a larger company.
- Have an annual turnover of no more than ECU 40 million.

3.3.2 The Role of SME's in World Economy

Small and Medium size Enterprises are regarded as the cornerstone of Europe's competitive position and job creation. Cigolini *et al.,* (1997) stated that small and medium-sized businesses in Italy, and in most other European countries, are the backbone of the manufacturing industry and ultimately the kernel of the economic system.

Admiraal (1996) states that small firms make two indispensable contributions to the American economy:

- First, they are an integral part of the renewal process that pervades and defines market economies. New and small firms play a crucial role in experimentation and innovation that leads to technological change and productivity growth. In short, small firms are about change and competition because they change market structure.

- Second, small firms are the essential mechanism by which millions enter the economic and social mainstream of American society. Small business enables millions, including women, minorities, and immigrants, to access the American Dream. The greatest source of American strength has always been the American Dream of economic growth, equal opportunity, and upward mobility.

The Organization for Economic Co-operation and Development (OECD), acknowledges that SME's play an important role in the well being of nations. In particular, it has been recognized for some 15 years that their dynamism, related in part to the technological and economic changes which have occurred over this period, has made an important contribution to the creation of new jobs, the economic revival of certain regions, and also to technological progress.

In the role of creating jobs, studies on this issue shows that small companies are responsible of providing most of the jobs. In a survey conducted by the Small Business Service that small business, including those without employees, accounted for over 99 percent of business in the UK, with about 43 percent of non-government employment and 31 percent of turnover. For Canada, Baldwin and Garnett, (1995) states that net job creation by smaller establishments is greater than that by large establishments.

In the case of Germany, Wagner (1995) suggests that small firms create quite a large share of all new jobs. Hart *et al.*, (1995) also highlight the important role of new and small indigenous firms in the job generation process in the United Kingdom for the period 1986-1990.

3.3.3 Challenges Facing Small Companies in Business

There are many barriers that could face SME's growth and survival in today's market. Some of the basic problems that could face these SME's are as follows:

1. ***Limited Finance and Human Resources***

   There are many potential barriers to a small firm's growth, but perhaps finance is one of the greatest barriers facing them. Compared with large firms, small businesses have more limited access to the necessary capital and human resources (Langley *et al.*, 1994).

   In addition to the finance limitation small companies face a shortage of the number of employees. They are therefore unable to have more flexibility in carrying out the different tasks required to compete in the market. This is strongly linked with the limitation in the finance to provide salaries.

2. ***The Owner is the Business***

In SME's, usually the owner is the manager who takes all decisions and, at work, he has no equal in stature or responsibility. A business in which one or two people are required to make all the critical management decisions, i.e. finance, accounting, personnel, purchasing, processing or servicing, marketing, selling, without input from colleagues or other managers, then owners (managers) are unlikely to consider all relevant options and risks in their decision making.

The business depends at the start, and often for a long time afterwards, upon the personal characteristics, abilities and resources of the owner-manager. There is an initial shortage in resources to manage the firm, unlike a big firm with a number of managers/supervisors for different functions.

3. ***Isolation***

Small business managers do not have opportunities for mutual discussion or for the sharing of problems, which are available to the management in larger companies. There is no doubt that many people start their own business motivated, at least in part, by a need for independence and to control their own destiny.

However, this can mean isolation from peers, colleagues and specialists that are available to managers in a large organisation. Gumpert *et al.*, (1984) summarised the effects of 'the loneliness of the small business owner' based on their research:

> *"Smaller ventures have little room at the top. At the beginning, the people in charge and those at the bottom are usually one and the same. And even after the survival stage has passed, small companies tend to run lean*

because their limited resources are typically used to maximize sales and production rather than to recruit managerial talent. Founders fill in the lower levels through hiring, while keeping authority in their own hands. As a consequence, entrepreneurs often lack colleagues with whom to share experiences, explore ideas, and commiserate."

4. ***Lack of Information***

Friedlander and Pickle (1968), stated that small firms tend to treat the organisation as a closed system by concentrating upon principles of internal functioning as if these were independent of the external environment. Such firms therefore tend to look for solutions to problems within the firm. However, there is only limited information within a small firm because there is only one manager (or a small team), isolated from other managers and specialists, and a general lack of resources including information. There tends to be a lack of information acquired by small firms because of unawareness that it is needed.

An imbalance of functional skills can lead to a failure to recognise, or tardiness in recognising, impending difficulties and the need to find early solutions. Where such a lack of awareness exists it explains a failure to seek outside advice, or to acquire the knowledge, which would avoid such difficulties.

5. ***Pressure***

The responsibility imposed on one or two people for all management decisions usually leads them into working long hours in an atmosphere of constant pressure. This pressure is partly due to lack of management know-how, and has the unfortunate result of preventing participation in activities designed to alleviate these pressures.

6. *Product Dedication*

Although it is often argued that an advantage of smallness is flexibility, small firms also tend to be "more product-dedicated" than big firms; they are likely to be dominated by the things they make or the services they provide. Because they have much smaller portfolios of products/services than large firms, it is more difficult for them to shift easily to something radically different.

As they are more product intensive, small firms tend to tie their objectives much more closely to the product line than other matters. For example, the use of funds, training of staff or planning, resulting in undiversified objectives, strategies and performance, which do little to reduce the inherent riskiness of the small firm.

7. *External Changes are Critical*

External forces tend to have more impact on small businesses than on large firms, which have deeper resources to cushion change. Changes in issues such as government regulations, employment requirements and industrial relations, finance charges and interest rates, can make a major impact on a small business.

8. *Small Businesses are Seldom in Equilibrium or Even Near it*

In large firms, rates of change and growth are normally smaller than for the volatile small business and their financial statements tend to 'describe a system in approximate equilibrium (Welsh and White, 1981). Today's markets and competition are more volatile and fluid than in previous decades, but large companies have available strategies unknown to the small firm - diversification of operations and geographical locations, control over parts of the environment, and buffer resources to draw upon.

Small businesses are seldom in equilibrium, or even near it, and a picture of changes and learning is more appropriate. Because many of the models, principles and prescriptions of business disciplines such as economics, accountancy, business finance and management, are based on steady-state situations they are of little relevance to the small firm.

9. ***High Business Risk***

Factors such as those above are unique to the small enterprise and 'create a special condition' which can be referred to as *resource poverty* - that distinguishes them from their larger counterparts and requires some different management approaches (Welsh and White, 1981).

These limitations create a high degree of inherent risk in small business; mistakes and misjudgements can result in closure and failure. Given a background of the generic problems of the small business, we now turn to what we know about causes of failure according to research studies.

3.3.4 Root Causes of Small Business Failure

Studies have consistently found that causes, due to poor management, are the main reason of failures (Peacock, 1985):

- US business failures, 92% due to management;
- US 17,000 business failures, 94% due to management; and
- Canada 2,598 business failures, 96% due to management.

In a study of South Australian legal failures by Williams (1986), for the period of 1974-85, the main cause of failure was management inefficiency (incompetence and inexperience) - for 81% of companies.

In Williams' (1986) study, 5,456 failed owners were asked to provide up to 5 reasons why their enterprise had failed. Of all responses, 18% comprised uncontrollable reasons and 82% were reasons subject to management control.

There is an agreement that management inefficiency is the underlying root cause of small business failure and, therefore, probably the main cause of many of the problems of surviving firms.

Another key cause of failure could be a lack of finance. In the Williams' survey, 8% of owners said that an inability to borrow required funds was a major reason for failure. Berryman (1994) carried out surveys, and found that out of the 76% of references, which are the main aspect of management inefficiency, 45% of references responsible for failure was financial management.

Other key aspects of the finance function ranked in order of importance were:

1. Credit management.
2. Inventory control.
3. Cash flow analysis/liquidity.
4. Lack of initial capital.
5. Control of accounts payable.
6. Administration of fixed assets.
7. Lack of finance.

Taking into consideration all the above points, we can identify four main challenges for SME's implementing TPM (as described by Nakajima 1988 and Suzuki 1994). These four points are:

1 SME's have a limited number of people working for them and, is not always feasible to form TPM teams who concentrate on the implementation steps. Suzuki (1994) raised this point in focused improvement in defining it as cross-functional project teams.

2 One of Nakajima's (1988) five pillars of TPM is early equipment management, which is establishing budgets to change equipment design and manufacture to deliver equipment that is easy to maintain. This is

difficult for small and medium companies, which have limited financial resources. These kinds of companies buy machines from larger companies, and they buy a limited number of machines. This does not give them the privilege of changing the machine designs of larger companies.

3 Because of the limited financial resources in these companies, the consultation and training of their workers will be a significant issue: these companies often do not have the financial ability to train workers by outside consultants to improve workers skills.

4 Successful implementation of TPM requires commitment over a long period of time, up to three years. However, in SME's, the decision making process is in the hands of one, or a few people, and since their main concern is to survive and to concentrate on immediate results rather than long-term strategies, it is therefore difficult to initiate the implementation of TPM.

3.4 Summary and Conclusion

The challenges discussed in this chapter do not represent all those that companies face in today's industrial world but it does give an indication of what problems face the successful implementation of TPM. There may be other factors that we do not know about that prevent companies from planning and implementing new maintenance methods.

In view of these major obstacles that for whatever reason prevent companies from implementing any new maintenance method, it is necessary to consider solutions to these difficulties. This is to find a proposed solution for any company (of any size) to improve their production equipment.

The main question asked here is, do managers know how to find out whether they can afford not to have TPM, or any other maintenance method, to improve their production equipment? The reason could be that managers do not recognise the cost benefit due to unreliable data or lack of technical information to guide them. This point will be discussed further in the next chapter.

In addition, another important question that should be asked here is whether the implementation of TPM, as proposed by Nakajima and Suzuki, is suitable for small and medium sized enterprises?

Is it possible for SME's to implement TPM in the way it has been mentioned? In order to address this question the solution could lie in a simple and practical maintenance model for these companies to follow, and allow them to improve their situations, taking into consideration their time, abilities and resources.

The Practical Maintenance Framework (PMF), which will be discussed in Chapter five, could be the solution that SME's need to compete in their markets.

CHAPTER FOUR
COST ANALYSIS

CHAPTER FOUR
COST ANALYSIS

4.1 Introduction

We have already discussed, in chapter Two, that maintenance costs represent a high percentage of total production costs, yet some companies have been slow to address the issue of recognising this maintenance cost. Maintenance spending, accounts for a significant part of the operating budget in organisations with heavy investments in plant, machinery and equipment. Tracking the performance of maintenance operations should be a key management issue in organisations.

Through TPM, these companies can control and reduce their maintenance costs by equipment management. However, many managers still have to be convinced of the usefulness of TPM, and many more are, perhaps, unsure of the losses which can accrue as a consequence of not having an appropriate maintenance programme implemented in their organisations. Managers do not recognise the improvement that TPM could have for their companies due to unreliable data or shortness of technical information. Unrecognising the improvement that TPM could offer is one of the big challenges that face companies in today's market. To help solve this problem, we introduce a quantitative method in this chapter, which is designed to help managers recognise the cost loss that they are facing, due to not having a clear maintenance strategy in their companies.

The chapter is divided into three parts. The first part is to calculate the efficiency of manufacturing equipment using Overall Equipment Effectiveness (OEE). OEE is discussed in detail, and a simple and reliable formula will be introduced that can help managers and engineers calculate the efficiency of their equipment, with less effort. In addition, this formula can also help managers and engineers to calculate and monitor the efficiency of their production line. The second part will cover a different and important matter that concerns companies more. This is the profit loss on their equipment and production line if they do not implement TPM or any other maintenance strategy. The third and final part of this chapter is an extension of other quantitative methods using the Markov Model to predict and calculate the running cost for the case of two similar, but not identical, production lines with different numbers of machines and different production rates.

4.2 Overall Equipment Effectiveness (OEE)

In this section we introduce the idea of Overall Equipment Effectiveness (OEE) introduced by Nakajima (1988). We show how to derive a more simple mathematical formula that will reduce effort and time when used; in addition OEE cannot easily be used to calculate the efficiency of a whole production line, whilst the simplified formula can. First, we recall the way OEE has been defined by Nakajima (1988) in terms of Availability, Performance Efficiency, and The Rate of Quality as shown:

Availability:

This is the proportion of the loading time (maximum availability time) that the system is actually operational.

Loading Time = Total available time – Planned Downtime

Where the Planned Downtime refers to the amount of downtime officially scheduled in the production plan, which includes

- Downtime for Scheduled Maintenance
- Management Activities (such as morning meetings)

The operating time refers to the time during which the equipment is actually operating.

Operating Time = $LoadingTime - DownTime$

Downtime involves equipment stoppage losses resulting from:

- Sudden Breakdown
- Set-up & Adjustment
- Exchange of dies, etc

$$Availability = \frac{\text{Operating Time}}{\text{Loading Time}} = \frac{\text{Loading Time - Downtime}}{\text{Loading Time}}$$

<u>Performance Efficiency:</u>

This is the speed at which the system is operating, producing goods irrespective of quality, relative to some predefined maximum speed.

Operating Speed Rate = Ideal (Theoretical) Cycle Time / Actual Cycle Time

The Ideal Cycle Time mentioned here is the theoretical minimum time of the operation, which includes the time from inserting the material in the machine to the time it has been moved to its final location near the machine.

$$\text{Net Operating Rate} = \frac{\text{Actual Processing Time}}{\text{Operating Time}} = \frac{\text{Processed Amount} \times \text{Actual Cycle Time}}{\text{Operation Time}}$$

$$\text{Performance Efficiency} = \text{Net Operation Rate} \times \text{Operating Speed Rate}$$

$$\text{Performance Efficiency} = \frac{\text{Processed Amount} \times \text{Ideal Cycle Time}}{\text{Operation Time}}$$

One of the factors affecting Performance Efficiency is minor (relatively brief) stoppage.

<u>Rate of quality products:</u>

This is the proportion of goods produced that is of acceptable quality.

$$\text{Rate of Quality} = \frac{\text{Acceptable Quality Produced}}{\text{Total Number of Products Produced}}$$

Factors affecting Rate of Quality are process defect losses and reduced yield losses.

In terms of these three variables OEE can be written as follow:

$$OEE = Availability \times Performance\ efficiency \times Rate\ of\ quality\ products$$

For a single machine it is relatively easy to measure these three variables at regular intervals, and the efficiency of the machine can then be monitored over a period of prolonged production.

So,

$$\text{OEE} = \frac{\text{Operation Time}}{\text{Loading Time}} \times \frac{\text{Total Amount Produced} \times \text{Ideal Cycle Time}}{\text{Operation Time}} \times \frac{\text{Acceptable Quality Produced}}{\text{Total Amount Produced}}$$

After canceling common factors in this formula we are left with a simple formula. That can be represented as SOEE:

$$\text{SOEE} = \frac{\text{Ideal Cycle Time} \times \text{Acceptable Quality Produced}}{\text{Loading Time}}$$

This represents: $\dfrac{\text{Rate of Production}}{\text{Maximum Rate of Production}}$

Where it is impractical, or undesirable, to calculate the production line efficiency or monitor all machines on a production line using OEE, the efficiency of the entire line can still be assessed using SOEE. To apply this formula, it is necessary to satisfy two assumptions:

1. The production line should be in series.
2. There should be no buffer stock on machines.

The SOEE formula gives exactly the same result as the more detailed OEE formula. The OEE formula, when its factors are analysed, shows the six big losses. OEE requires accurate collection of data during time to fill in the formula and calculate the efficiency. The OEE formula requires the measuring of the breakdown time, and calculating the operation time and the processed amount of products for each machine, in addition to the ideal cycle time.

The difference with SOEE formula is that it loses these features that detect what exactly is going on with the machine (it does not show where the problems occur on the machine). On the other hand, it reduces the time that it could take engineers to calculate and monitor the efficiency of each machine, and requires less data to be collected. In the next section, we will show how SOEE could be used to calculate the production line's efficiency.

4.2.1 Calculating a Production Line's Efficiency using SOEE

In order to calculate the efficiency of a production line using the SOEE equation, it is necessary to consider the way the production line is formulated. The machines on the production line are usually in series as shown in Figure 4.1. In some cases, machines on the production line have the same ideal cycle time and, in other cases, they do not.

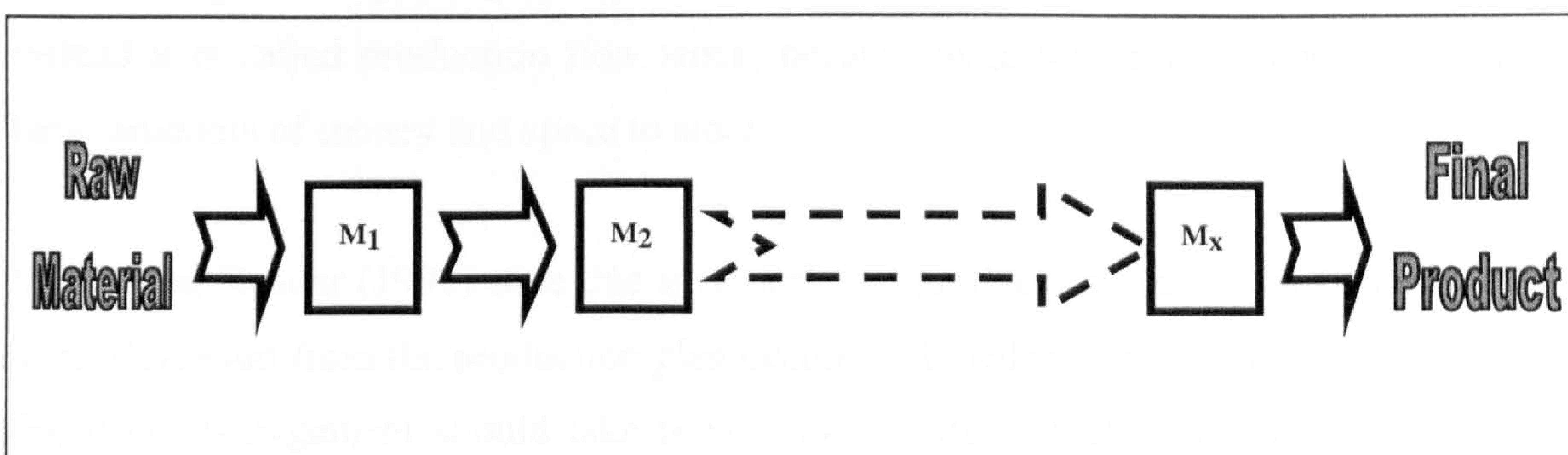

Figure 4.1: Production Machines in Series

Case One:

The production line works in series, as shown in Figure 4.1, and all machines have the same ideal cycle time.

For the first case, the ideal cycle time used for the SOEE formula will be the ideal cycle time of any machine on the production line, the loading time is the loading time of the factory (which is constant), and the acceptable products produced is the total number of acceptable products that comes out of the final machine on the production line.

Case Two:

The machines on the production line have different ideal cycle time (speed).

In this case, the ideal cycle time used will be the ideal cycle time of the slowest machine. This is because the slowest machine on the production line is the machine that controls the whole production line. The production line cannot work faster than the slowest machine's speed because, as assumed, each machine depends on the previous machine to provide it with products.

In all the cases described above, there is usually a small amount of stock left from the previous shift. This stock allows all machines to operate from the very beginning of each shift. In a realistic case there should be a stock, but this stock is only used for keeping the sequence of the machines on the production running in the same time in the morning (the beginning of the work shift). This stock is not called buffer stock; instead it is called production flow stock, because huge buffer stock cost companies large amounts of money and space to store.

Heizer and Render (1991) state that inventories in production often exist 'just in case' some deviation from the production plan occurs. Schroeder (1993) adds that one of the decisions management should take is how much safety stock to carry in relation to safety lead-time and safety capacity.

In the case of production flow stock, the SOEE formula could be used in the case of a production line, but it requires that the calculation of efficiency is to be monitored through a long period of time. This is to show any changes through time; however, it could be misleading if SOEE is used for one particular day while there is stock on all machines. If a breakdown happens on one machine for a period of one hour, and this machine has a 90 minute buffer, then the SOEE formula will show no disturbance on the production line.

The problem that could face the SOEE formula is if there was an infinite buffer stock on the machines and the final machine is the fastest machine on the production line. In this case the result is misleading. This is because, when calculating SOEE by taking the ideal cycle time of the slowest machine on the production line with the final acceptable products produced by the final machine, which for example, has a high level of quality, the result will exceed 100%, which is not practical.

In addition, SOEE can be used to supply information into other models, such as the Markov Model, which will be discussed later in this chapter, to calculate the production cost and the existence of buffer stock. Using SOEE over a long timescale helps define mean time between failures (MTBF), and the mean repair time (MRT).

4.3 Cost Analysis

We have mentioned previously, in the introduction, that the motive of producing and introducing the cost analysis quantitative method was that managers in some companies do not recognise the maintenance cost loss that they are facing, due to not having a clear maintenance strategy.

The reason that managers do not recognise these losses is due to unreliable data or not having reliable technical information. As mentioned in Chapter Two, studies reported that 15-40%, with an average of 28% of the total cost of finished goods, could be attributed to maintenance activities in the factory.

The cost analysis designed here is simple, and easy to use, to help managers calculate their cost loss compared to the ideal situation associated in implementing TPM, where TPM guarantees, as discussed in Chapter Two, to provide companies with zero breakdown and defect. We will discuss this cost analysis in two parts; the first part will be using the formula on one machine to manufacture a product. The second part will be using the formula on a whole production line with several machines.

4.3.1 Cost Analysis in the Case of One Machine

In this part, for simplicity, we will start by introducing and discussing the method of calculating the profit loss of a product, where all the production operations is done on only one machine (the product is produced by one machine only). This means that the product does not need to be shifted to another machine to do any further operations on it. We will start by introducing some notations and definitions:

NI: *Ideal number of items that should be produced*
NG: *Number of good items produced*
NR: *Number of reworked items*
NB: *Number of rejected items*
NT: *Total number of items produced = NG + NR + NB*
C: *Cost of producing one item*
CR: *Cost of reworking one item*
S: *Selling price of one item*
Cs: *Cost of maintenance in the case of breakdown*
CT: *Total cost of production*
CI: *Ideal cost for the ideal number of items*

The total cost of producing a total number of items during a shift can be written:

$$CT = (NG \times C) + NR\ (C + CR) + (NB \times C) + Cs$$

This calculation contains the sum of the costs of producing good and bad items when bad items are rejected they still cost money. In addition, the cost of rework is added to the production cost for the reworked items.

The Revenue for items sold is given by = $(NG + NR) \times S$

This is the selling price of the sum of all good and reworked items (if all items are to be sold).

So that:

Actual Total Profit = $((NG + NR) \times S) - CT$

The actual total profit is the result of subtracting the total cost of items from the revenue.

And the ideal total cost is:

$CI = NI \times C$

On the other hand, the ideal revenue is = $NI \times S$

So the ideal profit is the difference between the ideal revenue and the ideal cost:

Ideal Profit = $(NI \times S) - (NI \times C)$

Total Profit Loss is then given by (ΔP) = Ideal Profit – Actual Profit

$$\Delta P = ((NI \times S) - (NI \times C)) - ((NG + NR) \times S - CT)$$

And using the above relationships this can be written

$$\mathbf{\Delta P = ((NI - (NG + NR)) \times (S - C)) + (NR \times CR) + (NB \times C) + Cs}$$

It becomes economically unprofitable to rework products if:

$(S-C)-CR < -C$

That is

$CR > S$

The cost of rework should always be less than the selling price of the product and, from an economical point of view, it is wise to ignore reworking products when the cost of rework exceeds the selling price of the product. In some cases this financial consideration is not the only factor on which the management's decision is based on.

There are other factors that could influence the management's decision to rework products even when the cost of rework exceeds the selling price: for example, when companies face a high demand on their product, and they have no time to start producing their products from the start, or in the case of a shortage of raw material in the market, that will drive the management's decision to rework products.

An Illustrative Case study:

As an example to work on, we have collected live data for a product that is produced in a factory, which manufactures machine motors. This product is sold as a spare part for motors and it is produced on one machine only. The data analysis and results collected are shown in the Table 4.1:

Current Profit Loss										
Loading Time	Ideal Cycle Time	N (Ideal)	N (Good)	N (Rework)	N (Bad)	Product Cost	Sale Price	Rework Cost	Cost of Spare Part	Total Profit Loss
300	4	75	56	6	3	11	15	4.4	0	111.4

Current Efficiency & Profit									
SOEE	k	Beta	Gamma	r	Ideal Total Profit	Actual Total Profit	Total Profit Loss	%
74.67%	0.3333	595.00	-295.00	0.86667	300	188.6	111.4	37.13%

Table 4.1: The Company's current profit loss

In the situation of our case study, we can identify that the total profit loss during one day, and on the chosen machine, is equal to £111.40 and this loss represents a 37.13% loss towards the ideal total profit, which is high. This considerable loss is the result of the reduction in the machine's efficiency. This calculation is considered as a start by which companies can use to calculate their losses on equipment.

The spreadsheet used to produce the above tables provides a simple tool that a production manager could use to assess the consequences of the current performance of his production factory, and to highlight the financial consequences of inadequate efficiency; it is not always transparent how inefficiencies translate into lost profit. To emphasise this point further, it may also be useful to consider the monetary consequences of improving efficiency. Specifically, to quantify the reduced loss associated with a target efficiency $E^{`} > E$. although $E^{`} = 100\%$ is the obvious target, realistically this is not attainable. Moreover, there are typically additional costs incurred as $E^{`}$ approaches this ideal.

The optimal practical efficiency that could be reached is around 86%. This is because, according to a study conducted by Murty & Naikan (1995), the optimum availability achieved is 86% and that any extra availability can be achieved only through extra spending. This extra expense is due to the expenses for reducing plant/machinery downtime through various methods such as storing more spare parts, application of periodic and predictive maintenance techniques, better training of workers and engineers, usage of high reliability instruments, etc.

When the optimum availability is 86%, and if we consider a 100% for both the performance efficiency and the rate of quality the result of multiplying all three factors as mentioned in Section 4.2, gives us an OEE of 86%. In any case, the ideal is just to illustrate how financial implications and increasing efficiency to some specified value is considered realistic.

For further calculations of equipment efficiency and targets we need to consider how efficiency can be calculated (as in OEE) and how ΔP varies with E. To this end we define:

$$E\text{: Efficiency} = \frac{NG}{NI}$$

Given current data for system (defining E, ΔP etc.) we want to assess the improvement of the system (reduction in ΔP) that would be obtained from specified target criteria. In particular, if we set a new target efficiency $E^{`}$ we then have, by definition, target value for number of good items produced.

$NG` = E`NI$

In order to define $\Delta P`$ we must specify NR`, NB`.

This requires the specification of two more constraints here. For the purpose of illustration and simplicity we make the following assumptions:

$$\frac{NB`}{NR`+NB`} = \frac{NB}{NR+NB} = k \quad \text{(Fixed constant)}$$

This seems a reasonable modelling approximation taken from the collection of daily data over a long period of time. Over a long period of time, and without any change in the condition of the equipment, this ratio will not vary too much. This change could be considered neglectable and this assumption is reasonable.

The second assumption is to introduce a target variable:

$r` = \dfrac{NT`}{NI}$ (which is a product ratio) and this definition is reasonable as well when daily data is taken over a long period of time.

Note that:

$r` > \dfrac{NT`}{NI} = E`$ , so E` is the lower bound on r.

Now we write P in terms of E, r and k:

Recall:

Profit = $(NG+NR) \times (S-C) - (NB \times C + NR \times CR + Cs)$

Given that:

$$E = \frac{NG}{NI}, \; r = \frac{Nt}{NI}, \text{ and } k = \frac{NB}{NR+NB}$$

So, $NT = r \times NI$, $NG = E \times NI$

Then, $NR + NB = NT - NG = (r - E) \times NI$

So,

$NB = k \times (r - E) \times NI$

And,

$NR = (1 - k) \times (r - E) \times NI$

Giving:

$$\begin{aligned}
\text{Profit} &= (E + (1-k)(r-E)) \times NI \times (S-C) - (k \times (r-E\,) \times C + (1-k)(r-E) \times CR) \times NI - Cs \\
&= NI\,\{E[k(S-C)+k \times C+(1\text{-}k) \times CR] + r \times [(1\text{-}k)(S\text{-}C)- k \times C- (1\text{-}k) \times CR]\} - Cs \\
&= NI\,\{E[k \times S + (1\text{-}k) \times CR] + r[(1\text{-}k)(S\text{-}Cr) - C]\} - Cs
\end{aligned}$$

Which we can write as:

$\text{Profit} = \alpha + (\beta \times E) + (\gamma \times r)$

Where:

$\alpha = -Cs$

$\beta = NI\,[k \times S + (1\text{-}k) \times CR] > 0$ (so increasing E increases the Profit)

$\gamma = NI\,[(1\text{-}k) \times (S\text{-}CR) - C]$

The sign of γ determines the optimum value of r` (either E or 1)

If $\gamma > 0$, then take r` = 1

If $\gamma < 0$ then take r` = E`

So, $\gamma = NI\,[(1\text{-}k) \times (S\text{-}CR) - C]$

Where, (1-k) should be > 0, and (S-CR) > 0, as discussed previously.

To put these equations into practice we have taken the same data from the case study to illustrate the above model for different input values of E` and r` for any further improvement that could be decided.

Targeted Efficiency							
r'	E'	NG'	NB'	NR'	NT	Total Profit Loss	% Recovered
0.84	84%	63	0	0	63	£48.00	56.91%
0.85	84%	63	0	1	64	£50.95	54.26%
0.86	84%	63	1	1	65	£53.90	51.62%
0.87	87%	65	0	0	65	£39.00	64.99%
0.9	90%	68	0	0	68	£30.00	73.07%
0.93	90%	68	1	2	70	£38.85	65.13%
0.92	92%	69	0	0	69	£24.00	78.46%
0.93	93%	70	0	0	70	£21.00	81.15%
0.94	94%	71	0	0	71	£18.00	83.84%
0.96	96%	72	0	0	72	£12.00	89.23%
0.98	98%	74	0	0	74	£6.00	94.61%
1	100%	75	0	0	75	£0.00	100.00%

Table 4.2: Assessment of improvement

Again, the purpose of this is to illustrate how profit losses can be significantly reduced through increases in efficiency. It is these sets of figures that can help persuade a production manager of the need to reconsider his maintenance strategy and to treat maintenance as a crucial factor in determining plant productivity.

According to the company's data the ratio k, for the number of bad products and products that need rework is:

$$k = \frac{\mathrm{NB}}{\mathrm{NR} + \mathrm{NB}} = \frac{1}{2+1} = 0.333$$

And,

$$r = \frac{\mathrm{NT}}{\mathrm{NI}} = \frac{65}{75} = 0.867$$

According to the data recorded in Table 4.1 ($\gamma < 0$) and, as mentioned, for maximum profit r` = E` should be considered and improving the efficiency E` to 84% r` should be 0.84 and this results in a 56.91% with 63 items as the total number of products, and no rework or bad items produced. However, if r` is to be set higher than E`, as shown in the second line, r` = 0.85 results in producing one reworked item and less percentage in the profit loss recovered than the first line. This concludes that, for the optimum profit recovery, r` should always be equal to E`.

This calculation represents a simple introduction on how to calculate the profit loss on one machine. In the next section, we will extend these equations to work on the profit loss for several machines that represent a production line.

4.3.2 Cost Analysis on One Production Line

Here, we consider an extension of the previous cost analysis that will be appropriate for a production line in which the product goes through different machines and each machine has a different ideal cycle time, different operation and rework cost, in addition to a different maintenance cost. First we introduce some additional notations:

c_m : Is the cost of raw material per item

c_o : Is the operation cost per item excluding the cost of raw material

cr_i : Cost of rework per item

cs_i : Is the maintenance cost on each machine (because this cost differs from one machine to another it should be added to the cost of every machine on the production line).

To illustrate this process, consider 3 machines in series, as illustrated in Figure 4.2:

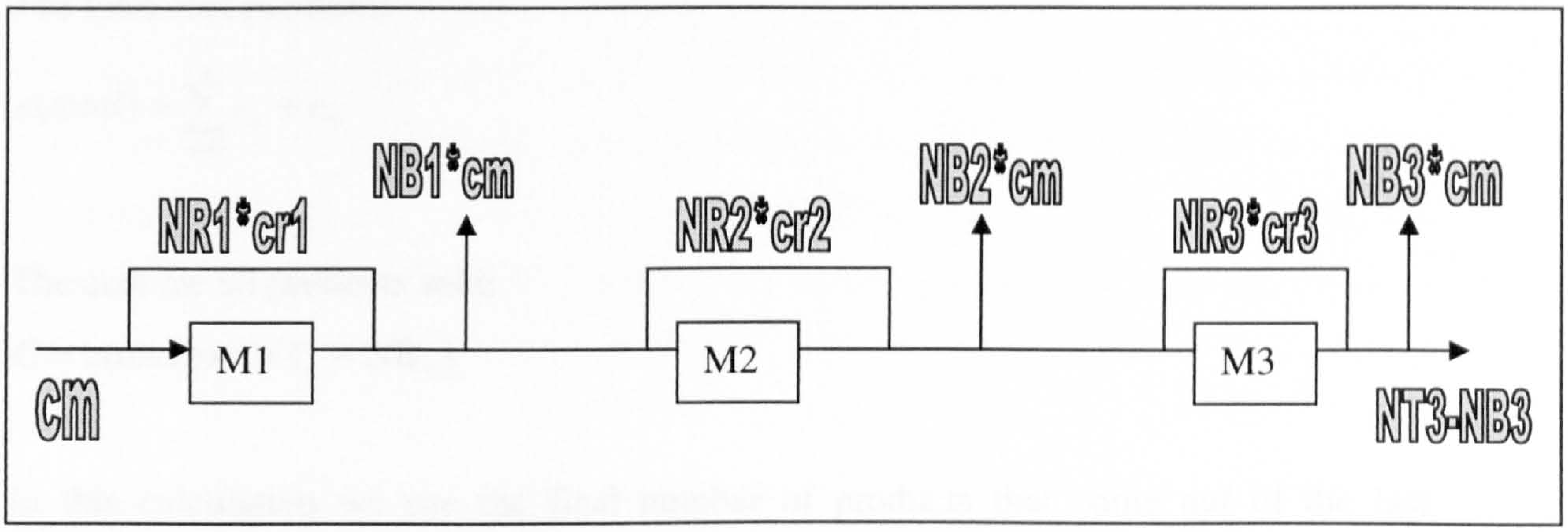

Figure 4.2: Cost analysis in the case of several machines

In Figure 4.2, we can see that the input of the production line at machine 1 is the raw material (c_m), and the output is ($NT_1 = NG_1 + NB_1 + NR_1$). The products that need rework, NR_1, are returned back to the machine to be reworked and the cost associated with it is (cr_1). For the defected products, NB_1, it is rejected and the cost associated with it is (c_m), which is the cost of raw material. What is left to enter the second machine is ($NT_1 - NB_1$), and this is what happens in the case of all other machines on the production line.

To calculate the total cost of products, we first start calculating the cost per item, which dose not include rejects and assumes all rework to be acceptable as shown for machine 1. This is:

$$c_1 = \frac{NT_1 * \mathrm{c}_{o1} + NB_1 * \mathrm{c}_m + NR_1 * \mathrm{cr}_1 + Cs_1}{NT_1 - \mathrm{NB}_1},$$

In general, this could be written as:

$$c_n = \frac{(NT_n \times c_{on}) + (NB_n \times c_m) + (NR_n \times cr_n) + Cs_n}{(NT_n - NB_n)}$$

The total cost per item:

$$c(total) = \sum_{n=1}^{x} c_n + c_m$$

The cost for all products sold:

$$\mathrm{C} = \mathrm{c(total)} \times (\mathrm{NT_x} - \mathrm{NB_x})$$

In this calculation we use the final number of products that come out of the last machine, (x), to calculate the total cost associated with all products sold (since cost also accounts for defects).

To calculate the profit loss, we first define the actual and ideal profit:

$$\text{Actual Profit} = (\mathrm{NT_x} - \mathrm{NB_x}) \times (\mathrm{S} - \mathrm{c(total)})$$

And

$$\text{IdealProfit} = (\mathrm{NI} \times \mathrm{S}) - (\mathrm{NI} \times \mathrm{c(total)})$$

To calculate (NI), which is the ideal number of products that should be sold, we should define the loading time and the ideal cycle time. The ideal cycle in this situation is the ideal cycle time of the slowest machine on the production line.

$$\mathrm{NI} = \frac{\text{Loading time}}{\text{Ideal cycle time}}$$

$$\text{Total Profit Loss} = \text{Ideal Profit} - \text{Actual Profit}$$

$$\begin{aligned}\text{Total Profit Loss} &= \mathrm{NI(S - c(total))} - (\mathrm{NT_x} - \mathrm{NB_x}) \times (\mathrm{S} - \mathrm{c(total)}) \\ &= (\mathrm{NI} - (\mathrm{NT_x} - \mathrm{NB_x})) \times (\mathrm{S} - \mathrm{c(total)})\end{aligned}$$

An Illustrative Case Study:

To illustrate the above cost analysis approach we have taken an example of a company that produces air condition units. For simplicity, we have chosen to take one part of the air condition production process; this is the base of the unit. This product, according the company's manager, is sold separately if needed as a spare part and has a selling price of £16.5.

In the first part of Table 4.3 we can see the result of profit loss that this company faces according to their current performance, compared with the ideal situation. In this case study, the profit loss on their production line was £1350 for one day, with an overall efficiency on the production line of only 75%.

SOEE	Total Cost per Item	Total Cost	Loading Time/sec	NI	Selling Price per item	Actual Profit	Ideal Profit	Total Profit Loss	% Profit Loss
75.00%	7.503333	3376.5	36000	600	16.5	4049	5398	1350	25%

Table 4.3: Current Efficiency & Profit loss for several machines

For the second part of our calculation we need to consider the optimal value of r; from the data provided by the company:

$$r = \frac{NT}{NI} = \frac{452}{600} = .7533$$

With k=1.

And the Profit is calculated as:

$$\text{Profit} = NI\{E[(k \times S) + ((1 - k) \times cr)] + r[(1 - k)(S - cr) - C]\}$$

For the production line the maintenance cost has already been added in the calculation of the total cost per item and is different from one machine to another. In addition, the rework cost used to calculate β and γ is the average rework cost of all machines.

So we are left with β and γ where:

$\beta = NI[k \times S+(1-k) \times cr]$, with NI=600, k=1, S=16.5, and cr=£0.803

$\beta = 9900$

On the other hand

$\gamma = NI[(1-k)(S-CR)-P]$

$\gamma = -4501.8 < 0$,

Targeted Efficiency

k	r	cr Average	Beta	Gamma
1	0.7533	0.803	9900	-4502.0

E'	r'	NG'	NB'	NR'	NT'	Total Profit Loss	% Recovered
80%	0.84	480	24	0	504	1080	20%
80%	0.8	480	0	0	480	1080	20%
84%	0.8	504	-24	0	480	863.7	36%
84%	0.84	504	0	0	504	863.7	36%
94%	0.95	564	6	0	570	323.9	76%
95%	0.95	570	0	0	570	269.9	80%
100%	1	600	0	0	600	0	100%

Table 4.4: Target Efficiency Improvement

The purpose of this calculation is to illustrate how profit losses can be significantly reduced through increases in efficiency. It is these sets of figures that can help persuade a production manager of the need to reconsider his maintenance strategy, and to treat maintenance as a crucial factor in determining plant productivity. In this case, because $\gamma = -4501.8 < 0$, maximum reduction in the profit loss requires that r\` = E\`, as mentioned before. It can be seen from the table that the profit percentage recovered, when E\` is set to 80% and r\` is set at .84 is equal to 20%. This requires that the production line produce 504 items as the total number of products with 24 rejected items, which is a loss.

On the other hand, when r` = E`= 80% the result is 20% as well, and this is the optimum profit recovered as the production line only produces 480 items and there are no rejected items. This 20% recovery in profit loss is the result of increasing the efficiency by only 5%.

For this company to reach these targets, it requires planning of the maintenance strategy and accepting the implementation of new maintenance methods that can help reduce this cost. In the next chapter, we will demonstrate how companies can plan their maintenance strategy by using a simple maintenance framework.

In the next section, we will take this cost analysis and calculation further to predict the behaviour of multiple production lines.

4.4 Cost Analysis for Several Production Lines using Markov Models

In this section, we will use the Markov Model as a further extension, which uses the data collected for OEE type calculations to monitor the Mean Time Between Failure (MTBF), Failure Rates (FR), and the Repair Time (RT) to predict the behaviour of multiple production lines with the association of costs.

The basic of this work is the simple Markov model (sMm), which was introduced by Al-Hassan(1) *et al.* (2000), as a technique for identifying the prime costs involved in production line downtimes, and for assessing the benefits of the replacement of unreliable equipment and improved maintenance strategies.

Here, the simple Markov model (sMm) has been further developed in order to identify the running costs for the case of two similar, but not identical, production lines. The lines consist of different numbers of machines with different production rates. The information is fed in the Markov model in the form of mean time between failure, repair time, and the machine's speed has been taken from the Overall Equipment Effectiveness (OEE). In this situation, inventory will accumulate during a normal production run because of the differences in the machine's speed. If one of the machines breaks down, the other machines in the line can still be engaged in production until such a time when the stock at the machines runs out. This is because the rest of the machines on the production line will be fed with the buffer stock, which has been accumulated during production. The line containing the failed machine will only stop, therefore, if this machine is not repaired in time.

To make use of the previously developed sMm, we replace machines that build up buffer (inventory) with fictitious machines, with reduced failure rates that are approximately equivalent. Perry and Posner (2000) give an exact analysis for a general repair time distribution, but their solution, even in the special case of exponentially distributed repair times, requires numerical computation. Here, by contrast, we simply apply our fictitious machine approximation (FMA) and sMm to analyse the cost-effectiveness of such a reduction in failure rate.

The FMA is presented in Section 4.4.1, where it is evaluated by reference to simulation results for the case of exponential failure and repair times. In Section 4.4.2, we review the sMm in the context of reduced failure rates. An illustration of the application of our FMA/sMm is given, where it is applied in a simple case study using data obtained from a medium size factory manufacturing plastic containers used in the dairy industry.

4.4.1 Fictitious Machine Approximation - A Simple Algebraic Model

We consider a single machine within a production line and assume that the running time X_1, of the machine is exponentially distributed with mean μ_1. The failure rate is then $\lambda = 1/\mu_1$. We further assume that the repair time X_2 for the machine is independent of X_1 and exponentially distributed with mean μ_2. So the repair rate for the machine is $\theta = 1/\mu_2$. As an aside, it follows that the proportion of time that the machine is operative is given by

$$p = \frac{\theta}{(\lambda + \theta)} . \qquad (1)$$

We denote by b_{in} the rate of accumulation of items within the buffer of this machine during those periods when the machine is operative, and by b_{out}, the rate of depletion of these items during the periods when the machine is under repair. It is convenient to quantify the state of the buffer in terms of the time in the buffer; that is, the time the current level of inventory could sustain operation of the following machine, taking items from this buffer at the rate b_{out}. The time equivalent rate of buffer accumulation (a) is then given by

$$a = \frac{b_{in}}{b_{out}} . \qquad (2)$$

This can be interpreted as the time equivalent buffer accumulation rate (the time equivalent added to the buffer per unit operation time of the machine). Let $X_1^{(i)}$ and $X_2^{(i)}$ give the operation and repair times during the i^{th} operation-repair cycle, i = 1, 2,...n If $X_b^{(i)}$ denotes the time in the buffer at the point of failure in the i^{th} cycle, then these values are related by

$$X_b^{(i)} = aX_1^{(i)} + \max\left\{0, X_b^{(i-1)} - X_2^{(i-1)}\right\} , \qquad (3)$$

Of interest is the asymptotic behaviour of the system and, in particular, the limit in distribution of $X_b^{(i)}$ as $i \rightarrow \infty$. We assume that this limit exists and, moreover, that it is independent of the initial state. Taking expectations in (3) we obtain, in this limit,

$$\mu_b = \lim_{i \rightarrow \infty} E\left[X_b^{(i)}\right] = a\mu_1 + E\left[Y \middle| Y \succ 0\right] \Pr(Y \succ 0) , \qquad (4)$$

Where $Y = X_b - X_2$. We note that $\Pr(Y \succ 0)$ represents the (long-term) probability that the line does not stop due to failure of the machine. The approximation in this work is to assume that X_b can be adequately modelled as an exponential variable X_3 with mean μ_3 and rate $\phi = 1/\mu_3$. With this approximation we obtain $\mu_b \approx \mu_3$ (see Appendix A1) and

$$\Pr(Y \succ 0) \approx \frac{\theta}{\phi + \theta}, \tag{5}$$

$$E[Y \mid Y \succ 0] \approx \mu_3. \tag{6}$$

The last result is a consequence of the exponential forms of both X_3 and X_2. Equation (4) then gives

$$\mu_3 = a\mu_1 + \mu_3 \frac{\theta}{\phi + \theta}, \tag{7}$$

Which reduces to the following expression for ϕ

$$\phi = \frac{\lambda}{\mathrm{a}} - \theta, \tag{8}$$

Or, equivalently, for u_3

$$\mu_3 = \frac{\alpha}{1 - r}, \tag{9}$$

Where $\alpha = a/\lambda$ and $r = a\theta/\lambda$. Implicit in the above, is the assumption that $r < 1$, which represents the condition that the buffer does not accumulate stock indefinitely.

We now replace the machine with a fictitious machine that does not build up buffer but which has, instead, a reduced failure rate $\tilde{\lambda}$, and repair rate $\tilde{\theta}$. These are chosen so as to produce the same overall effect on the line. The reduced failure rate is modelled as the actual failure rate multiplied by the probability that the line stops. That is

$$\tilde{\lambda} = \lambda\left(\frac{\phi}{\phi+\theta}\right) \tag{10}$$

Which, using (8), becomes

$$\tilde{\lambda} = \lambda - a\theta \tag{11}$$

To determine the fictitious repair rate $\tilde{\theta}$, we note that the actual repair time per hour is given by λ/θ. The reduced repair time per hour $\tilde{\lambda}/\tilde{\theta}$ is then taken as

$$\frac{\tilde{\lambda}}{\tilde{\theta}} = \frac{\lambda}{\theta} - a \tag{12}$$

And, using (11), this gives $\tilde{\theta} = \theta$.

In order to evaluate the accuracy of the approximation X_3 to X_b, and so of μ_3 given by (9) to μ_b, we have performed a simple numerical simulation of this system: Figure 4.3 shows simulation estimates of μ_b plotted against r for various values of the parameter α, and compares these with corresponding values of μ_3.

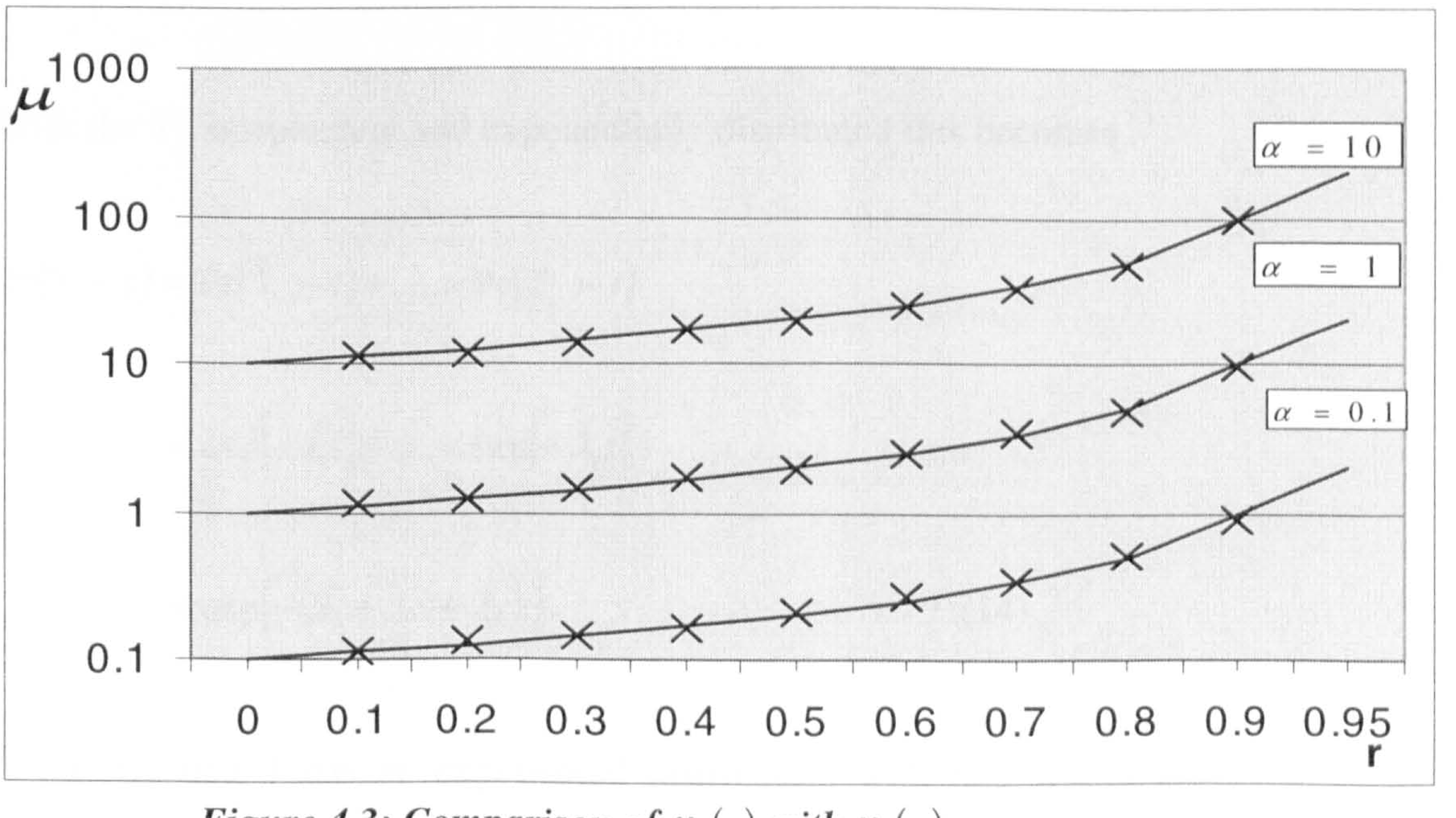

Figure 4.3: Comparison of μ_b (×) with μ_3 (–)

As can be seen from this result, μ_3 provides a remarkably good approximation to μ_b over a large range of parameter values. The next section shows how the FMA can be incorporated into the sMm.

4.4.2 sMm for Different Production Lines

In this section, we will present different models that could be used for a single and multiple lines in addition of using an example.

4.4.2.1 Model for One Production Line

We consider a line consisting of n machines arranged in series. These machines have failure rates or, in the cases that they build up buffer, equivalent failure rates, $\tilde{\lambda}_j$, and hence mean time between failures (MTBF) $1/\tilde{\lambda}_j, j=1,\cdots,n$. Now, if any one machine fails, the line fails and so, if T_j denotes the time between failures for machine j, and T the time until the line fails, then

$$\Pr(\mathrm{T} \succ t) = \Pr(\mathrm{T}_1 \succ t,....,\mathrm{T}_n \succ t)\,. \qquad (13)$$

With the T_j independent and exponentially distributed this becomes

$$\begin{aligned}\Pr(\mathrm{T} \succ t) &= \Pr(\mathrm{T}_1 \succ t) \times ..... \times \Pr(\mathrm{T}_n \succ t)\\ &= \exp\left[-\tilde{\lambda}_1 t\right] \times ..... \times \exp\left[-\tilde{\lambda}_n t\right]\\ &= \exp\left[-\left(\tilde{\lambda}_1 + ... + \tilde{\lambda}_n\right)t\right]\,. \qquad (14)\end{aligned}$$

It follows that T has an exponential distribution with rate $\lambda = \tilde{\lambda}_1 + ... + \tilde{\lambda}_n$, and hence the MTBF for the line is $1/\lambda$.

If θ_j denotes the repair rate for machine j, then the mean repair time for the line $(1/\theta)$ is given by

$$\frac{1}{\theta}=\frac{1}{\lambda}\sum_{j=1}^{n}\frac{\tilde{\lambda}}{\theta_j}. \tag{15}$$

4.4.2.2 Models For Multiple Lines

(i) First we consider (m) lines with single failure rate λ and repair rate θ.

The case of a single repair crew with exponential repair times of mean $1/\theta$ is covered by the Erlang loss formula: Let ω_k be the proportion of the time that k lines are in operation. Then

$$\omega_k=\frac{1}{k!}\left(\frac{\theta}{\lambda}\right)^k\omega_0,\quad k=1,\cdots,m\ , \tag{16}$$

With $\sum_{k=0}^{m}\omega_k=1$.

In this application, repair times for the line will not be exactly exponential, even though repair times for individual machines are, but the result is a close approximation. It is straightforward to modify this formula to allow for more than one repair crew, and for co-operation between crews. However, the algebra becomes substantially more awkward if lines have different failure and/or repair rates.

(ii) Two lines with different failure rates λ_A,λ_B, and repair rates θ_A,θ_B.

It is now necessary to introduce 4 states: If the lines are designated A and B the labelling of the states is: 0 if A and B failed; 1 if A operating and B failed; 2 if A failed and B operating; 3 if A and B operating. If we assume that there is only one repair crew, and that the priority is to repair line A first, then it is straightforward to establish that the rate matrix Λ for the process is given by

$$\Lambda = \begin{pmatrix} -\theta_A & \theta_A & 0 & 0 \\ \lambda_A & -\lambda_A-\theta_B & 0 & \theta_B \\ \lambda_B & 0 & -\lambda_B-\theta_A & \theta_A \\ 0 & \lambda_B & \lambda_A & -\lambda_A-\lambda_B \end{pmatrix} \qquad (17)$$

The proportion of time ω_k in state k is then given by the solution of

$w\Lambda = 0, w = (\omega_0, \omega_1, \omega_2, \omega_3)$, subject to $\sum_{k=0}^{3} \omega_k = 1$. This gives

$$\begin{aligned} \omega_0 &= \lambda_A\lambda_B(\lambda_A+\lambda_B+\theta_A+\theta_B)/\Delta \\ \omega_1 &= \lambda_B\theta_A(\lambda_A+\lambda_B+\theta_A)/\Delta \\ \omega_2 &= \lambda_A\theta_A\theta_B/\Delta \\ \omega_3 &= \theta_A\theta_B(\lambda_B+\theta_A)/\Delta \end{aligned} \qquad (18)$$

Where

$$\Delta = \theta_A^2(\lambda_B+\theta_B)+\theta_A\theta_B(\lambda_A+\lambda_B)+\theta_A\lambda_B(2\lambda_A+\lambda_B)+\lambda_A\lambda_B(\lambda_A+\lambda_B+\theta_B). \qquad (19)$$

To evaluate the total cost incurred due to losses in production resulting from states 0, 1, and 2 define

c_A, c_B : Costs per unit production lost on lines A and B during periods in state 0,

c'_A : Cost per unit production lost on line B during periods in state 1,

c'_B : Cost per unit production lost on line A during periods in state 2,

N_A, N_B : Number of units produced (per shift) from lines A and B with no failures.

The overall cost per shift, c, due to loss in production is then given by

$$c = \omega_0(c_A N_A + c_B N_B) + \omega_1 c'_B N_B + \omega_2 c'_A N_A \ . \qquad (20)$$

A simple Excel macro for evaluating this cost, given estimates of the various production line parameters, is listed in (Appendix A2).

The value of c gives some information regarding the performance of the plant and serves as a simple measure to quantify poor performance. Remedial action, to reduce the down-time of the lines, might involve increasing the buffer accumulation rate at one or more of the machines and/or decreasing (increasing) the failure (repair) rates of some machines.

The above analysis then provides a predictive tool for assessing the cost-effectiveness of such actions. In addition to this, in cases where there are significant costs associated with buffer storage, it may be appropriate to estimate what savings, if any, can be made by reducing or eliminating the dependence on buffer to maintain production during machine failures. For example, if S is the cost of storage per unit time of one item of production from a given machine, μ the mean buffer time for the machine, and b_{out} the buffer depletion rate, then a simple estimate for the storage cost per unit time on this machine is $S\mu b_{out}$.

To eliminate this cost, without affecting the overall production performance, it is necessary to reduce (if possible) the machine failure rate from λ to $\tilde{\lambda}$, as given by (11). If some estimate of the cost of this reduction can be formulated then the cost-effectiveness of eliminating the buffer in this way can be given. To conclude this work we present a simple case study, which we use to illustrate the application of formula (20).

An Illustrative Case Study

A production line survey has been conducted in a medium size factory that manufactures plastic containers for milk and other dairy products. This factory forms part of a larger manufacturing company.

A feature of the production lines is that the machines can work at different rates. It follows that the faster machines are capable of building up a buffer stock, which can be used in the event of a breakdown. However, there are storage and handling costs associated with building buffer stock. Another complication arises from the fact that the production lines in the factory are not identical.

Two production lines, A and B, are considered here, and Tables 4.5 and 4.6 summarise estimates of machine parameters based on data collected from the two lines, and assumes that the lines are in operation for 8 hours per day. Line A consists of 5 machines (in series), and products from this line sells at a unit price of 15p.

It costs the company 60% of this unit price to produce each unit at a rate of 1296 units per hour. The product from line B, which contains 4 machines, sells at a unit price of 12p, and costs the company 60% of this unit price to produce at a rate of 1833 units per hour.

The cost items include raw material, energy and fuel, maintenance, administration overhead, direct labour and delivery.

Machine No.	A1	A2	A3	A4	A5
MTBF	112.62	79.26	112.67	43.67	22.56
Repair Time	2.63	6.89	4.04	4.86	1.19
Availability	0.9772	0.92	0.9654	0.8999	0.9499
Production Rate when operating	1330	1395	1324	1378	1296
b_{in}	15	5	38	9	-
b_{out}	1283	1278	1240	1231	-

Table 4.5: Parameter Values for Line A.

Machine No.	B1	B2	B3	B4
MTBF	99.31	67.2	58.68	64.08
Repair Time	2.976	2.48	1.94	1.72
Availability	0.9709	0.9644	0.968	0.9739
Production Rate when operating	1856	1864	1853	1833
b_{in}	4	4	9	-
b_{out}	1798	1794	1785	1833

Table 4.6: Parameter Values for Line B.

Applying the FMA/sMm, set out in Sections 4.4.1 and 4.4.2, results in the following values for the ω_k

$\omega_0 = 0.0508, \omega_1 = 0.0997, \omega_2 = 0.1535, \omega_3 = 0.6961.$

To apply formula (20) for estimating the overall cost, it is necessary to assess the various costs associated with this production system: The principle costs incurred by the factory are those involved in making up lost production through overtime work. Wages for such work are 150% of the standard rate. In addition, there will be costs associated with the extra energy requirements and administrative work.

These costs are estimated at an additional 15%, and are essentially unaffected by whether one or both of the lines are engaged in overtime work. Based on these figures, the corresponding values for the cost per unit production lost for the various states is

$$c_A = 2.125p \ , \quad c_B = 1.470p \ , \quad c'_A = 3.250p \ , \quad c'_B = 2.370p \ ,$$

And the total additional cost per day to recover lost production from these two lines is

$$c = 1.0087 \times 10^4 p \approx £108.$$

Estimates for the average number of items in each buffer are

A1 = 3383, A2 = 415, A3 = 29035, A4 = 421,

B1 = 429, B2 = 286, B3 = 623.

The cost benefit of the buffer is easily obtained by setting the buffer accumulation rates, b_{in}, to zero. (This would have to be accompanied by reduced machine speeds, except for the last machine on each line, to balance the throughput rates and leave unaltered the b_{out} values).

This gives a 14% increase in total cost per day ($c \approx$ £123). Whether or not this additional cost is offset by the elimination of buffer handling and storage costs might be a question for further consideration in production planning.

By varying the operational parameters we can also test how sensitive this system is to changes in performance: For example, if all the machine failure rates could be decreased by 50% then the total cost is reduced from £108 to approximately £72. Whilst if, in addition, the repair rates could be increased by a similar amount the total cost is further reduced to about £34. All these estimates are easily obtained using the Excel macro listed in (Appendix A2).

In this section, we have presented a simple model to analyse downtime costs due to production loss from one or more production lines. The lines consist of machines running in series, working at different rates, and accumulating buffer that may be used to maintain line operation during machine failures. An important feature of the model is the introduction of fictitious failure rates, which take into account the influence of the buffers.

The accuracy of the approximation underlying the formulation of these failure rates has been assessed by reference to simulation studies, and found to give very good estimates across the entire range of parameter values. These fictitious failure rates allow the application of a simple Markov model to estimate the overall cost due to stoppage of the various lines, and so avoid the need to perform lengthy numerical simulations.

A simple Excel macro for evaluating this cost is given, and used in a case study to demonstrate the diagnostic value of such of tool, which could assist line managers in making strategic decisions. Although the work has only considered the application of the model to 2 lines, the extension to 3 or more lines is, in principle, straightforward.

4.5 Summary and Conclusion

In this chapter, we have addressed an important challenge that managers face, which was recognising the losses that companies face due to not having a reliable data or the right technical information needed for calculating the losses on their production lines. The calculations in this chapter are simple and reliable and can be used by companies to recognise what they are losing by not planning and improving their maintenance capabilities and strategies.

The losses in profit, shown in the case studies, are due to the condition of their equipment and these companies have been slow to address the issue of reducing maintenance costs through equipment management.

The condition of the production equipment increasingly affects the production output, quality, cost, delivery, and health and safety. The purpose of this calculation is to persuade companies to change their attitude towards their maintenance strategies. As shown in this chapter we have used an Excel program, which is widely used by many managers who find it simple to use.

The next chapter concentrates on discussing a simple and practical maintenance method for companies to plan, and follow, to help them improve their production capabilities. This maintenance method could help companies approach the targets that they have set using the quantitative methods discussed in this chapter.

CHAPTER FIVE

PRACTICAL MAINTENANCE FRAMEWORK (PMF)

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CHAPTER FIVE
PRACTICAL MAINTENANCE FRAMEWORK (PMF)

5.1 Introduction

As discussed in Chapter Three, one of the main reasons why SME's look at their maintenance as a non-core function that might need to be reduced, is due to the limited financial resource that they face. In addition, to implement TPM, as Nakajima (1988) stated in his book, requires companies to follow the twelve steps of TPM development activities, which takes at least three years of TPM implementation before prize winning results can be achieved. However, in SME's the management concentrates on immediate results rather than long-term strategies.

In addition, according to Nakajima's steps, TPM requires assigning staff to work as committees and project teams, as well as small groups, to promote TPM in the organization. However, one of the main obstacles that SME's face is the limited number of human resources. Assigning more responsibilities to this limited number will cause an additional resistance to any maintenance method.

To address this resistance, the development of a simple and practical maintenance framework that captures many of the essential features of TPM, as defined by Nakajima, but which is easier to implement may be the solution that SME's require.

In this chapter, a Practical Maintenance Framework (PMF) is introduced. The model's detail and procedures are simple to use and it supports companies of any size to implement the main features of TPM. The company's workforce can implement PMF steps without the need for an external consultant. The steps are flexible and can be tailored by engineers and the management to the individual company's capabilities, where each company could develop its plans differently because of different needs and challenges faced, depending on the different equipment types, equipment conditions, and type of industry. The fundamental measure of the method is the overall equipment effectiveness (OEE) value, which as described by Nakajima (1989), should be the driving force and provides direction for improvement-based activities within manufacturing organizations.

In the first section, PMF is defined and its linkage to Nakajima's twelve steps of TPM illustrated. Then each PMF step is defined in detail and the way it could be used and implemented.

5.2 Defining the Practical Maintenance Framework (PMF)

Managers in companies usually think of re-evaluating and improving their business strategies to help them at least stay in business. Improving their business is built on the way their production lines function, and the condition of their machines and equipment, and this will lead them to recognize the need to improve the equipment conditions by thinking of implementing a new maintenance method in their companies.

This awareness could be established, as Nakajima (1988) states, by consulting other managers who have successfully implemented TPM or any other maintenance method. Alternatively, visiting other company's operations, already implementing a maintenance method, would help to eliminate doubt and improve their support to these methods.

Our Practical Maintenance Framework can be defined as a procedure that provides a practical maintenance system for companies. This procedure involves operators and maintenance technicians acting as a team to monitor equipment and prevent production losses.

According to Nakajima (1988), the basic TPM development activities, which Shirose[(2)] (1992) calls the five pillars of TPM, are:

1. Elimination of the six big losses to improve equipment effectiveness using OEE.
2. An autonomous maintenance program.
3. A scheduled maintenance program for the maintenance department.
4. Increased skills of operations and maintenance personnel by training.

5. An initial equipment management program.

The Practical Maintenance Framework (PMF) focuses on the first four of these pillars of TPM. However, the last pillar is difficult for SME's to accomplish. This pillar is the early equipment management program, which is to design equipment taking into consideration maintenance prevention (MP), which is designing and manufacturing machines that do not require too much maintenance attention. This is because such companies do not have the power to force equipment manufacturers to design machines according to their specifications with less maintenance responsibilities.

The reason for this is that these companies only buy equipment in limited numbers from equipment manufacturers and the equipment manufacturers benefit from maintenance and spare parts assistance.

The first four pillars are perhaps the most important activities in that they have a strong effect of improvement on the production line and equipment. The last pillar is an important issue as well, but the range of effect is less than the rest. As Shirose[(2)] (1992) pointed out, while all five pillars are essential to the TPM development, the first three are the most important for equipment operators.

In addition, PMF is built on the collection and analysis of the OEE data gathered by the workers on the production line, as well as SOEE to monitor their equipment during time as a statistic reference of progress. These measurements help the management to assess progress and help workers identify the sources of problems on their equipment.

The PMF six steps are strongly based on the twelve steps of Nakajima's development program with a different degree of sophistication. PMF, as a method, concentrates on the elements that are practical and suitable for SME's in their maintenance development program, which are training, autonomous maintenance, and periodic maintenance. The PMF steps are shown in Figure 5.1:

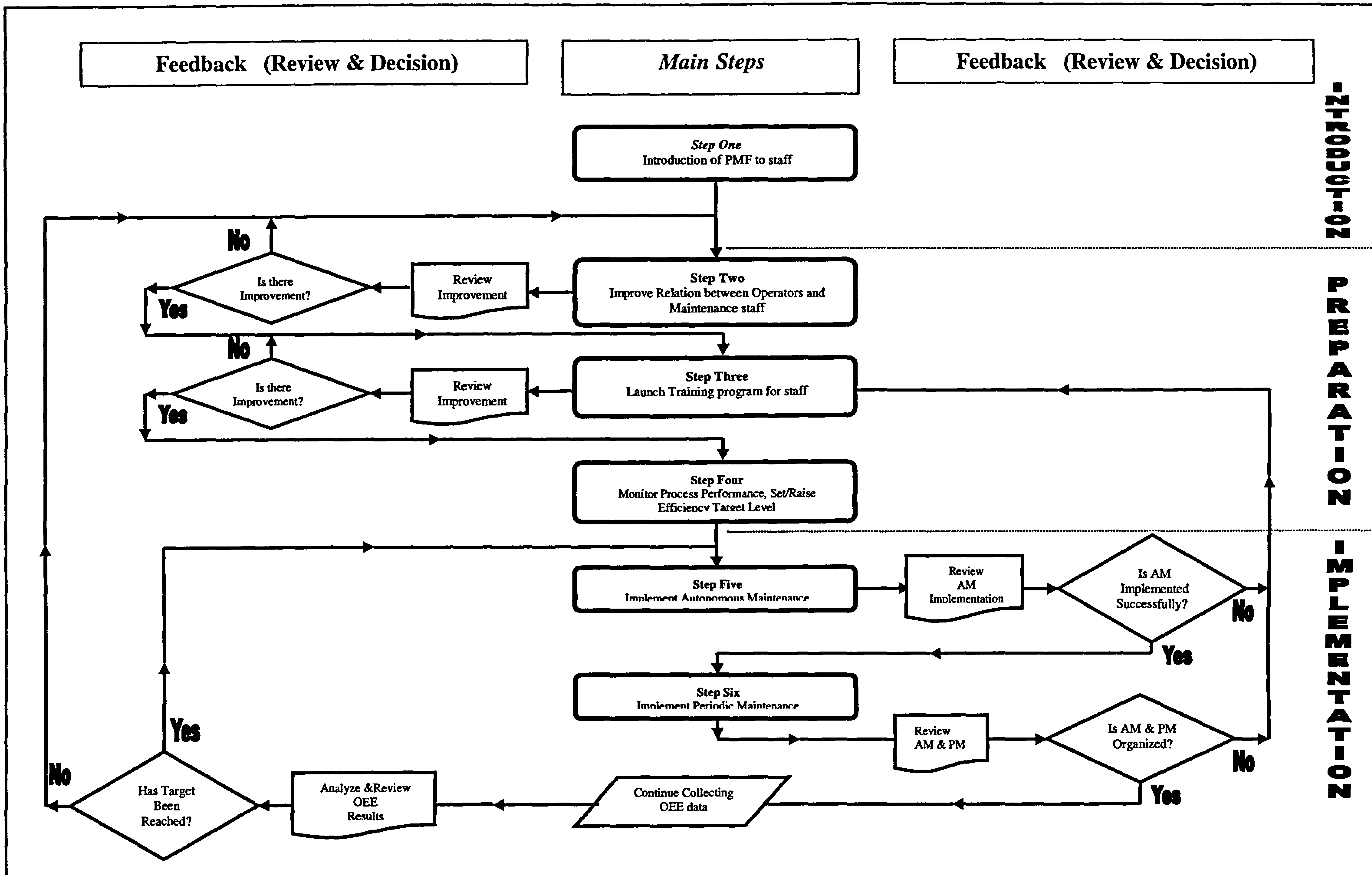

Figure 5.1: Practical Maintenance Framework (PMF)

Here we will discuss the practical elements that PMF concentrates on, which are Autonomous Maintenance, Periodic Maintenance, and Training. What makes Autonomous Maintenance (AM) highly desirable is that it helps to prevent damage to equipment due to dirt and contamination. It is essential in manufacturing to reduce breakdowns and to produce a constant production flow.

Another benefit of AM is that it changes workers' attitudes towards their work, As Chen (1994) stated, housekeeping helps to improve morale by improving the physical surroundings of the work and also helps in the prevention of damage to the equipment due to nonessential particles, such as dust and shavings on motors. In the case of inventory, McKone *et al.* (2000) conducted a study, which showed that there is an optimal investment in planned autonomous maintenance to reduce inventory levels.

In addition to AM, Periodic Maintenance is an important and essential factor that can significantly help in improving equipment effectiveness. Nakajima (1989) states that the ultimate goal of TPM, with respect to equipment, is to increase its effectiveness to its highest potential and to maintain it at that level. Periodic maintenance involves the repair, replacement and maintenance of equipment in order to avoid unexpected failure. Periodic Maintenance is important in helping to avoid any unexpected failure that can affect the production line and cause delay on it.

To improve equipment efficiency requires the development of an effective preventive maintenance program that keeps the equipment at a high level of overall effectiveness, (Ben-Daya, 2000); (Mitchell *et al,* 2002). Lawrence *et al.*, (1995) supports this by stating that the objective of any periodic maintenance program is the minimisation of the total cost of inspection, repair and equipment downtime.

To accomplish the level of satisfaction in applying periodic maintenance and autonomous maintenance these two programs have to be associated with training. Training is important in improving the worker's skills and knowledge, which reflect, and gain, the benefits that implementing PM and AM carries on the quality of products on the production line. A.Raouf and Ben-Daya, (1995) supports this issue by stating that training is essential to good quality maintenance work in raising workers' awareness towards the essential way of implementing AM and PM.

Referring back to PMF we can see that most of the steps in Figure 5.1 contain feedback loops to ensure constant improvement before implementing the next step. These loops, which give feedback on how well the implementation progress is carried out, enable a review of the implementation progress and any decisions that have to be made as to whether to proceed with the next step or to further improve the implementation of that particular step. As stated by Malcolm (1996), feedback loops within processes ensure ease of communication throughout the workplace.

PMF Stages	**Nakajima Steps**	**Status in PMF**
Introduction Stage	**S1:** Announce top management decision to introduce TPM. **S4:** Establish basic TPM policies and goals. **S5:** Formulate master plan for TPM development.	Introduction of PMF to the staff.
	S3: Create organisation to promote TPM.	Improve relation between operators and maintenance people.
Preparation Stage	**S2:** Launch education and campaign to introduce TPM. **S10:** Conduct training to improve operation and maintenance skills.	Launch education and training to improve worker skills.
	S7: Improve effectiveness of each piece of equipment. **S12:** Perfect TPM implementation and raise TPM levels (set higher goals).	Monitor process performance, set/raise efficiency target level.

Implementation Stage	**S8:** Develop an Autonomous Maintenance program. **S9:** Develop a Scheduled Maintenance program for the Maintenance Department.	Implement Autonomous Maintenance. Implement Periodic Maintenance.

Table 5.1: Linkage between PMF and TPM steps

We state in Table 5.1 a description of the linkage between PMF and Nakajima's twelve steps. As a method, PMF can simplify a TPM development program for SME's, as PMF has only six steps. These six steps actually represent most of the twelve steps of Nakajima's TPM development program. Only two steps are not quite covered by PMF: Step 11, "developing early equipment management program", is not covered because, as stated before, SME's do not have the power to force equipment manufacturers to design machines to their specification.

Also, Step 9, described by Nakajima as "developing a scheduled maintenance plan", consists of periodic and predictive maintenance. PMF only covers the periodic maintenance program and not the predictive maintenance program because a predictive maintenance program requires the use of special approaches to monitor equipment behaviour and analysis labs to analyse and predict any unusual behaviour of the equipment. Predictive maintenance is desirable but forces more financial pressure on companies and further system training to develop full use of these systems.

PMF does not require teams or committees for implementation because all the workers are working as one single team, which is responsible for the success of the implementation. In contrast, a TPM development program, as proposed by Nakajima (1988), requires the formulation of special committees at every level, and establish central headquarters, and to assign staff as group teams for the purpose of insuring the implementation of TPM. In the next section each step of the framework is discussed in more detail.

The PMF steps are linked to each other and there is no gap between the preparation and the implementation stages. As shown in Figure 5.1, the implementation stage is linked with both the introduction and the preparation stages in loops of reviewing and decision-making.

It is clear that in the preparation stage of Nakajima's twelve steps, the procedures involved will take time and effort. As Nakajima stated, the preparation stage alone will take between three and six months depending on the size of the company, level of technology, management standards and current level of planned maintenance. This is true for large companies because of the many levels of management between the top management and the shop floor. For small and medium size companies the situation is different; there are fewer levels of management.

The PMF method supports SME's in four ways; first, the model is simple and easy to follow as it only has three stages and six steps. Second, PMF does not require a significant financial commitment; steps could be implemented by the company's staff (there is no need for a consultant to explain and help implement the method) and training is carried out by the workers and this reduces the additional financial pressure. The maintenance technicians will train the operators on autonomous maintenance and will be responsible for planning their own periodic maintenance program. This is because maintenance technicians are the best people, who have the maintenance skills to train operators, and also have the knowledge and experience to plan their periodic maintenance program. Third, improvements could be achieved shortly after implementation, as will be shown and discussed in the next chapter. Fourth, the model does not involve specialist TPM teams and committees; instead there is only a single team to which every one in the company will be attached. The benefit that companies will gain by applying PMF is through the reduction of lost time, wasted effort and incurred cost.

However, with PMF there is a limitation on improvement: When all its steps have been implemented the performance of the equipment can reach a high level of availability, but not 100%. If companies are seeking to extend the equipment's availability further then these companies need to implement TPM fully. PMF is a fundamental method that covers most of the TPM's steps, as shown in Table 5.1, and to continue to implement TPM, companies need to cover the missing steps mentioned earlier, which are "predictive maintenance" and "developing early equipment management program". Figure 5.2 shows the relationship between PMF, TPM and performance.

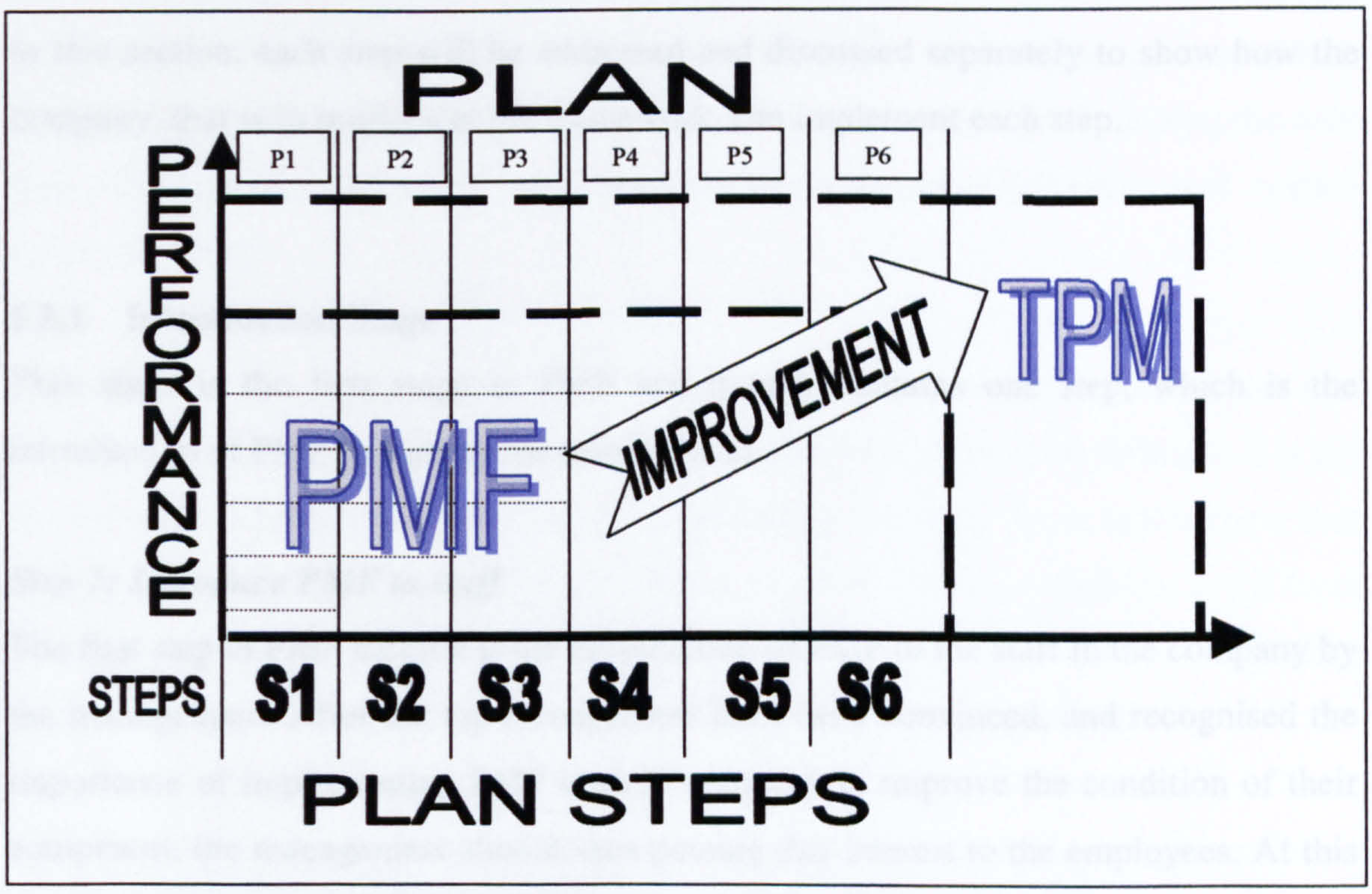

Figure 5.2: The Relationship between PMF, TPM and Performance

As shown in Figure 5.2, PMF covers the first few steps of TPM and it does not have any conflict or large differences from the ordinary initial steps of TPM. As mentioned previously, for any company seeking to improve their equipment efficiency further than the maximum limit that PMF can provide will require to implement the remaining steps of TPM. In the next section, we will present and discuss the steps of PMF in more detail.

5.3 The PMF Steps

As mentioned before, PMF consists of six steps and it is difficult to associate a time limit to each of these steps. This is because different companies have different maintenance capabilities, they come from different cultures, have different working unions, and the people working in these companies have different perspectives. PMF should be treated as a framework or guidance, which suggests the way these steps can be implemented and it is not necessary for companies to follow the exact procedures that these steps have been introduced.

In this section, each step will be addressed and discussed separately to show how the company, that is to implement the framework, can implement each step.

5.3.1 Introduction Stage

This stage is the first stage in PMF and it only contains one step, which is the introduction of PMF to staff by the management.

Step 1: Introduce PMF to staff

The first step in PMF method is the introduction of PMF to the staff in the company by the management. After the top management have been convinced, and recognised the importance of implementing PMF in their company to improve the condition of their equipment, the management should start passing this interest to the employees. At this stage, a condition for successful acceptance and implementation of PMF is to create support for the method from senior management and employees. The most effective way to begin an improvement process is to have it driven by the top management of the company.

As Jostes and Helms, (1994) illustrates, when the improvement process is driven by the chief executive officer (CEO) it breaks down any barriers inherent in an organisation and gives the co-ordinator of the change the credibility necessary to work at all levels of the organisation. In addition, by using this CEO-driven approach, the change has the most probability of becoming a permanent part of the business culture.

As a result of a study carried out by McAdam and McGeough, (2000) to investigate TPM applications in multi-unionised and heavily demarcated manufacturing organisations, it was reported that barriers to implementing TPM were perceived to be lack of top management commitment and follow through, and a lack of middle management support. They reported that employee resistance to change, due to increased workload without appropriate reward and recognition (mainly from operators), are also barriers to implementing TPM.

It is important for the management to make an obligation towards the implementation of PMF. This obligation comes by the full confidence that PMF could deliver the help that the company needs to improve their maintenance capabilities and reduce production cost.

However, if the top management is not obligated to the framework and convinced that it can help their companies, then the implementation of PMF will be difficult. It is the management who helps in supporting the method by breaking down any barriers that could jeopardise the success of the implementation. These barriers could be in the form of employee resistance towards new methods, or the incorporation of the supporting departments between each other, like the storing and finance departments.

The management needs to set meetings with the middle management to announce their decision for implementing PMF within the company and to ask them to support this decision. Through these meetings the top management, with the middle managers, can use the cost analysis described in Chapter Four to discuss in numbers the recent efficiency of the equipment, the loss on their production lines, and the amount of money lost as a result of these difficulties. The use of numbers is the best way to capture management's attention. The top management could start establishing the main strategic plans and procedures for the departments and employees to follow with the assistance of the middle managers and in some cases supervisors. These plans should contain policies and strategic goals that the management is seeking to reach.

As Thilander (1992) illustrates, that lack of responsibility and commitment from workers, foremen and senior managers, can cause a large part of the breakdowns.

On the other hand, the middle managers can set meetings with supervisors and foremen to discuss the details of the implementation and obstacles that could be faced with supervisors providing feedback on behalf of the working staff on the production lines. This is because the supervisors and foremen can represent the workers responses towards these policies. The policies should be clear, the goals should be associated with time limits, and must be practical and reachable. As Hutchins (1998) states, it is important to be careful and not to take on anything too challenging in the early stages, where a failure at this stage, would be a major upset in the implementation process.

The supervisors and foremen can now introduce these plans and procedures of implementation to their working staff on the shop floor by informal meetings. The supervisors can discuss any new ideas that these workers can provide and these ideas can be passed through to the management.

Giving the staff the opportunity to discuss their ideas and express their thoughts can help in building a healthy environment of communication. It is difficult to enforce ideas on people without first discussing it with them. In some cases these ideas have to be discussed with the unions that represent them and, without their approval, it is difficult to get their support. The implementation of PMF is built on the support and effort of these workers and without their cooperation it is not possible to implement the framework.

To support the implementation of PMF the management could use reward schemes, job security plans, or any other method that the management prefers, and could help to eliminate employee resistance.

The environment of the workers is important to the attitude they bring to their work, most environment changes are simple things, such as rewards (Chen, 1994); (Parker, 1995). In addition, Jostes and Helms, (1994) supports this point by stating that human nature moves people towards doing the things for which they are positively rewarded, and away from things for which they may be punished.

5.3.2 Preparation Stage

The stage contains steps 2, 3, and 4, and this stage cannot be preceded until the introduction stage has been accomplished. If the introduction stage was not well secured then moving to the next stage would prove difficult to accomplish.

Step 2: Improve relationship between operators and maintenance people

The second step is to improve the relationship between the operators and the maintenance staff. After introducing the new idea of implementing PMF to the staff in the company, it should be recognised that one of the most important factors in successfully implementing PMF is having a good relationship between the operators and the maintenance staff. This is because these departments are directly involved in the implementation of PMF. However, if the relationship between the two parties is not improved, and the co-operation between them is not secured and accomplished, then the implementation of PMF can fail. Jostes and Helms, (1994) stated that TPM describes a synergistic relationship among all organisational functions, but particularly between production and maintenance, for continuous improvement of product quality, operational efficiency, capacity assurance and safety.

This does not mean that other departments are not as important, but these two departments are most directly responsible for implementing most of the PMF steps. The support of other departments is important, as positive results are hard to accomplish when other departments are isolated and not committed. For example, the store department in the company is important in providing the maintenance department and operation department with spare parts. The financial department helps in planning any reward schemes, which the management might wish to use.

The precondition of improving the relationship between the operators and maintenance people seems to be the recognition of the major importance of achieving success. People tend to resist change of any kind if they cannot see how they can benefit from it. Because of that, the management should secure this relationship between the operators and the maintenance people by setting formal meetings with the employees to discuss the benefits that could be reached in implementing PMF, and to avoid challenges facing the success of this implementation. As Ben-Daya (2000) stated, with TPM, operators and mechanics must realise that they both have the same goal and consequently must co-operate and have a teamwork spirit.

First, during the meetings the management could discuss the implementation plans and explain to the staff the linkage between PMF and the company's goals and aims that are to be achieved. The management could discuss in these meetings with the employees the financial advantages that could be gained as a result of this implementation. The management could discuss that profit gained by these improvements can help to keep the company running, thereby resulting in job security. It could be discussed that part of this gained profit loss could be used for additional training, research and development, and rewards.

Bamber *et al.* (1999) states that reward and recognition should be used to encourage and motivate people towards the TPM program. Jostes and Helms, (1994) also discusses the reward system, stating that if your measurement system rewards operators for the number of pieces they run, their tendency would be to run the machinery just as fast and hard as they can. If, however, the criteria for the reward system were changed to reflect a set of values that reflected management's concern for quality and process reliability, there would be a significant shift in how the equipment was run.

It is important to let the operators and maintenance staff participates in formulating plans for the implementation steps, taking into consideration the workload that the operators and maintenance staff carry. The operators and maintenance staff should have the opportunity to meet and discuss the procedures and responsibilities that they will take on board whenever they have the time during work shift or after work.

As illustrated by McKone *et al.* (2001), TPM changes the structure of the organisation by breaking down traditional barriers between maintenance and production. The main goal of the management should be to change the traditional relationship between the operators and maintenance people.

These meetings could help develop an atmosphere in which employees feel that their work is important to the organisation, and that they are considered an important asset to the company. During this stage of the implementation, the management could start planning to support the change and formulate a clear vision, strategy or policy for the PMF activities. In addition, the management should support the framework by explaining, through the supervisors, the procedures and steps of PMF to everybody in the enterprise, providing a strong organisation responsible for supporting the implementation and promoting the deployment of change methods.

As Thilander (1992) found during case studies, competence, information and motivation were important prerequisites for effective maintenance, job satisfaction and overall productivity.

Management should move people towards changing the way they behave and to increase their motivation. As stated previously the management could use a reward system. These meetings help to change the traditional way of "operators working on their machines until it breaks down then call for the maintenance people to fix it" into a teamwork relationship by communicating with both parties. This communication could be built by explaining to the operators and maintenance people how their combined efforts not only affects their own departments and their organisation, but also how it could affect their customers as well. As Lawrence (1999) argues, successful TPM implementation requires finding a way to breakdown the walls between the production and maintenance organisations.

The management should start shifting their operator thinking from just operators towards machine owners. Their responsibility moves towards setting up their machines, cleaning it, lubricating and carrying out minor repairs.

At this step the management could arrange to control and assess progress by using questionnaires, auditing the progress of the work during time, or even in setting up short meetings with each party alone.

The assessment systems used should be reviewed to decide either to continue or to rearrange a different way to reach improvement in this step. This is done by reviewing the progress of the improvement, or lack of improvement, which will help in finding the reasons for problems and eliminating the sources of problems in the early stages of the implementation. When this step is fully accomplished the management can move to the next step, which is to start the education and training of company staff.

Step 3: Launch education and training to improve workers' skills

The third step of PMF is to launch the education, and to start training the company staff. In this step of the framework, if the management decides to continue to implement PMF, they must design a plan for implementation. This should include what needs to be changed and how the change should be exercised. At this stage the commitment of all the staff should be secured, as this commitment towards the new method is important before proceeding with the training. However, if people are not completely committed and convinced of the advantages that PMF offers to their work, then it is more likely to be a waste of time and effort.

After educating all employees on the importance of PMF, and showing them the advantages, the maintenance technicians and the operators can work together to plan and detail the training program, and produce documented training instructions. Patterson *et al.* (1996) stated that Asten Co. placed the maintenance department associates in charge of developing an autonomous maintenance program, and this meant that the maintenance associates were responsible for training operators in setting up maintenance programs.

These training instructions should cover the tasks to be carried out by the operators, the starting level of training, the time the training should be carried out, and the way the training should be assessed. If management begins introducing autonomous maintenance without involving the maintenance staff, then there is little chance of effectively progressing autonomous maintenance.

Yeomans and Millington, (1997) stated, that if production begins introducing AM without involving the maintenance function, then there is little chance of effectively progressing, and the maintenance department holds the essential facts and the experts in the care and servicing of the equipment.

Using the maintenance staff to train the operators on autonomous maintenance tasks helps companies to reduce the cost of training operators by a third party from outside the company. In addition, the maintenance staff in the company have the knowledge needed to accomplish this step, while outside training contractors will need time to gain this knowledge.

However, if the maintenance staff refuse to take over the responsibility of training operators, the company will have to use an outside training contractor to accomplish the training procedure. This will result in an additional financial commitment that the company will have to face, which will reduce the benefits that PMF carries to companies.

The maintenance department's first priority is to start planning for their periodic maintenance program in co-ordination with the autonomous maintenance activities that the operators are to be trained on. This step should be arranged with the cooperation of the maintenance and production departments so that the two departments can work together. The development of the scheduled or periodic maintenance program should begin before the start of autonomous maintenance training and implementation. This is so that a clear separation of the responsibilities of the two tasks can be accomplished.

In addition, during the training, and at the beginning of the implementation of autonomous maintenance activities, the maintenance staff will be busy coaching and supporting the operators, and they will not have the time to work on their scheduled periodic maintenance program. As such, the plans should be formed and compared against the standards being set by the operation department before starting autonomous maintenance.

Maintenance technicians and the production team, working together, should detail the tasks to be carried out and then produce job instructions. This should include specified tooling, protective clothing where appropriate, health and safety regulations and any other special information relevant to the training and implementation of the steps of PMF.

The operators are then trained on the job on how to implement autonomous maintenance (AM). This training is carried out by the company's maintenance technicians who provide awareness, coaching and support during the introduction of each AM task. The training time should be agreed and settled to suit both parties to stop any interference with the day-to-day running of the plant. The training could be carried out at the beginning or end of each shift, or even during break time when agreed by operators and maintenance staff.

Steudel and Desruelle (1992) stated that the combination of involvement and training at all levels of the organisation is the key to manufacturing and maintenance success. A.Raouf and Ben-Daya (1995) stated that training is essential to good quality maintenance work.

This training, when carried out by the maintenance technicians of the company, could accomplish the aim of improving the relationship between operators and maintenance staff. Patterson *et al.* (1996) stated in his case study that while maintenance technicians were training operators, this cascade in training kept the maintenance team in close contact with the operators and helped them understand their needs for training, while making them aware of equipment problems.

The maintenance and production associates should agree a competence level, which is recorded against each operator on a skill status document to control autonomous maintenance activities effectively. The appropriate level of training that the operators should have is important, and this should be arranged with the maintenance staff who will train operators, and the training should be carefully studied and planned before proceeding. This is because, if the level of training is higher than the operator's ability,

then it is difficult for them to gain the knowledge needed to perform their tasks. On the other hand, if the level of the training is below their ability then it is a waste of time and effort.
By providing training, firms also empower their workers and help to push problem-solving skills nearer to the problem. When training is fully understood and applied, operators will develop greater morale and competence and become independent, skilled and confident and can monitor their own work and start improving their performance.

Chen (1994) argues that the commitment to training means rigorous requirements, continual education and formalised training procedures. The emphasis on training reflects the belief that people are the company's greatest assets. It is only by utilising the assets of well-trained workers fully, that a firm can maximise the creativity, energy and skills of the entire workforce in order to compete effectively.

In addition, Tata (2000) states, that training programs will have to be designed to help socialize employees to new values, to signal the company's desire for greater employee involvement and to help employees cope with skills required for teaming.

When maintenance people train operators on autonomous maintenance the lack of trust that the maintenance people feel about operators (as discussed in Chapter 3) will reduce gradually, since the maintenance people will feel a responsibility to pass on all information needed for operators to guarantee that they are capable of repairing their equipment. This step is designed with a closed-loop so that all actions can be monitored, results can be reviewed, and the achieved improvement is measured.

The operators and maintenance technicians should discuss with the management an appropriate assessment program. The assessment could be in the form of short exam assessments, performance appraisal carried out by the maintenance technicians to assess the operator's progress, or any other assessment accepted by both parties. The feedback of this assessment should be documented and reviewed for the purpose of improving the training task, as shown in Figure 5.3.

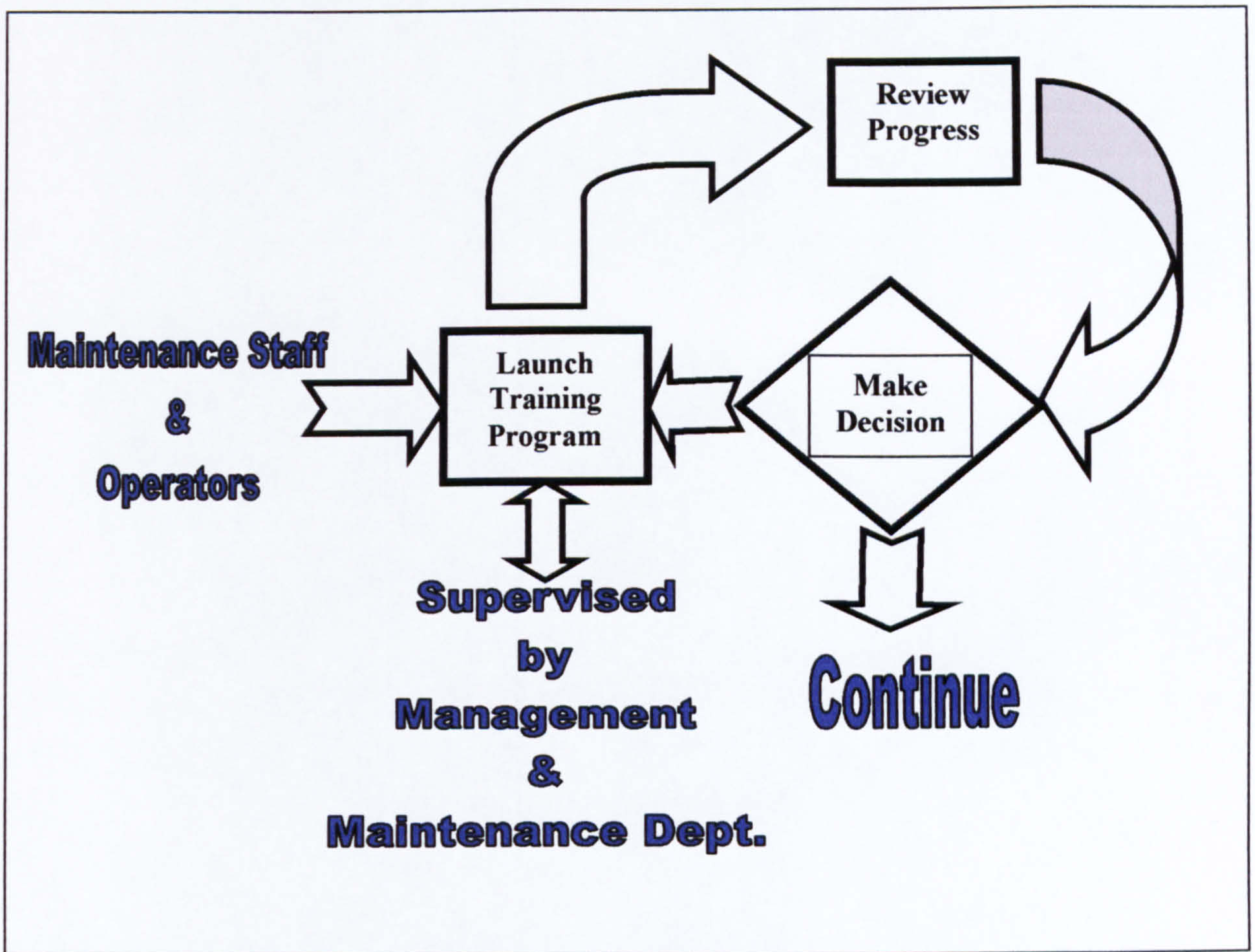

Figure 5.3: Closed loops of Education and Training

The closed loop, as shown in Figure 5.3, contains the assessment data collected and analyzed component. These results are reviewed and a decision is taken either to move to the next step or to make any necessary changes to improve the level or procedures of the training program.

If failure to achieve the required results is seen at the review stage, analysis of why the expectations have not been met must be carried out, and corrections of the activities must be made so that inappropriate practice or direction is not continued.

The company should continue to invest in training to improve the skills of the workforce. More advanced training could be considered for the operators to train them on more advanced maintenance techniques, which could help them to go on to more difficult maintenance tasks.

As Chen (1994) stated, companies who invest in their workers, extend and increase the utility of the workers and, at the same time, lifetime employment protects the investments the firm has made through extensive training.

Step 4: Monitor process performance, set/raise efficiency target level

The fourth step in PMF is to start monitoring process performance and setting/raising the efficiency target level. Measurement is considered as an important requisite of the continuous improvement process, as stated by (Jostes and Helms, 1994). One of the best ways to measure the effectiveness of TPM is by using Overall Equipment Effectiveness (OEE).

As argued by Mileham *et al.* (1997), overall equipment effectiveness is frequently taken as a highly important measure of the performance of a business. In addition, Chand and Shirvani, (2000) states, that the goal of TPM is to increase equipment effectiveness so that each piece of equipment can be operated to its full potential and maintained at that level.

OEE is a measure of the value added to production through equipment, and is a function of machine availability, performance efficiency and the rate of quality as defined before in Chapter Four. OEE is used to provide directions in an effort to eliminate the six big losses (Nakajima, 1988). In order to improve the effectiveness of the equipment it is important to recognise, measure and reduce these losses.

$$OEE = Availability \times Performance\ efficiency \times Rate\ of\ quality\ products$$

To begin with, before trying to find the possible causes, it is also important to record the current state of equipment, this is done by the maintenance staff with the assistance of the operators as part of the training scheme. Data needed and required should be gathered and used to calculate the efficiency of the equipment and the cost associated with it, using the cost analysis quantitative method mentioned in Chapter Four.

This is done to provide a reference against which improvements resulting from any work undertaken could be measured. The OEE factors are then analysed by engineers in the company to locate where the problems occur.

The advantage of designating and using OEE as a measure is that it clearly identifies causes of losses in manufacturing effectiveness, and allows the continuous monitoring of the most important factors which influence system performance. The factors of OEE should be tracked and trended to observe changes in performance of critical equipment in the process stream. In some processes, quality losses of "yield" and losses associated with transitions from one product to another become big opportunities for improvement. The factors of OEE, and the six big losses linked with each factor, can be briefly shown in Figure 5.4.

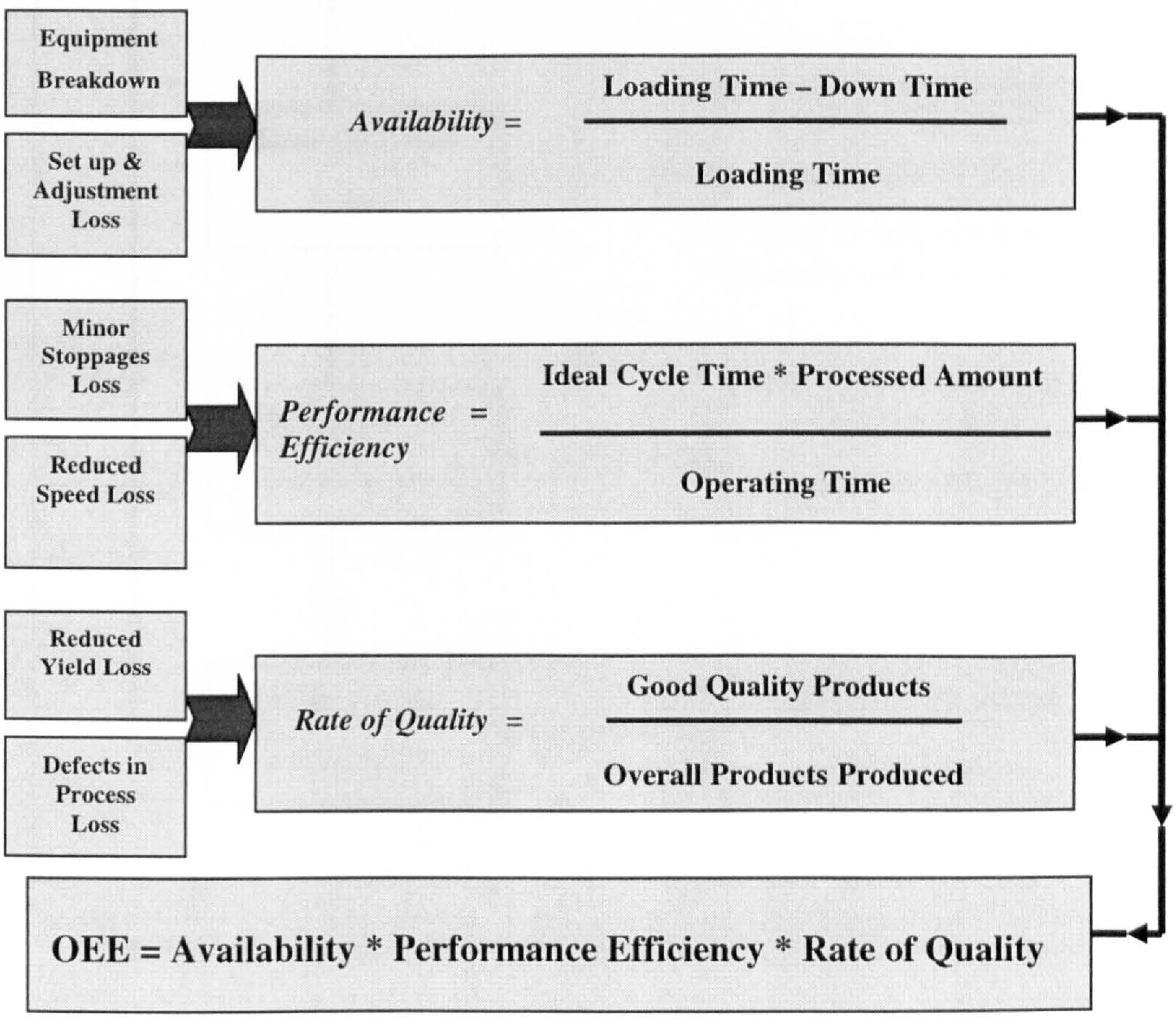

Figure 5.4: OEE Factors and the Six Big Losses

The OEE measure provides a single number on which to base comparisons of equipment performance. The real benefits however, come from using the factors of OEE, which lead to root cause analysis and eliminate the causes of the six big losses, which needs to be concentrated on to increase equipment efficiency. It is all about collecting, trending, and analysing the right data on critical equipment performance and reliability. Choosing a non-accurate monitoring system may not reflect the real situation. In Figure 5.5, a diagram that briefly explains the action of monitoring and setting higher goals is demonstrated.

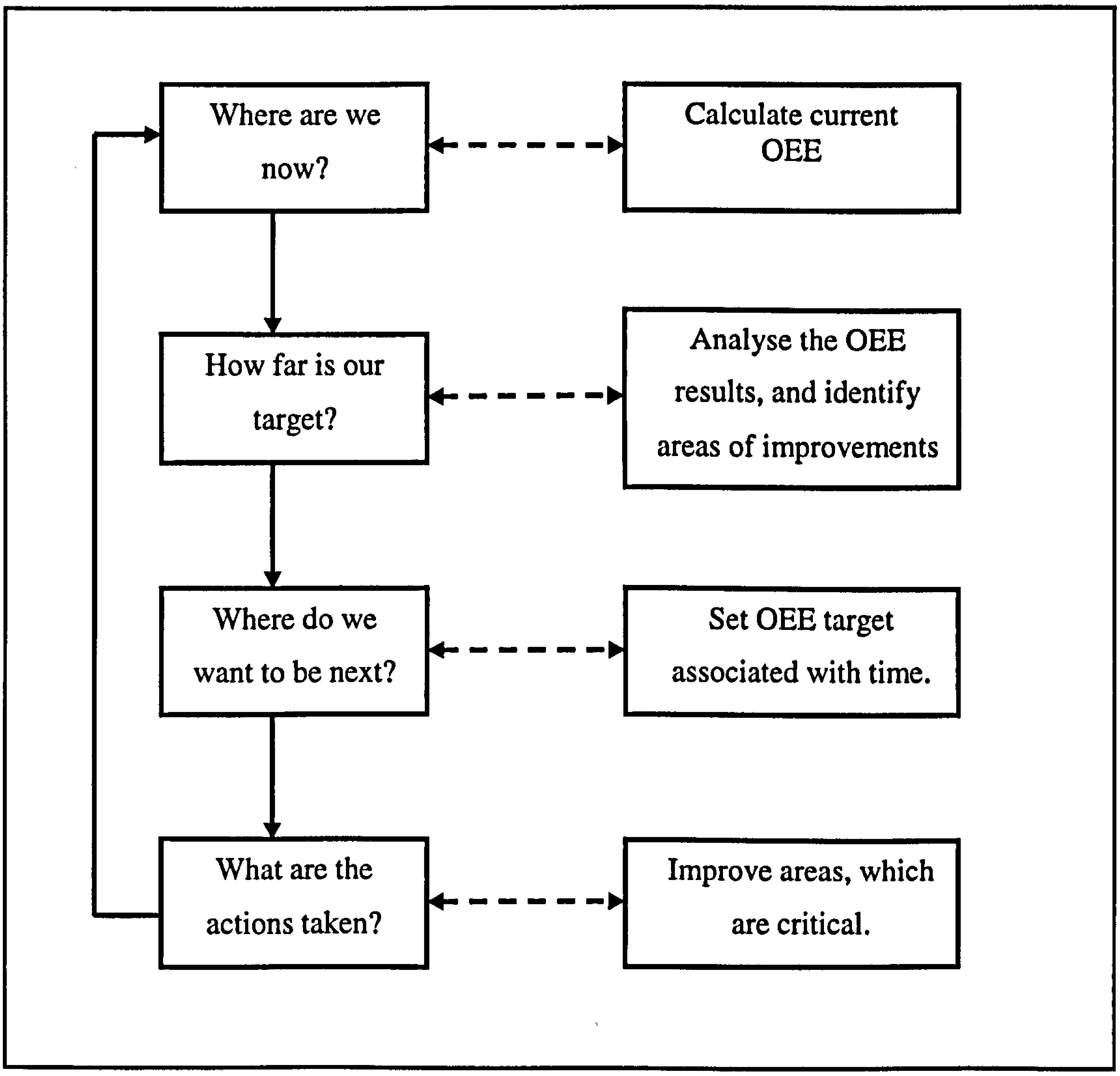

Figure 5.5: The steps of monitoring equipment efficiency

After analysing the OEE factors the engineers, with the assistance of the workers, should start planning and setting their goals during formal meetings. These goals should be both appropriate and achievable because there is no point in setting very high goals and not reaching them. These goals should be linked to a suitable time scale. For example, increasing OEE by 3% during the next three months.

Setting the goals should be accompanied by plans to follow in order to achieve them. To avoid conflict, these plans should be set out in detail and should show the responsibilities of each individual. The operators and the maintenance staff, under the supervision of the management and the engineers, then implement these plans. All improvements should be scaled and documented and kept as a reference for comparison.

5.3.3 Implementation Stage

The implementation stage contains the last two steps of PMF, steps 5 and 6, which are the result of accomplishing the first two stages where the introduction, training program and the procedure plans have been implemented. The implementation stage is the final stage that formulates and shows the results needed for improvement.

Step 5: Implement Autonomous Maintenance

The purpose of autonomous maintenance is to teach operators how to maintain their equipment. Autonomous maintenance is based on education and training, it is about raising awareness of the operators on their knowledge and understanding of the operation principles of their machines. To that purpose, autonomous maintenance will help operators develop the ability to judge if operating conditions become abnormal, and the ability to preserve normal conditions. Autonomous maintenance helps improve workers' moral and motivation.

Bamber *et al.* (1999) stated that the practice of cleaning, identifying faults and improvement had led to the operators talking proudly about TPM, and recognising the impact they could make on manufacturing improvement and contribution to the program. A study by Maggard and Rhyne (1992) shows that 75% of maintenance problems can be prevented by operators at an early stage, by frequently looking, listening, smelling and testing, which are all parts of autonomous maintenance.

Autonomous Maintenance (AM) is the cleaning, inspection, and simple adjustments performed by operators systematically trained through a step-by-step program, Shirose (1992). The work that is carried out by the operators is in the form of what has been stated by Nakajima (1988) as organisation, tidiness, purity, cleanliness, and discipline, which are the five basic principles of operation management.

Operators, with the co-operation of the maintenance people, should continue to refine the inspection process with an aim to generate improvements that increase equipment effectiveness. The operators should concentrate their efforts on the elements shown below, as illustrated by Shirose (1992):

- Initial cleaning: in this step operators are shown the proper way to clean their equipment. The physical act of touching the equipment and cleaning it reveals abnormalities and increase the operator's awareness of defects. As McAdam and Duffner, (1996) stated, cleaning is inspection, when an operator cleans a machine, he/she will also touch, feel, inspect, seek for heated areas or hot points and in this way the operator comes to have an understanding of the equipment. Cleaning, in the form of taking some parts of the equipment apart to clean an internal part, is a kind of inspection that naturally leads to the discovery of abnormalities, and this is linked with the operator's own experience.

  However, after cleaning, missing screws can be easily identified, and after a few days if the equipment becomes dirty, that will mean that there is a source of dirt or oil leakage, indicating worn oil seals or potential bearing failures. This will not be visible unless the equipment is thoroughly cleaned. This step will prompt the operator to look for causes and ways to reduce or eliminate the contamination. The cleaning regime can help to change an operator's attitudes and to reveal hidden defects that usually go unnoticed.

- Eliminating the source of dirt and dust: in this step operators start making cleaning and inspecting easier by controlling the sources of dirt and dust and other forms of contamination they find during initial cleaning. The more difficult it is for the operator to perform initial cleaning, the stronger will be his desire to keep the equipment clean and reduce cleaning time (Shirose(2), 1992). Measures to eliminate the causes of dust and dirt could be done by using covers and shields or preventing oil contamination by finding the source of leakage, and repairing it, or even tightening bolts that cause vibration. If a cause cannot be removed completely, more efficient cleaning and inspection procedures could be designed for the problem area.

- Conduct general inspection: in this step operators are trained on common systems that all types of equipment share. They receive basic instruction in equipment subsystems such as lubrication, equipment elements, pneumatics and hydraulic valves, electrical circuits and other basic technologies. This part of the training is given in brief to the operators to help them identify the elements and the best and proper way in cleaning and inspecting them, and finding any abnormalities on these elements. In addition, this step will help them describe to the maintenance staff the problem in a more technical form to reduce the time that it takes the repairmen.

- Develop cleaning and lubrication standards: in this step operators use their experience to determine the optimal cleaning and lubrication conditions for their equipment, and to draft work standards to maintain those conditions. The work standards specify what to inspect while cleaning and lubricating, which parts of the equipment need cleaning and lubrication, and when it should be done. Obviously the time for cleaning and lubricating is limited and supervisors must give operators reasonable targets for time to be spent. Cleaning and lubrication standards will be followed if operators understand, theoretically and practically, why they are so important.

- Organise the workplace: in this step operators should start concentrating on the surrounding area. This is done by eliminating unnecessary items around their work areas and organising the tools and measuring instruments that they need during their work. They should start establishing standard quantities and locations for the raw material and final products. This will help operating standards, including the set-up and change over or adjustment procedures, because all parts are in place and this will help the operator to reduce the set-up time and adjustment.

As McAdam and Duffner,(1996) illustrates, a clean, neat, workplace allows for better control, better inventory control, and better work practices to allow the path of continuous improvement to be pursued, which in turn has the desired effect on productivity of the line and hence its profitability. In addition, when all items and materials are in place, it will become easy to check the quality and quantity of items so that when needed, they can be easily located and used to full advantage.

Autonomous maintenance helps to unite the effort of operators and maintenance personnel to accomplish the company's goal of reducing breakdown and improving the equipment performance. As McKone *et al.* (1999) states, autonomous maintenance brings production and maintenance people together to stabilise condition, and halt deterioration of equipment, and improve the overall health of the equipment.

At this stage the operators should start implementing autonomous maintenance and, during the implementation step, the maintenance technicians should supervise, support and coach the operators to make sure that they implement AM according to the planned program and training scheme. As illustrated by Hutchins (1998), when the operators begin to mature, they will soon be able to look after the machines themselves. As they become more confident, there is a marked change in attitude and a will to take wider responsibility for the performance of their operations.

During this step, the progress should be reviewed on the basis of the results of OEE calculated, or according to the assessment of performance appraisal carried out by the maintenance personnel in assessing the operator's progress.

After the review, a decision is then made by the management and with the assistance of the maintenance people. This decision is either to move to the next step, which is implementing periodic maintenance, or to go back to the training step to improve the training level and set higher training standards as shown in Figure 5.6.

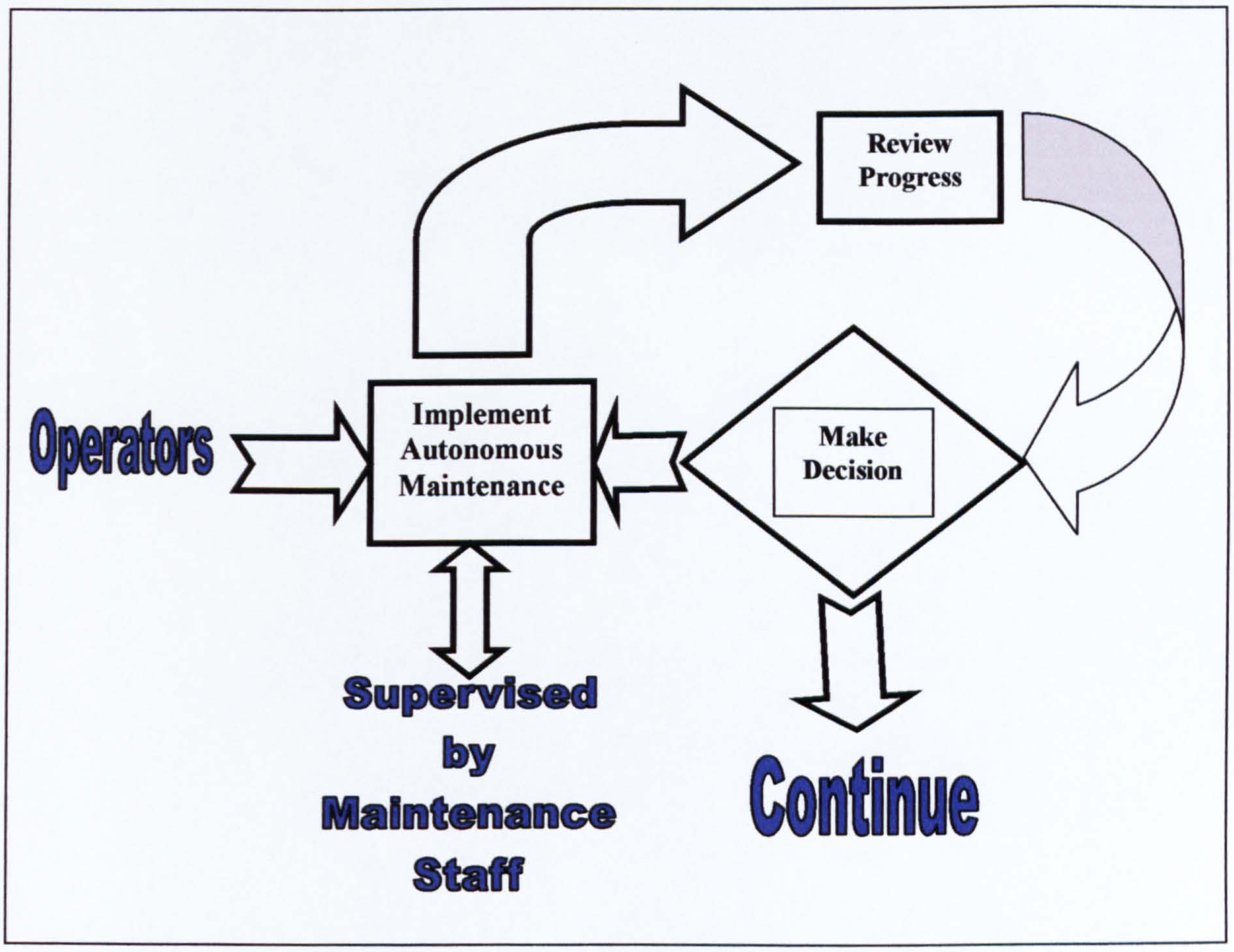

Figure 5.6: Closed loop of Autonomous Maintenance step

The management should, like with all the other steps, carefully control the autonomous maintenance implementation step, with the assistance of the maintenance personnel, to ensure maximum effectiveness.

The management could control this step by receiving the feedback result of the review and, for example, forming a reward scheme for accomplishments. The maintenance personnel, on the other hand, should monitor autonomous maintenance by calculating and analysing OEE results with the help of operators as part of the training, and should observe the operators work closely.

The maintenance technicians should understand that by sharing their expertise with the operators, they are contributing towards a positive environment. When the maintenance technicians have less to do with the cleaning, lubrication, inspection, adjustment and set-up of the machines, they will be able to develop higher skill demanding tasks. For example, they will be able to comply with the periodic maintenance schedule. As McAdam and McGeough, (2000) illustrated, by applying autonomous maintenance, the craft workers are freed from these routine tasks to work on preventive maintenance and development type work, which requires a trained specialist or craftsman.

It must be recognised that, in developing fully autonomous maintenance systems, all relevant data relating to OEE and the state and performance of the machine system, should be recorded. This can then be analysed and the results used to support more effective maintenance. This data should be recorded by the operators and then analysed by both the maintenance staff and operators. The result of the analysis will help and allow the operators to maintain equipment and to identify and resolve many basic equipment problems. This will encourage operators to become active partners, along with maintenance and engineering personnel, in improving the overall performance and reliability of the equipment.

As stated by Prickett (1999), that it must recognised in developing fully autonomous maintenance systems that all relevant data related to the state and performance of the machine system should be recorded. This can then be analysed and the result used to support more effective maintenance.

To achieve the goals of the autonomous maintenance program, it is clear that the program must include the involvement of operators and maintenance people, daily activities to maintain the condition of the equipment, cross training to improve operator skills, and participation of operating personnel in the maintenance delivery process.

Mckone and McGeough, (2000), stated that training operators on the equipment and creating a clean and organized environment help operators detect and correct potential problems prior to equipment failure, since these activities help operators to reduce the time it takes to inspect and fix problems, the response rate is increased.

Step 6: Implement Periodic Maintenance

Following on from the previous step of autonomous maintenance comes the implementation of periodic maintenance. Periodic maintenance is aimed at the prevention of breakdowns and defects on equipment by daily activities that include equipment checks, precision measurements, partial or complete overhauls at specified periods, oil changes, lubrication, etc. Nakajima (1989) defines periodic maintenance as a periodic inspection to detect conditions that might cause breakdowns, production stoppages, or detrimental loss of function combined with maintenance to eliminate, control or reverse such conditions in their early stages.

Lawrence *et al.*, (1995) defined periodic maintenance as repair, replacement and maintenance of equipment in order to avoid unexpected failure during use. The objective of periodic maintenance is to minimize the cost of equipment downtime measured in terms of lost production capacity. Bloch and Geitner (1983) have stated that certain signs, conditions or indications that a failure was going to occur, precede 99% of all machine failures.

It is cheaper to repair the equipment on a periodic basis rather than to wait until it has completely broke down. At that stage, the cost of restoring equipment is enormous. Factories that fail to implement periodic maintenance are, in essence, accelerating the possibility of breakdown of their equipment. In such factories, dust and powdered metal chips fly in all directions and when dust and dirt stick to moving parts and sliding surfaces of the machinery, the surfaces are scratched, causing deterioration.

A general inspection often reveals that many of the nuts and bolts are loose. When loosening and deterioration go unattended they can cause excessive shaking, which encourages abnormal abrasion and triggers further deterioration. In addition, leaks may develop resulting in excessive waste of precious materials and, when lubrication and oil drip is neglected, excessive friction or burning can result in wasting energy.

In factories where such neglect is out of control, sudden failures and minor stoppages are certain and common. These factories do not have the flexibility to implement periodic maintenance. Breakdowns and minor stoppages continue and conditions go from bad to worse.

On the other hand, when the operators have the ability to recognise any abnormalities on their equipment, and with the planned periodic maintenance, these signs and conditions will be recognised before any failure happens. At this stage, maintenance staff will start to implement the periodic maintenance program that they have planned. The amount of work, in the form of supervising operators, will reduce when autonomous maintenance has become part of the operator's routine.

The number of breakdowns will decrease and this will give the maintenance department the time to focus on implementing their periodic maintenance program. As mentioned earlier, the maintenance plans should be coordinated with the autonomous maintenance activities of the operations department, so that no conflict in responsibilities occurs during the process.

In addition, the maintenance department re-evaluates control of spare parts, inspection devices, tools and drawings before starting their periodic maintenance program. The periodic maintenance program requires a full recognition of spare parts in the company to help the program to continue.

This means organizing spare parts so that the right parts are always in the right place at the right time. This should include reducing the variety of parts by finding out which are necessary and which are not, and which can be used in common by different departments. However, if this data of the spare parts is not organized with the association of the store department, this will produce a delay in the periodic maintenance program.

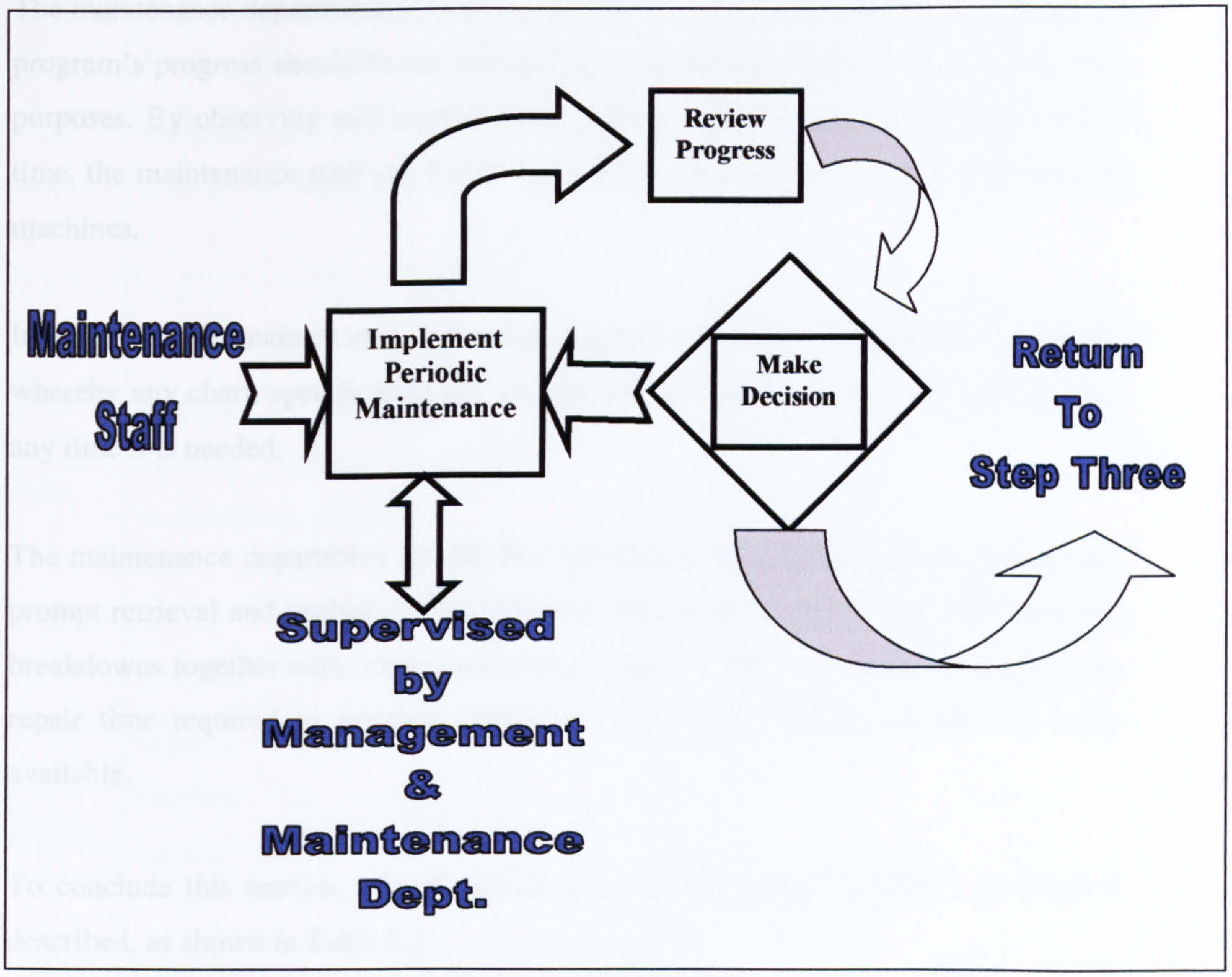

Figure 5.7: Closed loop of Periodic Maintenance step

Figure 5.7 shows how the implementation of periodic maintenance is controlled and reviewed. With the help of the OEE results, the maintenance technicians can reveal any improvement followed by the implementation of the periodic maintenance program.

This is associated with a decision of either continuing with the implementation in the case of finding improvement, or re-arranging operation procedures in the case of conflict arising between the periodic maintenance and autonomous maintenance programs.

The maintenance department should control the periodic maintenance program and the program's progress should be documented and reviewed for improvement and finance purposes. By observing and implementing periodic maintenance, through a period of time, the maintenance staff can locate any conflict in repeating the same operation on machines.

In addition, the maintenance department should establish a documentation system whereby any chart, specification list, or equipment manuals can be easily retrieved at any time it is needed.

The maintenance department should also develop an information system that enables prompt retrieval and analysis of the history record of the machines improvements and breakdowns together with other maintenance statistics. This will help them reduce the repair time required to maintain equipment when these history records are easily available.

To conclude this section, a brief description and explanation of PMF's six steps is described, as shown in Table 5.2.

Steps	Description	Detail
One	Introduction of PMF to staff by the management	Present PMF to staff, by the management, through meetings and explain the benefits of adopting PMF.
Two	Improve relationship between operators and maintenance people	• Arrange weekly meetings between operators and maintenance people to discuss how to accomplish company's goals and aims. • Initiate training of operators, performed and coached by maintenance people. • Provide job security for staff in the company.
Three	Launch education and training to improve worker's skills	• Educate staff of the importance and benefits of TPM. • Start training operators on autonomous and plan periodic maintenance by the maintenance staff.
Four	Monitor process performance, set/raise target level	• Use Overall Equipment Effectiveness as a tool to calculate machines and production line efficiency. • Start analysing OEE results to find the cause of reduction in efficiency. • Start setting and planning targets with time.
Five	Implement autonomous maintenance	Start implementing autonomous maintenance by operators under the supervision of the maintenance staff.
Six	Implement periodic maintenance	Start implementing periodic maintenance in co-ordination with the autonomous maintenance activities.

Table 5.2: Brief description of PMF steps

5.4 Summary and Conclusion

In previous chapters we have discussed the importance of maintenance in helping companies achieve their planned business strategies, and how, by improving their maintenance capabilities these companies, can improve their equipment availability and reduce their production costs. In addition, as stated previously, that Small and Medium Enterprises (SME's) represent an important part in today's economy but face the difficulty of limited human and financial resources. These challenges that face SME's have lead the author to develop a simple and practical maintenance framework, which companies of any size can follow.

PMF consists of six steps only, with large similarity to TPM's twelve steps, but with less sophistication. These six steps are not associated with a time limit due to the differences in the background that companies have, as discussed previously in the chapter. PMF is a maintenance-based method that is simple to follow and flexible enough to allow companies to undertake its implementation according to their maintenance and production capabilities.

PMF presented in this research is only guidance for companies to help them plan and control their maintenance. In this chapter we have shown that PMF is built on the first four pillars of TPM; improving equipment effectiveness, autonomous maintenance, scheduled maintenance program, and training.

PMF does not require a significant financial commitment, as the company's staff can implement it and does not require teams and committees for its implementation. Instead, all staff should work as one team.

To conclude, if a company implements TPM using the twelve steps stated in Chapter Two, in the exact and right way, then the efficiency gained could reach approximately 100% in a period between three and five years, as claimed by Nakajima. On the other hand, if a company implements PMF, the efficiency could increase to reach 70-80% but in a shorter time, between 6 and 12 months, and with less expense, as to be shown and discussed in Chapter Six.

CHAPTER SIX

IMPLEMENTING PMF

(*Micron Case Study*)

CHAPTER SIX

IMPLEMENTING PMF
(MICRON COMPANY CASE STUDY)

6.1 Introduction

In the previous chapter, we presented the Practical Maintenance Framework (PMF) and discussed how this could help SME's toward implementing TPM, and demonstrated how each step could be implemented. In this chapter, we present results based on putting into practice this framework in a Saudi company, Micron, located in Riyadh, the capital city of Saudi Arabia. This study was carried out in order to examine and investigate how successful PMF could be in helping SME's to improve equipment and production line efficiency, and to draw conclusions from the results obtained.

We worked with the staff of the company for seven weeks in one of the factories that the company operates. The project was monitored and carefully examined throughout a period of eight months starting from the 17th June 2000. Through this period the results of improvement using OEE were collected and analysed to observe the equipment's efficiency under investigation.

In the first part of this chapter, a review of the company's background is presented to show the company's resources and abilities. This is intended to illustrate the way in which the maintenance is handled within the company. In the next section, the implementation steps will be discussed to show how PMF was implemented in this case study. In the third part, a description of the data and the way it was analysed is discussed, together with the ways of improvement that the staff performed to increase their equipment's efficiency. Finally, we discuss some important findings that came out of this case study.

6.2 Company's Background

Micron Company is in the business of bespoke (made to order) manufacturing of spare parts using metal, plastic and, recently, wood. It also undertakes special projects, e.g.

special designed metal doors, and water pumps. It was established in 1984 with one factory located in Riyadh. In 1988 the company expanded its business with their second factory located in Al-Kharj, which is a city 75km to the south of Riyadh. In 1995 the company opened its newest factory in Riyadh, which uses up-to-date technology in machinery. This factory was named as Factory Number Three and the machines used are all Computerised Numerical Control (CNC) machines. This is the factory at which our study was undertaken. The capital cost of the company is now approximately £5,000,000. The total number of staff in all three factories is 113 employees including the management. The company owns 85 different kinds of machines. Figure 6.1 represents one of the products that the company produces, which is a special designed metal door.

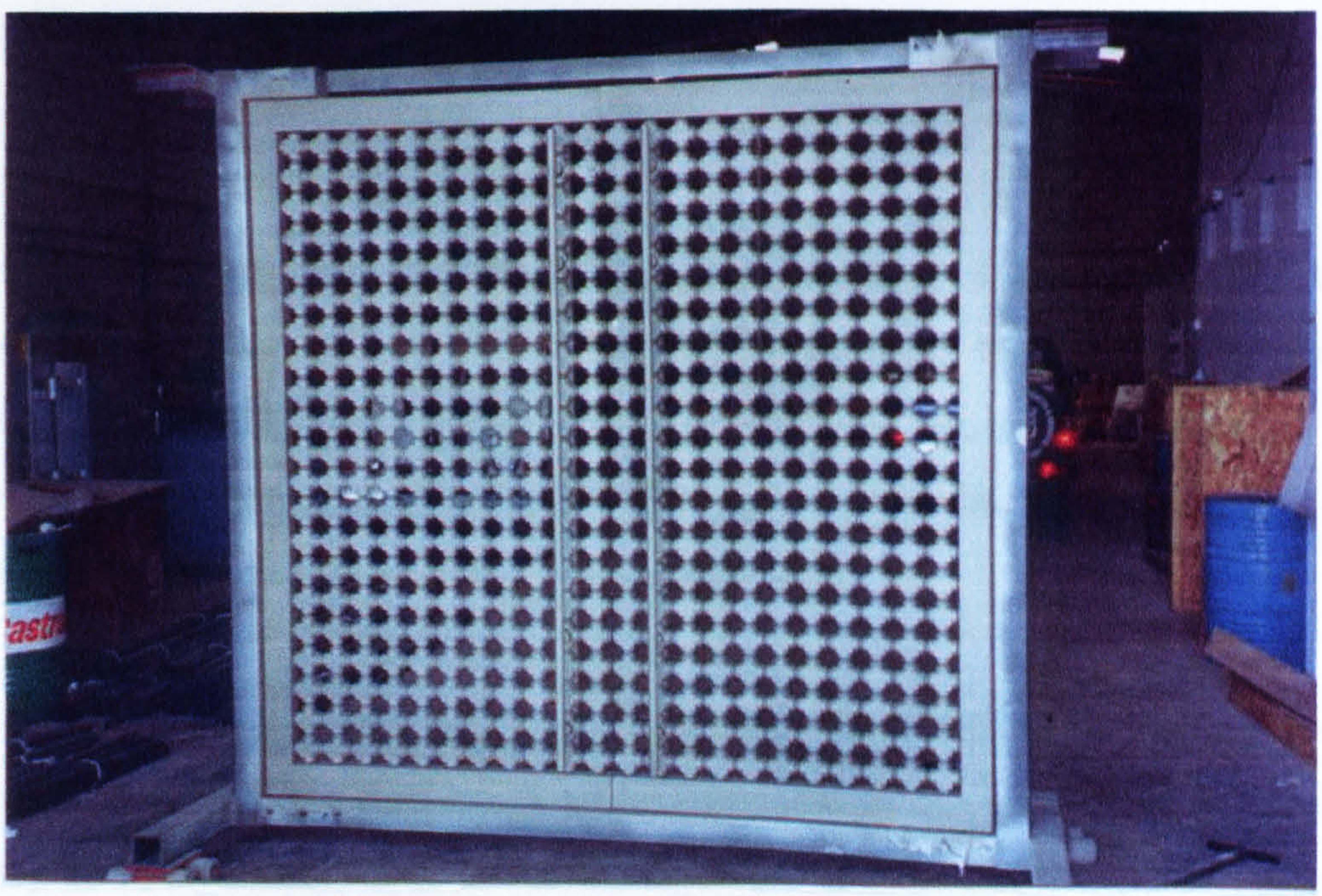

Figure 6.1: One of the company's products

The company has a maintenance division at each factory, which is responsible for repairing breakdowns on machines; in addition to that, the maintenance people take over the lubrication of machines according to a schedule. The maintenance technicians on critical machines, but not on all machines apply periodic maintenance. The operators are responsible for cleaning their machines at the end of each shift. There is no training provided to operators on repairing minor faults. The only training given is concentrated on how to operate the machine when the worker starts employment with the company or when a new machine has been purchased.

Employees in the company are of various nationalities, including from the United Kingdom, Philippines, India and Saudi Arabians. Usually, the company uses two different ways of manufacturing the spare parts. Either the customer provides the company with the drawings and the design of the spare part that needs to be produced, or the customer provides the company with the part that is to be produced, so that the engineering department in the company can reengineer the part, study the material used, and draw the redesign of the part. After that, the accounts department starts calculating the cost, dependent on the quantity to be produced, and adds overheads and a profit margin to reach the final price for producing the parts.

6.3 Implementation Steps

The case study has been chosen due to the relationship that we had with the top management in this company. Due to the busy schedules of the top management, after much correspondence, they responded to our enquiry and set up a meeting in the company at the beginning of June 2000. We had to travel to Saudi Arabia to conduct the research a few days prior to the given date.

After reaching the company we proceeded to introduce PMF to the management and started to implement the framework at the company. In this section we will introduce the way PMF was introduced to the management and the implementation steps. The introduction and preparation stages took seven working days, and the research was agreed to be applied on one machine only.

6.3.1 Introduction stage

The introduction stage took two working days and two meetings with the top management were arranged to discuss the procedures to be followed for the project. The two meetings were conducted on $10^{th}/11^{th}$ June 2000 and the meetings will be described in detail. The result of the meetings was satisfactory in that the management were convinced to proceed with the project and to give us the opportunity to implement PMF in the company as shown:

Day One: In the first meeting with the management we presented PMF. The presentation conducted was in two parts. First, a brief history of TPM, the stages of its development, the importance of TPM in supporting manufacturing aims and goals, business strategies and improving the effectiveness of their process. Second, a detailed presentation of the six steps of PMF was given, showing how each step could be implemented. The best tool that we used to convince the manager of the benefits that PMF could offer their company was through illustrative figures, which highlights the true story behind improvements. The management gave us permission to use data collected during the previous day for one machine, as an example to explain the way to use OEE. The data is presented in Table 6.1:

Loading Time	Equipment Downtime	Operation Time	Availability	Processed Amount	Ideal Cycle Time	Performance Efficiency	Good Quality	Rate Of Quality	OEE
405	45	380	88.89%	700	25 sec	81.02%	638	91.14%	65.64%

Table 6.1: OEE for Machine Data

The data obtained from the machine in Table 6.1 showed that efficiency was only 65.64%. After OEE was analysed we were able to show the management the causes of loss on the equipment.

The result of the analysis showed that the loading time is 75 minutes less than the total working shift in the company, which was 480 minutes. The 45 minutes in the equipment downtime is due to the set up time of the machine, and a 10 minute loss as a result of a minor stoppage, but without a major breakdown on the machine that day as stated by the operator who collected the data. In addition, the speed of the machine was low due to the difference between the ideal cycle time that takes the machine to produce one item and the actual time. In addition, the minor stoppages on the machine helped in reducing the machine's speed.

The difference between the number of good products produced and the total number showed that there were defects in the process of the machine. All these factors, when discussed with the management, gave a clear picture on how OEE can help to locate where the causes of reduction are.

When the causes were located and identified, it was explained to the management how the workers could eliminate the causes of these problems with the help of PMF. We explained to the management that when autonomous maintenance is implemented on the machine it could help reduce and eliminate the causes of reduction in the speed of the machine.

We explained to the management that periodic maintenance would help reduce major and minor breakdowns on the machine thereby improving the condition of the machine. In addition, we explained how OEE could help the workers to track any causes of reduction in the machine's efficiency.

The purpose of using numbers was to show the management the reduction in the equipment's efficiency and the money loss the company could prevent on one machine. We can say that these numbers caught the management's attention. It was explained to the management that when PMF is implemented fully, then processes in the organisation will be improved, and this will give the management the opportunity to set plans to ensure they reach the level of satisfaction in their policy and strategy.

Day two: How did the management respond to PMF after the first day of discussions? At this point we can say that the management's approval and support had been achieved; the manager was interested in the framework and its implementation. In supporting the idea, the management accepted a project to be carried out, initially on one machine only because of the heavy workload the company was experiencing. In addition, the management agreed to arrange a formal meeting with the two operators working on the chosen machine and together with one of the maintenance technicians.

In the presence of the management, we discussed with the staff the goal of the project and how the implementation would take place. The worker's reaction towards the project was not uncooperative; in that they did not hesitate to accept the changes that the management had asked of them. This behaviour could be interpreted as a result of the management having a strong influence and control over its workers. This could be the result of how the human resource systems in private sectors work in Saudi Arabia, where the management has the freedom of terminating any worker's contract without considering any labour unions. There are no labour unions in the industrial sector in Saudi Arabia.

6.3.2 Preparation Stage

The preparation stage took in total 5 days to implement in this case study and will be discussed in detail in the coming steps:

Step Two, improving the relationship between the operators and the maintenance technicians (1 Day).

Firstly, we considered the existing relationship between the operators and maintenance people in this company. According to the management, the relationship between the operators and the maintenance staff was very good. During separate, short, meetings with the operators and maintenance people separately, they also stated that relationships were good.

A simple questionnaire (introduced in Appendix B1) was given to each of the three workers associated with the project to assess the relationship. The questionnaire is in two parts, one part is for operators to answer and the maintenance technician answers the second part.

The result of the outcome of this questionnaire seemed to be good. The questionnaire, designed by us, concentrated on different aspects; the affect of their work on the company, another aspect focused on how their work was appreciated by the management, and rating the relationship between operators and maintenance workers. The rating, for all parts of the questionnaire, was between 1 as low and 5 as high.

The result of the questionnaire showed that two out of the three workers rated the relationship as 4 and one rated it as 5 (the worker was the maintenance technician), which represents a high rate. The result of the questionnaire was documented and left with the management to compare it with further assessment.

Step Three, launching education and training (2 Days)

Due to the fact that the factory was experiencing a heavy workload, concentrating on a new product, the management approved only two days for training.

Day One: A meeting was arranged to discuss with the workers the importance of PMF and to show them the steps, and how to use the feedback loops in the case of implementation. In addition, during the meeting we showed staff the way to use OEE, by first collecting the data needed for the calculation, and then the right way to use and analyse OEE.

The meeting took half a day and all the project workers, from both the production and maintenance divisions, attended the meeting. The rest of the first day of training was left to the maintenance technician, with the cooperation of the operators, to concentrate on setting up the autonomous maintenance-training program.

Day Two: The training program started with the maintenance technicians instructing the operators on the autonomous maintenance procedures that had been set by the operators and maintenance technician. As already mentioned, initially the operators had only cleaned their machines, with all the other tasks being performed by the maintenance staff.

The maintenance technician who was assigned to the research started to train the two operators, first on cleaning their equipment thoroughly and in the proper way to eliminate the source of contamination. Then the maintenance technician started training the operators on how to lubricate their machine according to the manual procedures, and how frequent the oil should be changed as part of the training program.

The operators, with the help of the maintenance technician, started to organise the workplace to eliminate unnecessary items around their work areas, and organising their tools and measuring instruments. This was also included in the operator's training course.

In addition to that, the regular tightening of screws, nuts and other parts, which were likely to become loose because of vibration on the machine, was carried out. The operators started working on setting standards on sheets for specific cleaning and lubrication action after the training had finished, which was documented to enable them to refer to, so that no task was missed.

The training period was very short and it was considered only as a guideline for the operators to follow. It was not the complete training schedule that is needed to guarantee the complete implementation of AM, but it was to give the operators a starting point and the feel of their machines.

Initially, in discussing the importance of AM with the management, they considered AM to be kind of an overload on operators, and that taking care of their production is more important than working on AM. The management's opinion changed after observing the training that was undertaken and the way the responsibility of AM is carried out and arranged to avoid conflict with daily operation work. The management was planning to apply more training to operators, provided that they were convinced by the results that training could bring to the company.

Operators were keen to learn the procedures, as could be seen from the way these workers were interested in setting these standards themselves. In addition, the operators who attended the training started forming tables for the procedures of the daily duties done for lubrication; these tables were hung on their machine.

When the operators took over the responsibility of autonomous maintenance it gave the maintenance technician the freedom to work and concentrate his effort on planning the periodic maintenance program.

The maintenance technician started to plan a schedule for the periodic maintenance program, to replace or repair worn parts before problems arose. The maintenance technician started setting up a quarterly maintenance calendar for the machine according to the manuals.

For the machine, the maintenance technician issued a record, which contained the parts that needed to be changed every specified number of working hours. This record helped the maintenance technician to keep a clear track of the machine's spare parts, and the proper time to order them, to avoid having big inventories or stocks of spare parts in the company.

Step Four, monitor process performance, set/raise efficiency target level (2 Days)
The fourth step was to show the operators and maintenance technician how to complete the OEE form sheet. Showing them the way to quantify and record the loading time, breakdown time, ideal cycle time, number of products produced and the number of good quality products on the form. The staff were shown how to analyse these factors to locate losses on their machines and the ways to reduce and prevent them. The operators started collecting the data after completing the two-day training program held in the company.

To ensure that operators were not turned into "accountants" by collecting the data, and working on the calculations, the form was divided into two parts. The operator completed one part, which records the loading time and equipment downtime only. The control department completed the second part, which concerned the processed amount and the good quality products.

The ideal cycle time is a standard known value for the machine. The operators and the maintenance technician were responsible for investigating any problems on the machine that caused the decline in OEE. The results are analysed to understand where the problem actually occurs, and who is responsible for repairing it.

6.3.3 Implementation stage

Step Five, implement autonomous maintenance, the operators at this stage started to implement autonomous maintenance on their machine. The implementation of autonomous maintenance took the form of daily cleaning of the machine (in more detail than before), checking and greasing the machine, and organising the machine's surrounding area.

The maintenance technician assigned to this machine supervised all the work performed by the two operators. The maintenance technician helped the operators to clean some areas of the machine that they had never cleaned before, for example, inside the machine. The maintenance technician, to ensure a full understanding and implementation of AM, supervised the first two weeks of its implementation very carefully. After these two weeks, the maintenance technician started working on the periodic maintenance program.

Step Six, implementing periodic maintenance, the maintenance technician started to carry out the responsibility of applying periodic maintenance on the machine after work, to avoid interfering with the production load that the machine had.

The maintenance technician started working according to the plan that he had drawn up for the machine, taking into consideration the AM work carried out by the operators. All the spare parts lists needed for the program were documented and ready in case the need arose to replace any part on the machine.

Because the periodic maintenance program was scheduled to be performed after work, the management set a special timetable for the maintenance technician's working time. This was to start three hours after the start of the working shift, and he was to carry on working for three hours after the work shift ended.

The improvement progress and findings will be discussed in the next section in more detail. However, Table 6.2 represents a brief explanation of the implementation steps carried out in the case study.

PMF Stages	*Case Study Condition*
Introduction Stage	The management set a master plan for the project to be initially carried out on one machine. The management assigned two operators and the maintenance division to work on the project. The management held a formal meeting with two operators working on the chosen machine and the maintenance technician, and discussed with them the goal of the project and how the implementation was to be accomplished.
Preparation Stage	A meeting was established to discuss with the workers the importance of PMF and the ways that it could help in improving equipment efficiency. Training started, with a maintenance technician training the operators on the autonomous maintenance program. The staff were shown how to use and analyse OEE's factors to locate losses on their machines and the ways to reduce and prevent them.
Implementation Stage	The operators started implementing Autonomous Maintenance on the machine. The maintenance technician started to implement Periodic Maintenance after shift time on the project machine.

Table 6.2: Brief description of PMF steps in the case study

The implementation of PMF on one machine took only a short time to be accomplished in this case study. The total time of the introduction and preparation stages was only seven working days. On the other hand, the TPM 12-step development program, as stated by Nakajima (1988), would have taken, for the preparation stage alone, three to six months.

In observing the reason for implementing the first two stages of PMF in such a short time, could be due to several factors: It could be because the company was a medium sized company, with only two management levels between the top management and the workers. It could be the result of applying PMF on only one machine, and with a limited number of staff. As Bamber *et al.* (1999) stated, Land Rover failed to implement TPM during the early attempts because of the simultaneous introduction of TPM on too many machines.

In addition, another factor could be the company's culture, in the form of the strong influence and control the management may have over workers, and the absence of trade unions. As McAdam and McGeough (2000) state, approaches to business improvement within organisations, which have a long history of trade unionism, are usually met with stiff resistance. All these factors probably had an affect on the implementation of PMF in the company within a very short period of time.

In the next section an explanation of how the data was analysed is given in detail together with figures. Further implementation, which the management decided to carry out in the case study, is also discussed.

6.4 Data Analysis

At the beginning of the project, Micron's engineers had been using an equation to calculate what they call the efficiency of their machines and production line. This efficiency is calculated by dividing the number of good quality products produced from the machine by the total number of products produced. In the context of OEE, this calculation represents the rate of quality. Their results showed a high efficiency on the project machine, which ranged between 90-95%. However, this calculation does not reflect the true story of the other losses that exist such as breakdown, set-up and adjustment, reduced speed, and minor stoppage losses.

The equation used by the company only covers two losses, which are reduced yield, and defects in process losses. The OEE is a measure of the value added to production through equipment, which is a function of machine availability, performance efficiency and the rate of quality. The result, taking all these into account, gave a calculated OEE at the start of the project of less than 66%, a large difference between the OEE calculation and the calculation used by the company.

As such, OEE is more representative than the equation previously used by the company. As stated by Chand and Shirvani (2000), in order to improve the effectiveness of the cell "equipment", it is important to recognise, measure and reduce all these losses.

This is where the factors of OEE become more important than the percentage value of OEE itself. By tracking and trending the factors of OEE (data), one can quickly spot whether the machine experienced more downtime (planned or unplanned), or was running at a slower pace, had minor stops, or produced more defects. Root cause analysis begins by focusing on the type and extent of loss, not simply the OEE percentage rating.

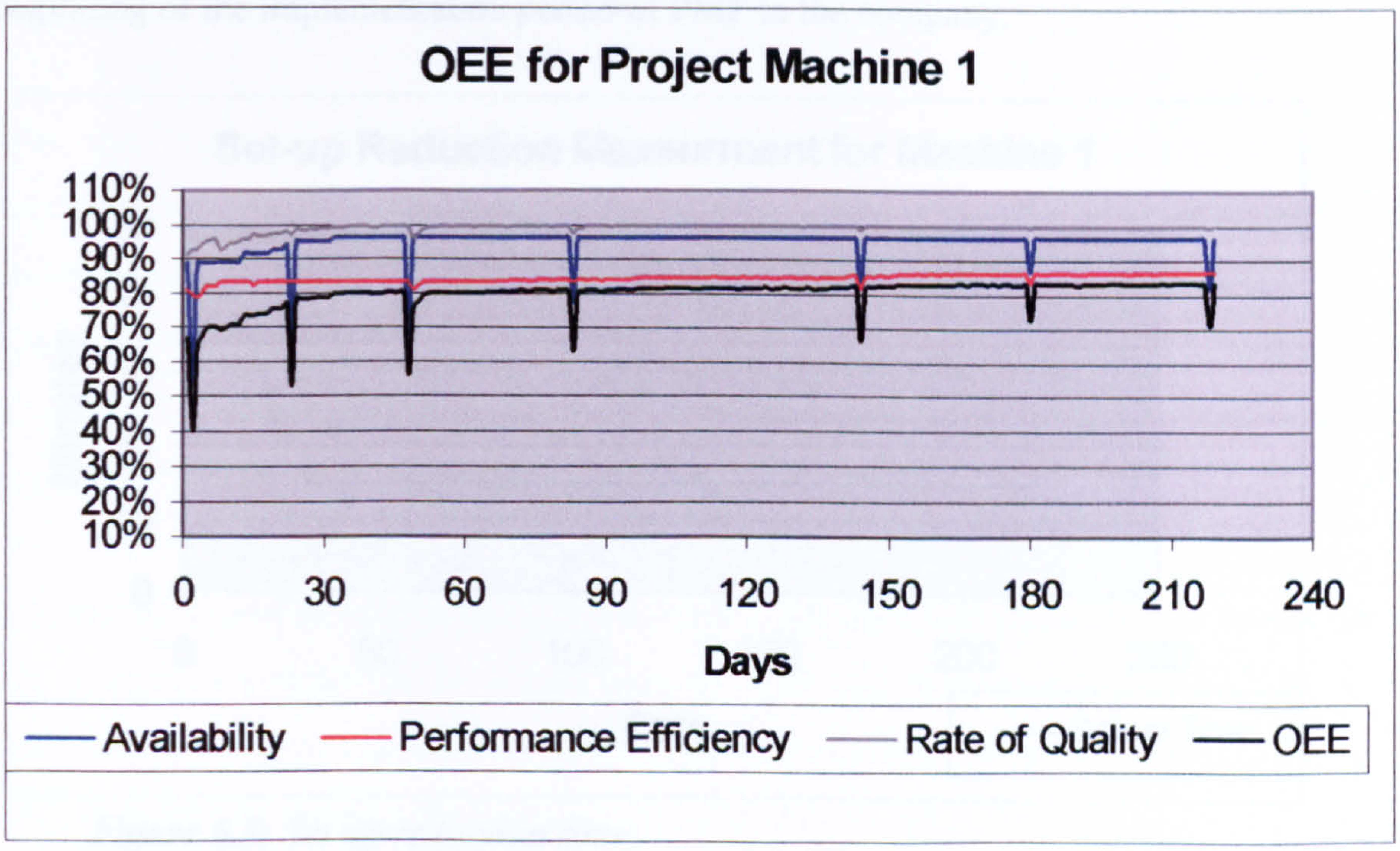

Figure 6.2: OEE and its factors for project machine 1

Figure 6.2 above, shows the calculation of OEE on the chosen machine during a period of eight months (starting form 19th June 2000), which was the period following the seven-day introduction and preparation of PMF in the company. As can be seen, the overall efficiency of the machine has increased from approximately 65.84% to 83.63%.

This efficiency increase is the combination of improvements in all of the three factors that formulate OEE, where the availability has increased from 88.89% to 96.43% and the performance efficiency has increased from 83% to 86%. In addition, the rate of quality has also increased from 92% at the start to reach 100% on some days. The data is shown in (Appendix B2), and each factor will be discussed separately in more detail as follows:

Availability:

The availability is associated with two losses, which are set-up and adjustment, and equipment breakdown losses. Starting with set-up and adjustment, it is clear from the data in (Appendix B2) that it has been reduced from 45 minutes to 15 minutes during the period from 19th June to 25th July, as shown in Figure 6.3. This was in the beginning of the implementation period of PMF in the company.

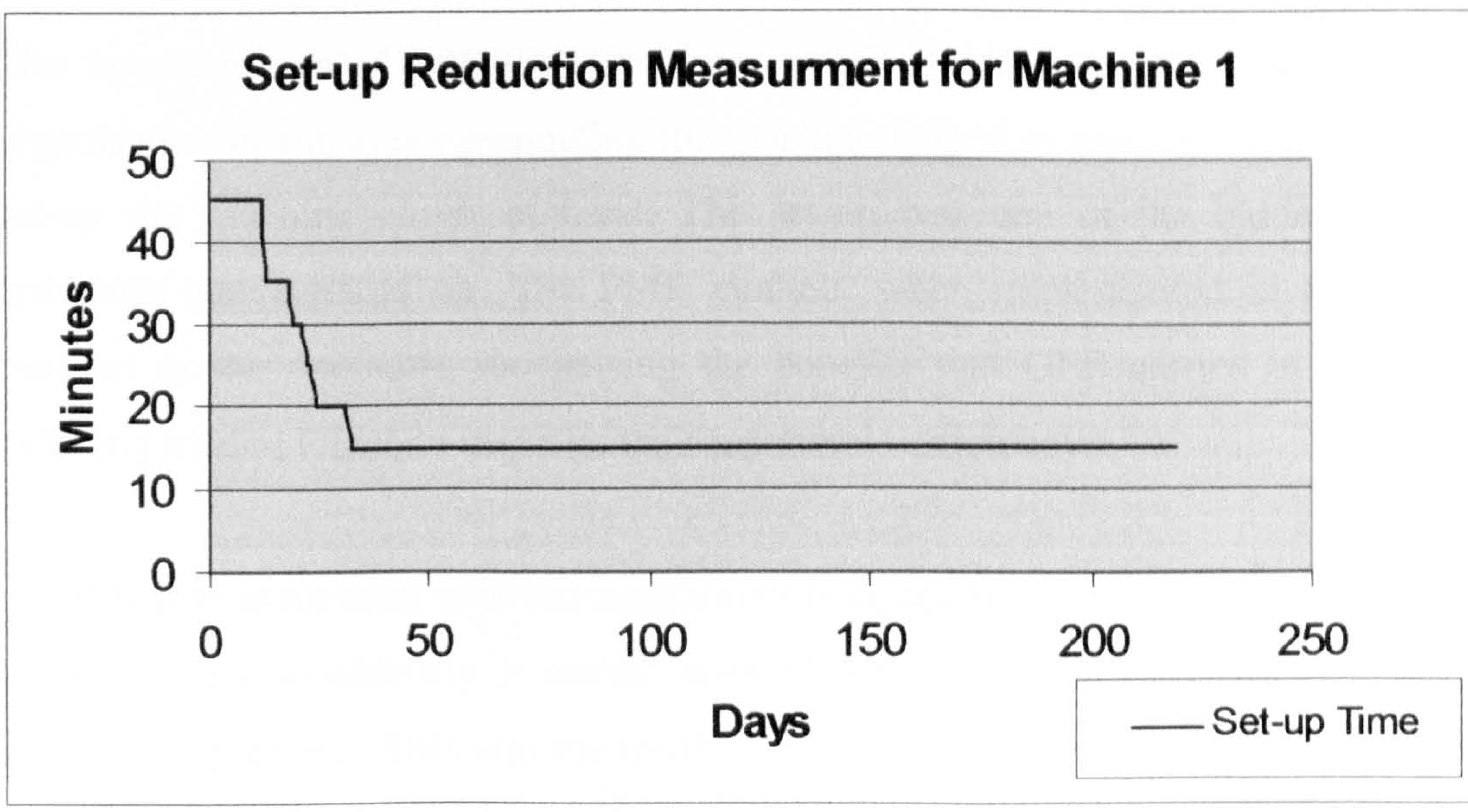

Figure 6.3: Set up reduction time

The effect of set-up is one of the factors that increased the overall efficiency of the machine, other factors also helped in increasing it. Edwards (1997), stated that costs can be reduced by attacking manufacturing cost drivers such as set up times.

In addition, Geraphty (1996), states that many TPM sites have made excellent progress in a number of areas, one of these areas is improved procedures for set ups.

The set-up increased the time the machine was available to produce more products. The 30 minutes increase in the availability, with the 30 seconds of the actual time to produce one product, shows that this small improvement increased the number of products by at least 60 pieces.

These reductions in the set-up time and breakdown have increased the availability of the machine from 88.89% to 96.43%. Of course, this rise has increased OEE value for the machine.

Why did this increase happen? This improvement is the result of operators taking responsibility of improving the time their machine was running to accomplish the goals and targets set by the project group.

The operators started reducing the time it took them to set the machine, and the organisation of the area surrounding the machine helped in placing the tools needed to set-up the machine closer at hand. The set-up was one of the hidden losses that operators concentrated on. The PMF method, when implemented in the company, resulted in the operators recognising the benefits that OEE carries in tracking and reducing hidden losses to improve their machine's efficiency.

Another loss associated with the availability is equipment breakdown loss. Looking to the machine's availability it started with 88.89% and then dropped to 54.32%, as shown in Figure 6.2. This was the result of a sudden breakdown in the machine, which took an extra 140 minutes for repair.

This breakdown affected the availability in a direct way, by reducing the operation time to 220 min, instead of 360 minutes. In addition, this reduction in the operation time reduced the number of products produced that day from 700 to 420 products.

In addition, the equipment breakdown time has reduced from 140 min to 40/60 min, this is the time that it takes the machine to come back to production. This reduction shows that the maintenance staff or operators have improved the condition of the machine and that it does not require the same time to be maintained as before.

The machine's breakdown affected the rate of quality indirectly, where after repair work is carried out, the machine needs time before it is fully adjusted, and to reach the steady state of production. This affects the yield of the equipment as Nakajima (1988) states, which is the time from machine start-up after a breakdown to the time production is stable.

The improvement in the availability of this machine can be seen in the increase of the Time Between Failures (TBF), which has increased slightly through the eight-month period the machine has been monitored.

This could be the result of the implementation of autonomous and periodic maintenance on the machine, which helps in reducing the sudden breakdown of equipment. Lawrence *et al.* (1995) stated that the objective of any preventive maintenance program is the minimisation of equipment downtime. In addition, Ben-Daya (2000), mentioned that the development of an effective preventive maintenance program keeps the equipment at a high level of overall effectiveness.

As a result of set-up improvement, and equipment breakdown, the availability had increased and, in a way, increased the overall equipment efficiency.

Performance Efficiency

Performance efficiency is associated with two hidden losses; these losses are reduced speed loss and minor stoppage loss. When the project team calculated the actual cycle time that it took the operator to produce one product, the result was approximately 30 seconds. In calculating the operating speed rate, by dividing the theoretical cycle time, 25 seconds (as shown in the data in Appendix B2), by the actual cycle time we get:

$$\text{Operating Speed Rate} = \frac{25}{30} \times 100 = 83.33\%$$

The 16.67% loss is the result of reduced speed loss on the machine. When the project team started investigating this point, they found that there was no space near the machine, and the operator had to reach out to pick up the parts from the place they were located and insert them into the machine.

When they provided space nearer to the machine, so that the operator did not have to reach as far to pick-up the pieces, the result was that, starting from 2nd September, the performance efficiency began to increase slightly. The actual speed was reduced to 27 seconds, three seconds faster than before. This improvement is due to the organisation of the machines surrounding area, which is part of the autonomous maintenance program, and this led to a reduction in the actual cycle time. They launched an investigation to study this point, in more detail, by calculating the net operating rate for the machine. The result was as follows:

On the 9th of September:

$$\text{Net Operating Rate} = \frac{\text{Proceseed Amount} \times \text{Actual Cycle Time (min)}}{\text{Operation Time(min)}} = \frac{815 \times \left(\frac{27}{60}\right)}{405} \times 100 = 90.55\%$$

On 17th December:

The Net Operating Rate = 93.22%

This increase in the net operating rate from 90.55% to 93.22% was the result of the improvement of the operator's skills in reducing the actual cycle time to 27 seconds, which is 3 seconds faster than before.

In addition, the project team started examining the number of minor losses; they discovered that the number of minor stoppages began to reduce. This meant that the time between minor stoppages had increased from 21 days to 38 days.

The result of this improvement increased the performance efficiency of the machine from 81.02% to 86.73%.

This, in turn, was due to the training provided to the operators by the maintenance technician. The introduction of autonomous maintenance and periodic maintenance will also have helped to improve the condition of the machine.

Rate of Quality

The Rate of quality is associated with two big losses, which are defects in process and reduced yield. In Figure 6.4 we can see that the number of defected products has decreased from 60 to almost 0. The number of yield product loss has decreased from 10 to almost 0. As a result of the reduction in the number of defects produced, and the yield loss, the rate of quality increased from approximately 91.43% to approximately 100% on some days.

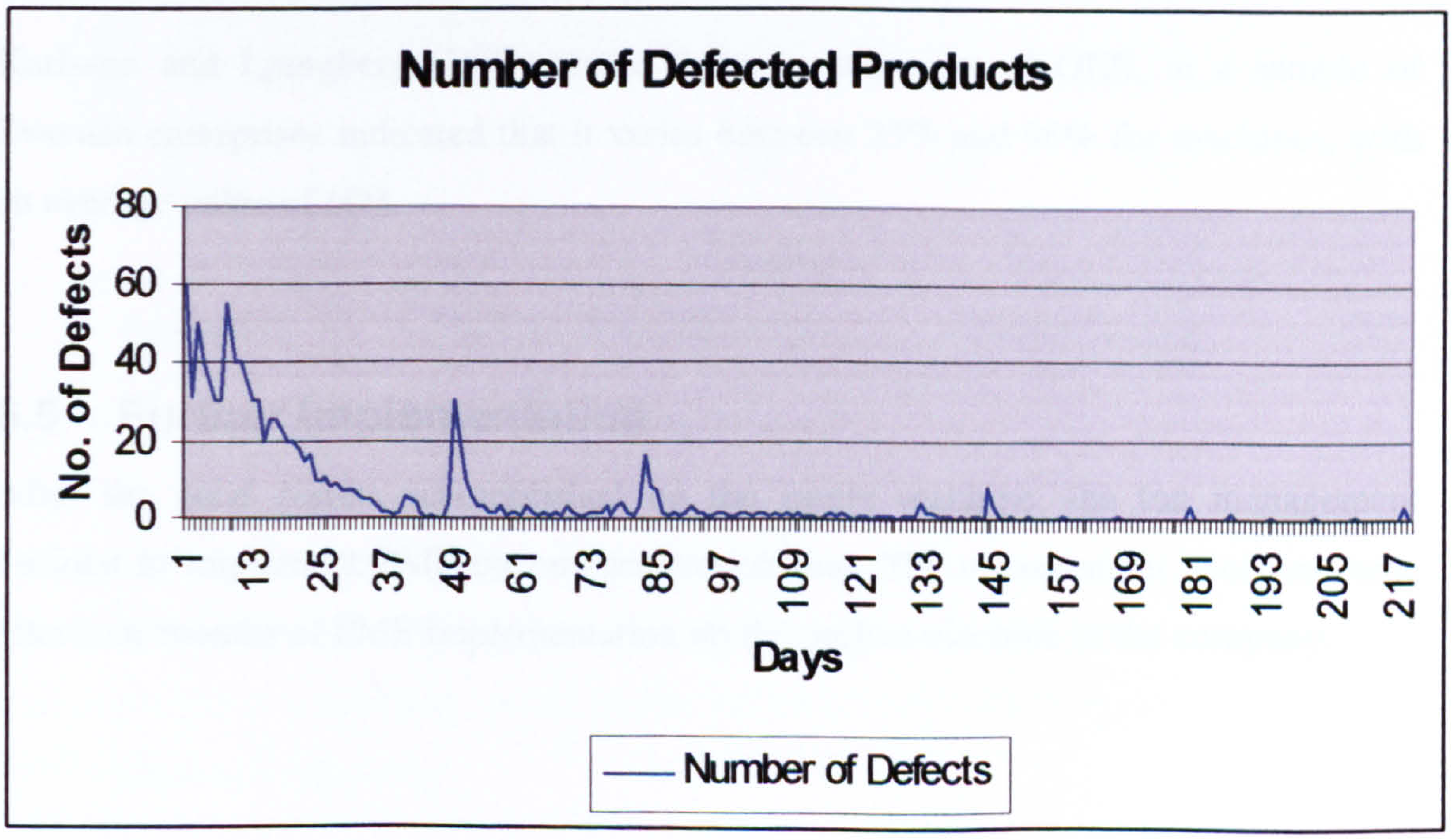

Figure 6.4: Number of defected products for project machine 1

Figure 6.4 shows this improvement by the reduction in the number of defects produced every day. The target that every manufacturer is trying to reach is 0 defects. The measured improvement was the result of autonomous maintenance and periodic maintenance that helped to keep the machine in good condition.

This means that both autonomous maintenance and periodic maintenance, carried out by the operators and the maintenance staff, was done in an effective way.

This effectiveness could also be, in part, a result of the operator's attitude, in addition to the change in the culture of the project team, where their main goal is to improve the machine's condition. The indirect benefit is the co-operation between the two departments, and the direct measurement that reflects improvement, is the reduction in the defect percentage.

To conclude this section, all the improvements in the three factors of OEE have led to an increase in the overall equipment efficiency of the machine, which increased from 65.84% to 83.63%. This represented a very good improvement over the eight-month period. This figure is pleasing, as it is difficult for some companies to attain such a high level.

Karlsson and Ljungberg (1994) stated that measurements of OEE, in a sample of Swedish enterprises indicated that it varies between 35% and 90% for machines, with an average value of 60%.

6.5 Further Implementation

After the good results accomplished on the single machine, the top management decided to implement PMF on one production line. The management decision came after four months of PMF implementation on the project machine in the company.

It was on 14th October 2000 that the management announced they were to introduce PMF on one of the production lines (four machines in total), which included the project machine, as a second step towards implementing PMF in the company.

The management made the decision of introducing PMF step-by-step to the factory and monitoring the improvements to keep the implementation situation under control. Figures 6.5, 6.6 and 6.7 show the results of the OEE calculation for machines 2, 3 and 4 respectively, and the data is shown in Appendix B3.

The OEE diagram covers the period of approximately four months, starting from 21st October 2000 to 28th February 2001 as shown:

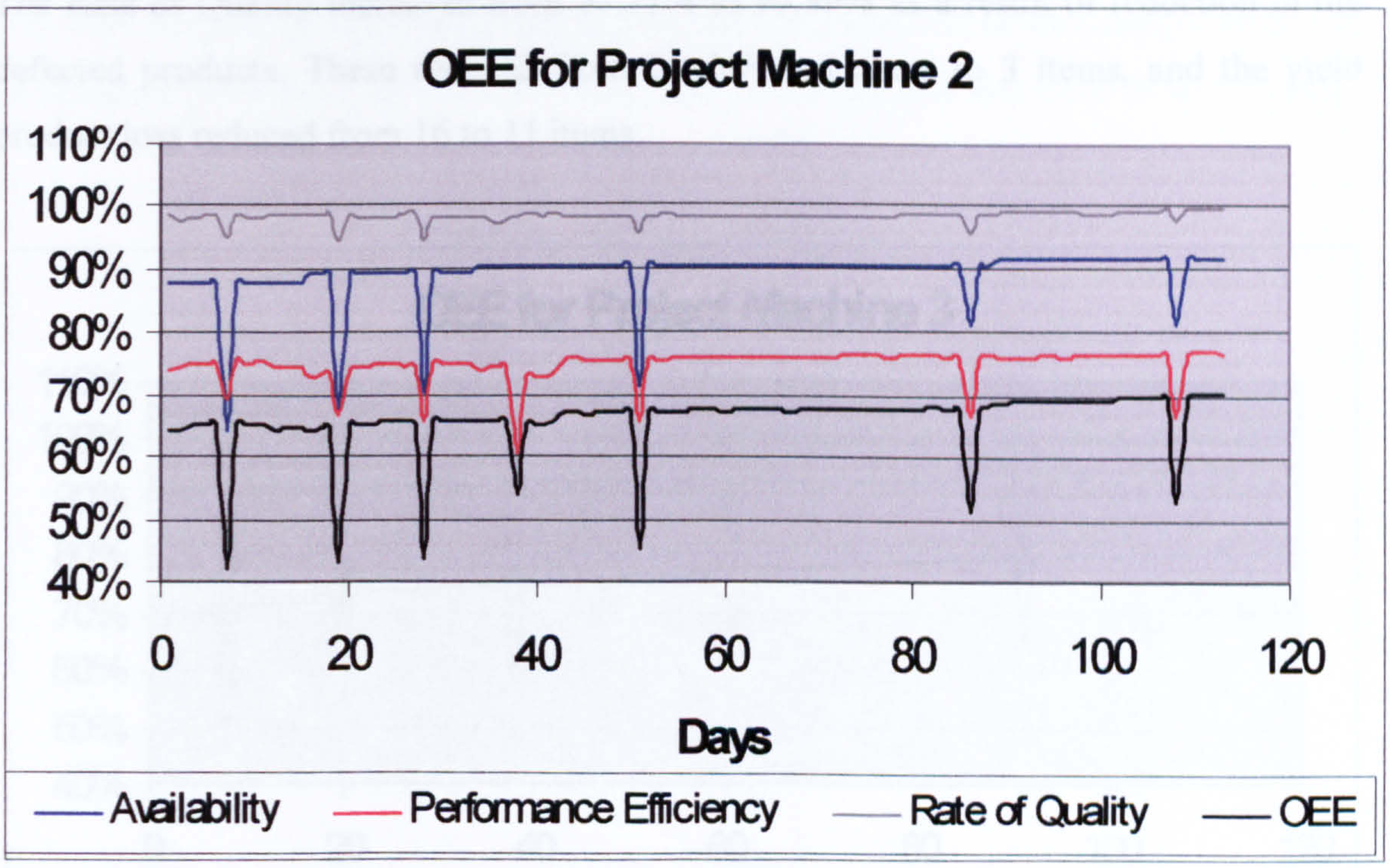

Figure 6.5: OEE and its factors for machine 2

In Figure 6.5, we can see that during the four months, improvement of OEE on machine 2 has increased from approximately 64.13% to 70.32%. This is the result of improvement in: availability, performance efficiency and rate of quality. Every factor will be discussed separately:

Availability:

Availability has increased from 88.1% to 91.67% as a result of a decrease in the set up time from 50 minutes to 35 minutes. In addition, the breakdown time was reduced from 100 minutes to 45 minutes.

Performance Efficiency:

Performance Efficiency increased from 74.57% to 76.8% as a result of reduction in the actual cycle time that was reduced from 27 seconds to 26 seconds. The time between minor stoppages increased from 9 days to 26 days (minor stoppages are less frequent).

Rate of Quality:

The Rate of Quality increased from 97.71% to 99.89% as a result of reduction in the defected products. These reduced from 14 defected items to 3 items, and the yield product loss reduced from 16 to 11 items.

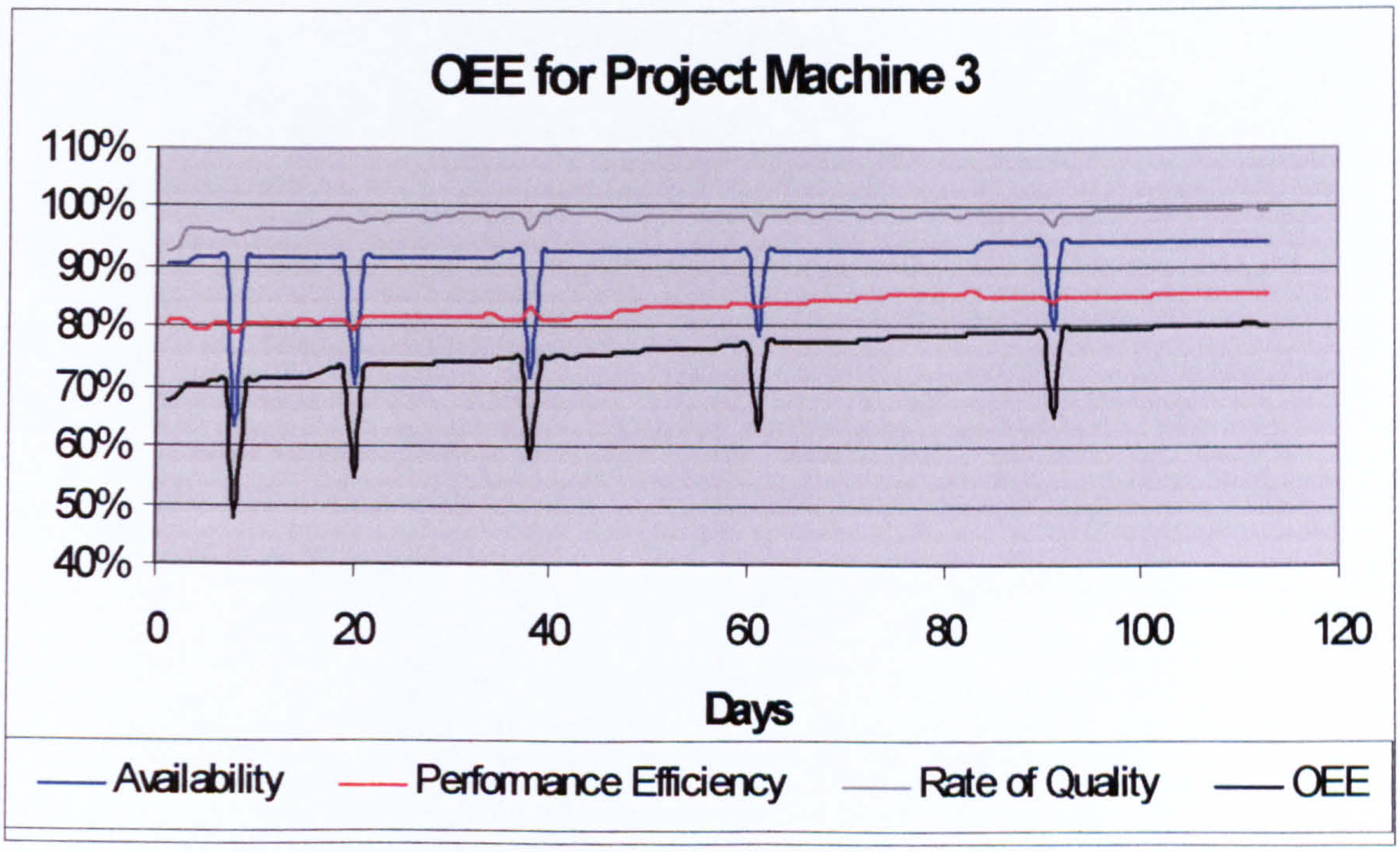

Figure 6.6: OEE and its factors for machine 3

As shown in Figure 6.6, for machine 3 on the production line, OEE increased from 67.46% to 80.36% at the end of the four-month research period. This increase is the result of improvements in:

Availability:

Availability improved for this machine from 90.48% to 94.05%, which is the result of a decrease in the set up time from 40 minutes to 25 minutes, and a decrease in breakdown time from 120 minutes to 60 minutes.

Performance Efficiency:

The Performance Efficiency increased from 80.59% to 85.55% as a result of a drop in the actual time of producing one item from 31 seconds to 29 seconds, while the ideal cycle time is 25 seconds, as shown in Appendix B3. In addition, the time between minor stoppages increased from 15 days to 27 days.

Rate of Quality:

The Rate of Quality improved from 92.52% to 99.88%, which is the result of reduction of defected items from 33 to 2 items only, and yields product loss from 22 to 14 items.

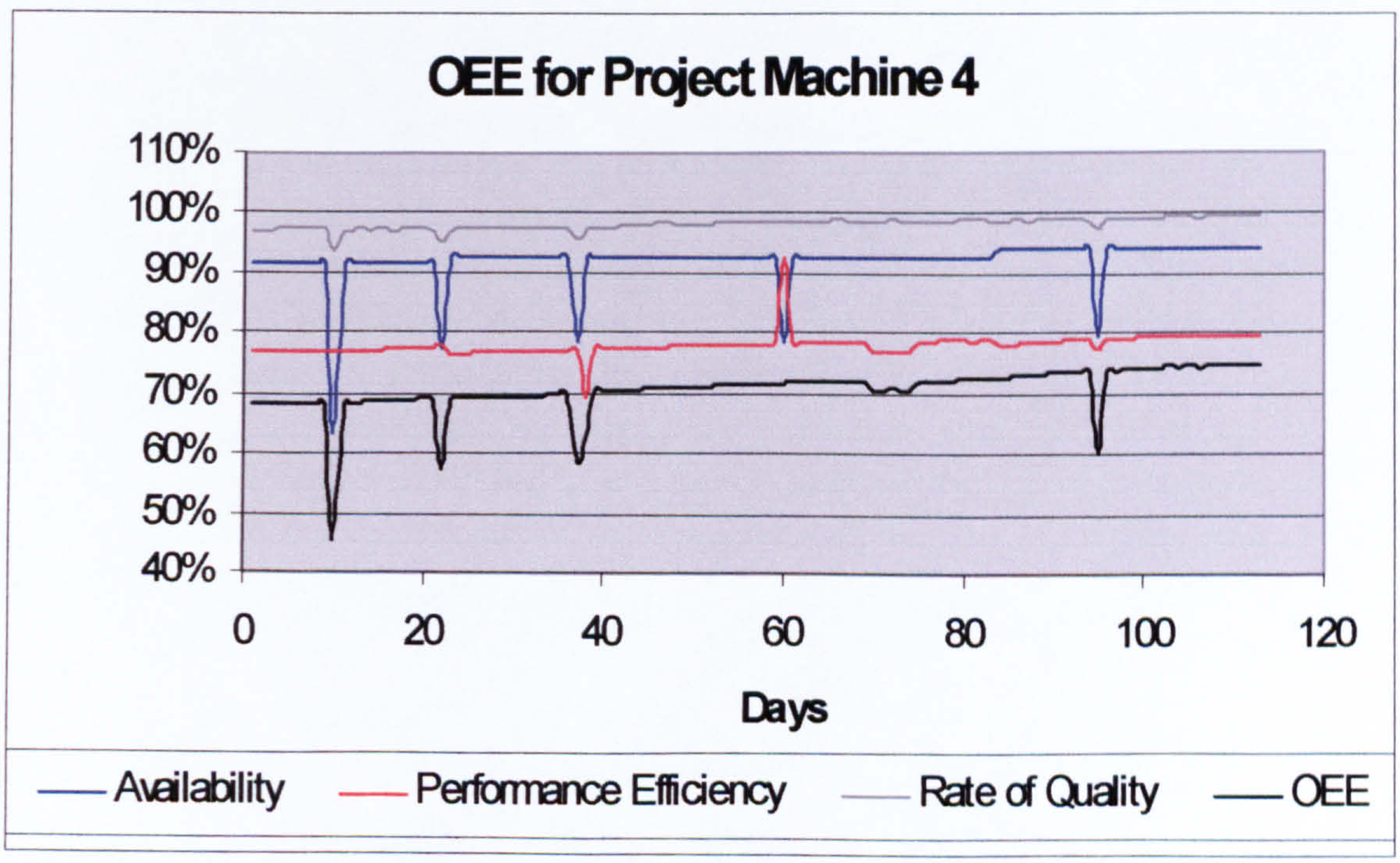

Figure 6.7: OEE and its factors for machine 4

In Figure 6.7, we can see that for machine 4 the overall efficiency OEE increased from 68.27% to 74.93%, which is the result of improvement in all the three main factors as shown:

Availability:

Availability increased from 91.67% to 94.05%. This is because the set up time was reduced from 35 to 25 minutes, and the breakdown average time was reduced from 120 to 60 minutes.

Performance Efficiency:

The performance Efficiency improved from 76.67% to 79.87%. This was because the actual cycle time was reduced from 30 to 28 seconds, and the time between minor stoppages increased from 13 to 29 days.

Rate of Quality:

The Rate of Quality increased from 97.14% to 99.76%. This was due to the reduction in the number of defected items that was reduced from 21 to 3 items, and the reduction in the number of yield loss from 13 to 7 defected items.

The use of SOEE on the production line

We introduced to the company the Simplified Overall Equipment Efficiency (discussed in Chapter Four), which was to be used on the whole production line. This measure helped the management to monitor performance progress of their whole production line and to recognise any abnormalities on it, as shown in Figure 6.7. In the case study, the production line was in series (each machine depended on the machine before it to provide it with a product), and there were no large buffer stocks on machines. The data used to produce Figure 6.8 is shown in (Appendix B4).

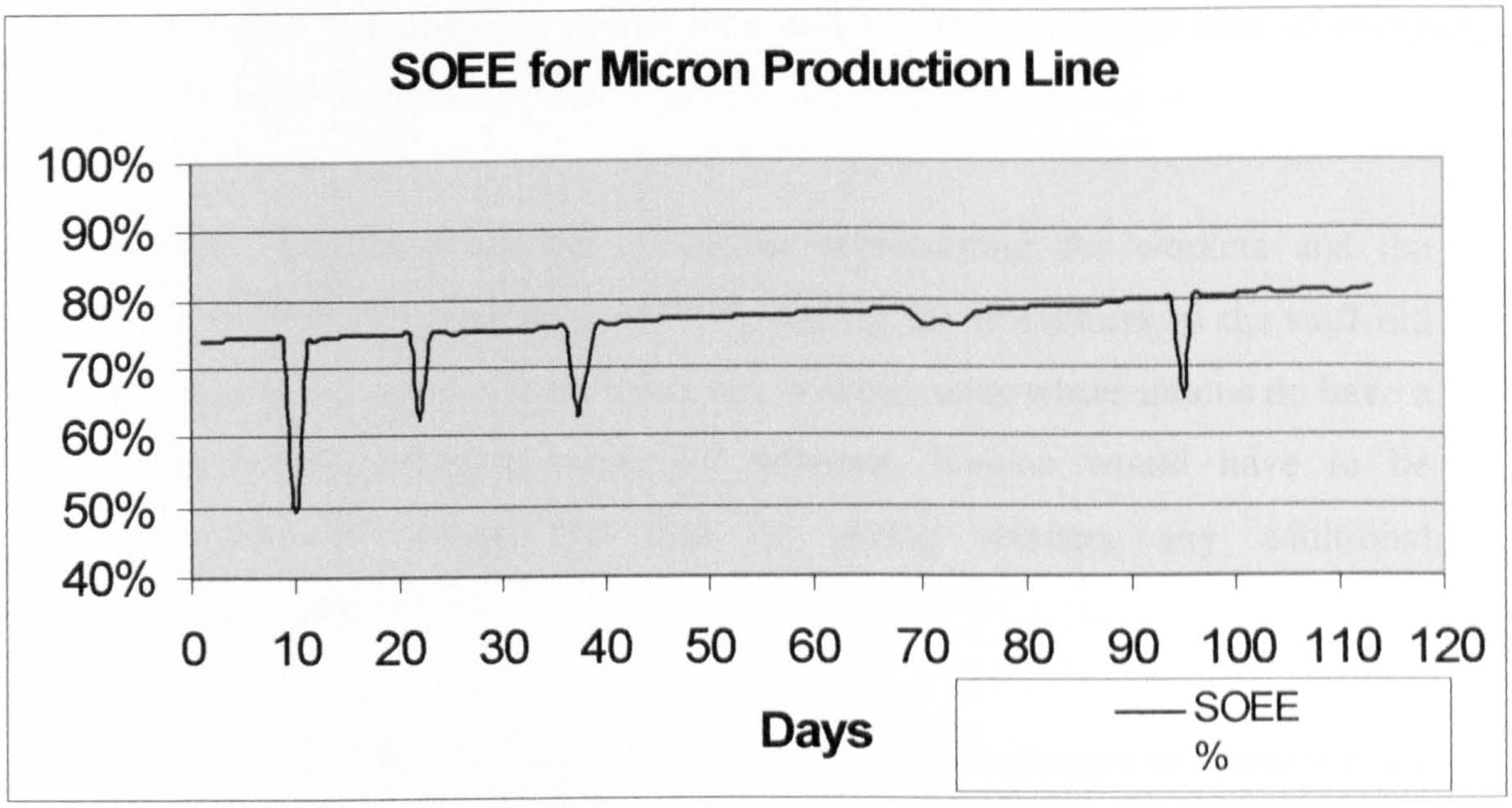

Figure 6.8: SOEE for the production line

As we can see in Figure 6.8, it shows an improvement in the efficiency of the production line from approximately 74% to 82% for a period of four months, with some sudden drops in efficiency. These drops, which become less frequent, represents the breakdowns on machines, as the Time Between Failure (TBF).

The calculation of the SOEE, discussed previously in Chapter Four, recommends using the ideal cycle time of the slowest machine, which in this case study was machines, M1 and M3, with an ideal cycle time of 25 seconds. The loading time is standard on the production line, namely 420 minutes. The number of good quality items produced is the number produced at machine 4, which is the last machine on the production line.

6.6 Important Findings

In this section we consider some important points that have been identified as the result of the research carried out in this case study. These points are the result of implementing PMF, in what can be considered as a medium company, because of the limited number of workers and the company's limited financial resource.

The success that was demonstrated within this company is the result of implementing PMF in a simple and easy way. PMF was suited to this particular kind of company, which is facing a competitive market and an overload of work.

- In this company there are no unions representing the workers and the management had control on staff. Presenting the framework to the staff did not require too much effort. However, in other cases where unions do have a presence, the situation could be different. Unions would have to be convinced to accept the idea of giving workers any additional responsibilities.

- As shown in the case study, there were no extra expenses in implementing the framework, and the result of improvement encouraged the management to decide to implement PMF on a whole production line. Here, PMF was gradually and properly implemented on one machine, and then on a few machines, rather than initial implementation on many machines at the same time. This gave the management the advantage of being able to control the implementation steps more effectively. As stated by Bohoris *et al.,* (1995), when TPM is implemented on too many machines simultaneously, it can cause failure in the early stages, as in the case of Land Rover.

- Implementing PMF in this company showed that the framework had an average efficiency limit of approximately 80%, and if this company is seeking to improve their equipment further, the company should start thinking of implementing the remaining steps of TPM.

- It has been discussed previously in Chapter Two, that TPM plays an important role in the business excellence model, and each of the fundamentals of TPM was linked with one of the factors of the business excellence model. In this case study, the results of improvement accomplished could be linked with some of these factors as presented:

Leadership factor, in this case study the management in the company recognised the benefits of PMF and were personally involved in ensuring that PMF was implemented on the whole production line in the company. The management was committed to work with the employees to set targets, and helped in supporting the staff to accomplish these targets. The involvement of the management in the project showed commitment to develop long-term success and appropriate implementation of PMF in the company.

On the *People management* factor, it was clear from the start that the relationship between the operators and the maintenance staff was an essential step, when PMF was implemented in the company. The operators and the maintenance staff cooperated to eliminate the defects, and stated their own targets, and worked hard to reach these targets. The training performed in the company helped to secure this relationship and to provide the training needed to improve the staff's knowledge. This relationship helped to support the company's strategy and the effective operation of its equipment.

On the *Policy and strategy* factor, the management in this company started to monitor their efficiency and, according to these figures, they had the opportunity to predict an accurate estimation for their production time. These estimated figures helped the engineering and finance departments to formulate their future plans and strategies of their product quantities.

Furthermore, the *Resources* factor showed that during the project the operators, under the supervision of the maintenance staff, planned and performed autonomous maintenance tasks. The implementation of AM helped in reducing breakdowns on the machines by controlling and eliminating contamination on the machine and in the surrounding area.

This approach helped in improving the equipment's performance and expanding the life cycle of the equipment.

On the part of *Process* factor, the maintenance staff in the company implemented periodic and autonomous maintenance on machines in the production line. The implementation of periodic and autonomous maintenance in this company helped in supporting the company's policy and strategy. This was in the form of reducing the number of defects and improving the equipment's performance. This resulted in producing products with less cost and better quality, which represents their customer's expectation.

In addition, *People satisfaction* factor, showed that the operators in this case study had received training on autonomous maintenance to upgrade their equipment related skills and knowledge. On the other hand, the maintenance staff had the opportunity to plan and implement the periodic maintenance program. The combination of their work had a strong influence on their feelings that they are important in the company, and that their work is appreciated. This can be seen in the form of the improvement in their productivity.

Finally, the *Customer satisfaction* factor, the company's customers are seeking to receive products that are low in price with high quality and received when needed. When PMF was fully implemented in this company, it helped in increasing the speed of production, improving the quality of their products as well as reducing the number of breakdowns. All these factors helped the company to reduce the cost of production, provide high quality products, and deliver according to their target values.

6.7 Summary and Conclusion

In this chapter, we have shown from the results obtained, that when PMF is put into practice, it proved how effective it could be in improving equipment effectiveness for SME's. The company that took over the project could be considered as a medium size company that has limited human and financial resources.

The result of the study was impressive, in that PMF helped improve the overall equipment effectiveness of a chosen machine, from 65% to approximately 83%. This was the result of a cooperative effort of the operators and the maintenance staff. The period of improvement was short, being eight months only. Due to this success, the management decided to commit to further implementation of PMF on other production lines.

The management recognised that, with a little effort, a large improvement in the efficiency, and reduction in cost, could be accomplished within a short period. The implementation of the PMF steps in this case study did not cost the company any extra money.

However, if another company, with a different maintenance capability, used the framework in the exact same way, they might not reach the same results within the same period of time. This is because, in this company, there are no unions representing the workers and the machines are considered new. However, PMF should be considered as guidance for companies and these companies can implement it in the way that suits their resources and capability.

In addition, it has been mentioned and discussed how the results of improvement which PMF provided to this company, can play a role in the business excellence model. Some of the business excellence factors were linked to the steps of PMF, when it was conducted.

To conclude, PMF has its limitations. Equipment's efficiency reached a steady level of improvement of approximately 83%. To accomplish further improvements companies should consider taking over the remaining steps of TPM. PMF typically covers most of TPM's initial steps, but with slight difference to suit SME's.

CHAPTER SEVEN

COMPARATIVE STUDY OF MAINTENANCE STRATEGIES

CHAPTER SEVEN
COMPARATIVE STUDY OF MAINTENANCE STRATEGIES

7.1 Introduction

In Chapter Five we discussed how companies could implement PMF, which may be a preliminary step towards implementing TPM. In Chapter Six we put PMF in practice into a medium size company. In this chapter, we present and review the maintenance approach of 24 companies from 8 different countries, and show how these companies carry out maintenance on their production lines.

This survey provides some insight into how different companies, from different backgrounds, plan their maintenance strategies. The results presented in the study were obtained from data based on questionnaires completed by company managers and staff, and from detailed personal observations and interviews with production and maintenance managers during site visits and, in some cases, with the general management of the relevant companies. The companies featured in the study are of different sizes; Small, Medium and Large Enterprises.

In the first section, we summarize details of the maintenance approach that each company has implemented. In the second section, we discuss the classification of these companies into two main sectors, according to the nature of their products. Finally, a comparison of how the maintenance in these categories is handled, is made to analyse the maintenance approaches that these companies implement.

7.2 The Case Study

The visits conducted to these companies have been arranged in different ways. The production manager in the company for which we work arranged some of the companies, especially in Germany, France, Switzerland and Belgium. These companies usually provide our company with many of our machinery and tools. When arranging the visits, the production manager informed these companies of the nature of our research. In addition, the university department arranged another visit to a company in Britain.

Also, our company's British based coordinator arranged the rest of the visits to companies in Britain, in addition to three companies one based in Spain, and two in Italy. The companies in Saudi Arabia had been chosen randomly. We sent them questionnaires, and requesting the possibility of visiting them. Some of these companies replied to our request, while others did not replay at all. The study focused on the maintenance and production strategies, training procedures and preventive maintenance that the visited companies operated.

At the start of any visit, the questionnaire (the form is shown in Appendix C) is handled to the appropriate persons in these companies for completion, and then we continued with our visit. The visits included giving presentations on the steps of PMF, and how it could be implemented. In addition, the visit included tours of the production lines and maintenance facilities to observe the way they perform their maintenance. Usually, at the end of these visits, we have the opportunity to discuss with the maintenance and production managers the possibility of implementing PMF and how PMF could benefit their companies.

Cooperation and confidentiality differ from one company to another, where many companies were cooperative and open in answering all our questions and discussion including providing us with numbers and figures, others were slightly less cooperative in providing these figures.

In this section we give a brief summary of the data obtained from the 24 companies during the six visits to the eight different countries. These countries were; England, France, Germany, Switzerland, Saudi Arabia, Belgium, Italy, and Spain. The data represented in Table 7.1 shows the similarities and differences between these companies in their approach to maintenance. In the next section, we will classify these companies according to their maintenance conditions and similarities. A brief description of each company in the six visits is as follows:

No.	Name	Location	Product	Total No. of Employees	Maintenance Crew	Cleaning	Lubrication	Minor Defaults	Machine Breakdown Records	Overhaul	Preventive Maintenance
1	MANURHIN EQUIPMENT	France	Ammunition Machines	189	*	Operators	Maintenance Staff	Operators	No	Machine Manufacture	No
2	MANURHIN KMX	France	Automatic Lathe Machines	93	×	Operators	Unskilled Worker	Operators	No	Machine Manufacture	No
3	FRITZ WERNER	Germany	Light Ammunition	189	*	Operators	Maintenance Staff	Maintenance Staff	Job Orders	Machine Manufacture	No
4	PROCTER & GAMBLE	Britain	Health and Beauty Care Products	500	**M**	Operators	Operators	Operators	Monitor & Study	Machine Manufacture & Maintenance Staff	Yes
5	SAVOLA PACKING SYSTEMS	Saudi Arabia	Dairy Plastic Containers	160	*	Operators	Maintenance Staff	Operators	Machine Maintenance History	Machine Manufacture	No
6	RIYADH FURNITURE INDUSTRIES	Saudi Arabia	Stationery Furniture	200	**M**	Operators	Maintenance Staff	Operators	No	Machine Manufacture	Yes
7	ARABIAN MEDICAL PRODUCTS	Saudi Arabia	Non-woven Disposable Medical Products	217	**M**	Operators	Maintenance Staff	Maintenance Staff	No	Machine Manufacture	Yes
8	SAUDI PLASTIC FACTORY	Saudi Arabia	Different Plastic Products	450	**M**	Operators	Maintenance Staff	Operators	No	Machine Manufacture	Yes
9	AL-SHARQ FACTORIES	Saudi Arabia	Plastic and Paper Products	95	×	Operators	Unskilled Worker	Operators	Financial Purpose	External Maintenance Contractor	No

No.	Name	Location	Product	Total No. of Employees	Maintenance Crew	Cleaning	Lubrication	Minor Defaults	Machine Breakdown Records	Overhaul	Preventive Maintenance
10	AL-RAED ALARABI GROUP	Saudi Arabia	Lighting, Ventilating Fans & Electric Junction Boxes	90	×	Operators	Unskilled Worker	Operators	No	Machine Manufacture	No
11	SAUDI CERAMICS	Saudi Arabia	Ceramic Tiles	250	M	Operators	Maintenance Staff	Operators	Monitoring Machine Performance	Machine Manufacture	Yes
12	ALSULTAN GROUP	Saudi Arabia	Sweets and Chocolate Bars	163	*	Operators	Maintenance Staff	Operators	No	Machine Manufacture	No
13	RIYADH CABLES	Saudi Arabia	Cables, Wires and Copper Rods	320	M	Operators	Maintenance Staff	Operators	Monitoring Machine Performance	Machine Manufacture & Maintenance Staff	Yes
14	SAUDI ELECTRONIC TARGET SYSTEMS	Saudi Arabia	Electronic Target Systems	130	*	Operators	Maintenance Staff	Operators	No	Machine Manufacture	No
15	NEW LACHAUSSEE	Belgium	Different Types of Machines	78	×	Operators	Unskilled Worker	Operators	Financial Purpose	Machine Manufacture	No
16	MECHANICA	Belgium	Electric Generators for Automobiles	96	×	Unskilled Worker	Unskilled Worker	Operators	Financial Purpose	Machine Manufacture	No
17	HECKLER & KOCH	Germany	Light Weapons	380	M	Operators	Maintenance Staff	Operators	Monitoring and Finance	Machine Manufacture and Maintenance staff	Yes

No.	Name	Location	Product	Total No. Of Employees	Maintenance Crew	Cleaning	Lubrication	Minor Defaults	Machine Breakdown Records	Overhaul	Preventive Maintenance
18	FEINTOOL	Switzerland	Pressing Machines & Tools	350	**M**	Operators	Maintenance Staff	Operators	Financial Purpose	Machine Manufacture	No
19	T.D.A	France	Heavy Ammunitio n	236	**M**	Operators	Maintenance Staff	Operators	Financial Purpose	Machine Manufacture	Yes
20	JONES & SHIPMAN INTERNATION AL	Britain	Grinding Machines	136	*	Operators	Operators	Operators	Monitoring & Financial	Maintenance Staff	Yes
21	CINCINNATI MACHINE	Britain	Milling & Lathe Machines	353	*	Operators	External Contractor	Operators	Monitoring & Finance	Machine Manufacture & Maintenance Staff	On Critical Machines Only
22	IMAL GROUP	Italy	Metal Sheet cutting and bending machines	134	*	Operators	Operators	Operators	Financial and Cost Analysis	Machine Manufacture	Parts of Machines
23	FAVRETTO	Italy	Grinding Machines	100	×	Operators	Operators	Operators	No	Machine Manufacture	No
24	ONA ELECTRO-EROSION	Spain	Wire cutting & Die Sinking Machines	180	*	Operators	Operators and Maintenance Staff	Operators	Monitoring Machine Performance	Machine Manufacture	Yes

M Companies with a Maintenance Department
* Companies with a Maintenance Division
× Companies without Internal Maintenance Staff.

Table 7.1: Company's maintenance strategies

7.3 Production Classification and Companies

From Table 7.1, we can identify several significant features regarding the differences and similarities between the various companies. The main difference between these companies is in the nature of their products. The 24 manufacturing companies can be classified into two main distinct sectors according to their production.

7.3.1 Production Equipment Manufactures (PEM)

The first main sector, we call the Production Equipment Manufacturer (PEM), which are companies that provide the market with machines and tools for use by other manufacturing companies to produce goods for customers. From Table 7.1, we can observe that 11 companies fall into this sector. This sector contains companies' number 1, 2, 3, 15, 17, 18, 20, 21, 22, 23 and 24. The PEM companies usually produce their machines according to their customer's orders and specifications.

7.3.2 Production Equipment Users (PEU)

The second main sector represents the Production Equipment Users (PEU), which are companies that use these machines, and this consists of the remaining 13 companies mentioned in the table. These companies use the equipment manufactured by PEM, to produce their products in large quantities to provide the market with goods. Their main customers, indirectly, are individuals through distributors, and in some cases, companies.

Maintenance difference between PEM and PEU

The two main sectors described above usually differ in terms of the number of maintenance staff. The PEM sector typically employs fewer maintenance staff than PEU. There are two reasons for this:

First, according to the statements of some managers in the companies that fall into the PEM sector, their companies produce machines according to their customer's order, and usually production is less time critical. On the other hand, managers in the PEU sector always state that they need to produce large quantities in a limited time.

Second, in almost all the PEM companies, the production and maintenance managers state that operators have the expertise needed to maintain machines. They state that the operators are usually involved in building machines in the company and because of that, they have obtained the knowledge needed. In one of the companies, the production manager in company 2 stated that, in the case of a breakdown that the operator cannot maintain individually they use their assembly engineers to help maintain their machines. On the other hand, the production manager in company number 7, which is a PEU company, stated that their company only uses the machines to produce goods. Also, their operators did not have the knowledge required to maintain the machines, which meant that maintenance staff are frequently needed.

Whilst the distinction between PEMs and PEUs is a natural classification, there are other classifications in the way they perform their maintenance tasks. This will be discussed in detail in the next section.

7.4 Maintenance Classification

Due to the differences in the way companies listed in Table 7.1 handle their maintenance strategies, we can classify these companies into three categories, as shown in Figure 7.1. We will list these categories, and then discuss each category separately, according to their maintenance situation:

Category One refers to companies were no maintenance staff are employed so that, usually, an external maintenance contractor manages and provides the maintenance tasks.

Category Two refers to companies, which have a small maintenance division, where typically, the total number of maintenance staff is between 2 and 10 technicians.

Category Three contains companies that have a maintenance department with a larger number of maintenance crew; typically the number is usually over 10 technicians responsible for maintaining the machines in the company.

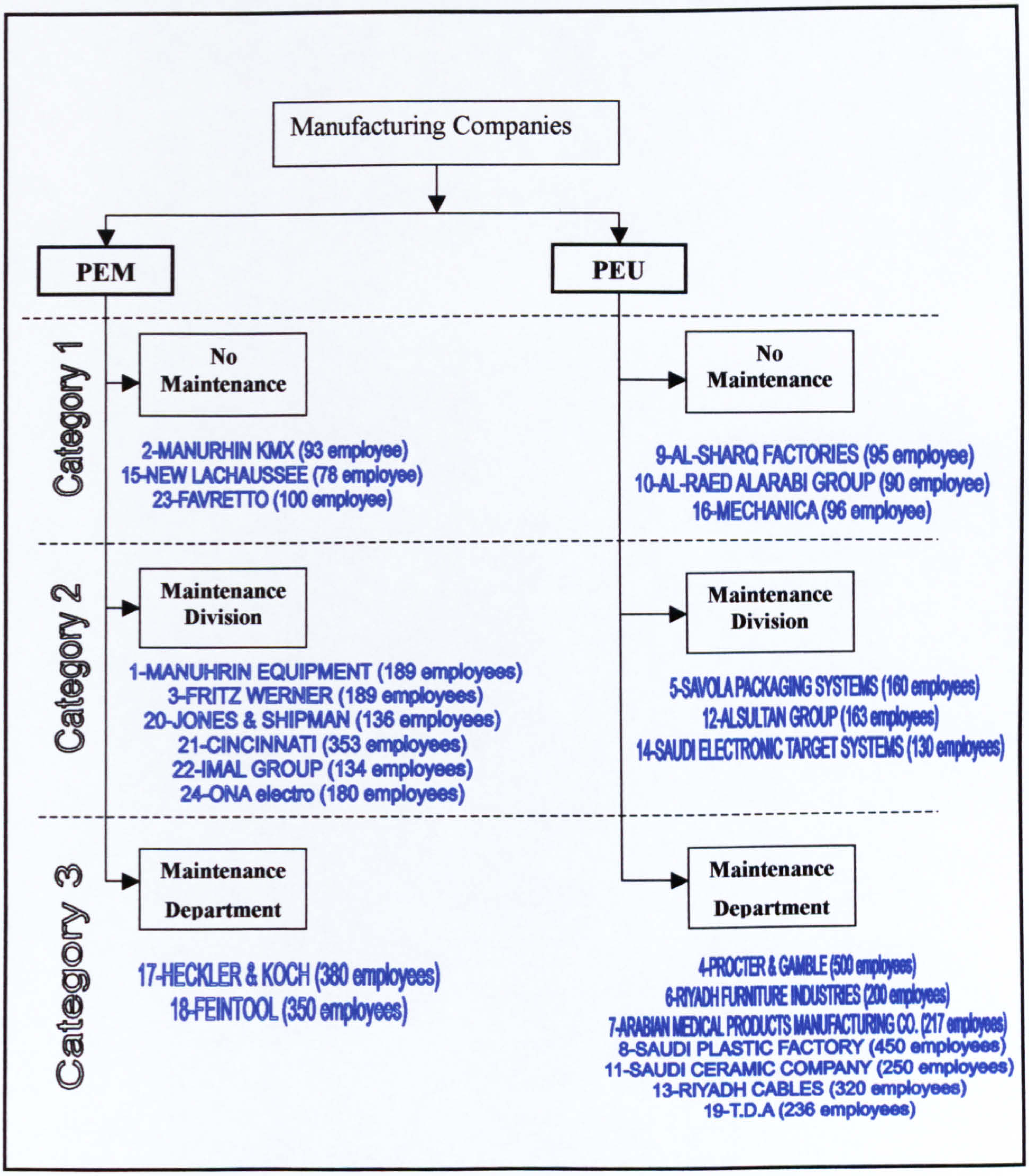

Figure 7.1 Case study classification

According to the data presented in Table 7.1, it led us to classify these companies into sectors and categories, as shown in Figure 7.1. We can see that the total number of companies in category one is six, from both PEM and PEU, while category two contains nine companies, and in category three there are nine companies. The large similarity in the maintenance approach between companies in each of the three categories, regardless of being either a PEM or a PEU, allows us to focus our discussion on differences between these three categories and not distinguish between PEM and PEU. We consider this below where we discuss each category separately.

7.4.1 Category One

In our study, companies 2, 9, 10, 15, 16 and 23 fall into this category, from both PEM and PEU sectors. By observing Table 7.1, we notice that the companies in this category have a total number of employees of usually 100 and less. In companies 2, 9, 10 and 15, we can identify that an unskilled worker (with no prior knowledge of production) is employed in these companies to perform lubrication while, in company 16, this worker also performs machine cleaning. In addition, companies 2, 10, and 23 do not have any machine breakdown records, while companies 9, 15, and 16 have breakdown records for financial purposes only. In all the companies listed in this category, the operators maintain minor defaults on their equipment. However, preventive maintenance is not implemented in any of these companies.

In almost all the companies in this category, the managers had the same point of view. This was centred on financial concerns only, where they argue that it is more economical for them to contract the maintenance rather than to employ maintenance staff. The non-employment of any internal maintenance staff in these companies could be regarded as evidence that these companies referred to maintenance as a high cost that needs to be reduced.

However, as Madu (2000), Yam *et al.* (2000) and Hutchins (1998) all discuss, new technologies in machinery, and the need for a high quality product with minimum costs, has positioned the maintenance function to be an integral part of the overall profitability of many businesses.

The issue of employing an external contractor, rather than maintenance staff, was discussed in more detail with a senior manager in company 23. The manager stated that they pay their external maintenance contractor by the hour, and they may have to wait anything from several hours to a few days for the maintenance technician to arrive. In comparing the cost between external contractors, and employing internal maintenance staff, the manager indicated that they had calculated the cost of recruiting a maintenance crew. The manager stated that this cost exceeded the cost of employing an external maintenance company. The calculation that the management discussed with us was only based on estimating the annual salary of four technicians and comparing it with the annual payment that the company pays the external contractor.

An important factor had not been taken into account in this analysis. This is the time that takes the external maintenance technicians to respond to the fault, during which the machine is not producing. As mentioned previously, this time could be anything from several hours to a few days.

In discussing this matter with the manager, he stated that this calculation was not taken into account in their comparison because it only represents a small percentage, which could be neglected. This loss could be neglected, as stated by the manager, as long as it does not extend to a few days. In this case, it could result in stopping other machines on the production line when there are no reserved inventories stocked on the rest of the machines.

If we consider company 23 as an example, and add the annual salary of this unskilled worker to the cost of repairing the machines, in addition to the time lost in waiting for the maintenance technician to arrive, then the calculation mentioned by the manager could change. All these factors can be illustrated in our simple, and easy to use, calculation in Table 7.2

Cost of External Maintenance Contract

Average maintenance Hours Hrs/month	Cost/hr	Waiting time Loss Hrs/month	No. of Items/hr	Cost/item	Cost of Unskilled Worker Salary/month	Total Cost
75.00	£50.00	125.00	60	£0.50	£1,000	£8,500

Cost of Maintenance Recruitment

No. of maintenance Staff	Salary/month	Total Cost	% Difference
3	£2,500	£7,500	13.33%

Table 7.2: The cost comparison of a contractor and recruitment

The numbers stated in Table 7.2 do not represent any data provided by any case study; it is only used to compare the two calculations. The calculation in Table 7.2 contains two parts, the first part calculates the current condition in the company, and the second part calculates the cost of employing maintenance technicians.

For the first part, the average maintenance hours per month represents the monthly average repair time. This repair time could differ from one month to another due to the condition of the machine, the weather, or the worker's performance. If we take, as an example, a company that has 50 different machines and every machine has an average time between failures of 60 days, with only a three-hour repair time (typically this repair time could be more), then the average monthly maintenance time would be 75 hours. If the external contractor charges this company £50 per hour, then the maintenance monthly cost will equal £3750.

On the other hand, if each machine, when it breaks down, has to wait 5 hours only for the technician to arrive (as mentioned before this time could be more than two days), then the waiting time loss is equal to 125 hours. During this stopping time the machine does not produce any products and, if the average number of products produced during an hour is 60 items and each item costs £0.5, then the total cost of waiting is equal to £3750. In addition, the monthly salary of the unskilled worker could be £1000, including his national security and holidays. If we add all these figures together then the total cost is equal to £8500.

In the second part of Table 7.2, if we consider employing three maintenance technicians, and each one of maintenance staff requires a salary of £2500, then the total cost of employing maintenance technicians would be £7500. The basic salary, in addition to the cost salaries, should include allowances for National Insurance, holidays, training and education, redundancy payments and managerial overhead.

In addition, Table 7.2 points out the percentage difference between the cost of external contractor and the cost of recruiting maintenance staff. If we compare the two costs, we can see that, in our example, it is cheaper to employ maintenance technicians rather than to continue with an external contractor.

Such a calculation can help managers decide on whether or not to recruit maintenance staff. As mentioned before, the figures used here are an example and do not represent any case study. It is a simple matter to replace that data shown with appropriate values, and the spreadsheet calculation gives the final result.

Another important aspect was discussed with a manager in company number 9. This considered the possibility of an increase in the cost per hour, that the maintenance contractors could charge the company. In response, the manager stated that there were other maintenance companies in the market who could take over the contract, should a large increase in the rate occur.

However, in changing the external contractor, there are two important points that should be taken into consideration. First, the trust built up between the two companies in responding on time to the deferred defaults, and the financial flexibility between them, in the form of payment for service and spare parts.

Second, the knowledge of machine maintenance history and methodology. While visiting these companies, it was clear that they had different types of machines supplied by different manufacturers. Will the change of external contractor result in more time loss in maintaining the company's equipment? It is unlikely that one maintenance supplier would be familiar with all these machines, and be able to acquire the necessary maintenance skill in a short time, avoiding additional losses.

The manager's response to the first point concerning trust between them and the new external contractor, was that before terminating the contract, the company could look for a reliable external maintenance contractor. They would ensure that this contractor would respond quickly to maintenance problems and that through time the financial flexibility and trust could come. Due to this statement, gaining this trust will take time.

On the second point, the manager said that any new contracted supplier could need time to gain the knowledge and experience on their different machines. This means taking more time to repair these machines. This time would cause disturbance on their production line in the form of waiting for their machines to go back to production again. In addition, the cost of maintenance will increase due to this time lost, because the external contractor will charge them for this repair time. This will lead to reduction on their production lines and increase in their expenses.

These two major points will affect the company's production capability and will cause disturbance to the production line. This is where these companies need to stop and think differently towards their maintenance strategies. They need to consider taking all these important factors into consideration when calculating their expenses.

The explanation of the managers in this category for not employing maintenance staff is due to their companies once being large but, due to economic changes, they have had to reduce the number of employees to try to survive in the market. Any additional expense, in the form of employing maintenance staff, is not possible at the present time. In addition, they stated that in order to be leaders in their field, they concentrated only on their production and left the responsibility of maintenance to other professionals.

7.4.2 Category Two

In our study, companies 1, 3, 5, 12, 14, 20, 21, 22 and 24 fall into this category from both PEM and PEU. This category typically contains companies with a total number of staff between 101 and 200 employees, except company 21, which has 353 employees. If we consider the maintenance tasks performed in these companies, we can see that in them all, the operators perform machine cleaning. In these companies, the maintenance staff performs lubrication, except in cases 20 and 22, where operators perform this task. In company 24, the operators, along with the maintenance staff, join efforts to lubricate their machines, as stated by their production manager. In all cases, except company 3, the operators deal with the minor defaults on their machines.

Regarding machine breakdown records, these cases differ, where some do not keep records, others use these records for maintenance purposes, and others for monitoring machine performance and finance. In all cases, in this category, the equipment manufacturer performs the equipment overhaul. Out of all the companies in this category, companies 20 and 24, only perform a preventive maintenance program, while company 22 performs preventive maintenance on only parts of their machines. As stated by the maintenance supervisor in company 5, the maintenance staff do not have the ability to perform preventive maintenance due to their limited numbers.

It was stated clearly, by the maintenance supervisor in company 12, that the maintenance crew are only "fire fighting" breakdowns on the production line. This, he said, was because of the limited human resources in the maintenance division, which meant that they could not attend all machine breakdowns in time.

This causes delay on some machines that have to wait to be repaired. This was the case with most companies that fall into this category. Their maintenance staff cannot always cover all maintenance problems on the production line. The main maintenance problem that these companies face is the lack of planning of their maintenance. The maintenance crew is so busy responding to breakdowns that they do not have time to implement a maintenance strategy.

The question we should recognise, "Is the shortage of human resource the main cause of delay on the production line?" It is not only the shortage of maintenance staff that causes the delay; most of the companies in category two do not implement preventive maintenance, and those that do, only implement it partially or on critical machines. These companies should, perhaps, consider the implementation of preventive maintenance to help reduce the number of breakdowns on machines. This will give the maintenance staff time to work on further maintenance improvements.

When the issue of implementing preventive maintenance on their machine was discussed with the maintenance supervisor in company 14, the supervisor stated that they do not have the time for planning a preventive maintenance program due to the many defaults that they have to attend. These breakdowns could range between minor defaults that operators cannot manage, and major breakdowns that is their responsibility to maintain. For these companies to find the time to implement preventive maintenance, they might need to consider ways to reduce the number of minor and sudden breakdowns. Shifting some of the maintenance responsibility, and training the operators on autonomous maintenance, could do this.

The definition of autonomous maintenance, given by Shirose (1992), states that the purpose of autonomous maintenance is to teach operators how to maintain their equipment by performing: daily checks, lubrication, replacements of parts, repairs, precision checks and early detection of abnormal conditions.

In many of the companies in this category, the production managers claim that their operators have the knowledge and skills to repair minor defaults, and clean their machines daily, at the end of each shift. Operators should not then have difficulties taking on maintenance responsibility as part of their daily job.

Shirose (1992) states that initial cleaning, and eliminating sources of contamination and inaccessible areas, helps to improve the ability to recognize equipment abnormalities and make improvements.

In discussing the maintenance importance issue with managers of the companies that fall into this category, they all state that they consider maintenance as an important factor towards their business. So, it is not only the shortage of staff in their maintenance divisions that is the main cause of delay on the production lines, but also the need to organize their human resources to achieve maximum improvement.

7.4.3 Category Three

In our study, companies 4, 6, 7, 8, 11, 13, 17, 18 and 19 fall into this category and the total number of employees in these companies exceeds 200. In all cases, the operators clean their machines, and the maintenance staff performs the equipment lubrication either through the preventive maintenance program, or as a daily job. This is except for company 4, where the operators perform both tasks.

Operators in all cases, except company 7, perform the repairing of minor default where the maintenance staff are responsible for this task. These companies keep records of machine breakdowns to follow up any reduction on their production line, or for financial purposes.

Despite the similarity between the companies in our study that fall into this category, there were differences in the way they manage their maintenance. All of the companies in this category implement preventive maintenance, except company 18. All managers in these companies state that they look at maintenance as an important factor in their companies.

During discussions with the production and maintenance managers of the companies in this category, that implement preventive maintenance, the feedback on the importance of maintenance was the same in each case. The production managers in these companies stated that maintenance was seen to be a very important factor when considering the company's strategies and goals.

However, the situation with respect to the planning of this maintenance, or accepting a new maintenance method that could improve the equipment's effectiveness, is not so clear, except for company 4, which already implements TPM. These companies accept maintenance as an important issue in the company but, typically, they do not have clear strategies or conducted further research on the best way to plan it.

In discussing preventive maintenance with the production manager in company 18, which does not implement PM, it appeared that they were not interested in implementing any additional maintenance tasks. The production manager claims that this will affect, or delay, the production target that the company has to achieve. He claims that any delay on the production line would cause the company money and time and result in losing jobs.

The general manager in company 18 claimed that preventive maintenance would cost a large amount of money, in the form of stopping the production line, and in the price of spare parts required. When discussing the advantages of implementing preventive maintenance, and its role in increasing the lifetime of the machine, the manager argued that their maintenance staff, with the assistance of their engineers, had carried out a study on the cost of implementing preventive maintenance on one machine for a period of six years.

The decision that the management made is based on the result of their research, which states that the cost of implementing preventive maintenance on one machine for six years, approximately equals the price of a new machine of the same type. He mentioned that their study was based on calculating the cost for spare parts that need to be replaced during the six years period, and this cost was compared with the price of the equipment when new.

The cost of preventive maintenance could be measured in respect of the cost of spare parts that needs to be changed, according to either the equipment's manual or the staff's experience. However, calculating the cost of breakdown, when preventive maintenance is not implemented, seems impossible. This is because a breakdown on equipment happens suddenly, and is not predictable or controllable, so this breakdown cannot be measured correctly in figures.

However, if we look through the same period, without implementing preventive maintenance, what will be the result? It is possible that the number of breakdowns would increase because of small faults that could cause larger maintenance problems, and these breakdowns are not measurable because they appear suddenly and cannot be predicted.

Mobely (1990) states that cost of repair performed in the corrective run-to-failure mode will average about three times higher than the same repair made within a preventive mode. This means that corrective maintenance methods are more expensive than preventive maintenance.

In addition, Tomlingson (1993) conducted a study and states that the normal maintenance force operates at about 50% capacity; due to lack of maintenance planning and control, and that an average of 60-70% of maintenance time in US manufacturing firms is spent on emergencies.

These breakdowns will stop the machine from producing, which leads to a reduction in the number of items that should have been produced. In addition, if this breakdown was major, it could cause the replacement of expensive spare parts, which could have been prevented if the cause of this breakdown was managed earlier. If all these factors could be measured, then the result of their study could change, and could be in favour of implementing preventive maintenance.

We discussed with the manager that it is cheaper to repair the equipment on a periodic basis than to wait until it has completely broken down. At that stage, the cost of restoring equipment is enormous. Failing to implement periodic maintenance is, in essence, accelerating the possibility of breakdown on their equipment.

The response that we received from the manager, on the importance of preventive maintenance in their factories, was not encouraging. He stated that what they are doing was the right thing for their company, and that they were not interested in undertaking any changes, or additions to the way they perform their maintenance. The attitude to maintenance that this manager adopts could lead to reduction in the quantity or quality of products through maintenance difficulties.

As a result of our study, we can point out some findings in brief, which describes the maintenance situations in the companies that we have visited. These are as follows:

- In category one, the way the top management think, is concentrated on surviving in the market and they feel that approaching new maintenance methods could cost additional expenses and eliminate their chances of surviving.

- In addition, in category one, some companies do not use accurate data in comparing the costs between having an internal maintenance staff and employing an external contractor.

- In category two, many managers in these companies stated that they have a tight time schedule for producing, and providing goods to the market, and that they do not have time to plan their maintenance.

- In addition, in category two, some cases, on the other hand, could not recognize the cost benefit that new maintenance methods and strategies could carry to their companies.

- Resistance to change; where some managers, from all three categories, encounter the culture of not accepting a change and to follow new methods.

To conclude, we can advise any manufacturing company that falls into any category, to consider planning their maintenance and implementing new maintenance methods. The implementation of new maintenance methods could help to reduce their production costs, rather than reducing the number of staff or continue in fire fighting the maintenance tasks.

TPM is one of the most successful maintenance methods in today's manufacturing, which helps improve availability, performance efficiency, and rate of quality of equipment. Research on TPM has been widely discussed, through websites on the Internet, and through many articles in scientific journals. There are many private and public training facilities in many countries that train people on how to implement TPM in their companies.

However, with all the exposure that TPM has had, the number of companies who address its importance are few. In a recent survey conducted in 2002 by the Plant Maintenance Resource Centre, showed that out of the 17 entries of different companies, only 23% of the companies apply TPM.

7.5 Summary and Conclusion

The result of the field visits to these 24 companies, that come from different cultures, have led us to classify them into different sectors and categories according to their similarities and differences in their maintenance approaches. We have classified companies into two main sectors due to the nature of their product, and into three categories according to their maintenance differences.

Companies in category one were companies that do not have internal maintenance staff, and considered maintenance as a minor function, rather than a core function. They believe that it is economically cheaper for an external maintenance company, rather than themselves to handle maintenance.

While, in category two, reducing the number of staff working in their maintenance has the outcome of reducing their maintenance cost. When these companies reduce the number of maintenance staff they automatically shift their responsibilities to the remaining maintenance staff, which leads to the "fire-fighting" approach.

Companies in category three, that do not implement preventive maintenance, should realize that many breakdowns are caused by small unnoticed, equipment defects, and preventing them from happening can reduce large breakdowns.

The strategies that all the companies are adopting are considered here to be short-term solutions and, as long as these companies use equipment and machines, the need for a maintenance strategy is there. Even with the more sophisticated machinery in the market this could lead to the increased need for maintenance.

The result of analysing the different maintenance strategies has led the author to conclude that these companies require implementing PMF in different ways, according to their maintenance resources and capabilities. In the next chapter, a proposal will be discussed in more depth on how PMF can be implemented in these companies combining efforts of both PEM and PEU, and taking into account the maintenance resources that they have.

CHAPTER EIGHT

PROPOSALS TOWARD IMPLEMENTING PMF IN DIFFERENT CATEGORIES

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PROPOSALS TOWARD IMPLEMENTING PMF IN DIFFERENT CATEGORIES

8.1 Introduction

In the previous chapter we discussed, with reference to data obtained from a variety of different companies, how these different companies, with different maintenance capabilities, handled their maintenance strategies. In this chapter, maintenance strategies will be proposed to address these different situations implementing TPM with a view to the Practical Maintenance Framework (PMF).

To address this important issue we first present and discuss the manufacturing process chain to show how the market behaves and how the business responds towards products that are produced by companies. In Section 8.3, we present and discuss how companies in the different categories mentioned in Chapter Seven, could implement PMF according to their maintenance capabilities but irrespective of being either companies that are equipment manufactures or users.

There are three different categories; category one is companies with no maintenance staff, category two is companies with a maintenance division, and category three is companies with maintenance departments. These three different categories plan and perform maintenance strategies in different ways according to their maintenance abilities. A proposal of how each category can implement PMF will be described separately. This proposal will show the best way to accomplish the implementation with the lowest cost possible. Finally, we discuss how cooperation between PEM and PEU towards implementing the PMF's steps can help in improving maintenance.

8.2 Manufacturing Process Chain

The manufacturing process chain contains companies that produce equipment (PEM), and the companies that use this equipment (PEU), to provide their individual customers who buy their final products. The three different elements in this manufacturing chain are important for a continuous process of products and financial flow in the market. A general view of the process chain is shown in Figure 8.1:

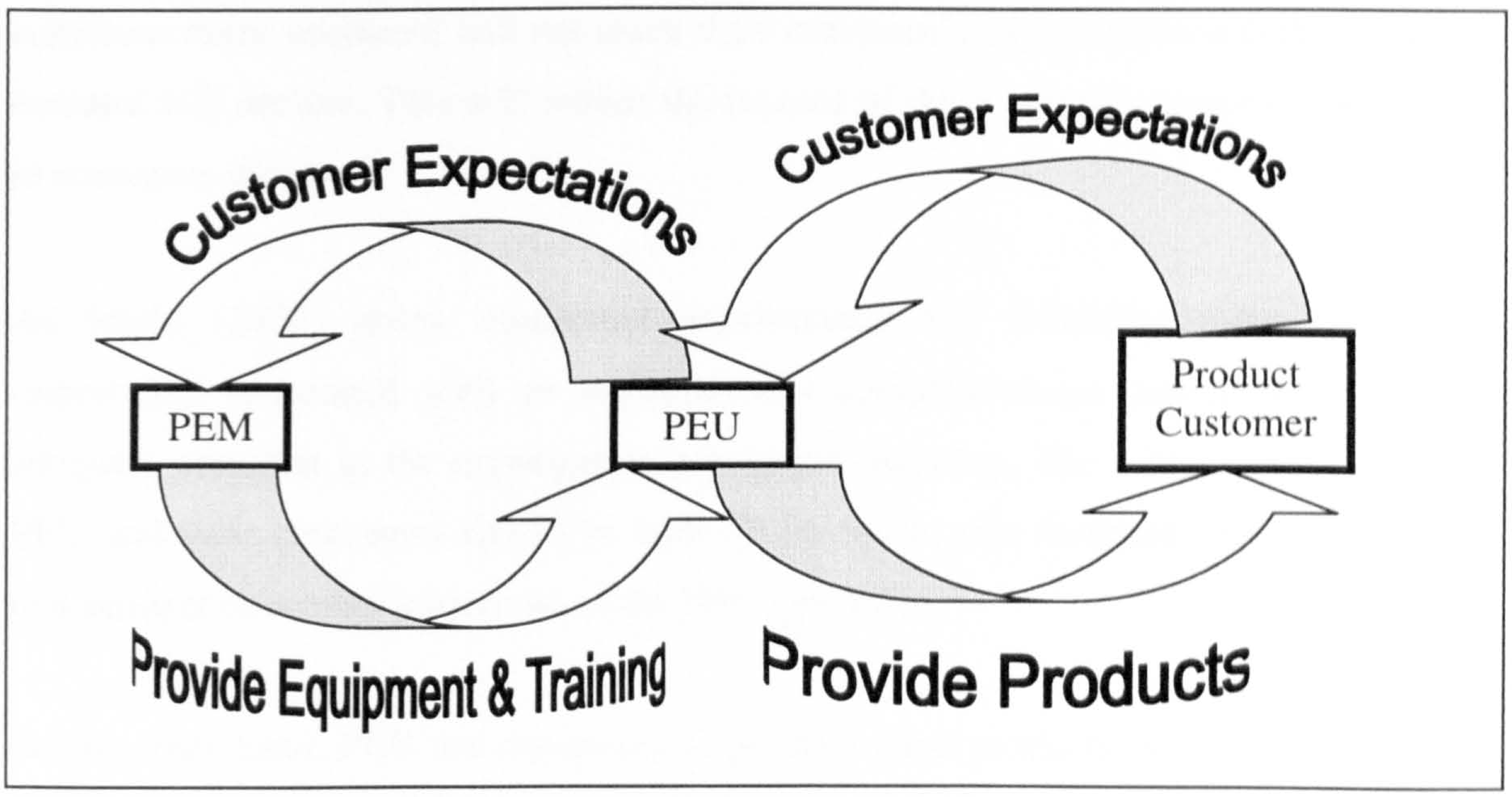

Figure 8.1: Manufacturing Process Chain

With Reference to this figure, we start our discussion with the product customer; the expectations of these consumers toward their products are a product that is low in price, has a high quality, and is available in the market. When these requirements are met, the product consumers will continue purchasing products and this will lead to a continued demand on products.

The continuous demand on products will help PEU to increase their financial input and market share. This increase in financial input would help PEU companies concentrate on their research to develop and provide the market with more, new products that their customers require. The financial income and development will help maintain a steady economic growth in the business. For PEU to provide their customers with this kind of products it would depend on the condition of their equipment that produces these products.

PEU companies need to continue to keep their equipment in good condition by improving the reliability of equipment and this can only happen when their equipment is well maintained. When their equipment is in good condition they guarantee a flow of high quality and low cost products. However, if their equipment is not in a good condition items produced will not reach their customer's expectations and the product demand will decline. This will reduce the income of these companies and could result in economic disaster.

As Madu (2000) states, equipment maintenance and reliability management is importantly associated with an organization's competitiveness and must be given adequate attention in the organization's strategic planning. The relationship between PEU and their customers should be built on feedback; this feedback represents what that product consumer's need out of the PEU's product.

On the other hand, PEU use equipment to produce these products and so represent the PEM customers. The PEU companies, as customers, have their own demand and expectations of their products. They require equipment that produces items with high quality, and low cost, to meet their own customer's expectations. They need equipment that does not require too much maintenance attention. These demands can only be met when the PEM can provide equipment that satisfies their customer's expectations. For PEM to have a continuous financial input from the PEU they need to have production lines that are in good condition as well.

To accomplish this requires that PEM consider planning and implementing TPM, or any other maintenance strategy, in their company to improve their equipment's reliability. In addition, there should be a close relationship between PEM and their customers PEU with ongoing discussions.

Clearly, both PEU's and PEM's should have appropriate maintenance strategies that help both parties to maintain a steady economic growth, and to continue functioning in the business market. Riis *et al.* (1997) argues that maintenance should be treated as a strategic function to be more closely linked with other activities in the firm, such as quality improvement strategies and corporate strategy.

In the next section, we discuss the different ways that manufacturing companies can use PMF to improve their equipment conditions, regardless of being either PEU or PEM.

8.3 Proposal on How to Implement PMF in Different Categories

The case studies, presented in Chapter Seven, can give a clear picture of how the companies involved perform their daily tasks and their strategic approach to maintenance. The companies were grouped into three different categories; companies that do not have maintenance workers, companies that have a small maintenance division and companies with a maintenance department.

In this section, the PMF implementation plans for each category will be reviewed; our aim is to provide guidelines for them on how to control their maintenance situation. The implementation of the framework does not have to be followed rigorously. Companies could consider adapting the framework to the specific conditions of their plant, personnel and culture.

8.3.1 Companies with No Maintenance Crew (Category One)

This type of company relies on an external maintenance company to provide them with a maintenance service for their equipment. In this case, when a breakdown happens on any of their equipment all they have to do is to report the fault to the external contractor, and wait for the maintenance technician to arrive and repair the fault. In this case, as mentioned in the previous chapter, there is a loss in the time between the breakdown and the time the technician arrives to the company to repair the equipment. This time is the production lost.

Companies in this category cannot perform preventive maintenance on their machines, as they do not have the workforce and skills to perform it. These companies do not control the maintenance function in their company; the maintenance process is in the hands of the external contractor. According to Chopey and Fisher (1999), a recent report by DuPont notes that a single controllable factor in a plant is maintenance expenditure and, in many cases, this could exceed annual net profit.

For companies in this category, the implementation of some steps of PMF should be shared with the external maintenance contractor. These companies can implement some of the PMF steps, but they need the external contractor to help them with the remaining steps, as to be discussed.

Considering PMF step by step, the first step, which is the introduction of PMF to the staff by the management, is obviously the same for all categories. The management in these companies should consider introducing the framework to the staff in their company. In this case, there is no maintenance staff and the management can discuss with the operators the implementation plans and the training procedures.

The second step is improving relations between the operators and maintenance people. In the situation where there are no maintenance people, this step could be interpreted in terms of improved cooperation between the operators and the external maintenance crew. The external maintenance crews represent the maintenance people in the framework, and to achieve the best results from PMF, the cooperation between them and the operators is essential. In this case, meetings could be set between the external maintenance staff and the company's operators to discuss plans and procedures on the best way to implement PMF.

When the operators are engaged in this process this could help improve their morale towards their work. It could be argued, what's in it for the external contractor? This is where the role of the management comes in by renegotiating the contract and paying additional expenses to the external contractor to take a role in the implementation process. This additional cost can be gained through time, as a result of the reduction of breakdown on equipment that the company pays to the external contractor to maintain.

The third step in PMF is educating and training workers. The training process was designed with the intention that the maintenance technicians in the company train and coach the operators on autonomous maintenance. For this category, where there is no maintenance staff in the company, it may be possible for the external maintenance crew to train operators.

The role of the management is a very important factor in suiting this step to the ability and resources of the company. The management could add the Autonomous Maintenance (AM) training task in the original contract if the external contractor is willing. Another solution could be that the management hands the training to a consultant, or even to another external Maintenance Company, or sends some of the operators on autonomous maintenance courses. Any of the proposed solutions will imply financial commitments on these companies, which could be significant, especially for small companies.

Another proposed solution that these companies can do, is to try to implement autonomous maintenance using detailed manuals or books, which describes these procedures in detail. This solution could be dangerous if care is not taken and, if the operators are over confident, it could lead to damage to their equipment through unprofessional implementation of any of the AM steps.

If the training were added to the original contract, then the external maintenance company would take full responsibility for training the operators on autonomous maintenance and the use of OEE, according to an agreed plan between the management and the external company. The training provided should be simple and undertaken at the end of the working shift and during the cleaning process. The technician from the external contractor can help the operators at the beginning of the training process to collect and analyse the findings of the collected data.

This procedure would add extra financial outlay to the original contract but the results of breakdown reduction, and the improvement of the equipment's condition, could compensate for this over time. It is important that the training should cover most of

AM. This will help the operators to build up knowledge and understanding of their machines, and help them recognize any abnormality on their equipment. The training process will only take a limited time until the operators have the confidence required to take over the responsibility of applying AM by themselves.

The fourth step is monitoring process performance and to set/raise the target efficiency level to be accomplished. At this stage, the operators can start collecting the OEE data from their machines, and start analysing the results to find any hidden losses, and start planning possible ways to improve their equipment's efficiency.

This step could be done with the association of the engineers in the company or the external contractor if needed. The OEE should not be that difficult for operators to use at this stage because of the knowledge gained from the training they have already undergone. The operators can inform the outside maintenance technicians about their findings and, where appropriate, cooperate with the outside contractor to address the causes of the loss.

The management could arrange any help necessary for the operators in analysing the results of data collected, so that the operators feel supported with this important task. Davis (1997) mentioned that one of the key factors for successful implementation of TPM is to put in place relevant measures of performance, and continually monitor and publicize, benefits achieved in financial terms.

The management should consider having regular meetings and cooperate with the operators in setting the company's goals. These goals should be reachable, and associated with time, and should be planned with the help and support of the outside contractor. Maskell (1994) states that it is considered extremely important to measure performance as it gives managers the possibility to base their decisions on facts, not opinions.

The fifth step is the implementation of autonomous maintenance. In this step the operators start implementing AM under the supervision of the external maintenance staff and management. Autonomous maintenance should be carried out by the operators, as autonomous maintenance states that the most frequent user, or operator of the equipment, is the one empowered with the task of caring for and maintaining that same equipment (McAdam and McGeough, 2000).

At this stage, the operators should start cleaning, greasing and lubricating their machines, and recognizing any defects in the form of leaking pipes or unscrewed bolts. The AM procedures should be monitored and assessed by the management, with the association of the external contractor, to measure the performance of their operators. As Karlsson and Ljungberg (1994) stated, the integration of maintenance activities into production is an efficient way of enhancing a company's capability to handle production losses and quality defects, which will improve competitiveness and extend the work content for production personnel.

The last step is implementing periodic maintenance. As the company does not have any maintenance staff, this step cannot be performed by the company's own workforce. The periodic maintenance could be organized by the external contractor on the original contract, or by a separate contract, or even by a different maintenance company.

The cost associated with this step needs to be assessed of course, but in many cases will be worth it, because preventive maintenance will help increase the life cycle of the equipment and reduce maintenance cost (A.Raouf and Ben-Daya, 1995). Companies hesitating in taking on periodic maintenance must consider a cost comparison between their recent costs and the cost of a Periodic Maintenance contract. This calculation should take into consideration the time lost in waiting for the external maintenance technician to arrive while the equipment is not producing.

With the support of autonomous maintenance, periodic maintenance will help in reducing breakdowns and ease the production flow and ensure delivery schedules are met. PM could be done after working hours, or over company holidays, to ensure production flow during the working hours of the shifts.

As already discussed, the control of the financial situation for this category is difficult because of the lack of maintenance staff in the company. These companies, at the beginning of PMF implementation, will typically face significant expenses in the form of training given by an external contractor or consultant, and the implementation of periodic maintenance done by an external specialist.

These expenses could be worth it in the long run, due to improvements of their equipment. These improvements are in the form of a reduction in the unplanned breakdowns and the improvement of the product's quality. The time spent on waiting for the external specialist to arrive to solve a problem on any of the machines will be reduced due to the decrease in the failure rate.

8.3.2 Companies with a Small Maintenance Division (Category Two)

The second category comprises companies with a small maintenance division, with staff that carries out the breakdown repair. They will be very busy in "fire fighting" these breakdowns on the production line, and this will leave them with little time to perform any other important maintenance tasks. If maintenance staff had the time to perform periodic maintenance, such as other companies that are capable of implementing it, then the number of breakdowns could decrease.

According to Raouf and Ben-Daya (1995), experience shows that preventive maintenance reduces maintenance costs in the form of breakdown reduction. The problem that companies in category two face is the result of unplanned maintenance leading to a continuing increase in the number of breakdowns and maintenance cost. These companies cannot control the maintenance situation and, as such, they will continue to struggle.

For category two, the first step in PMF is the same as for category one. The introduction of PMF to the staff is an important initial step towards recognizing the importance of the maintenance and starting to plan for it. But in this category the management will introduce the framework to both the operators and the maintenance staff in the company.

PMF step two, is to improve relations between the maintenance people and the operators in the company. In this case, the number of maintenance people is few, so it will not be too difficult for the management to arrange this step.

At this stage the management should consider dividing the maintenance staff into two groups, the first group will be responsible for the implementation of PMF. The second group can deal with the current daily maintenance task on the production line. The advantage of this procedure is to eliminate any additional cost in the form of training the operators by an external instructor or association.

It could be argued at this point, that the remaining number of the maintenance staff that will face the daily maintenance breakdown is less than before, and they will be facing additional responsibilities. This is true, but the situation is only for a limited time, because when the operators start implementing AM, and the first group implement periodic maintenance, the number of breakdowns will decrease and this will help reduce the pressure on the second group.

The management should consider setting weekly meetings, with both the operators and the first group of the maintenance staff, to discuss and plan the procedures of PMF implementation according to the company's goals and aims. The limited number of maintenance staff gives the management the advantage to implement solutions much easier than other cases where the number of maintenance staff is higher. This is because; dealing with a limited number of people is easier than dealing with large number of people, with different backgrounds and attitudes.

Step three is to launch training to improve workers' skills. In this step, the management can arrange a time for the first group of the maintenance staff to start training the operators on autonomous maintenance, while the second group of maintenance staff control the daily breakdown maintenance task.

The training provided could be performed during the cleaning process time, at the end of the daily shift, to avoid interference with the production process and to allow the first maintenance group the chance to help the second group on their daily task.

The company does not have to rush the training process, the training could be arranged as a daily half an hour session, spread over a long time, to guarantee that the operators will gain the knowledge needed to carry out autonomous maintenance correctly. The autonomous maintenance steps could be spread over several courses and these courses could be held at different times.

Step four is to monitor process performance and to set/raise the efficiency target level. At this stage, the operators and maintenance group can join efforts to collect and analyse the OEE data, as in every category. The management and the workers could arrange meetings to discuss results and set the goals that they feel are reasonable to be accomplished, as mentioned before in Chapter Five.

Step five is implementing autonomous maintenance. In this step the operators start to implement autonomous maintenance under the supervision of their instructors, which are the maintenance staff associated with the training. This supervision helps to control the implementation, as well as giving the maintenance staff the ability to recognize if there are any gaps in the training.

Step six is to implement periodic maintenance. When the maintenance staff have more time, because of the reduction of the breakdowns on the machines, they can set their own periodic maintenance plan and start implementing it on the machines.

Because of their limited number, the maintenance staff in group one can start by implementing their periodic maintenance program on a limited number of machines, which are critical. During time, when the number of breakdowns reduces, the second group could join efforts with the first group to arrange the implementation of periodic maintenance on the remaining machines on the production lines.

8.3.3 Companies with a Maintenance Department (Category Three)

The third group, consists of companies with a maintenance department, where the number of maintenance staff is not an issue because the company has enough maintenance staff to cover their maintenance situation.

Nevertheless, in cases where the management does not set a clear maintenance plan, nor has sufficient vision to cover their production systems, financial losses will still be an issue.

In such cases, the maintenance workers will still be fire fighting, because they do not have a clear maintenance plan. The company needs to apply periodic and autonomous maintenance to reduce the number of breakdowns and reduce cost, and is in a position to do so, because of staff.

This is where these kinds of companies can use PMF to help them plan and organize their maintenance strategy. Such companies could follow the steps of the framework mentioned in Chapter Five, taking into consideration their employee's ability and resources. These companies can adapt the framework to fit their own culture and resources.

8.4 Cooperation between PEM and PEU in Implementing PMF

We discussed, in the previous section, the way that PMF could be implemented in the different categories regardless of being PEM or PEU.

In this section, we will demonstrate how PMF could be implemented from the origin as a result of the cooperation of the two main sectors that all the categories belong to. This is done to show how this cooperation between the two parties can lead to improving their relationship, and build up trust between them as shown in Figure 8.2.

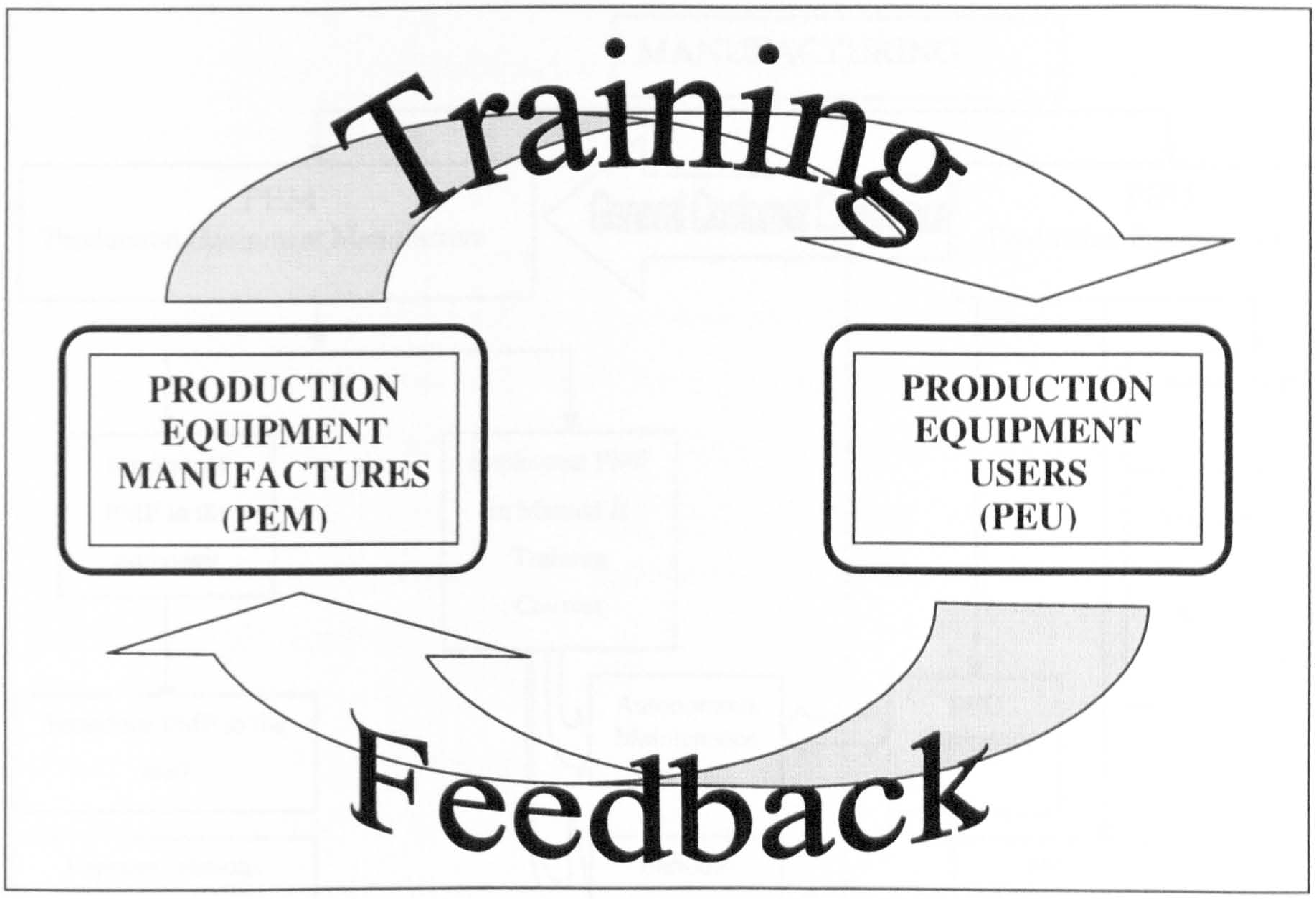

Figure 8.2: The cooperation between PEM and PEU

PEM and PEU require distinct maintenance strategies. The size of some PEM and PEU is such that they are not in a position to fully implement TPM. Typically, this is the case with SME's.

Because of this, these SME's could consider implementing PMF in an interactive way as proposed in Figure 8.3.

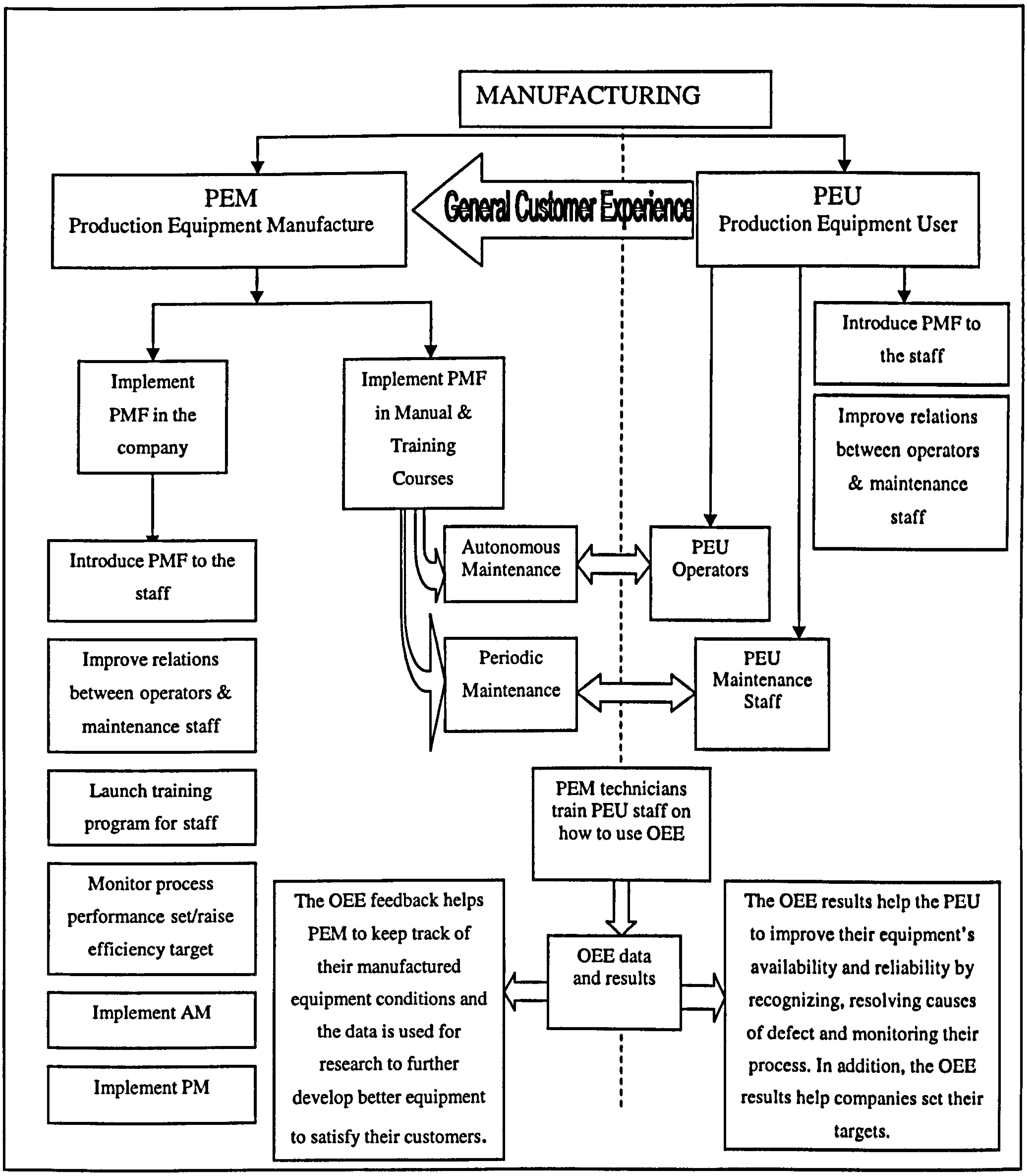

Figure 8.3: Proposal for an interactive PMF between PEM & PEU

The procedure attained in Figure 8.3 for implementing PMF contains two main parts; first, PEM implement PMF in their company using their own staff to accomplish all the six steps of PMF. The second is the implementation of PMF in PEU with the association of PEM.

The implementation of PMF in PEM is, as discussed before, straightforward because the staffs in these companies have the knowledge to implement autonomous maintenance and periodic maintenance.

Turning now to PEU's, these companies can implement the first two steps of PMF in their company by themselves and, in some cases, with the association of PEM's staff and management. PEM personnel, with their experience in implementing PMF in their company, can give guidance to PEU's management on how to introduce the framework to the staff in the company, and how to improve the relationship between their operators and maintenance staff. The other four steps of PMF will be a joint effort between the PEM and PEU.

Starting with training, in general, when PEU buy equipment from PEM companies they are usually entitled to receive training on the new equipment. This training includes instructing the operators on how to run the equipment, and training maintenance technicians on how to maintain the machinery. This training is usually conducted either on the PEU's production line, or at the PEM's company, according to the agreement between the two parties.

We suggest that, in addition to this initial training, further training can also be provided for the PEU staff, which includes autonomous and periodic maintenance procedures, and the ways to collect and analyse OEE data. This training will require extending the training period an extra few days to accomplish the task. The cost associated with this task is not sufficient for PEM.

Because this training offers advantages to PEM; it helps build good relationships between PEM and their PEU customers, which can lead to improved trust and improvement in sales. In addition, it helps reduce any abnormalities on the equipment, and this will reduce the cost associated with the maintenance responsibility that PEM has to conduct during the guarantee period of the equipment. When PEM sell a piece of equipment, there is a guarantee period.

During this period, any abnormality in this equipment is the responsibility of the PEM to fix, and this is considered as an additional cost.

PEM could also consider including PMF in the equipment manuals supplied to PEU. In addition to the normal content of such manuals, consisting of the different functions of the equipment, the manual could also summarize all the steps and procedures of PMF (or at least AM, PM, and OEE), which the PEU staff could employ.

Finally, the use of OEE is vital for both PEM and PEU. PEU can start using OEE to monitor their equipment's performance, and use it to set their own targets. This part could be done under the supervision of the PEM staff at the start. PEU can use OEE to recognize and eliminate the causes of any reduction of their equipment performance. Such results on performance can be passed back to the PEM company, and can be used to help the equipment manufactures keep a record of machines they have supplied.

In addition, PEM staff can analyse the OEE data; the results can be used by their research and development department to discover any faults on their product, and help to design better equipment. The use of the OEE feedback results, help both PEM and PEU to achieve improvements on their production lines and serves their purpose of producing low cost and high quality products to meet their customer's expectations.

8.5 Summary and Conclusion

In this chapter, plans have been proposed describing the way the companies, within different categories, might implement PMF in an effort to control maintenance expenses. Each category has been discussed separately, and a way in which the framework could be used, has been presented.

We have shown that the first category, which contained companies that handle their maintenance problems through an outside contractor, will face additional expenses due to the need for providing their operators with training by an external instructor.

While the second category that has a small division, they would need to divide their maintenance staff into two groups to manage the training task. The third category dealt with companies who had a large maintenance department, and it has been discussed that if this resource was not well planned and controlled, their losses will continue to increase.

It could be argued that the framework would cost some of these different categories an additional amount of money at the beginning. In some cases, this amount could be regarded as significant. It should be realized that the amount paid at the start would very likely be recovered over a short time, after accomplishing full implementation of the framework.

Finally, we have introduced a proposal to combine the effort of both PEM and PEU to implement PMF. This cooperation between PEM and PEU proposed that PEM could include in their manuals the procedures and steps of PMF.

The extra effort that PEM puts in the training, results in them receiving OEE feedback from PEU on how their equipment is functioning. This feedback helps equipment manufacturers improve their products. The joint effort would help improve the relationship between the two parties and, at the same time, serve their own manufacturing interest in producing low cost and high quality products.

CHAPTER NINE

CONCLUSION

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9.1 Research Achievements

Within this project we have developed a range of methodologies designed to help manufacturers plan and control their maintenance, and so reduce the maintenance cost. Achievements are as follow:

- We have linked Total Productive Maintenance (TPM) to the Business Excellence Model, Al-Hassan[2] *et al.*, 2000.

- We have developed a simple formula, (SOEE) that could help companies calculate the efficiency on their production lines.

- We have developed a simple cost analysis procedure that companies could use to assess the consequences of the current performance of its production facility, and to highlight the financial consequences of inadequate efficiency.

- We have developed a simple mathematical model, which uses the data collected for OEE type calculations, to predict the behaviour of multiple production lines and calculates resulting costs, Al-Hassan[1] *et al.*, 2000, and Al-Hassan *et al.*, 2002.

- We have introduced a Practical Maintenance Framework (PMF) that companies can use to plan their maintenance procedures and improve their equipment's efficiency. This framework captures many of the features of TPM but does not require significant financial commitment from these companies.

- Based on data obtained from field trips, we have clustered the manufacturing companies according to their products into sectors; equipment manufactures and equipment users. In addition, according to their maintenance resources, we have clustered the manufacturing companies into categories; companies without maintenance crew, companies with a small maintenance division, and companies with large maintenance departments. This classification reflects various attitudes of company management to maintenance, and has helped us refine our proposed maintenance framework model.

9.2 Research Findings

An interesting, and somewhat surprising, finding was the number of companies that did not appear to recognise the importance of maintenance and the many others that were slow to address this issue. These companies do not recognise the potential and actual losses to profits that can be incurred, if maintenance procedures are not managed optimally. There is often a lack of data, or insufficient use of quantitative techniques, to allow accurate managing of system performance.

As a result of the visits conducted by us, we found that managers, in some of the companies visited, resisted suggestions of reassessing the maintenance method being carried out in their companies. The primary reason given for this lack of receptiveness being the heavy workload they face. Furthermore, the information gathered during these visits confirmed our view, that companies perform their maintenance strategies in a variety of different ways, according to their maintenance resources and capabilities, but that there is some commonality between different companies. In some cases, companies prefer handling their maintenance to an external contractor, others do not perform preventive maintenance on their equipment, and so on.

The maintenance framework (PMF) that we have developed within the course of this work, was put to the test in a particular manufacturing company. Results from this indicated that this PMF has the potential to deliver sufficient reduction of lost profit over a relatively short period of time (eight months). Furthermore, our experience has confirmed that such improvements can be obtained using PMF without the need to allocate excessive human or financial resources. The framework was found to be easy to implement; no external consultant is required, and company staff can do training of operators on autonomous maintenance in-house. Whilst this framework has been shown to deliver tangible improvements, we also recognise the limitation of this model where the maximum efficiency was increased from 65.84% to 83.63% in the Micron case study.

9.3 Recommendations

It is clearly important for companies to recognise the importance of maintenance in their production process, since it can represent between 14-30% of the total cost of production. We recommend that one way of recognising this cost is through the use of some quantitative measures, such as the SOEE formula, and the type of related cost analysis presented in the research.

We also recommend that any company considering implementing TPM should first consider starting with PMF; PMF captures many of the essential features of TPM. When a company is satisfied with the results of improvement obtained from using PMF, then they can proceed with introducing the remaining steps of TPM.

In many cases, it might be an advantage for Production Equipment Manufacture (PEM) to consider adding some training on maintenance to their training program for their customer's staff. The training program could contain Autonomous Maintenance (AM) for operators and Preventive Maintenance (PM) for maintenance technicians. In addition, PEM might consider including instructions on maintenance procedures in their equipment manuals. The maintenance procedure could be based on PMF, for example.

We also feel that there is considerable scope for improved cooperation between PEM and PEU, with a greater exchange of information beneficial to both parties. One way of doing this would be by using the data and results of OEE feedback, where the result of OEE could be passed from PEU to PEM.

9.4 Further Research

In our research, PMF has been implemented in one company located in Saudi Arabia, and has resulted in a significant improvement in the efficiency of that company's production. A natural extension of this work is to initiate further studies on the effectiveness of PMF, based on different companies with different cultural backgrounds. This would enable a comparison of the applicability of the method to different companies results with the research finding. In addition, further research on the extension of the cost analysis, with its application on further different case studies to evaluate its success, is also a natural extension of the work performed here.

The Markov Model technique introduced in the research could be undertaken to include modifications to accommodate machines working in parallel, and alternative distributions for failure and repair times. Finally, the recommendation to include documentation of autonomous and preventive maintenance within the PEM training manuals, should be evaluated to establish the effectiveness of such an approach.

9.5 Conclusion and Summary

The driving force behind this research was the recognition of the importance of maintenance in the production process and perception that some companies do not really appreciate this aspect of production. There is still a lot of resistance to change in regard to how maintenance is performed. Equipment maintenance and reliability management are important in the effective running of business enterprise today, and maintenance should be treated as a strategic function to be more closely linked with the corporate strategy.

The established and most widely documented strategy for maintenance is Total Productive Maintenance (TPM). However, TPM puts a considerable demand on a company's resources; it requires extra financial and human commitment in the implementation stages. These requirements put pressure on Small and Medium size Enterprises (SME's) that have limited human and financial resources. The practical Maintenance Framework (PMF), introduced in this research, captures many of the essential features of TPM. However, it is easier to implement, and may offer a solution for SME's who seek to improve their equipment's capabilities with less effort and expense that is required for TPM.

PMF has been tested, and has been seen to improve production efficiency during a period of eight months. However, PMF has its own limitations, specifically in terms of the maximum attainable of production efficiency that is likely to be achieved. To increase the equipment's efficiency further, companies should consider implementing TPM, taking into consideration the additional expenses associated with this implementation.

In addition to the development of PMF, the work has involved a survey of maintenance strategies currently in operation within a variety of manufacturing companies based in Europe and elsewhere. The visits performed during this survey helped in investigating how companies with different sizes and maintenance capabilities manage their maintenance strategies. As a result of these visits, proposed methods have been presented on how the framework could be implemented within these companies to help them plan their maintenance strategies.

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APPENDIXES

Appendix A1

Expressions for Pr(Y>0) and E [Y |Y>0]

Let X_2 (repair time) and X_3 (time in buffer) be exponentially distributed with rates θ and φ respectively. Then

$$\Pr(X_3 - X_2 \prec c) = \int_0^{\infty} \Pr(X_3 - X_2 \prec c) \mid X_3 = x)\varphi e^{-\varphi x}\, dx. \tag{A1}$$

Now

$$\Pr(X_3 - X_2 \prec c) = \begin{cases} \exp[-\theta(x-c)] & x \succ c \\ 1 & x \prec c, \end{cases}$$

And substituting this into (A_1) we obtain

$$\Pr(X_3 - X_2 \prec c) = \begin{cases} 1 - \dfrac{\theta}{\varphi+\theta}\exp[-\varphi c], c \succ 0, \\ \dfrac{\varphi}{\varphi+\theta}\exp[-\varphi c], c \prec 0, \end{cases} \tag{A2}$$

Taking c = 0 then gives (Ross, 2000)

$$\Pr(X_3 - X_2 \prec 0) = \frac{\varphi}{\varphi+\theta},$$

and hence, writing Y= $X_3 - X_2, \Pr(Y \succ 0) = \theta/(\varphi+\theta)$.

further,

$$E[Y \mid Y \succ 0] = \frac{1}{\rho}\int_0^{\infty} yf(y)dy$$

where f(y) is the density function for $Y = X_3 - X_2$ and $\rho = \int_0^{\infty} fdy$. From (A2) we obtain

$$f(y) = \frac{\varphi\theta}{\varphi+\theta}\exp[-\varphi y], y \succ 0,$$

$$\rho = \frac{\theta}{\varphi+\theta},$$

so that $E[Y \mid Y \succ 0] = 1/\varphi = \mu_3$.

Appendix A2

Excel macro for evaluating cost due to loss in production.

n1 , n2	number of machines in each line
mft1 , mft2	mean failure times
mrt1 , mrt2	mean repair times
bin1 , bin2	buffer accumulation rates
bout1 , bout2	buffer depletion rates
NA , NB	number of items produced from each line
c	costs: c(1)} $=c_A$, c(2) = c_B, c(3) = c'_B, c(4) = c'_A.

```
Function cost (n1,mft1,mrt1,b1in,b1out,NA,n2,mft2,mrt2,b2in,b2out,NB,c)
suml=0
sumt=0
for j = 1 To n1
a = b1in(j)/b1out(j)
lam = 1/mft1(j) - a/mrt1(j)
suml = suml + lam
sumt = sumt + lam*mrt1(j)
Next j
lA=suml
tA=lA/sumt
suml=0
sumt=0
for j = 1 To n2
a = b2in(j)/b2out(j)
lam = 1/mft2(j) - a/mrt2(j)
suml = suml + lam
sumt = sumt + lam*mrt2(j)
Next j
```

```
lB=suml
tB=lB/sumt
det = tA^2*(lA+tB) + tA*tB*(lA+lB) + tA*lB*(2*lA+lB) + lA*lB*(lA+lB+tB)
w0  = lA*lB*(lA+lB+tA+tB)/det
w1  = lB*tA*(lA+lB+tA)/det
w2  = lA*tA*tB/det
w3 =  tA*tB*(lA+lB)/det
cost = w0*(c(1)*NA+c(2)*NB) + w1*c(3)*NB + w2*c(4)*NA
```

Appendix B1
QUESTIONNAIRE
FOR
MAINTENANCE STAFF

Q1: Do operators clean their machines?

[Yes] [No]

If Yes when [ ]

Q2: How good do they perform the machine cleaning?

Poor	Satisfactory	Good	Very Good	Excellent
1	2	3	4	5

Q3: How reliable do you think Operators are to perform Lubrication?

Not reliable				Very reliable
1	2	3	4	5

Q4: How reliable do you think Operators are to maintain minor default?

Not reliable				Very reliable
1	2	3	4	5

Q5: Do you feel that your job is important to the company?

Not important				Very important
1	2	3	4	5

Q6: Do you feel that your superiors appreciate your work?

Not appreciated				Highly appreciated
1	2	3	4	5

Q7: How do you classify your relationship with operators?

Poor	Satisfactory	Good	Very Good	Excellent
1	2	3	4	5

QUESTIONNAIRE
FOR
OPERATORS

Q1: Do you clean your machine?

[Yes] [No]

If Yes when [ ]

Q2: How long does it take you to finish cleaning your machine?

5-10 min 10-20 min 20-30 min 30-40 min more than 40 min

Q3: How reliable do you think you are to perform Lubrication on your machine?

Not reliable				Very reliable
1	2	3	4	5

Q4: How reliable do you think you are to maintain minor default on your machine?

Not reliable				Very reliable
1	2	3	4	5

Q5: Do you feel that your job is important to the company?

Not important				Very important
1	2	3	4	5

Q6: Do you feel that your superiors appreciate your work?

Not appreciated				Highly appreciated
1	2	3	4	5

Q7: How do you classify your relationship with the maintenance staff?

Poor	Satisfactory	Good	Very Good	Excellent
1	2	3	4	5

Appendix B2

Micron Company, Machine No. 1											
Day	Loading Time	Equipment Downtime	Operation Time	**Availability %**	Processed Amount	Ideal Cycle Time	**Performance Efficiency %**	Good Quality Products	Overall Products Produced %	**Rate of Quality Produced**	**OEE %**
19June	405	45	360	88.89%	700	25 sec	81.02%	640	700	91.43%	65.84%
20June	405	185	220	54.32%	420	25 sec	79.55%	389	420	92.62%	40.02%
21June	405	45	360	88.89%	680	25 sec	78.70%	630	680	92.65%	64.82%
22June	405	45	360	88.89%	690	25 sec	79.86%	650	690	94.20%	66.87%
24June	405	45	360	88.89%	710	25 sec	82.18%	675	710	95.07%	69.45%
25June	405	45	360	88.89%	710	25 sec	82.18%	680	710	95.77%	69.96%
26June	405	45	360	88.89%	710	25 sec	82.18%	680	710	95.77%	69.96%
27June	420	45	375	89.29%	750	25 sec	83.33%	695	750	92.67%	68.95%
28June	420	45	375	89.29%	750	25 sec	83.33%	700	750	93.33%	69.45%
29June	420	45	375	89.29%	750	25 sec	83.33%	710	750	94.67%	70.44%
1July	420	45	375	89.29%	750	25 sec	83.33%	710	750	94.67%	70.44%
2July	420	45	375	89.29%	750	25 sec	83.33%	715	750	95.33%	70.93%
3July	420	35	385	91.67%	770	25 sec	83.33%	740	770	96.10%	73.41%
4July	420	35	385	91.67%	770	25 sec	83.33%	740	770	96.10%	73.41%
5July	420	35	385	91.67%	760	25 sec	82.25%	740	760	97.37%	73.41%
6July	420	35	385	91.67%	770	25 sec	83.33%	745	770	96.75%	73.91%
8July	420	35	385	91.67%	770	25 sec	83.33%	745	770	96.75%	73.91%

9July	420	35	385	91.67%	770	25 sec	83.33%	747	770	97.01%	74.11%
10July	420	30	390	92.86%	780	25 sec	83.33%	760	780	97.44%	75.40%
11July	420	30	390	92.86%	780	25 sec	83.33%	760	780	97.44%	75.40%
12July	420	30	390	92.86%	780	25 sec	83.33%	762	780	97.69%	75.60%
13July	420	25	395	94.05%	790	25 sec	83.33%	775	790	98.10%	76.89%
15July	420	145	275	65.48%	550	25 sec	83.33%	534	550	97.09%	52.98%
16July	420	20	400	95.24%	800	25 sec	83.33%	790	800	98.75%	78.37%
17July	420	20	400	95.24%	800	25 sec	83.33%	790	800	98.75%	78.37%
18July	420	20	400	95.24%	800	25 sec	83.33%	789	800	98.63%	78.27%
19July	420	20	400	95.24%	800	25 sec	83.33%	792	800	99.00%	78.57%
20July	420	20	400	95.24%	800	25 sec	83.33%	791	800	98.88%	78.47%
22July	420	20	400	95.24%	800	25 sec	83.33%	793	800	99.13%	78.67%
23July	420	20	400	95.24%	800	25 sec	83.33%	793	800	99.13%	78.67%
24July	420	20	400	95.24%	800	25 sec	83.33%	793	800	99.13%	78.67%
25July	420	15	405	96.43%	810	25 sec	83.33%	804	810	99.26%	79.76%
26July	420	15	405	96.43%	810	25 sec	83.33%	805	810	99.38%	79.86%
27July	420	15	405	96.43%	810	25 sec	83.33%	805	810	99.38%	79.86%
29July	420	15	405	96.43%	810	25 sec	83.33%	807	810	99.63%	80.06%
30July	420	15	405	96.43%	810	25 sec	83.33%	808	810	99.75%	80.16%
31July	420	15	405	96.43%	810	25 sec	83.33%	808	810	99.75%	80.16%
1Aug	420	15	405	96.43%	810	25 sec	83.33%	809	810	99.88%	80.26%
2Aug	420	15	405	96.43%	810	25 sec	83.33%	808	810	99.75%	80.16%
3Aug	420	15	405	96.43%	810	25 sec	83.33%	804	810	99.26%	79.76%
5Aug	420	15	405	96.43%	810	25 sec	83.33%	805	810	99.38%	79.86%
6Aug	420	15	405	96.43%	810	25 sec	83.33%	806	810	99.51%	79.96%

7Aug	420	15	405	96.43%	810	25 sec	83.33%	808	810	99.75%	80.16%
8Aug	420	15	405	96.43%	810	25 sec	83.33%	810	810	100.00%	80.36%
9Aug	420	15	405	96.43%	810	25 sec	83.33%	809	810	99.88%	80.26%
10Aug	420	15	405	96.43%	810	25 sec	83.33%	810	810	100.00%	80.36%
12Aug	420	15	405	96.43%	810	25 sec	83.33%	810	810	100.00%	80.36%
13Aug	420	135	285	67.86%	570	25 sec	83.33%	566	570	99.30%	56.15%
14Aug	420	15	405	96.43%	790	25 sec	81.28%	760	790	96.20%	75.40%
15Aug	420	15	405	96.43%	800	25 sec	82.31%	780	800	97.50%	77.38%
16Aug	420	15	405	96.43%	810	25 sec	83.33%	800	810	98.77%	79.37%
17Aug	420	15	405	96.43%	810	25 sec	83.33%	804	810	99.26%	79.76%
19Aug	420	15	405	96.43%	810	25 sec	83.33%	807	810	99.63%	80.06%
20Aug	420	15	405	96.43%	810	25 sec	83.33%	807	810	99.63%	80.06%
21Aug	420	15	405	96.43%	810	25 sec	83.33%	808	810	99.75%	80.16%
22Aug	420	15	405	96.43%	810	25 sec	83.33%	808	810	99.75%	80.16%
23Aug	420	15	405	96.43%	810	25 sec	83.33%	807	810	99.63%	80.06%
24Aug	420	15	405	96.43%	810	25 sec	83.33%	809	810	99.88%	80.26%
26Aug	420	15	405	96.43%	810	25 sec	83.33%	808	810	99.75%	80.16%
27Aug	420	15	405	96.43%	810	25 sec	83.33%	808	810	99.75%	80.16%
28Aug	420	15	405	96.43%	810	25 sec	83.33%	809	810	99.88%	80.26%
29Aug	420	15	405	96.43%	810	25 sec	83.33%	807	810	99.63%	80.06%
30Aug	420	15	405	96.43%	810	25 sec	83.33%	808	810	99.75%	80.16%
31Aug	420	15	405	96.43%	810	25 sec	83.33%	809	810	99.88%	80.26%
2Sep	420	15	405	96.43%	812	25 sec	83.54%	810	812	99.75%	80.36%
3Sep	420	15	405	96.43%	812	25 sec	83.54%	811	812	99.88%	80.46%
4Sep	420	15	405	96.43%	813	25 sec	83.64%	811	813	99.75%	80.46%

5Sep	420	15	405	96.43%	813	25 sec	83.64%	812	813	99.88%	80.56%
6Sep	420	15	405	96.43%	813	25 sec	83.64%	810	813	99.63%	80.36%
7Sep	420	15	405	96.43%	815	25 sec	83.85%	813	815	99.75%	80.66%
9Sep	420	15	405	96.43%	815	25 sec	83.85%	814	815	99.88%	80.75%
10Sep	420	15	405	96.43%	816	25 sec	83.95%	815	816	99.88%	80.85%
11Sep	420	15	405	96.43%	815	25 sec	83.85%	813	815	99.75%	80.66%
12Sep	420	15	405	96.43%	814	25 sec	83.75%	812	814	99.75%	80.56%
13Sep	420	15	405	96.43%	817	25 sec	84.05%	815	817	99.76%	80.85%
14Sep	420	15	405	96.43%	818	25 sec	84.16%	815	818	99.63%	80.85%
16Sep	420	15	405	96.43%	818	25 sec	84.16%	817	818	99.88%	81.05%
17Sep	420	15	405	96.43%	817	25 sec	84.05%	814	817	99.63%	80.75%
18Sep	420	15	405	96.43%	816	25 sec	83.95%	812	816	99.51%	80.56%
19Sep	420	15	405	96.43%	819	25 sec	84.26%	817	819	99.76%	81.05%
20Sep	420	15	405	96.43%	818	25 sec	84.16%	817	818	99.88%	81.05%
21Sep	420	15	405	96.43%	815	25 sec	83.85%	812	815	99.63%	80.56%
23Sep	420	95	325	77.38%	650	25 sec	83.33%	634	650	97.54%	62.90%
24Sep	420	15	405	96.43%	818	25 sec	84.16%	810	818	99.02%	80.36%
25Sep	420	15	405	96.43%	819	25 sec	84.26%	812	819	99.15%	80.56%
26Sep	420	15	405	96.43%	817	25 sec	84.05%	815	817	99.76%	80.85%
27Sep	420	15	405	96.43%	818	25 sec	84.16%	817	818	99.88%	81.05%
28Sep	420	15	405	96.43%	818	25 sec	84.16%	816	818	99.76%	80.95%
30Sep	420	15	405	96.43%	814	25 sec	83.75%	813	814	99.88%	80.66%
1Oct	420	15	405	96.43%	819	25 sec	84.26%	817	819	99.76%	81.05%
2Oct	420	15	405	96.43%	819	25 sec	84.26%	816	819	99.63%	80.95%
3Oct	420	15	405	96.43%	819	25 sec	84.26%	817	819	99.76%	81.05%

4Oct	420	15	405	96.43%	820	25 sec	84.36%	818	820	99.76%	81.15%
5Oct	420	15	405	96.43%	819	25 sec	84.26%	818	819	99.88%	81.15%
7Oct	420	15	405	96.43%	818	25 sec	84.16%	817	818	99.88%	81.05%
8Oct	420	15	405	96.43%	822	25 sec	84.57%	820	822	99.76%	81.35%
9Oct	420	15	405	96.43%	823	25 sec	84.67%	821	823	99.76%	81.45%
10Oct	420	15	405	96.43%	823	25 sec	84.67%	822	823	99.88%	81.55%
11Oct	420	15	405	96.43%	823	25 sec	84.67%	822	823	99.88%	81.55%
12Oct	420	15	405	96.43%	824	25 sec	84.77%	822	824	99.76%	81.55%
14Oct	420	15	405	96.43%	824	25 sec	84.77%	822	824	99.76%	81.55%
15Oct	420	15	405	96.43%	823	25 sec	84.67%	822	823	99.88%	81.55%
16Oct	420	15	405	96.43%	825	25 sec	84.88%	823	825	99.76%	81.65%
17Oct	420	15	405	96.43%	825	25 sec	84.88%	823	825	99.76%	81.65%
18Oct	420	15	405	96.43%	825	25 sec	84.88%	824	825	99.88%	81.75%
19Oct	420	15	405	96.43%	825	25 sec	84.88%	823	825	99.76%	81.65%
21Oct	420	15	405	96.43%	825	25 sec	84.88%	824	825	99.88%	81.75%
22Oct	420	15	405	96.43%	824	25 sec	84.77%	822	824	99.76%	81.55%
23Oct	420	15	405	96.43%	823	25 sec	84.67%	822	823	99.88%	81.55%
24Oct	420	15	405	96.43%	824	25 sec	84.77%	822	824	99.76%	81.55%
25Oct	420	15	405	96.43%	824	25 sec	84.77%	823	824	99.88%	81.65%
26Oct	420	15	405	96.43%	825	25 sec	84.88%	824	825	99.88%	81.75%
28Oct	420	15	405	96.43%	826	25 sec	84.98%	825	826	99.88%	81.85%
29Oct	420	15	405	96.43%	825	25 sec	84.88%	825	825	100.00%	81.85%
30Oct	420	15	405	96.43%	825	25 sec	84.88%	824	825	99.88%	81.75%
31Oct	420	15	405	96.43%	825	25 sec	84.88%	823	825	99.76%	81.65%
1Nov	420	15	405	96.43%	825	25 sec	84.88%	824	825	99.88%	81.75%

2Nov	420	15	405	96.43%	824	25 sec	84.77%	822	824	99.76%	81.55%
4Nov	420	15	405	96.43%	826	25 sec	84.98%	825	826	99.88%	81.85%
5Nov	420	15	405	96.43%	824	25 sec	84.77%	824	824	100.00%	81.75%
6Nov	420	15	405	96.43%	825	25 sec	84.88%	824	825	99.88%	81.75%
7Nov	420	15	405	96.43%	826	25 sec	84.98%	825	826	99.88%	81.85%
8Nov	420	15	405	96.43%	823	25 sec	84.67%	823	823	100.00%	81.65%
9Nov	420	15	405	96.43%	827	25 sec	85.08%	826	827	99.88%	81.95%
11Nov	420	15	405	96.43%	823	25 sec	84.67%	822	823	99.88%	81.55%
12Nov	420	15	405	96.43%	824	25 sec	84.77%	823	824	99.88%	81.65%
13Nov	420	15	405	96.43%	825	25 sec	84.88%	824	825	99.88%	81.75%
14Nov	420	15	405	96.43%	826	25 sec	84.98%	826	826	100.00%	81.95%
15Nov	420	15	405	96.43%	826	25 sec	84.98%	825	826	99.88%	81.85%
16Nov	420	15	405	96.43%	826	25 sec	84.98%	825	826	99.88%	81.85%
18Nov	420	15	405	96.43%	825	25 sec	84.88%	824	825	99.88%	81.75%
19Nov	420	15	405	96.43%	827	25 sec	85.08%	823	827	99.52%	81.65%
20Nov	420	15	405	96.43%	828	25 sec	85.19%	826	828	99.76%	81.95%
21Nov	420	15	405	96.43%	824	25 sec	84.77%	822	824	99.76%	81.55%
22Nov	420	15	405	96.43%	824	25 sec	84.77%	823	824	99.88%	81.65%
23Nov	420	15	405	96.43%	826	25 sec	84.98%	825	826	99.88%	81.85%
25Nov	420	15	405	96.43%	826	25 sec	84.98%	825	826	99.88%	81.85%
26Nov	420	15	405	96.43%	827	25 sec	85.08%	827	827	100.00%	82.04%
27Nov	420	15	405	96.43%	827	25 sec	85.08%	826	827	99.88%	81.95%
28Nov	420	15	405	96.43%	827	25 sec	85.08%	827	827	100.00%	82.04%
29Nov	420	15	405	96.43%	829	25 sec	85.29%	828	829	99.88%	82.14%
30Nov	420	15	405	96.43%	834	25 sec	85.80%	833	834	99.88%	82.64%

2Dec	420	15	405	96.43%	833	25 sec	85.70%	833	833	100.00%	82.64%
3Dec	420	75	345	82.14%	679	25 sec	82.01%	671	679	98.82%	66.57%
4Dec	420	15	405	96.43%	830	25 sec	85.39%	827	830	99.64%	82.04%
5Dec	420	15	405	96.43%	831	25 sec	85.49%	830	831	99.88%	82.34%
6Dec	420	15	405	96.43%	829	25 sec	85.29%	829	829	100.00%	82.24%
7Dec	420	15	405	96.43%	834	25 sec	85.80%	833	834	99.88%	82.64%
9Dec	420	15	405	96.43%	833	25 sec	85.70%	833	833	100.00%	82.64%
10Dec	420	15	405	96.43%	833	25 sec	85.70%	833	833	100.00%	82.64%
11Dec	420	15	405	96.43%	835	25 sec	85.91%	834	835	99.88%	82.74%
12Dec	420	15	405	96.43%	837	25 sec	86.11%	837	837	100.00%	83.04%
13Dec	420	15	405	96.43%	837	25 sec	86.11%	837	837	100.00%	83.04%
14Dec	420	15	405	96.43%	837	25 sec	86.11%	837	837	100.00%	83.04%
16Dec	420	15	405	96.43%	838	25 sec	86.21%	838	838	100.00%	83.14%
17Dec	420	15	405	96.43%	839	25 sec	86.32%	839	839	100.00%	83.23%
18Dec	420	15	405	96.43%	838	25 sec	86.21%	837	838	99.88%	83.04%
19Dec	420	15	405	96.43%	838	25 sec	86.21%	838	838	100.00%	83.14%
20Dec	420	15	405	96.43%	839	25 sec	86.32%	839	839	100.00%	83.23%
21Dec	420	15	405	96.43%	837	25 sec	86.11%	837	837	100.00%	83.04%
23Dec	420	15	405	96.43%	838	25 sec	86.21%	838	838	100.00%	83.14%
24Dec	420	15	405	96.43%	839	25 sec	86.32%	839	839	100.00%	83.23%
25Dec	420	15	405	96.43%	838	25 sec	86.21%	838	838	100.00%	83.14%
26Dec	420	15	405	96.43%	839	25 sec	86.32%	839	839	100.00%	83.23%
27Dec	420	15	405	96.43%	840	25 sec	86.42%	840	840	100.00%	83.33%
28Dec	420	15	405	96.43%	839	25 sec	86.32%	839	839	100.00%	83.23%
30Dec	420	15	405	96.43%	840	25 sec	86.42%	839	840	99.88%	83.23%

31Dec	420	15	405	96.43%	840	25 sec	86.42%	840	840	100.00%	83.33%
1Jan	420	15	405	96.43%	840	25 sec	86.42%	840	840	100.00%	83.33%
2Jan	420	15	405	96.43%	840	25 sec	86.42%	840	840	100.00%	83.33%
3Jan	420	15	405	96.43%	839	25 sec	86.32%	839	839	100.00%	83.23%
4Jan	420	15	405	96.43%	841	25 sec	86.52%	841	841	100.00%	83.43%
6Jan	420	15	405	96.43%	839	25 sec	86.32%	839	839	100.00%	83.23%
7Jan	420	15	405	96.43%	840	25 sec	86.42%	840	840	100.00%	83.33%
8Jan	420	15	405	96.43%	840	25 sec	86.42%	840	840	100.00%	83.33%
9Jan	420	15	405	96.43%	839	25 sec	86.32%	839	839	100.00%	83.23%
10Jan	420	15	405	96.43%	839	25 sec	86.32%	839	839	100.00%	83.23%
11Jan	420	15	405	96.43%	839	25 sec	86.32%	839	839	100.00%	83.23%
13Jan	420	15	405	96.43%	841	25 sec	86.52%	841	841	100.00%	83.43%
14Jan	420	55	365	86.90%	735	25 sec	83.90%	732	735	99.59%	72.62%
15Jan	420	15	405	96.43%	841	25 sec	86.52%	841	841	100.00%	83.43%
16Jan	420	15	405	96.43%	840	25 sec	86.42%	840	840	100.00%	83.33%
17Jan	420	15	405	96.43%	840	25 sec	86.42%	840	840	100.00%	83.33%
18Jan	420	15	405	96.43%	841	25 sec	86.52%	841	841	100.00%	83.43%
20Jan	420	15	405	96.43%	842	25 sec	86.63%	842	842	100.00%	83.53%
21Jan	420	15	405	96.43%	842	25 sec	86.63%	842	842	100.00%	83.53%
22Jan	420	15	405	96.43%	842	25 sec	86.63%	840	842	99.76%	83.33%
23Jan	420	15	405	96.43%	842	25 sec	86.63%	842	842	100.00%	83.53%
24Jan	420	15	405	96.43%	840	25 sec	86.42%	840	840	100.00%	83.33%
25Jan	420	15	405	96.43%	839	25 sec	86.32%	839	839	100.00%	83.23%
27Jan	420	15	405	96.43%	841	25 sec	86.52%	841	841	100.00%	83.43%
28Jan	420	15	405	96.43%	840	25 sec	86.42%	840	840	100.00%	83.33%

29Jan	420	15	405	96.43%	842	25 sec	86.63%	842	842	100.00%	83.53%
30Jan	420	15	405	96.43%	842	25 sec	86.63%	841	842	99.88%	83.43%
1Jan	420	15	405	96.43%	842	25 sec	86.63%	842	842	100.00%	83.53%
1Feb	420	15	405	96.43%	842	25 sec	86.63%	842	842	100.00%	83.53%
3Feb	420	15	405	96.43%	843	25 sec	86.73%	843	843	100.00%	83.63%
4Feb	420	15	405	96.43%	843	25 sec	86.73%	843	843	100.00%	83.63%
5Feb	420	15	405	96.43%	843	25 sec	86.73%	843	843	100.00%	83.63%
6Feb	420	15	405	96.43%	842	25 sec	86.63%	842	842	100.00%	83.53%
7Feb	420	15	405	96.43%	841	25 sec	86.52%	841	841	100.00%	83.43%
8Feb	420	15	405	96.43%	843	25 sec	86.73%	842	843	99.88%	83.53%
10Feb	420	15	405	96.43%	842	25 sec	86.63%	842	842	100.00%	83.53%
11Feb	420	15	405	96.43%	842	25 sec	86.63%	842	842	100.00%	83.53%
12Feb	420	15	405	96.43%	842	25 sec	86.63%	842	842	100.00%	83.53%
13Feb	420	15	405	96.43%	841	25 sec	86.52%	841	841	100.00%	83.43%
14Feb	420	15	405	96.43%	840	25 sec	86.42%	840	840	100.00%	83.33%
15Feb	420	15	405	96.43%	843	25 sec	86.73%	843	843	100.00%	83.63%
17Feb	420	15	405	96.43%	843	25 sec	86.73%	842	843	99.88%	83.53%
18Feb	420	15	405	96.43%	843	25 sec	86.73%	843	843	100.00%	83.63%
19Feb	420	15	405	96.43%	843	25 sec	86.73%	843	843	100.00%	83.63%
20Feb	420	15	405	96.43%	843	25 sec	86.73%	843	843	100.00%	83.63%
21Feb	420	15	405	96.43%	843	25 sec	86.73%	843	843	100.00%	83.63%
22Feb	420	15	405	96.43%	843	25 sec	86.73%	843	843	100.00%	83.63%
24Feb	420	15	405	96.43%	843	25 sec	86.73%	843	843	100.00%	83.63%
25Feb	420	15	405	96.43%	842	25 sec	86.63%	842	842	100.00%	83.53%
26Feb	420	15	405	96.43%	842	25 sec	86.63%	842	842	100.00%	83.53%

27Feb	420	75	345	82.14%	720	25 sec	86.96%	717	720	99.58%	71.13%
28Feb	420	15	405	96.43%	843	25 sec	86.73%	843	843	100.00%	83.63%

Appendix B3

Micron Company, Machine No. 2											
Date	Loading Time	Equipment Downtime	Operation Time	**Availability %**	Processed Amount	Ideal Cycle Time	**Performance Efficiency %**	Good Quality Products	Overall Products Produced %	**Rate of Quality Produced**	**OEE %**
21Oct	420	50	370	88.10%	820	20sec	73.87%	808	820	98.54%	64.13%
22Oct	420	50	370	88.10%	828	20sec	74.59%	809	828	97.71%	64.21%
23Oct	420	50	370	88.10%	834	20sec	75.14%	818	834	98.08%	64.92%
24Oct	420	50	370	88.10%	835	20sec	75.23%	821	835	98.32%	65.16%
25Oct	420	50	370	88.10%	832	20sec	74.95%	821	832	98.68%	65.16%
26Oct	420	50	370	88.10%	834	20sec	75.14%	821	834	98.44%	65.16%
28Oct	420	150	270	64.29%	560	20sec	69.14%	532	560	95.00%	42.22%
29Oct	420	50	370	88.10%	838	20sec	75.50%	825	838	98.45%	65.48%
30Oct	420	50	370	88.10%	834	20sec	75.14%	820	834	98.32%	65.08%
31Oct	420	50	370	88.10%	838	20sec	75.50%	821	838	97.97%	65.16%
1Nov	420	50	370	88.10%	836	20sec	75.32%	822	836	98.33%	65.24%
2Nov	420	50	370	88.10%	824	20sec	74.23%	812	824	98.54%	64.44%
4Nov	420	50	370	88.10%	826	20sec	74.41%	813	826	98.43%	64.52%
5Nov	420	50	370	88.10%	824	20sec	74.23%	813	824	98.67%	64.52%
6Nov	420	50	370	88.10%	825	20sec	74.32%	814	825	98.67%	64.60%

7Nov	420	45	375	89.29%	823	20sec	73.16%	812	823	98.66%	64.44%
8Nov	420	45	375	89.29%	825	20sec	73.33%	813	825	98.55%	64.52%
9Nov	420	45	375	89.29%	826	20sec	73.42%	813	826	98.43%	64.52%
11Nov	420	135	285	67.86%	572	20sec	66.90%	541	572	94.58%	42.94%
12Nov	420	45	375	89.29%	833	20sec	74.04%	821	833	98.56%	65.16%
13Nov	420	45	375	89.29%	836	20sec	74.31%	821	836	98.21%	65.16%
14Nov	420	45	375	89.29%	839	20sec	74.58%	825	839	98.33%	65.48%
15Nov	420	45	375	89.29%	842	20sec	74.84%	825	842	97.98%	65.48%
16Nov	420	45	375	89.29%	841	20sec	74.76%	826	841	98.22%	65.56%
18Nov	420	45	375	89.29%	841	20sec	74.76%	826	841	98.22%	65.56%
19Nov	420	45	375	89.29%	839	20sec	74.58%	826	839	98.45%	65.56%
20Nov	420	45	375	89.29%	838	20sec	74.49%	825	838	98.45%	65.48%
21Nov	420	125	295	70.24%	583	20sec	65.88%	552	583	94.68%	43.81%
22Nov	420	45	375	89.29%	841	20sec	74.76%	827	841	98.34%	65.63%
23Nov	420	45	375	89.29%	842	20sec	74.84%	827	842	98.22%	65.63%
25Nov	420	45	375	89.29%	843	20sec	74.93%	828	843	98.22%	65.71%
26Nov	420	45	375	89.29%	844	20sec	75.02%	828	844	98.10%	65.71%
27Nov	420	45	375	89.29%	843	20sec	74.93%	829	843	98.34%	65.79%
28Nov	420	40	380	90.48%	845	20sec	74.12%	829	845	98.11%	65.79%
29Nov	420	40	380	90.48%	849	20sec	74.47%	829	849	97.64%	65.79%
30Nov	420	40	380	90.48%	851	20sec	74.65%	828	851	97.30%	65.71%
2Dec	420	40	380	90.48%	849	20sec	74.47%	827	849	97.41%	65.63%
3Dec	420	40	380	90.48%	692	20sec	60.70%	678	692	97.98%	53.81%
4Dec	420	40	380	90.48%	830	20sec	72.81%	819	830	98.67%	65.00%
5Dec	420	40	380	90.48%	830	20sec	72.81%	819	830	98.67%	65.00%

6Dec	420	40	380	90.48%	834	20sec	73.16%	820	834	98.32%	65.08%
7Dec	420	40	380	90.48%	839	20sec	73.60%	829	839	98.81%	65.79%
9Dec	420	40	380	90.48%	859	20sec	75.35%	845	859	98.37%	67.06%
10Dec	420	40	380	90.48%	864	20sec	75.79%	849	864	98.26%	67.38%
11Dec	420	40	380	90.48%	858	20sec	75.26%	844	858	98.37%	66.98%
12Dec	420	40	380	90.48%	859	20sec	75.35%	844	859	98.25%	66.98%
13Dec	420	40	380	90.48%	860	20sec	75.44%	845	860	98.26%	67.06%
14Dec	420	40	380	90.48%	861	20sec	75.53%	845	861	98.14%	67.06%
16Dec	420	40	380	90.48%	861	20sec	75.53%	845	861	98.14%	67.06%
17Dec	420	40	380	90.48%	861	20sec	75.53%	845	861	98.14%	67.06%
18Dec	420	120	300	71.43%	593	20sec	65.89%	568	593	95.78%	45.08%
19Dec	420	40	380	90.48%	863	20sec	75.70%	847	863	98.15%	67.22%
20Dec	420	40	380	90.48%	861	20sec	75.53%	847	861	98.37%	67.22%
21Dec	420	40	380	90.48%	860	20sec	75.44%	847	860	98.49%	67.22%
23Dec	420	40	380	90.48%	867	20sec	76.05%	850	867	98.04%	67.46%
24Dec	420	40	380	90.48%	867	20sec	76.05%	850	867	98.04%	67.46%
25Dec	420	40	380	90.48%	868	20sec	76.14%	851	868	98.04%	67.54%
26Dec	420	40	380	90.48%	868	20sec	76.14%	851	868	98.04%	67.54%
27Dec	420	40	380	90.48%	868	20sec	76.14%	851	868	98.04%	67.54%
28Dec	420	40	380	90.48%	867	20sec	76.05%	850	867	98.04%	67.46%
30Dec	420	40	380	90.48%	869	20sec	76.23%	853	869	98.16%	67.70%
31Dec	420	40	380	90.48%	869	20sec	76.23%	851	869	97.93%	67.54%
1Jan	420	40	380	90.48%	869	20sec	76.23%	852	869	98.04%	67.62%
2Jan	420	40	380	90.48%	868	20sec	76.14%	851	868	98.04%	67.54%
3Jan	420	40	380	90.48%	868	20sec	76.14%	851	868	98.04%	67.54%

4Jan	420	40	380	90.48%	868	20sec	76.14%	851	868	98.04%	67.54%
6Jan	420	40	380	90.48%	867	20sec	76.05%	850	867	98.04%	67.46%
7Jan	420	40	380	90.48%	869	20sec	76.23%	852	869	98.04%	67.62%
8Jan	420	40	380	90.48%	868	20sec	76.14%	852	868	98.16%	67.62%
9Jan	420	40	380	90.48%	869	20sec	76.23%	853	869	98.16%	67.70%
10Jan	420	40	380	90.48%	869	20sec	76.23%	853	869	98.16%	67.70%
11Jan	420	40	380	90.48%	868	20sec	76.14%	852	868	98.16%	67.62%
13Jan	420	40	380	90.48%	870	20sec	76.32%	855	870	98.28%	67.86%
14Jan	420	40	380	90.48%	870	20sec	76.32%	855	870	98.28%	67.86%
15Jan	420	40	380	90.48%	870	20sec	76.32%	854	870	98.16%	67.78%
16Jan	420	40	380	90.48%	871	20sec	76.40%	856	871	98.28%	67.94%
17Jan	420	40	380	90.48%	869	20sec	76.23%	853	869	98.16%	67.70%
18Jan	420	40	380	90.48%	869	20sec	76.23%	854	869	98.27%	67.78%
20Jan	420	40	380	90.48%	870	20sec	76.32%	857	870	98.51%	68.02%
21Jan	420	40	380	90.48%	870	20sec	76.32%	857	870	98.51%	68.02%
22Jan	420	40	380	90.48%	870	20sec	76.32%	857	870	98.51%	68.02%
23Jan	420	40	380	90.48%	871	20sec	76.40%	859	871	98.62%	68.17%
24Jan	420	40	380	90.48%	869	20sec	76.23%	856	869	98.50%	67.94%
25Jan	420	40	380	90.48%	868	20sec	76.14%	856	868	98.62%	67.94%
27Jan	420	40	380	90.48%	869	20sec	76.23%	856	869	98.50%	67.94%
28Jan	420	80	340	80.95%	680	20sec	66.67%	649	680	95.44%	51.51%
29Jan	420	40	380	90.48%	869	20sec	76.23%	856	869	98.50%	67.94%
30Jan	420	40	380	90.48%	870	20sec	76.32%	859	870	98.74%	68.17%
1Jan	420	35	385	91.67%	879	20sec	76.10%	867	879	98.63%	68.81%
1Feb	420	35	385	91.67%	878	20sec	76.02%	869	878	98.97%	68.97%

3Feb	420	35	385	91.67%	880	20sec	76.19%	871	880	98.98%	69.13%
4Feb	420	35	385	91.67%	880	20sec	76.19%	871	880	98.98%	69.13%
5Feb	420	35	385	91.67%	880	20sec	76.19%	872	880	99.09%	69.21%
6Feb	420	35	385	91.67%	882	20sec	76.36%	874	882	99.09%	69.37%
7Feb	420	35	385	91.67%	882	20sec	76.36%	874	882	99.09%	69.37%
8Feb	420	35	385	91.67%	881	20sec	76.28%	872	881	98.98%	69.21%
10Feb	420	35	385	91.67%	883	20sec	76.45%	875	883	99.09%	69.44%
11Feb	420	35	385	91.67%	884	20sec	76.54%	873	884	98.76%	69.29%
12Feb	420	35	385	91.67%	882	20sec	76.36%	871	882	98.75%	69.13%
13Feb	420	35	385	91.67%	882	20sec	76.36%	872	882	98.87%	69.21%
14Feb	420	35	385	91.67%	883	20sec	76.45%	873	883	98.87%	69.29%
15Feb	420	35	385	91.67%	884	20sec	76.54%	877	884	99.21%	69.60%
17Feb	420	35	385	91.67%	885	20sec	76.62%	878	885	99.21%	69.68%
18Feb	420	35	385	91.67%	884	20sec	76.54%	878	884	99.32%	69.68%
19Feb	420	35	385	91.67%	885	20sec	76.62%	879	885	99.32%	69.76%
20Feb	420	35	385	91.67%	887	20sec	76.80%	882	887	99.44%	70.00%
21Feb	420	35	385	91.67%	886	20sec	76.71%	882	886	99.55%	70.00%
22Feb	420	80	340	80.95%	683	20sec	66.96%	667	683	97.66%	52.94%
24Feb	420	35	385	91.67%	883	20sec	76.45%	881	883	99.77%	69.92%
25Feb	420	35	385	91.67%	888	20sec	76.88%	885	888	99.66%	70.24%
26Feb	420	35	385	91.67%	888	20sec	76.88%	885	888	99.66%	70.24%
27Feb	420	35	385	91.67%	888	20sec	76.88%	886	888	99.77%	70.32%
28Feb	420	35	385	91.67%	887	20sec	76.80%	886	887	99.89%	70.32%

Micron Company, Machine No.3											
Day	Loading Time	Equipment Downtime	Operation Time	**Availability %**	Processed Amount	Ideal Cycle Time	**Performance Efficiency %**	Good Quality Products	Overall Products Produced %	**Rate of Quality Produced**	**OEE %**
21Oct	420	40	380	90.48%	735	25sec	80.59%	680	735	92.52%	67.46%
22Oct	420	40	380	90.48%	740	25sec	81.14%	689	740	93.11%	68.35%
23Oct	420	40	380	90.48%	737	25sec	80.81%	710	737	96.34%	70.44%
24Oct	420	35	385	91.67%	738	25sec	79.87%	712	738	96.48%	70.64%
25Oct	420	35	385	91.67%	738	25sec	79.87%	712	738	96.48%	70.64%
26Oct	420	35	385	91.67%	745	25sec	80.63%	714	745	95.84%	70.83%
28Oct	420	35	385	91.67%	744	25sec	80.52%	713	744	95.83%	70.73%
29Oct	420	155	265	63.10%	502	25sec	78.93%	480	502	95.62%	47.62%
30Oct	420	35	385	91.67%	745	25sec	80.63%	716	745	96.11%	71.03%
31Oct	420	35	385	91.67%	747	25sec	80.84%	715	747	95.72%	70.93%
1Nov	420	35	385	91.67%	747	25sec	80.84%	720	747	96.39%	71.43%
2Nov	420	35	385	91.67%	748	25sec	80.95%	720	748	96.26%	71.43%
4Nov	420	35	385	91.67%	748	25sec	80.95%	720	748	96.26%	71.43%
5Nov	420	35	385	91.67%	748	25sec	80.95%	723	748	96.66%	71.73%
6Nov	420	35	385	91.67%	749	25sec	81.06%	723	749	96.53%	71.73%
7Nov	420	35	385	91.67%	747	25sec	80.84%	726	747	97.19%	72.02%
8Nov	420	35	385	91.67%	749	25sec	81.06%	730	749	97.46%	72.42%

9Nov	420	35	385	91.67%	751	25sec	81.28%	735	751	97.87%	72.92%
11Nov	420	35	385	91.67%	749	25sec	81.06%	735	749	98.13%	72.92%
12Nov	420	125	295	70.24%	564	25sec	79.66%	549	564	97.34%	54.46%
13Nov	420	35	385	91.67%	756	25sec	81.82%	738	756	97.62%	73.21%
14Nov	420	35	385	91.67%	756	25sec	81.82%	740	756	97.88%	73.41%
15Nov	420	35	385	91.67%	756	25sec	81.82%	740	756	97.88%	73.41%
16Nov	420	35	385	91.67%	757	25sec	81.93%	745	757	98.41%	73.91%
18Nov	420	35	385	91.67%	757	25sec	81.93%	745	757	98.41%	73.91%
19Nov	420	35	385	91.67%	757	25sec	81.93%	745	757	98.41%	73.91%
20Nov	420	35	385	91.67%	757	25sec	81.93%	745	757	98.41%	73.91%
21Nov	420	35	385	91.67%	758	25sec	82.04%	745	758	98.28%	73.91%
22Nov	420	35	385	91.67%	758	25sec	82.04%	748	758	98.68%	74.21%
23Nov	420	35	385	91.67%	758	25sec	82.04%	748	758	98.68%	74.21%
25Nov	420	35	385	91.67%	757	25sec	81.93%	749	757	98.94%	74.31%
26Nov	420	35	385	91.67%	757	25sec	81.93%	750	757	99.08%	74.41%
27Nov	420	35	385	91.67%	757	25sec	81.93%	750	757	99.08%	74.41%
28Nov	420	35	385	91.67%	759	25sec	82.14%	750	759	98.81%	74.41%
29Nov	420	30	390	92.86%	760	25sec	81.20%	752	760	98.95%	74.60%
30Nov	420	30	390	92.86%	760	25sec	81.20%	753	760	99.08%	74.70%
2Dec	420	30	390	92.86%	762	25sec	81.41%	752	762	98.69%	74.60%
3Dec	420	120	300	71.43%	601	25sec	83.47%	581	601	96.67%	57.64%
4Dec	420	30	390	92.86%	762	25sec	81.41%	754	762	98.95%	74.80%
5Dec	420	30	390	92.86%	761	25sec	81.30%	755	761	99.21%	74.90%
6Dec	420	30	390	92.86%	759	25sec	81.09%	756	759	99.60%	75.00%
7Dec	420	30	390	92.86%	760	25sec	81.20%	755	760	99.34%	74.90%

9Dec	420	30	390	92.86%	763	25sec	81.52%	758	763	99.34%	75.20%
10Dec	420	30	390	92.86%	763	25sec	81.52%	758	763	99.34%	75.20%
11Dec	420	30	390	92.86%	763	25sec	81.52%	757	763	99.21%	75.10%
12Dec	420	30	390	92.86%	767	25sec	81.95%	757	767	98.70%	75.10%
13Dec	420	30	390	92.86%	777	25sec	83.01%	762	777	98.07%	75.60%
14Dec	420	30	390	92.86%	777	25sec	83.01%	763	777	98.20%	75.70%
16Dec	420	30	390	92.86%	778	25sec	83.12%	763	778	98.07%	75.70%
17Dec	420	30	390	92.86%	779	25sec	83.23%	767	779	98.46%	76.09%
18Dec	420	30	390	92.86%	780	25sec	83.33%	770	780	98.72%	76.39%
19Dec	420	30	390	92.86%	780	25sec	83.33%	768	780	98.46%	76.19%
20Dec	420	30	390	92.86%	780	25sec	83.33%	769	780	98.59%	76.29%
21Dec	420	30	390	92.86%	780	25sec	83.33%	769	780	98.59%	76.29%
23Dec	420	30	390	92.86%	780	25sec	83.33%	770	780	98.72%	76.39%
24Dec	420	30	390	92.86%	780	25sec	83.33%	771	780	98.85%	76.49%
25Dec	420	30	390	92.86%	780	25sec	83.33%	771	780	98.85%	76.49%
26Dec	420	30	390	92.86%	783	25sec	83.65%	773	783	98.72%	76.69%
27Dec	420	30	390	92.86%	785	25sec	83.87%	774	785	98.60%	76.79%
28Dec	420	30	390	92.86%	786	25sec	83.98%	775	786	98.60%	76.89%
30Dec	420	90	330	78.57%	662	25sec	83.59%	635	662	95.92%	63.00%
31Dec	420	30	390	92.86%	788	25sec	84.19%	778	788	98.73%	77.18%
1Jan	420	30	390	92.86%	788	25sec	84.19%	778	788	98.73%	77.18%
2Jan	420	30	390	92.86%	788	25sec	84.19%	779	788	98.86%	77.28%
3Jan	420	30	390	92.86%	788	25sec	84.19%	780	788	98.98%	77.38%
4Jan	420	30	390	92.86%	788	25sec	84.19%	780	788	98.98%	77.38%
6Jan	420	30	390	92.86%	789	25sec	84.30%	780	789	98.86%	77.38%

7Jan	420	30	390	92.86%	789	25sec	84.30%	781	789	98.99%	77.48%
8Jan	420	30	390	92.86%	789	25sec	84.30%	781	789	98.99%	77.48%
9Jan	420	30	390	92.86%	790	25sec	84.40%	783	790	99.11%	77.68%
10Jan	420	30	390	92.86%	790	25sec	84.40%	782	790	98.99%	77.58%
11Jan	420	30	390	92.86%	795	25sec	84.94%	785	795	98.74%	77.88%
13Jan	420	30	390	92.86%	795	25sec	84.94%	788	795	99.12%	78.18%
14Jan	420	30	390	92.86%	795	25sec	84.94%	788	795	99.12%	78.18%
15Jan	420	30	390	92.86%	799	25sec	85.36%	789	799	98.75%	78.27%
16Jan	420	30	390	92.86%	799	25sec	85.36%	789	799	98.75%	78.27%
17Jan	420	30	390	92.86%	799	25sec	85.36%	789	799	98.75%	78.27%
18Jan	420	30	390	92.86%	799	25sec	85.36%	791	799	99.00%	78.47%
20Jan	420	30	390	92.86%	800	25sec	85.47%	792	800	99.00%	78.57%
21Jan	420	30	390	92.86%	800	25sec	85.47%	792	800	99.00%	78.57%
22Jan	420	30	390	92.86%	803	25sec	85.79%	793	803	98.75%	78.67%
23Jan	420	30	390	92.86%	803	25sec	85.79%	793	803	98.75%	78.67%
24Jan	420	30	390	92.86%	804	25sec	85.90%	795	804	98.88%	78.87%
25Jan	420	25	395	94.05%	804	25sec	84.81%	796	804	99.00%	78.97%
27Jan	420	25	395	94.05%	804	25sec	84.81%	796	804	99.00%	78.97%
28Jan	420	25	395	94.05%	804	25sec	84.81%	798	804	99.25%	79.17%
29Jan	420	25	395	94.05%	804	25sec	84.81%	798	804	99.25%	79.17%
30Jan	420	25	395	94.05%	805	25sec	84.92%	798	805	99.13%	79.17%
1Jan	420	25	395	94.05%	805	25sec	84.92%	799	805	99.25%	79.27%
1Feb	420	25	395	94.05%	805	25sec	84.92%	799	805	99.25%	79.27%
3Feb	420	85	335	79.76%	676	25sec	84.08%	654	676	96.75%	64.88%
4Feb	420	25	395	94.05%	806	25sec	85.02%	801	806	99.38%	79.46%

5Feb	420	25	395	94.05%	807	25sec	85.13%	801	807	99.26%	79.46%
6Feb	420	25	395	94.05%	807	25sec	85.13%	801	807	99.26%	79.46%
7Feb	420	25	395	94.05%	807	25sec	85.13%	802	807	99.38%	79.56%
8Feb	420	25	395	94.05%	807	25sec	85.13%	804	807	99.63%	79.76%
10Feb	420	25	395	94.05%	808	25sec	85.23%	804	808	99.50%	79.76%
11Feb	420	25	395	94.05%	808	25sec	85.23%	805	808	99.63%	79.86%
12Feb	420	25	395	94.05%	808	25sec	85.23%	805	808	99.63%	79.86%
13Feb	420	25	395	94.05%	808	25sec	85.23%	804	808	99.50%	79.76%
14Feb	420	25	395	94.05%	808	25sec	85.23%	804	808	99.50%	79.76%
15Feb	420	25	395	94.05%	810	25sec	85.44%	806	810	99.51%	79.96%
17Feb	420	25	395	94.05%	810	25sec	85.44%	807	810	99.63%	80.06%
18Feb	420	25	395	94.05%	810	25sec	85.44%	807	810	99.63%	80.06%
19Feb	420	25	395	94.05%	810	25sec	85.44%	808	810	99.75%	80.16%
20Feb	420	25	395	94.05%	810	25sec	85.44%	808	810	99.75%	80.16%
21Feb	420	25	395	94.05%	810	25sec	85.44%	808	810	99.75%	80.16%
22Feb	420	25	395	94.05%	810	25sec	85.44%	807	810	99.63%	80.06%
24Feb	420	25	395	94.05%	811	25sec	85.55%	808	811	99.63%	80.16%
25Feb	420	25	395	94.05%	811	25sec	85.55%	808	811	99.63%	80.16%
26Feb	420	25	395	94.05%	811	25sec	85.55%	811	811	100.00%	80.46%
27Feb	420	25	395	94.05%	811	25sec	85.55%	809	811	99.75%	80.26%
28Feb	420	25	395	94.05%	811	25sec	85.55%	810	811	99.88%	80.36%

Micron Company, Machine No. 4											
Day	Loading Time	Equipment Downtime	Operation Time	**Availability %**	Processed Amount	Ideal Cycle Time	**Performance Efficiency %**	Good Quality Products	Overall Products Produced	**Rate of Quality Produced %**	**OEE %**
21Oct	420	35	385	91.67%	770	23sec	76.67%	748	770	97.14%	68.27%
22Oct	420	35	385	91.67%	770	23sec	76.67%	748	770	97.14%	68.27%
23Oct	420	35	385	91.67%	770	23sec	76.67%	748	770	97.14%	68.27%
24Oct	420	35	385	91.67%	770	23sec	76.67%	749	770	97.27%	68.36%
25Oct	420	35	385	91.67%	770	23sec	76.67%	749	770	97.27%	68.36%
26Oct	420	35	385	91.67%	770	23sec	76.67%	750	770	97.40%	68.45%
28Oct	420	35	385	91.67%	770	23sec	76.67%	750	770	97.40%	68.45%
29Oct	420	35	385	91.67%	770	23sec	76.67%	750	770	97.40%	68.45%
30Oct	420	35	385	91.67%	770	23sec	76.67%	749	770	97.27%	68.36%
31Oct	420	155	265	63.10%	530	23sec	76.67%	496	530	93.58%	45.27%
1Nov	420	35	385	91.67%	770	23sec	76.67%	748	770	97.14%	68.27%
2Nov	420	35	385	91.67%	770	23sec	76.67%	748	770	97.14%	68.27%
4Nov	420	35	385	91.67%	770	23sec	76.67%	749	770	97.27%	68.36%
5Nov	420	35	385	91.67%	775	23sec	77.16%	752	775	97.03%	68.63%
6Nov	420	35	385	91.67%	774	23sec	77.06%	753	774	97.29%	68.73%
7Nov	420	35	385	91.67%	776	23sec	77.26%	753	776	97.04%	68.73%
8Nov	420	35	385	91.67%	776	23sec	77.26%	753	776	97.04%	68.73%

9Nov	420	35	385	91.67%	777	23sec	77.36%	756	777	97.30%	69.00%
11Nov	420	35	385	91.67%	777	23sec	77.36%	756	777	97.30%	69.00%
12Nov	420	35	385	91.67%	778	23sec	77.46%	757	778	97.30%	69.09%
13Nov	420	35	385	91.67%	778	23sec	77.46%	756	778	97.17%	69.00%
14Nov	420	95	325	77.38%	660	23sec	77.85%	631	660	95.61%	57.59%
15Nov	420	30	390	92.86%	779	23sec	76.57%	756	779	97.05%	69.00%
16Nov	420	30	390	92.86%	779	23sec	76.57%	758	779	97.30%	69.18%
18Nov	420	30	390	92.86%	778	23sec	76.47%	757	778	97.30%	69.09%
19Nov	420	30	390	92.86%	780	23sec	76.67%	759	780	97.31%	69.27%
20Nov	420	30	390	92.86%	780	23sec	76.67%	759	780	97.31%	69.27%
21Nov	420	30	390	92.86%	781	23sec	76.76%	760	781	97.31%	69.37%
22Nov	420	30	390	92.86%	781	23sec	76.76%	760	781	97.31%	69.37%
23Nov	420	30	390	92.86%	782	23sec	76.86%	761	782	97.31%	69.46%
25Nov	420	30	390	92.86%	781	23sec	76.76%	761	781	97.44%	69.46%
26Nov	420	30	390	92.86%	781	23sec	76.76%	761	781	97.44%	69.46%
27Nov	420	30	390	92.86%	782	23sec	76.86%	762	782	97.44%	69.55%
28Nov	420	30	390	92.86%	784	23sec	77.06%	764	784	97.45%	69.73%
29Nov	420	30	390	92.86%	784	23sec	77.06%	764	784	97.45%	69.73%
30Nov	420	30	390	92.86%	785	23sec	77.16%	764	785	97.32%	69.73%
2Dec	420	90	330	78.57%	664	23sec	77.13%	638	664	96.08%	58.23%
3Dec	420	30	390	92.86%	707	23sec	69.49%	689	707	97.45%	62.88%
4Dec	420	30	390	92.86%	789	23sec	77.55%	769	789	97.47%	70.19%
5Dec	420	30	390	92.86%	789	23sec	77.55%	769	789	97.47%	70.19%
6Dec	420	30	390	92.86%	789	23sec	77.55%	770	789	97.59%	70.28%
7Dec	420	30	390	92.86%	788	23sec	77.45%	773	788	98.10%	70.55%

9Dec	420	30	390	92.86%	788	23sec	77.45%	773	788	98.10%	70.55%
10Dec	420	30	390	92.86%	788	23sec	77.45%	774	788	98.22%	70.64%
11Dec	420	30	390	92.86%	789	23sec	77.55%	775	789	98.23%	70.73%
12Dec	420	30	390	92.86%	790	23sec	77.65%	777	790	98.35%	70.92%
13Dec	420	30	390	92.86%	790	23sec	77.65%	777	790	98.35%	70.92%
14Dec	420	30	390	92.86%	792	23sec	77.85%	778	792	98.23%	71.01%
16Dec	420	30	390	92.86%	794	23sec	78.04%	779	794	98.11%	71.10%
17Dec	420	30	390	92.86%	794	23sec	78.04%	779	794	98.11%	71.10%
18Dec	420	30	390	92.86%	794	23sec	78.04%	780	794	98.24%	71.19%
19Dec	420	30	390	92.86%	795	23sec	78.14%	780	795	98.11%	71.19%
20Dec	420	30	390	92.86%	795	23sec	78.14%	782	795	98.36%	71.37%
21Dec	420	30	390	92.86%	795	23sec	78.14%	782	795	98.36%	71.37%
23Dec	420	30	390	92.86%	795	23sec	78.14%	783	795	98.49%	71.46%
24Dec	420	30	390	92.86%	796	23sec	78.24%	784	796	98.49%	71.56%
25Dec	420	30	390	92.86%	796	23sec	78.24%	784	796	98.49%	71.56%
26Dec	420	30	390	92.86%	796	23sec	78.24%	784	796	98.49%	71.56%
27Dec	420	30	390	92.86%	797	23sec	78.34%	785	797	98.49%	71.65%
28Dec	420	90	330	78.57%	797	23sec	92.58%	786	797	98.62%	71.74%
30Dec	420	30	390	92.86%	798	23sec	78.44%	787	798	98.62%	71.83%
31Dec	420	30	390	92.86%	798	23sec	78.44%	789	798	98.87%	72.01%
1Jan	420	30	390	92.86%	798	23sec	78.44%	789	798	98.87%	72.01%
2Jan	420	30	390	92.86%	798	23sec	78.44%	789	798	98.87%	72.01%
3Jan	420	30	390	92.86%	798	23sec	78.44%	789	798	98.87%	72.01%
4Jan	420	30	390	92.86%	798	23sec	78.44%	790	798	99.00%	72.10%
6Jan	420	30	390	92.86%	800	23sec	78.63%	790	800	98.75%	72.10%

7Jan	420	30	390	92.86%	800	23sec	78.63%	790	800	98.75%	72.10%
8Jan	420	30	390	92.86%	799	23sec	78.53%	788	799	98.62%	71.92%
9Jan	420	30	390	92.86%	780	23sec	76.67%	770	780	98.72%	70.28%
10Jan	420	30	390	92.86%	782	23sec	76.86%	771	782	98.59%	70.37%
11Jan	420	30	390	92.86%	783	23sec	76.96%	775	783	98.98%	70.73%
13Jan	420	30	390	92.86%	780	23sec	76.67%	771	780	98.85%	70.37%
14Jan	420	30	390	92.86%	780	23sec	76.67%	771	780	98.85%	70.37%
15Jan	420	30	390	92.86%	798	23sec	78.44%	789	798	98.87%	72.01%
16Jan	420	30	390	92.86%	799	23sec	78.53%	789	799	98.75%	72.01%
17Jan	420	30	390	92.86%	800	23sec	78.63%	790	800	98.75%	72.10%
18Jan	420	30	390	92.86%	802	23sec	78.83%	792	802	98.75%	72.29%
20Jan	420	30	390	92.86%	802	23sec	78.83%	792	802	98.75%	72.29%
21Jan	420	30	390	92.86%	802	23sec	78.83%	793	802	98.88%	72.38%
22Jan	420	30	390	92.86%	801	23sec	78.73%	794	801	99.13%	72.47%
23Jan	420	30	390	92.86%	804	23sec	79.03%	795	804	98.88%	72.56%
24Jan	420	30	390	92.86%	805	23sec	79.12%	795	805	98.76%	72.56%
25Jan	420	25	395	94.05%	806	23sec	78.22%	796	806	98.76%	72.65%
27Jan	420	25	395	94.05%	806	23sec	78.22%	796	806	98.76%	72.65%
28Jan	420	25	395	94.05%	805	23sec	78.12%	798	805	99.13%	72.83%
29Jan	420	25	395	94.05%	809	23sec	78.51%	798	809	98.64%	72.83%
30Jan	420	25	395	94.05%	809	23sec	78.51%	800	809	98.89%	73.02%
1Jan	420	25	395	94.05%	809	23sec	78.51%	800	809	98.89%	73.02%
1Feb	420	25	395	94.05%	811	23sec	78.70%	804	811	99.14%	73.38%
3Feb	420	25	395	94.05%	811	23sec	78.70%	804	811	99.14%	73.38%
4Feb	420	25	395	94.05%	813	23sec	78.90%	805	813	99.02%	73.47%

5Feb	420	25	395	94.05%	815	23sec	79.09%	807	815	99.02%	73.65%
6Feb	420	25	395	94.05%	815	23sec	79.09%	804	815	98.65%	73.38%
7Feb	420	85	335	79.76%	678	23sec	77.58%	661	678	97.49%	60.33%
8Feb	420	25	395	94.05%	817	23sec	79.29%	809	817	99.02%	73.84%
10Feb	420	25	395	94.05%	817	23sec	79.29%	809	817	99.02%	73.84%
11Feb	420	25	395	94.05%	817	23sec	79.29%	810	817	99.14%	73.93%
12Feb	420	25	395	94.05%	817	23sec	79.29%	811	817	99.27%	74.02%
13Feb	420	25	395	94.05%	818	23sec	79.38%	811	818	99.14%	74.02%
14Feb	420	25	395	94.05%	820	23sec	79.58%	815	820	99.39%	74.38%
15Feb	420	25	395	94.05%	820	23sec	79.58%	815	820	99.39%	74.38%
17Feb	420	25	395	94.05%	820	23sec	79.58%	817	820	99.63%	74.57%
18Feb	420	25	395	94.05%	819	23sec	79.48%	815	819	99.51%	74.38%
19Feb	420	25	395	94.05%	819	23sec	79.48%	816	819	99.63%	74.48%
20Feb	420	25	395	94.05%	820	23sec	79.58%	815	820	99.39%	74.38%
21Feb	420	25	395	94.05%	821	23sec	79.68%	817	821	99.51%	74.57%
22Feb	420	25	395	94.05%	821	23sec	79.68%	817	821	99.51%	74.57%
24Feb	420	25	395	94.05%	822	23sec	79.77%	819	822	99.64%	74.75%
25Feb	420	25	395	94.05%	819	23sec	79.48%	816	819	99.63%	74.48%
26Feb	420	25	395	94.05%	820	23sec	79.58%	817	820	99.63%	74.57%
27Feb	420	25	395	94.05%	820	23sec	79.58%	817	820	99.63%	74.57%
28Feb	420	25	395	94.05%	823	23sec	79.87%	821	823	99.76%	74.93%

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Appendix B4

Day	Loading Time For Factory	Ideal Cycle Time Machine 1 or 3	Good Quality Products Machine 4	**SOEE %**
21Oct	420	0.4167	748	74.21%
22Oct	420	0.4167	748	74.21%
23Oct	420	0.4167	748	74.21%
24Oct	420	0.4167	749	74.31%
25Oct	420	0.4167	749	74.31%
26Oct	420	0.4167	750	74.41%
28Oct	420	0.4167	750	74.41%
29Oct	420	0.4167	750	74.41%
30Oct	420	0.4167	749	74.31%
31Oct	420	0.4167	496	49.21%
1Nov	420	0.4167	748	74.21%
2Nov	420	0.4167	748	74.21%
4Nov	420	0.4167	749	74.31%
5Nov	420	0.4167	752	74.60%
6Nov	420	0.4167	753	74.70%
7Nov	420	0.4167	753	74.70%
8Nov	420	0.4167	753	74.70%
9Nov	420	0.4167	756	75.00%
11Nov	420	0.4167	756	75.00%
12Nov	420	0.4167	757	75.10%
13Nov	420	0.4167	756	75.00%
14Nov	420	0.4167	631	62.60%
15Nov	420	0.4167	756	75.00%
16Nov	420	0.4167	758	75.20%
18Nov	420	0.4167	757	75.10%
19Nov	420	0.4167	759	75.30%
20Nov	420	0.4167	759	75.30%
21Nov	420	0.4167	760	75.40%
22Nov	420	0.4167	760	75.40%
23Nov	420	0.4167	761	75.50%
25Nov	420	0.4167	761	75.50%
26Nov	420	0.4167	761	75.50%
27Nov	420	0.4167	762	75.60%
28Nov	420	0.4167	764	75.79%
29Nov	420	0.4167	764	75.79%
30Nov	420	0.4167	764	75.79%

2Dec	420	0.4167	638	63.29%
3Dec	420	0.4167	689	68.35%
4Dec	420	0.4167	769	76.29%
5Dec	420	0.4167	769	76.29%
6Dec	420	0.4167	770	76.39%
7Dec	420	0.4167	773	76.69%
9Dec	420	0.4167	773	76.69%
10Dec	420	0.4167	774	76.79%
11Dec	420	0.4167	775	76.89%
12Dec	420	0.4167	777	77.08%
13Dec	420	0.4167	777	77.08%
14Dec	420	0.4167	778	77.18%
16Dec	420	0.4167	779	77.28%
17Dec	420	0.4167	779	77.28%
18Dec	420	0.4167	780	77.38%
19Dec	420	0.4167	780	77.38%
20Dec	420	0.4167	782	77.58%
21Dec	420	0.4167	782	77.58%
23Dec	420	0.4167	783	77.68%
24Dec	420	0.4167	784	77.78%
25Dec	420	0.4167	784	77.78%
26Dec	420	0.4167	784	77.78%
27Dec	420	0.4167	785	77.88%
28Dec	420	0.4167	786	77.98%
30Dec	420	0.4167	787	78.08%
31Dec	420	0.4167	789	78.27%
1Jan	420	0.4167	789	78.27%
2Jan	420	0.4167	789	78.27%
3Jan	420	0.4167	789	78.27%
4Jan	420	0.4167	790	78.37%
6Jan	420	0.4167	790	78.37%
7Jan	420	0.4167	790	78.37%
8Jan	420	0.4167	788	78.18%
9Jan	420	0.4167	770	76.39%
10Jan	420	0.4167	771	76.49%
11Jan	420	0.4167	775	76.89%
13Jan	420	0.4167	771	76.49%
14Jan	420	0.4167	771	76.49%
15Jan	420	0.4167	789	78.27%
16Jan	420	0.4167	789	78.27%
17Jan	420	0.4167	790	78.37%
18Jan	420	0.4167	792	78.57%

20Jan	420	0.4167	792	78.57%
21Jan	420	0.4167	793	78.67%
22Jan	420	0.4167	794	78.77%
23Jan	420	0.4167	795	78.87%
24Jan	420	0.4167	795	78.87%
25Jan	420	0.4167	796	78.97%
27Jan	420	0.4167	796	78.97%
28Jan	420	0.4167	798	79.17%
29Jan	420	0.4167	798	79.17%
30Jan	420	0.4167	800	79.37%
1Jan	420	0.4167	800	79.37%
1Feb	420	0.4167	804	79.76%
3Feb	420	0.4167	804	79.76%
4Feb	420	0.4167	805	79.86%
5Feb	420	0.4167	807	80.06%
6Feb	420	0.4167	804	79.76%
7Feb	420	0.4167	661	65.58%
8Feb	420	0.4167	809	80.26%
10Feb	420	0.4167	809	80.26%
11Feb	420	0.4167	810	80.36%
12Feb	420	0.4167	811	80.46%
13Feb	420	0.4167	811	80.46%
14Feb	420	0.4167	815	80.85%
15Feb	420	0.4167	815	80.85%
17Feb	420	0.4167	817	81.05%
18Feb	420	0.4167	815	80.85%
19Feb	420	0.4167	816	80.95%
20Feb	420	0.4167	815	80.85%
21Feb	420	0.4167	817	81.05%
22Feb	420	0.4167	817	81.05%
24Feb	420	0.4167	819	81.25%
25Feb	420	0.4167	816	80.95%
26Feb	420	0.4167	817	81.05%
27Feb	420	0.4167	817	81.05%
28Feb	420	0.4167	821	81.45%