AN ANALYSIS FOR
TOTAL PRODUCTIVE MAINTENANCE IMPLEMENTATION

by

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(ABSTRACT)

This report constitutes an evaluation of the effectiveness and cost of a maintenance program for a discrete parts manufacturing company. Total Productive Maintenance (TPM) is an integrated life-cycle approach to factory maintenance operations introduced by the Japanese. The main objective is to study the concepts and techniques of TPM. Details are provided on applicability, the establishment of goals, and the steps involved in TPM implementation. It was determined that an early prerequisite for TPM implementation within the company, is the development of a Computerized Maintenance Management System (CMMS) for collecting and recording the appropriate data for TPM implementation. Therefore, a brief discussion of CMMS goals and techniques is also included.

Acknowledgments

The ideas that stimulated this study effort were generated through Professor Benjamin S. Blanchard's class, "The Systems Engineering Process". I owe him special thanks for his guidance as my chairman, and helpfulness during the time I worked on this project.

I wish to thank Mr. Dan Paterra and Mr. Hank Schneider for their ongoing support in providing me the necessary guidance and input data covering the company's manufacturing operations. Additionally, I wish to thank Dr. Rod J. Reasor and Dr. Subash C. Sarin for their willingness to serve on my graduate committee.

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1.0 INTRODUCTION

Industry today is in a fight to survive. Competition is found everywhere, domestically and also on an international level. In an effort to survive, all forms of production analysis are made. However, one area many industries are now turning their attention toward is the maintenance function. While the maintenance function is often viewed as a necessary evil, it is also the last major area of cost reduction in both the public and private sector not receiving much attention until recently [19].

This report is about the application of productive maintenance methods, more specifically Total Productive Maintenance (TPM). The report summarizes the results of a maintenance analysis for a manufacturing company producing bearings for compressors. The company participating in this study prefers to remain anonymous.

In recent years many companies have become obsessed with copying and following new concepts in manufacturing. Just In-Time (JIT), Total Quality Management (TQM), and Factory Automation (FA) are well known concepts. Much literature is available about them, including a few success stories in the United States. The concept of Total Productive Maintenance (TPM) is less known. It was conceived in Japan in the early

1970's and is just recently being introduced in the United States. Mr. Seiichi Nakajima, a leading advocate of TPM says [13]: "Excellent Japanese companies have another secret, however, that has pushed productivity and quality to their limits, making possible production lines with zero breakdowns and zero defects. That secret is TPM, or Total Productive Maintenance". Figure 1 illustrates how one may view the factory of the future [8]. The Just-in-Time (JIT) production concept, which has been gaining an enormous popularity in the United States, stresses the importance of producing the right amount of items at the right time. It promotes "waste free" operations on the shop floor. Total Quality Control (TQC) dedicates the responsibility of quality assurance to the entire work force, not just the QC inspectors. Factory automation (FA) employes the current technology to improve the manufacturing operations, both in terms of efficiency and quality consistency. The high cost of FA systems compels the Japanese companies to keep their automated facilities in good running condition. Consequently, maintenance of facilities with a high degree of automation has become critical to the successful implementation of automation projects [8]. With a group of dedicated workers who are trained to handle multiple tasks and to identify and solve operational problems, JIT, TQC, FA, and TPM can be effectively integrated and implemented.

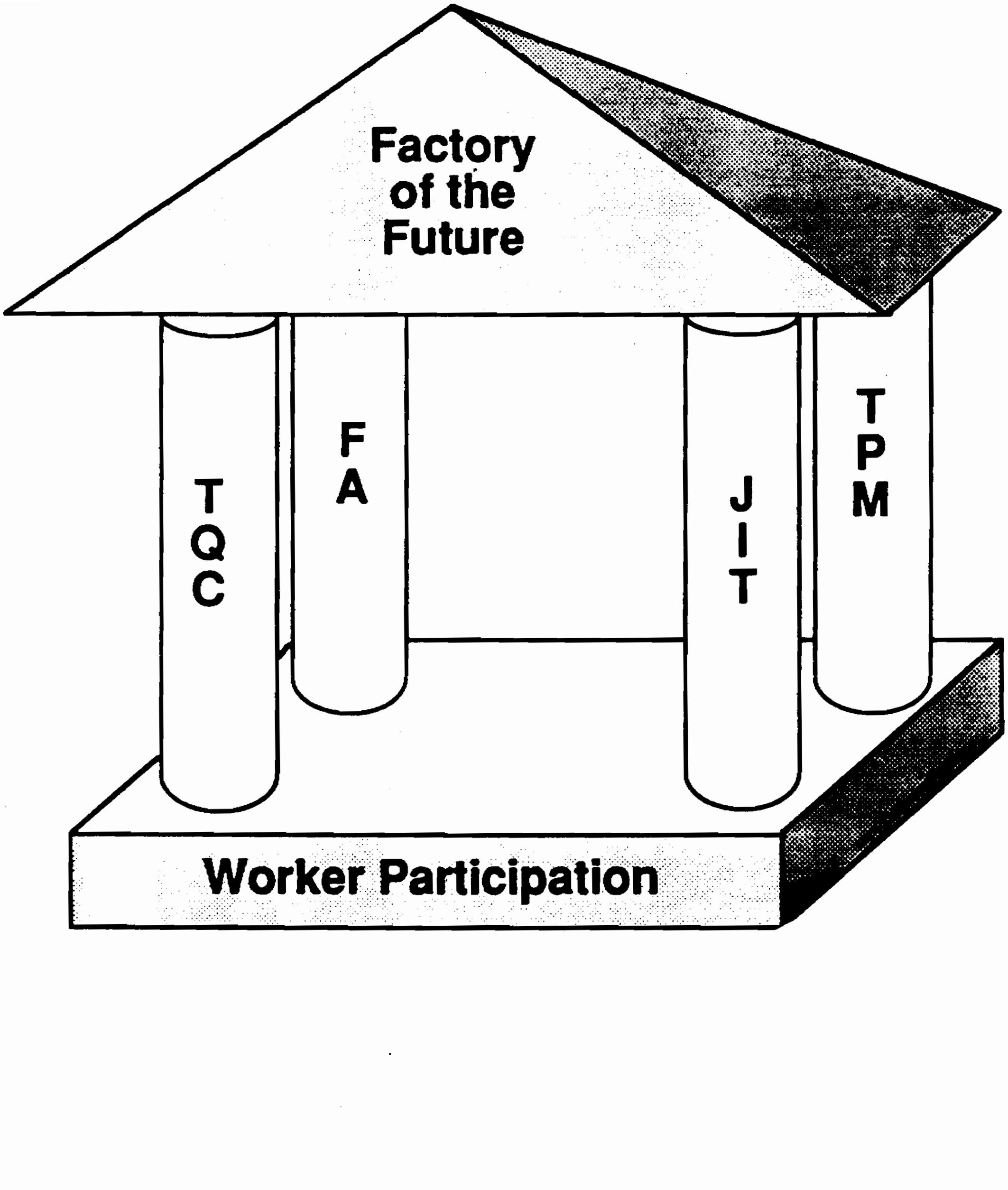

Figure 1 Factory of the Future

The application of TPM in the manufacturing environment, like at Toyota Motor Company, has been practiced in Japan with great success, and is growing in terms of application [13]. However, Total Productive Maintenance has still to make inroads into other areas such as processing and transportation industries.

Given the objectives and successes of TPM in Japan, it seems appropriate that such methods be "tested" in the United States. This project investigates the implementation of selected facets of TPM in a local manufacturing company. Several companies were visited and the company was selected because of the willingness of its management to cooperate.

1.1 Description of the Company

The company primarily manufactures bearings for compressors. A layout of the firm's 200,000 $ft.^2$ facility is shown in Figure 2. The company has approximately 400 employees and produces between 10 to 12 million bearings per month. The product mix changes steadily, and more importantly the demand for tighter tolerances has increased over the years and will likely continue to increase. The company has been able to keep up with increased competition from other countries in the past. There have been programs

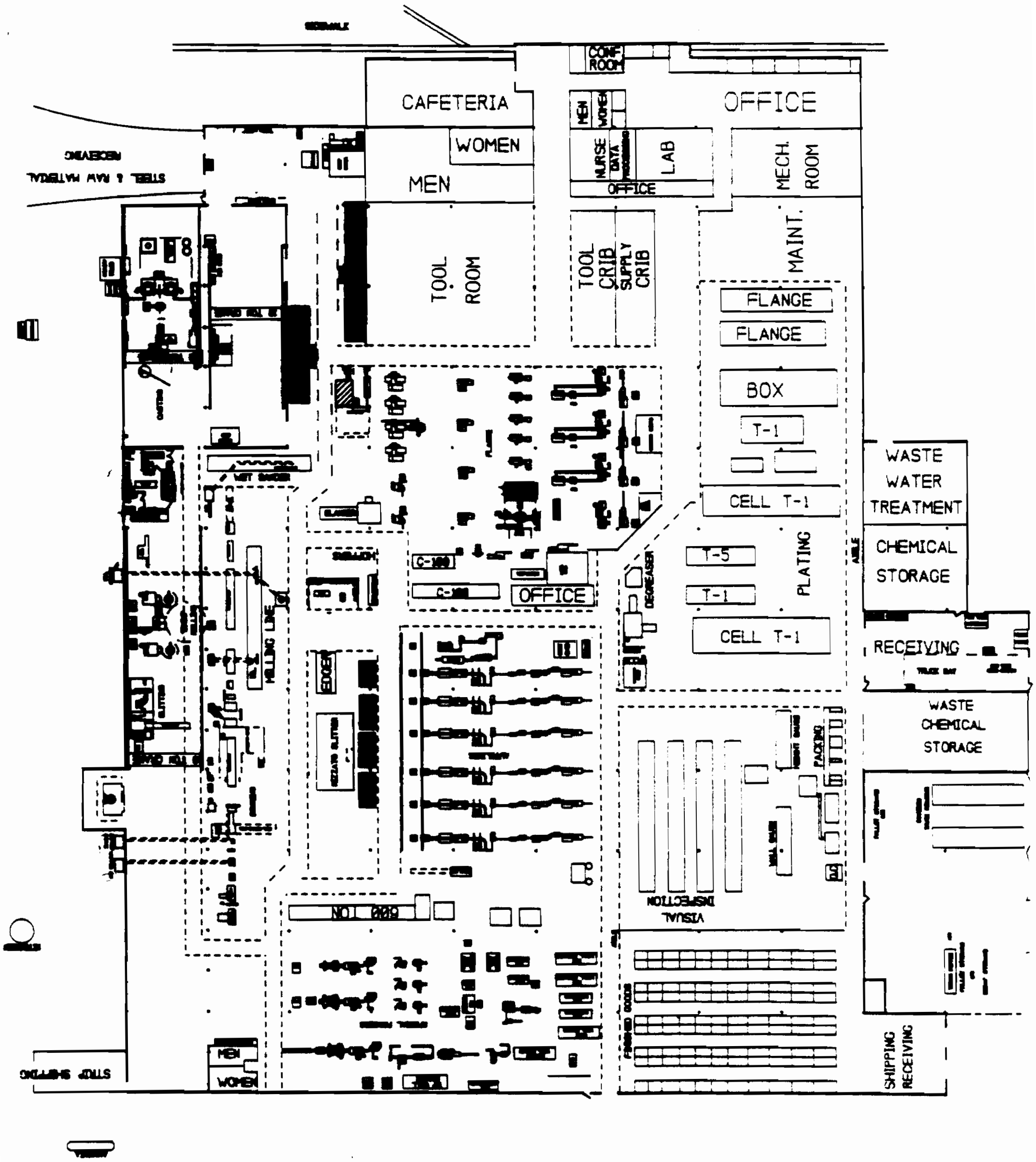

Figure 2 Company Layout

initiated from within the company to increase the competitiveness. Recently, a setup reduction program has been successfully implemented. This year alone production lot sizes have been cut in half on two different occasions. There have been examples of setup reductions from 15 hours down to 2 hours. These results have been accomplished by carefully studying internal and external setup actions [11]. The company has been able to significantly reduce work in process (WIP) as a result of this program, and will strive for even better results in the future.

The facility is being expanded (50,000 ft.^{2}) by adding a new line upfront in the manufacturing process. This new line is intended to produce aluminum coils from raw material (ingots) for the subsequent processes. There are two basic types of material used for bearings, aluminum and steel. The steel coils will continue to be bought from outside sources. The aluminum will in the future be bought in the form of ingots and processed in the factory into coils, (see Figure 3). This expansion should help reduce material cost for the company, and will also help to reduce the value of WIP, by replacing the inventory of expensive aluminum coils with less expensive raw materials.

In the future the company hopes to win new markets abroad. There are already signs of this taking place by recent sales to Japan. Another important step has been taken in South

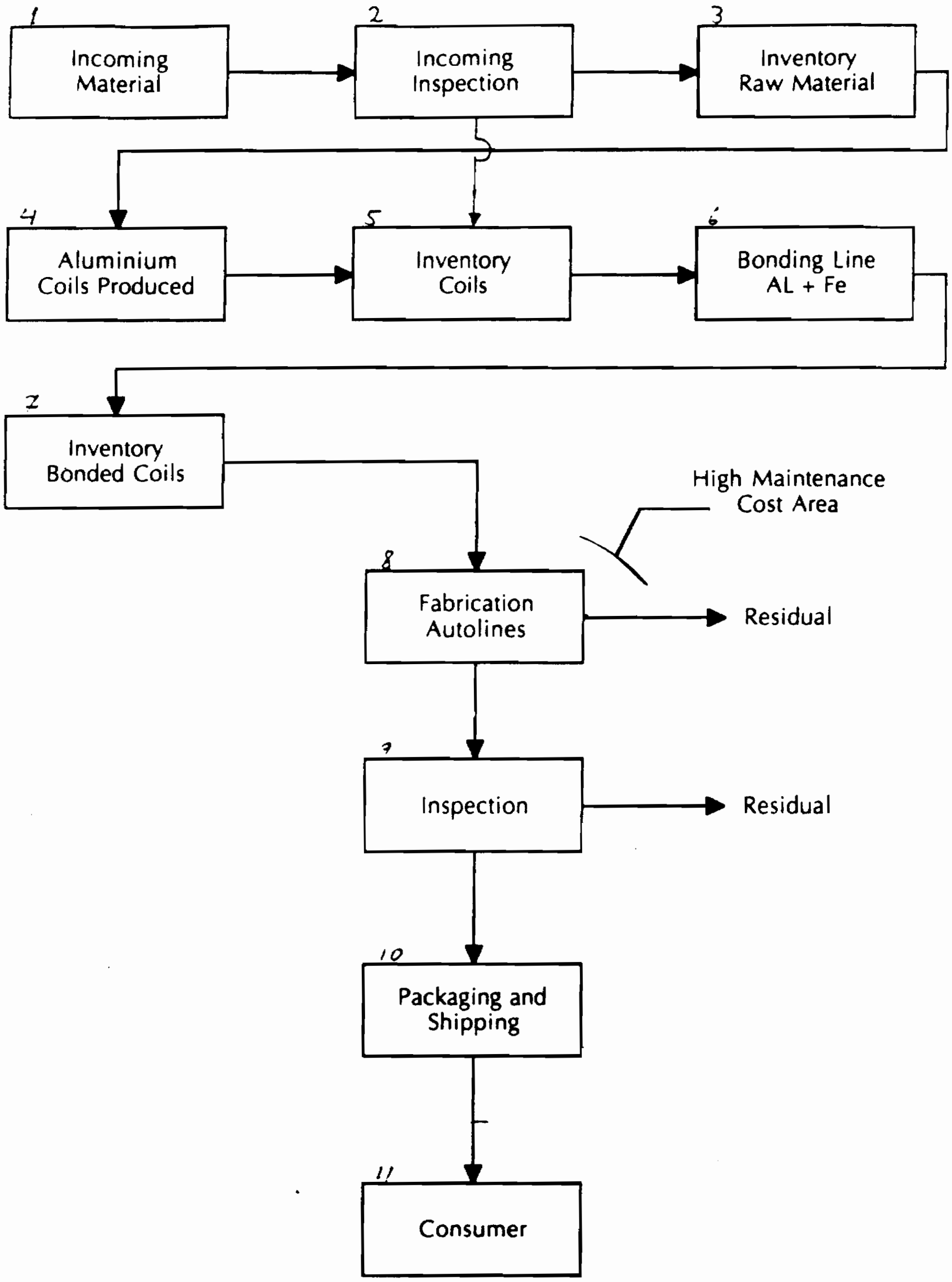

Figure 3 Production Operation Functional Flow Diagram, (only through Autolines).

Korea by opening a plant in cooperation with a company from that country. Such a cooperative manufacturing venture is likely to expand international sales even further.

1.2 Nature of the Problem

When visiting the company in the spring of 1990 for the first time, the willingness of the company to cooperate in any projects that could increase productivity was indicated. Maintenance was not mentioned, although Just-in-Time (JIT) and Total Quality Control (TQC) were discussed briefly. At a later point in time, interest was expressed by the company in accomplishing a study of its maintenance operations. The overall maintenance organization has never been given much attention and, until eight months ago, all maintenance was corrective in nature. Today, preventive maintenance is performed every six months. Management is particularly concerned about frequent shutdowns in the highly automated production process commonly called "The Autolines". Half of the company's production has to go through this area for processing, (see Figure 3).

In essence, the company has been experiencing frequent production line stoppages, an increase in maintenance requirements, and the costs associated with maintenance and support activities have been increasing.

1.3 Objective of the Project

The main objective of this project is to study the concepts and techniques of TPM. In view of the current dilemma of the company, this project also included the objectives of (1) providing a better assessment of the current status of the company's maintenance operations, and (2) providing some recommendations for possible improvement. With regard to providing an accurate assessment of the problem, it was necessary to develop and implement a data collection task in order to establishing a baseline for comparative purposes. The company did not have an adequate data collection, analysis and evaluation activity. Given a better definition of the problem, the objective was to investigate the feasibility of implementing TPM methods with the intent of identifying specific areas where the company can improve its maintenance operations for greater productivity.

The specific objectives of this project were as follows:

1. Study the concepts of TPM, its applications, measures, and the procedures for implementation.

2. Visit the company, identify its products, production goals, etc., and determine the methods for applying TPM principles.

3. Demonstrate an approach to the implementation of TPM within the company. TPM is a companywide equipment maintenance and therefore it is important to study a total integrated approach to the implementation of TPM.

4. Identify areas where changes for improvement can be initiated. In what areas is the company mainly lacking? Can the company improve those areas and how?

2.0 MAINTENANCE - OVERVIEW

Systems in use today are highly complex and can fulfill most performance requirements when operating. Maintaining the system so it can fulfill its intended mission is an important part of every organization. "Maintenance is the routine recurring work which is required to keep a system (plant, building, structure, machine, item of equipment, or any real property) in such a condition that it can be utilized at its original or designed capacity and efficiency" [10]. Maintenance activities comprise lubrication, modification, improvement, inspection, cleaning, and repairing. The prime function of maintenance is the ability to sustain running equipment so manufacturing and supporting activities can go on, the final product shipped and a profit made.

Nothing made by man is indestructible , but the useful life of a system can be extended by carrying out repairs at designated intervals through an activity known as maintenance [5]. With systems getting more and more sophisticated and complex every year, it is of extreme importance to make sure that the maintenance system utilized is capable of supporting this increased complexity. A policy decision must be made for each piece of equipment regarding its maintenance. Should the equipment be serviced by preventive or by corrective (emergency)maintenance ? The relationship between the cost of preventive and breakdown maintenance is shown in Figure 4 [19]. The cost of preventive maintenance must be weighed against the cost of a breakdown. Therefore, to ensure that the manufacturing capability is maintained at a desired level, the maintenance activity is essential. Its overall objective is to maximize the production output at a minimum cost [1].

The cost of maintenance is increasing faster than inflation [6,8]. It is estimated that since 1969, the average rise in maintenance cost has been 8.6% a year. This is primarily due to such factors as: increased automation and complexity, the lack of proper inventory control for spare parts, the lack of education and training, and limited understanding of how maintenance cost accumulates during the life-cycle resulting in little care for cost reductions in the maintenance area [16]. But, probably the most important contributor to escalating maintenance costs are the myths and misconceptions that surround Total Quality Control (TQC) and consequently not applying it in the maintenance function. By applying the principles of TQC to the maintenance activity, the increased cost of maintenance could have been largely avoided [18]. The most popular misconceptions about Total Quality Control (TQC) are [18]:

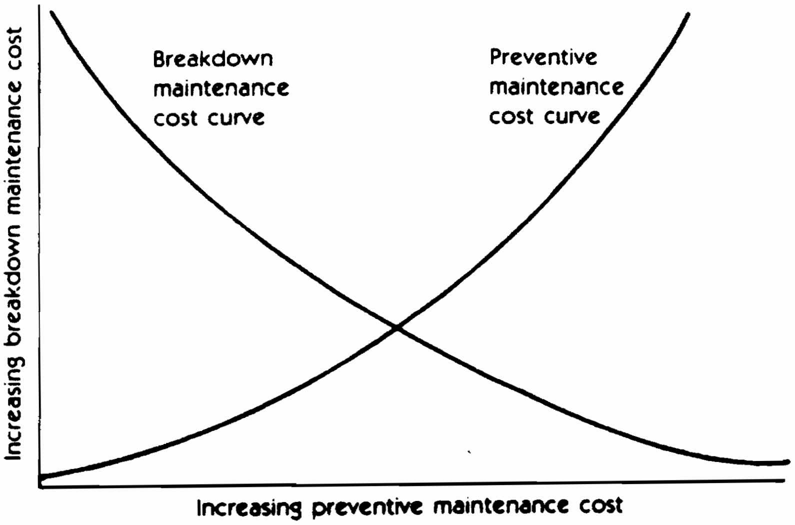

Figure 4 The Relationship Between The Cost of Preventive and Breakdown Maintenance [19]

TQC is very costly; TQC is a massive paper generator; and TQC places an emphasis on correcting deficiencies after the fact rather than preventing defects from occurring in the first place.

If TQC is none those things, then what is it ?:

TQC is cost effective;
TQC is an aid to productivity;
TQC is a means of getting it right the first time every time;
TQC is good management sense, and, most importantly;
TQC is the responsibility of every one.

Total Quality Control (TQC) is not quality control or inspection. The principles of TQC should be applied to the maintenance function as to every other activity within the organization. Although a TQC program will include quality control and inspection, both these activities form only a part of company's total commitment to the control of manufactured item.

2.1 Life-Cycle Cost and Maintenance Costs

Life-Cycle Cost (LCC) is the total cost associated with a system over its life cycle. The life cycle can be broken down into four phases [2]. These are the research and development phase, the manufacturing phase, the operations and maintenance phase, and finally the retirement phase. From an economic standpoint, total cost visibility is often lacking. Experience indicates that system maintenance has been a "high-cost contributor" to life cycle cost. [2,14]. The cost of maintaining equipment generally exceeds the original purchase price by a wide margin. It is not unusual, for example, for service and repair charges on an automobile to add up to more than double what was paid for it ten years ago. Savings in product maintenance costs can be translated into customer goodwill and reduced warranty expense. According to Marvin A. Moss [12], lifetime maintenance costs are determined by four things:

1. The different ways in which the product can fail to perform properly.
2. The frequencies of with which these different types of failures can occur.
3. The nature of the repairs required for correcting each type of failure.

4. The extent of the routine servicing described by the manufacturer.

The four different categories described are aimed at capturing all routine maintenance expenses. These include both preventive maintenance costs (PM) and breakdown maintenance costs (BM). Maintainability improvement costs (MI) are not accounted for in this listing. The concept of maintainability improvement is relatively new for many commercial manufacturers. The ratio of preventive maintenance cost to breakdown maintenance cost is a good measure of maintenance effectiveness [3]. The goal is to have all maintenance preventive and zero breakdowns. Maintenance must be addressed in the context of the total system, on an integrated basis, and in terms of the life cycle [2].

2.2 Reliability

Perhaps the best introduction to the meaning of reliability can be found in a couple stanzas of an old poem by Oliver Wendell Holmes, Sr., called "The Deacon's Masterpiece, or the Wonderful One-Hoss-Shay" [12].

Now in building chaises, I tell you what, There
is always somewhere a weakest spot,-- In hub,
tire, felloe, in spring or thill,
In panel, or crossbar, or floor, or still,
In screw, bolt, thoroughbrace, --lurking still,
Find it somewhere you must and will.--
Above or below, or within or without,--
And that's the reason, beyound a doubt,
A chaise breaks down but doesn't wear out.

But the Decon swore (as Decons do,
With an "I dew vum," or an " I tell yeou,"
He would build one shay to beat the taown
'n' the keounty 'n' all the kentry raoun',
It shall be so built that it couln' break daown,
--"Fur," said the Deacon, "'t's mighty plain
Thut the weakes' place mus' stan' the strain;
'n' the way t' fix it, uz I maintain,
Is only jest
T' make that place uz strong uz the rest.

The Deacon's view is, a reliable machine is one that wears out instead of breaking down, and the way to avoid breakdowns is to make "... that place uz strong uz the rest." One possible definition of reliability could be stated as follows [12]:

> "Any reliable device, whether it can be a horse-drawn chaise or any other kind of mechanism, is one that

> continues to perform its intended function throughout its intended useful lifetime, regardless of adverse operating conditions".

It must be added that a product cannot be expected to function reliably without proper maintenance or if it is subjected to adverse operating conditions which exceed reasonable limits. Whenever economically viable, the designer should design for no maintenance.

On the basis of lifetime testing, conducted on a great deal of different parts, it has been postulated that a curve representing failure rate plotted against hours of operation, actually depicts three successive stages of failure phenomena, (see Figure 5). Every product has a different curve, but the shape usually is along the lines described hereafter. This curve has become to be known as the "Bathtub Curve". The first stage, called the infant mortality stage or break in stage, has a high failure rate, because the manufacturing defects tend to show up in the beginning of use of a product.

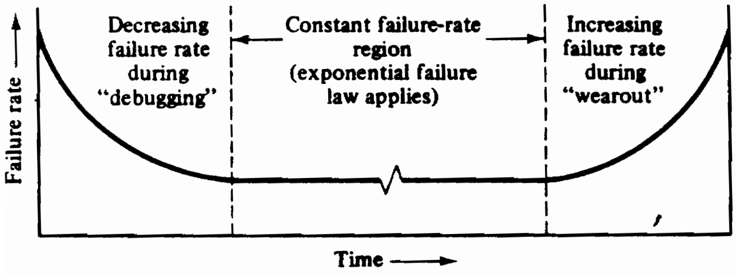

Figure 5 Bathtub Curve [2]

The second stage is taken as the safe useful service period, often modelled by an exponential equation for reliability calculations (e.g. electronic equipment)::

$$R(t) = e^{-t/MTBF}$$

The third and the last stage is represented by a wearout or deterioration phase, the product has delivered its useful (economical) life service, and is fastly approaching retirement.

If the operating time for a piece of equipment is the same as MTBF and the equation above used, the probability of success would be only 37% during the period. If the operating time used is only one fifth of MTBF, the probability of success should be 82% during that period. This indicates that a proper preventive maintenance interval should be much less than MTBF. A good maintenance schedule achieves between 70 and 90% probability of success [19].

2.3 Maintainability

Maintainability (like reliability) is a characteristic of equipment design and installation which is expressed in terms of ease and economy of maintenance, availability of the equipment, safety, and accuracy in the performance of maintenance actions [2]. Highly sophisticated systems have often very low inherent reliability, and if they also take a long time to maintain and troubleshoot, the availability or uptime of such systems becomes untolerably low.

Design for minimal maintenance costs is affected more by maintainability, rather than reliability. However to fully grasp and properly apply the principles of the former, the principles of the latter must first be understood and mastered. The reliability calculations can be used to estimated the failure rate for a design. Based on the knowledge of failure rate a maintainability policy can be determined. Parts with high failure rates need quick repair or replacement when they fail. For parts with low failure rates the emphasis on quick turnaround time is much less urgent, their affect on the systems availability is often insignificant. Because the user of a product needs a simple and convenient means of expressing the combined effect of product reliability and maintainability, in terms directly related to the way he or she uses that product, a design attribute called availability has been formulated. These three attributes -reliability, maintainability, and availability- are best understood when considered in that order [12]. Good maintainability can be assured by using fundamental maintenance principles such as: standardization, modularization, functional packaging, interchanageability, accessibility, malfunction annunciation, and fault isolation.

Logistics is also very important. Blanchard [3] defines logistics as "the art and science of management, engineering, and technical activities concerned with requirements, design, and supplying and maintaining resources to support objectives, plans, and operations." Attention must be given to having the spare parts ready when they are needed, as often as possible, otherwise all the maintainability improvements are of limited value.

2.4 Effectiveness Measures

An important part of any maintenance organization is the capability to monitor the system to be maintained. Without this, little is known about the effectiveness of a maintenance program and equally important the changes that take place over time.

The various performance indexes or effectiveness measures a company decides to use can often be conflicting by nature. Each company must decide which indexes are appropriate in its unique situation.

The most basic and appropriate effectiveness measures that are often used [2] are:

1. Availability (A):

$$\frac{\text{Production operating time}}{\text{Production operating time + Downtime}}$$

2. Meantime between failures (MTBF):

$$\frac{\text{Number of operating hours}}{\text{Number of breakdowns}}$$

3. Meantime to repair (MTTR) *:

$$\frac{\text{Sum of all repair time}}{\text{Number of breakdowns}}$$

4. Maintenance breakdown severity:

$$\frac{\text{Cost of breakdown repair}}{\text{Number of breakdowns}}$$

5. Maintenance improvement:

$$\frac{\text{Total maintenance man-hours on PM}}{\text{Total Maintenance man-hours available}}$$

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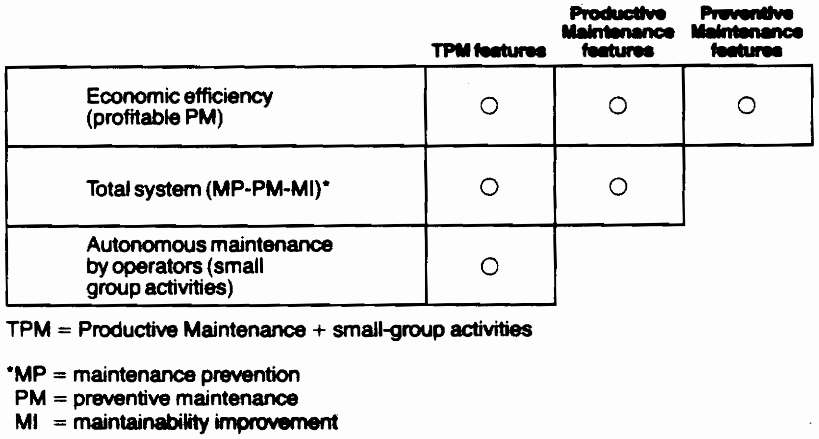
* An approximation to the MTTR formulation, see Blanchard [2].

3.0 TOTAL PRODUCTIVE MAINTENANCE (TPM)

One of the leading advocates for Total Productive Maintenance (TPM) is Mr. Seiichi Nakajima, currently Vice Chairman, Japan Institute of Plant Maintenance. He describes TPM as [13,14]: "Productive maintenance implemented by all employees, based on the principle that equipment improvement must involve everyone in the organization, from line operators to the top management. The key innovation in TPM is that operators perform basic maintenance on their own equipment. They maintain their machines in good running order and develop the ability to detect potential problems before they generate breakdowns". TPM was first introduced in Japan more than ten years ago and today is widely accepted as the next step in maintenance development and practice. In Figure 6, various sorts of maintenance activities are related to each other. Preventive maintenance was first introduced in the 1950's. The main idea of PM was to find a more economical way for performing maintenance. In other words, it is an economic trade off between frequent scheduled preventive maintenance and less frequent corrective maintenance. A more far reaching methodology was the introduction of productive maintenance which became popular during the 1960's. It



	TPM features	Productive Maintenance features	Preventive Maintenance features
Economic efficiency (profitable PM)	○	○	○
Total system (MP-PM-MI)*	○	○	
Autonomous maintenance by operators (small group activities)	○		

TPM = Productive Maintenance + small-group activities

*MP = maintenance prevention
PM = preventive maintenance
MI = maintainability improvement

Figure 6 Relationship Between TPM, Productive Maintenance, and Preventive Maintenance [14] extends the maintenance function further by finding ways to improve the equipment (system), reduce the failure rate through maintenance prevention, and using maintainability improvements (MI) in order to reduce meantime to repair (MTTR). TPM uses the ideas from preventive and productive maintenance, but the distinctive feature of TPM is the use of the equipment's operators in the maintenance function (autonomous maintenance).

Another well known Japanese, Mr. Taiichi Ohno defines the Toyota production system as an absolute elimination of waste [11,13]. TPM fits very well into this "waste" concept. Breakdowns and defects in production are certainly one important form of waste that should be eliminated. In Toyota's Just-in-Time production , only "the necessary items are produced, when needed, and in the amounts needed" [11]. This can only be accomplished when the operation is smooth and without any disruptions that could hinder the minimum waste goal becoming a reality. Toyota recognizes the importance of TPM [13]. In Mr. Ohno's words: "without TPM, the Toyota production system could probably not function".

In order for TPM to be effective, it must be implemented on a companywide basis. Without the support and commitment of top level management TPM can not be successful. The same can also be said about the workers involved. Their support is essential because they are the ones who carry out the autonomous maintenance work.

According to Mr. Nakajima, TPM must include the following five elements:

1. TPM aims to maximize equipment effectiveness (overall effectiveness).
2. TPM establishes a thorough system of Preventive Maintenance (PM) for the equipment's entire life span.
3. TPM is implemented by various departments (engineering, production, maintenance).
4. TPM involves every single employee, from top management to workers on the floor.
5. TPM is based on promotion of PM through motivation management: autonomous small group activities.

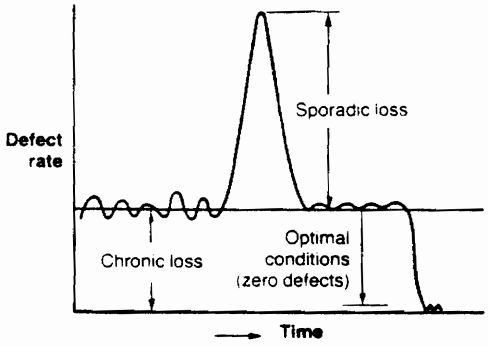
It is important to understand the meaning of the word "total" in TPM. It has three meanings:

1. Total effectiveness, or economic efficiency.
2. Total maintenance system, i.e., PM activities along with maintenance prevention (MP) and maintainability improvement (MI).
3. Total Participation: autonomous maintenance by

operators and small group activities in every department and at every level.

3.1 Chronic Losses

In striving for zero breakdowns, TPM promotes "defects free" production. Looking back at what was said in section 2.2 about reliability and the bathtub curve, it was stated that the flat part of the curve is "...the safe useful service period...". In other words, after the breakin period the failure rate is much lower and it is often assumed that we have reached a minimum failure rate. However, TPM treats this flat part of the Bathtub curve differently. It refuses to accept the flat part achieved as normal, but names it "chronic". Chronic losses are caused by hidden defects in machinery, equipment, and methods. If fundamental conditions in the manufacturing environment are to improve, chronic losses and hidden defects must be completely eliminated [13]. In Figure 7, a comparison is made between chronic and sporadic losses. Chronic is a reoccurring condition and is usually not attacked in the same way as a sporadic loss. A sporadic condition is a sudden adverse change in the status quo. It is an infrequent or unusual event that can leads to a sudden



Key is restoration

- To return to previous level

Key is innovation

- To achieve optimal conditions

Chronic losses become obvious when compared with optimal conditions

Figure 7 Chronic and Sporadic Losses [14] breakdown or obvious loss of quality (e.g., worn cutting tool). A chronic condition is a longstanding adverse situation, caused by hidden defects in machinery, equipment, and methods (e.g., unrealistic tolerances) [9,13].

To better understand the sources of the chronic losses, it is helpful to categorize equipment reliability into intrinsic reliability and operational reliability. Intrinsic reliability is based on design and is determined during the design, fabrication, and installation stages. Operational reliability is determined by the user and is related to how and under what conditions the equipment is operated and maintained. Total reliability is a product of intrinsic and operational reliability. When breakdowns and quality defects occur, the source of low reliability must be investigated. Five type of actions are necessary to uncover hidden defects and treat them properly [14]:

- Maintain basic equipment conditions (cleaning, lubrication, bolt tightening).
- Adhere to operating conditions.
- Eliminate deterioration.
- Correct design weaknesses.
- Improve operating and maintenance skills.

Failure to treat root causes results in the recurrence of similar problems, and the chronic losses are allowed to continue without the necessary actions. The problem is further amplified by tight production schedules, allowing no time for improvement activities. The earlier this vicious cycle can be broken, the better and the goal of reducing and eventually eliminating chronic losses realized.

3.2 Overall Equipment Effectiveness (OEE)

Equipment effectiveness is a measure of the value added to production through equipment. The value added is increased as equipment availability and productivity increase and defects in process and rework decreases. The value added to a product by equipment is significantly reduced by waste. TPM identifies six major types of losses or waste. The six types of losses are [13]:

Down time:

1. Breakdown losses
2. Setup and adjustment losses

Speed losses:

3. Speed losses (due to actual running speed is less than equipment capability).

4. Idling and minor stoppage losses

Defect losses:

5. Quality defect and rework losses
6. Startup (yield) losses

The downtime losses determine the availability of the equipment. The speed losses affect the performance rate, and the defect losses determine the quality rate in the overall production. If the six losses are known, overall equipment effectiveness (OEE) can be calculated using the formula:

$$OEE = \text{availability} \cdot \text{performance rate} \cdot \text{quality rate}$$

Nakajima [14] states that based upon experience, the ideal conditions are:

- **Availability...greater than 90%**
- **Performance efficiency...greater than 95%**
- **Rate of quality products...greater than 99%**

Therefore, the ideal overall equipment effectiveness should be:

$$0.90 \cdot 0.95 \cdot 0.99 \cdot 100\% = 85\% \text{ and greater.}$$

Nakajima adds that this ideal overall equipment effectiveness is not an unrealistic goal. Many manufacturing companies have achieved it and have even higher overall equipment effectiveness. Figure 8 gives an example of a calculation of overall equipment effectiveness for further clarification. In this example, the resulting OEE is only 42.6%, substantially less than Nakajima's ideal goal. However, most companies' overall equipment effectiveness is in the range of 40% to 60% before TPM implementation [14]. A high level of equipment effectiveness can only be achieved when all three effectiveness measures are high.

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. The following principles must be applied when attempting to improve the overall equipment effectiveness [14]:

- Make detailed and accurate measurements,
- Set firm priorities, and
- Establish clear directions or goals.

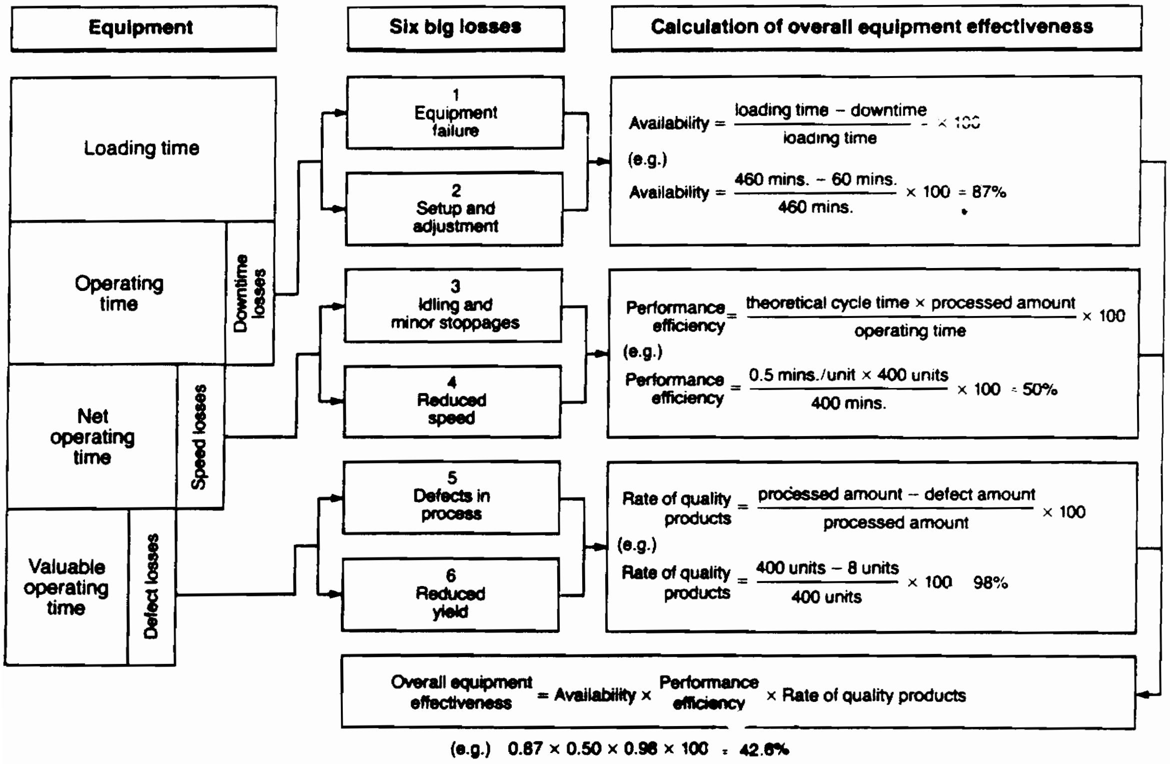


Figure 8 Overall Equipment Effectiveness (OEE) [14]

Once that the overall equipment effectiveness is known, priorities can be determined. If, for example, idling and minor stoppages are the main contributing factor to low overall equipment effectiveness, the root causes must be determined and proper action taken (e.g., inadequate lubrication or metal chips).

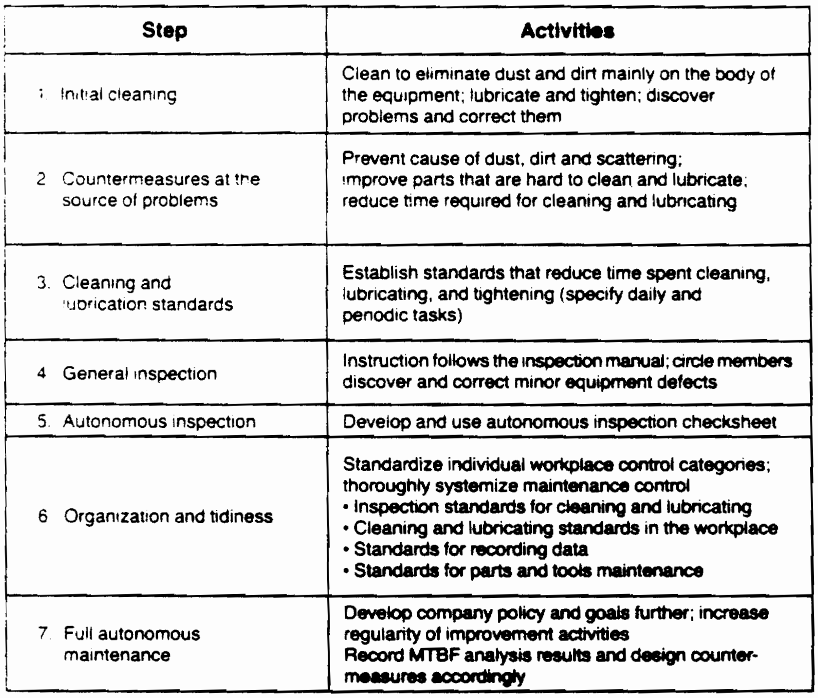
3.3 Autonomous Maintenance

The most unique feature of TPM is the "autonomous maintenance" by operators. This is not easy to achieve in today's environment of "I operate, you fix it". The separation of actual production and maintenance has not always been like it is today. In the beginning of the Industrial Revolution operators accepted the maintenance responsibility. If an engine broke down they fixed it. After all, they were the "operators" and that also included keeping the equipment "operational". As time went by, companies began to group themselves more and more into departments and divisions and at the same time erect walls between functions that used to be performed by the same person.

There are many factories where operators already check and lubricate the equipment. Unfortunately, this activity is often performed without any enthusiasm, understanding or interest. Inspection sheets are filled out because they have to be turned in. The information value is often little to none if the proper level of attention is not paid to the actual inspection of the equipment. This does not have to be so; in fact, the Japanese have realized the importance and advantage of involving the operators heavily in the maintenance of equipment. In Japan, the basic principles of industrial housekeeping are known as the five S's [13]: seiri (organization), seiton (tidiness), seiso (purity), seiketsu (cleanliness), and shitsuke (discipline). Often these principles are implemented only on a superficial level (e.g., painting floors and equipment), while actual maintenance of equipment is inadequate (e.g., neglecting the interior of the equipment, such as revolving parts) [13].

This superficiality is avoided in TPM's autonomous maintenance by breaking down training and practice into seven steps. Each step must be fully mastered and understood by the operator before he or she can attempt the next one. The seven steps and an explanation of each are shown in Table 1. The first step, initial cleaning, recognizes that cleaning is inspecting. Cleaning helps the operator to discover problems and to get more familiar with the equipment. In the steps that follow, the operator's capability is enhanced by going through extensive training

Table 1 Seven Steps for Developing Autonomous Maintenance [14].



Step	Activities
1. Initial cleaning	Clean to eliminate dust and dirt mainly on the body of the equipment; lubricate and tighten; discover problems and correct them
2. Countermeasures at the source of problems	Prevent cause of dust, dirt and scattering; improve parts that are hard to clean and lubricate; reduce time required for cleaning and lubricating
3. Cleaning and lubrication standards	Establish standards that reduce time spent cleaning, lubricating, and tightening (specify daily and periodic tasks)
4. General inspection	Instruction follows the inspection manual; circle members discover and correct minor equipment defects
5. Autonomous inspection	Develop and use autonomous inspection checksheet
6. Organization and tidiness	Standardize individual workplace control categories; thoroughly systemize maintenance control • Inspection standards for cleaning and lubricating • Cleaning and lubricating standards in the workplace • Standards for recording data • Standards for parts and tools maintenance
7. Full autonomous maintenance	Develop company policy and goals further; increase regularity of improvement activities Record MTBF analysis results and design countermeasures accordingly

and education. These provide the operator with the ability to find the sources of problems and take appropriate actions. In the last step, the operator uses rather sophisticated data to follow up on the maintenance and its effectiveness. The seven-step development takes many years to master. Often, three years is considered to be satisfactory progress [13,14].

The production and maintenance department must work together. They have to understand each other's situation and avoid confrontation. A classification of maintenance activities and allocation of tasks is necessary.

In TPM, the production department must carry out three deterioration-prevention activities:

1. Deterioration prevention:
   Operate equipment correctly, maintain basic equipment condition, record breakdown data, and make adjustments.

2. Deterioration measurement:
   conduct daily and other minor periodic inspections.
3. Equipment restoration.
   Make minor repairs, report breakdowns to maintenance department, reduce sporadic losses.

The responsibility of the maintenance department after TPM implementation, is to perform major periodic maintenance, predictive maintenance, maintainability improvement, research and development of maintenance technology, set maintenance standards, keep maintenance records, evaluate results of maintenance work, and cooperate with engineering and equipment design departments.

3.4 TPM Implementation, Education and Training

The task of implementing TPM and providing the proper education and training is not an easy one. Before attempting to do anything in terms of implementation, it is important to analyze the current situation within a company. The first step is to measure the overall equipment effectiveness. Based on these measurements, goals can be set for the company. Examples of TPM effectiveness (from Japan) are given in Table 2 [14]. These include goals in the area of productivity, quality, cost, delivery, safety and environment, and moral. These can all be measured and goals set for improvements.

The experience from Japan is it takes on the average 3 years to fully implement and see the benefits from a TPM

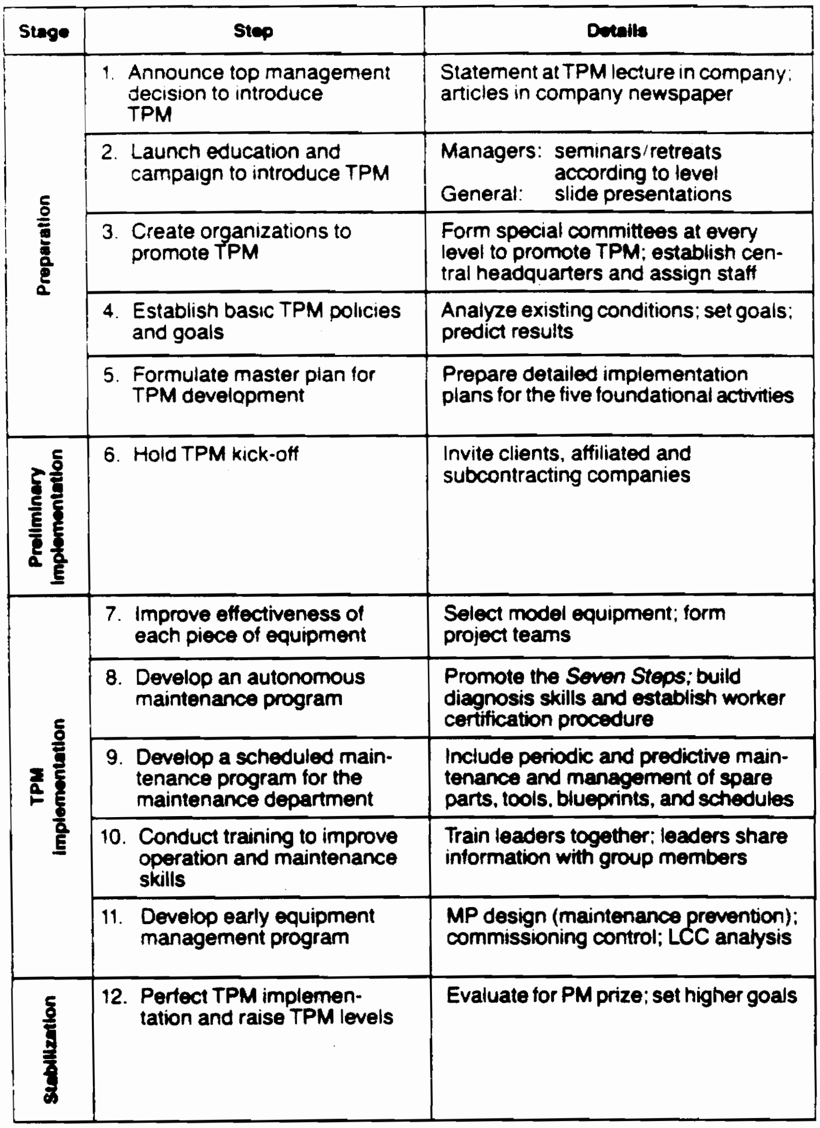
Table 2 Examples of TPM Effectiveness [14]

Category	Examples of TPM Effectiveness
P **(Productivity)**	• Labor productivity increased: 140% (Company M) 150% (Company F) • Value added per person increased: 147% (Company A) 117% increase (Company AS) • Rate of operation increased: 17% (68% → 85%) (Company T) • Breakdowns reduced: 98% (1,000 → 20 cases/mo.) (Company TK)
Q **(Quality)**	• Defects in process reduced: 90% (1.0% → 0.1%) (Company MS) • Defects reduced: 70% (0.23% → 0.08%) (Company T) • Claims from clients reduced: 50% (Company MS) 50% (Company F) 25% (Company NZ)
C **(Cost)**	• Reduction in manpower: 30% (Company TS) 30% (Company C) • Reduction in maintenance costs: 15% (Company TK) 30% (Company F) 30% (Company NZ) • Energy conserved: 30% (Company C)
D **(Delivery)**	• Stock reduced (by days): 50% (11 days → 5 days) (Company T) • Inventory turnover increased: 200% (3 → 6 times/mo.) (Company C)
S **(Safety/ Environment)**	• Zero accidents (Company M) • Zero pollution (every company)
M **(Morale)**	• Increase in improvement ideas submitted: 230% increase (36.8 → 83.6/person per year) (Company N) • Small group meetings increased: 200% (2 → 4 meetings/mo.) (Company C)

program [13,14]. It is extremely important not to expect much for the first 3 to 6 months. It will take time to provide the proper training for managers and group leaders who in turn train the operators. Table 3 breaks down the TPM development process into twelve steps. During TPM implementation, all activities related to it are carefully monitored, and employees compensated if extra time is spent outside regular work hours in meetings, training sessions, autonomous maintenance practices, and so forth. The most difficult task is probably to get the employees interested in these types of activities. This will be a totally different experience for the average employee.

By the time factory workers are able to conduct autonomous general inspection (step 4 in Table 3), they can enjoy a real sense of accomplishment. For example, their efforts may reduce breakdowns by as much as 80%, thereby increasing productivity and making work easier.

Table 3 The Twelve steps of TPM Development [14]



Stage	Step	Details
Preparation	1. Announce top management decision to introduce TPM	Statement at TPM lecture in company; articles in company newspaper
	2. Launch education and campaign to introduce TPM	Managers: seminars/retreats according to level General: slide presentations
	3. Create organizations to promote TPM	Form special committees at every level to promote TPM; establish central headquarters and assign staff
	4. Establish basic TPM policies and goals	Analyze existing conditions; set goals; predict results
	5. Formulate master plan for TPM development	Prepare detailed implementation plans for the five foundational activities
Preliminary Implementation	6. Hold TPM kick-off	Invite clients, affiliated and subcontracting companies
TPM Implementation	7. Improve effectiveness of each piece of equipment	Select model equipment; form project teams
	8. Develop an autonomous maintenance program	Promote the *Seven Steps;* build diagnosis skills and establish worker certification procedure
	9. Develop a scheduled maintenance program for the maintenance department	Include periodic and predictive maintenance and management of spare parts, tools, blueprints, and schedules
	10. Conduct training to improve operation and maintenance skills	Train leaders together; leaders share information with group members
	11. Develop early equipment management program	MP design (maintenance prevention); commissioning control; LCC analysis
Stabilization	12. Perfect TPM implementation and raise TPM levels	Evaluate for PM prize; set higher goals

4.0 MAINTENANCE ANALYSIS CASE STUDY

This chapter details the results of a maintenance analysis performed in the case study company over a period of several weeks. The factory is divided into five distinctive areas/lines. Some of those areas/lines are almost troublefree, in terms of downtime and disruptions in production. A good example of this is the bonding line (see Appendix A). Its function is to permanently bond together aluminum and steel strips, the material used for making the bearings. A less troublefree area was chosen for this analysis. This manufacturing area is highly automated and commonly called "The Autolines", or the automatic production lines.

Early on, it became apparent that maintenance data was not readily available. Therefore, it was necessary to find ways to estimate and measure the appropriate factors for the Autolines. Three different type of sources were used to get the necessary data: (1) the maintenance personnel kept a logbook for a week of all breakdown maintenance needed in the Autolines; (2) two weeks were spent monitoring the Autolines, logging their capability and minor disruptions that occurred; and (3) the use of data already available in the factory for quality rate, setup time estimates, etc.

There are six identical and parallel Autolines in the factory. These are currently operated on three 8 hour shifts a day, five days a week. Figure 9 illustrates the steps involved in producing a bearing. First, the coiled pre-bonded metal has to be uncoiled, then flattened out, cut, marked, bent, and so forth. All this has to be done keeping extremely tight tolerances (2 to 6 thousands of an inch) for the inner diameter (I.D.) of the bearing. Figure 10 shows a process flow chart for the manufacturing processes involved. The technology for manufacturing bearings has not changed much over the years. The same basic steps still take place, but the process is more automated now than in the past. Due to this increased automation, the company is trying to reduce the manpower needed to operate each Autoline. In the past, there have been three operators on each line. Today, the goal is to have only two operators per line.

The Autolines are very high volume production lines. Almost six million pieces a month are manufactured in this section of the company alone. The company, in total manufactures between ten and twelve million pieces a month.

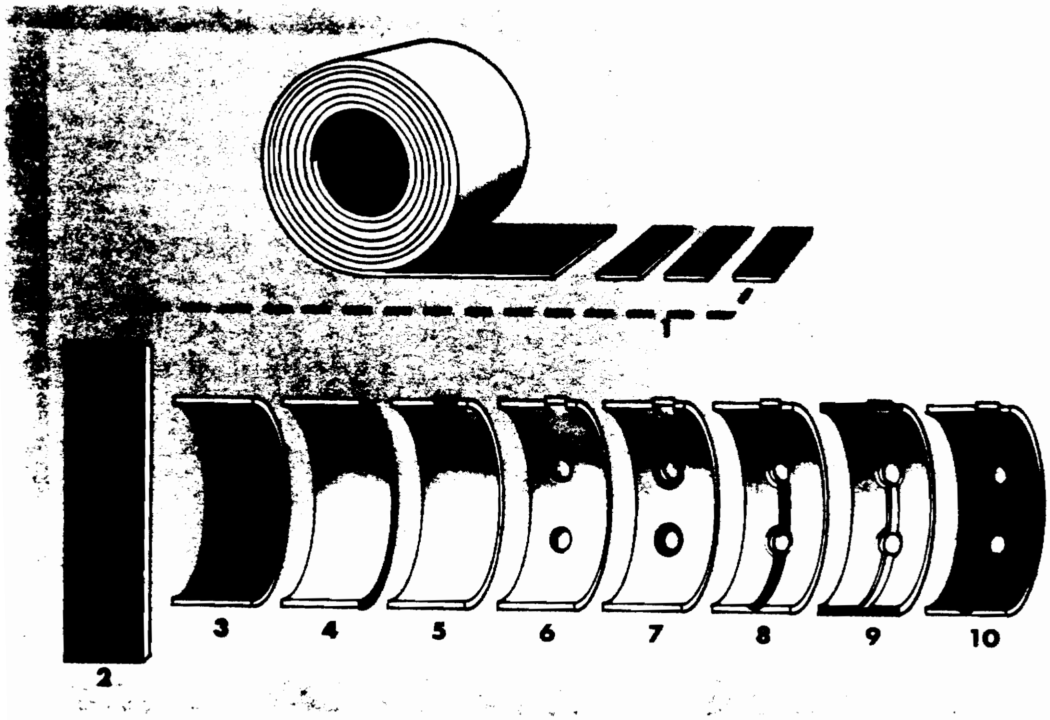


Figure 9 Basic Steps Involved in Producing a Bearing

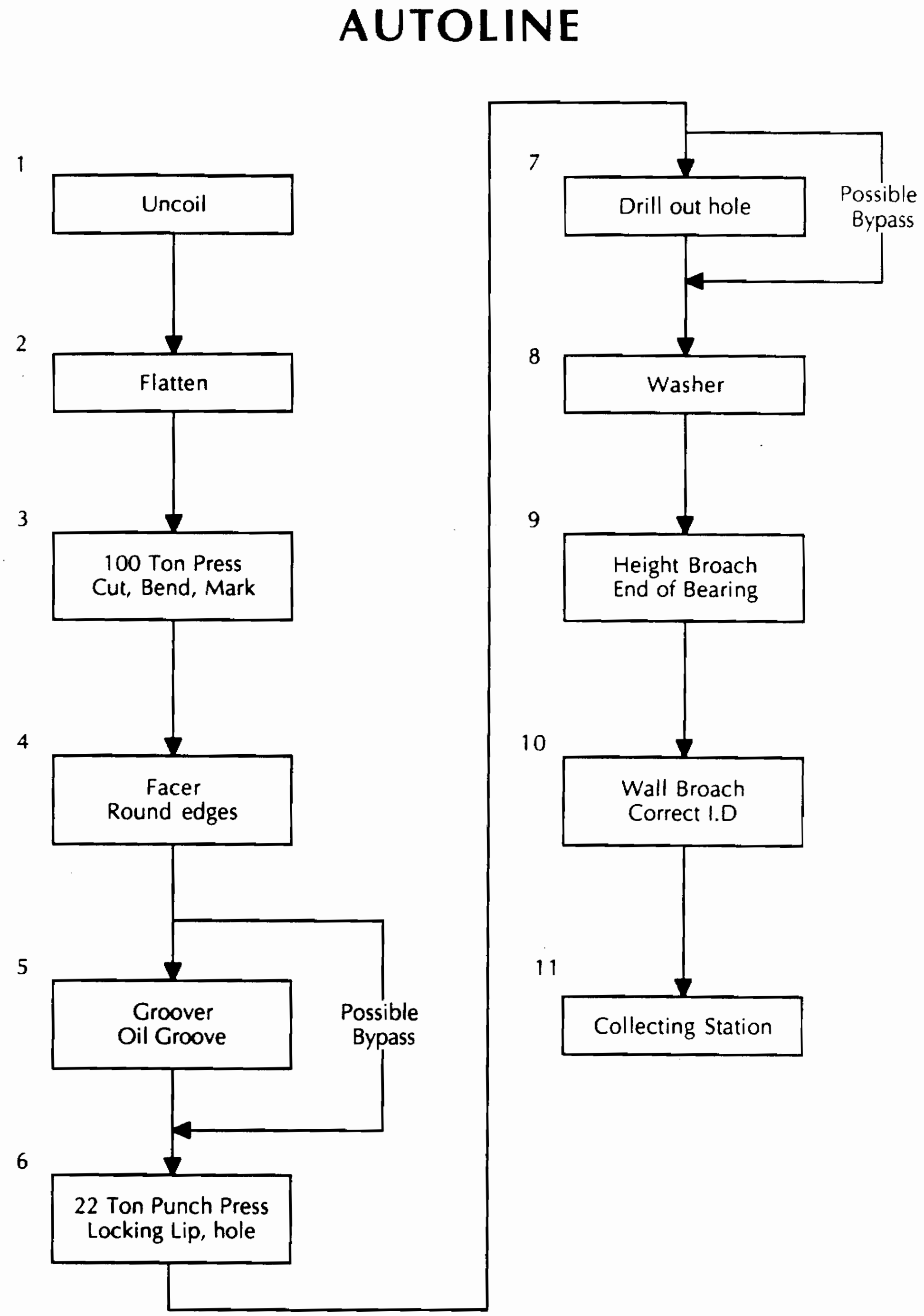


Figure 10 Autoline, Process Flow Chart

4.1 Basic Equipment Conditions

TPM describes three factors involved in maintaining basic equipment conditions [13]: cleanliness, proper lubrication, and bolting. Maintaining these basic conditions prevents equipment deterioration and eliminates potential sources of breakdowns. The following is a short description of each factor for the Autolines.

Cleanliness When one walks around the production lines, the atmosphere is comfortable, there is not a lot of dirt or chips on the floor, things are organized and people concentrate on their work. However, upon closer inspection, a lot of chips can be found in the manufacturing machines. At the end of a shift, the floor was cleaned but the machines were mostly left untouched.

Lubrication Oil can be found dripping here and there. Often the defected area is covered with a cloth and the oil either drips on the floor or into a basket, which has been put there for collecting the leaks. Empty oil containers could be found, although most oil containers had enough oil. Other lubrication seemed to be sufficient in most cases.

Bolting Another general observation concerns the structural integrity of the equipment itself. Is proper bolting maintained? The reason for mentioning this simple, but often overlooked item, is that surveys indicate that broken and loose connecting parts such as bolts and nuts play a large role in equipment breakdowns. One company discovered that defects in bolts and nuts accounted for 60% of all breakdowns [13]. A single loose bolt in a bearing unit, die, or flange, etc., can directly cause a breakdown. Also, loose bolts increase vibration. This can loosen other bolts and result in a serious breakdown. The surveys have found 20% to 45% of bolts slack or completely fallen out. In the Autolines, there were few bolts found that had fallen out. In one case, a stick made out of wood had been placed under a conveyor belt where it makes a 90 degree turn. Loose bolts are easy to see, but the condition of other bolts can only be checked with a torque wrench and that was not done. This is an area of great concern in terms of criticality, but requires relatively simple actions for improvements.

4.2 Measured Overall Equipment Effectiveness (OEE)

The determination of the Overall Equipment Effectiveness (OEE) was the next step in the analysis. As was said in chapter 3, the OEE is a measure of the value added to production through equipment. If there are problems and disruptions in production it will show up in the OEE measure. Recall that the definition of OEE is:

$$\text{OEE} = \text{availability} \cdot \text{performance rate} \cdot \text{quality rate}$$

Therefore, if one of these measures is low, the resulting OEE will be low. Only when all the measures are high can OEE be at a satisfactory level. The following is the result of the measurements performed in the case study company.

Availability

There are two types of losses that can drive down this measure: Setup and adjustment losses, and breakdown losses.

Setup and adjustment losses

The week that breakdowns and downtime were logged (Appendix B), the Autolines had 5 setup actions. Each setup action is estimated to take on the average 3 hours (rough estimate). Working 5 days a week, 3 shifts a day, following setup time per shift for all 6 lines is calculated.

Setup time:

$$\frac{5 \text{ setups} \cdot 180 \text{ min/setup}}{5 \text{ days} \cdot 3 \text{ shifts/day}} = 60 \text{ min/shift.}$$

Breakdown losses

In Appendix B, all the reported breakdowns for the week are recorded. There are two sources of breakdowns logged; mechanical and electrical. There is a short description of each problem and the estimated downtime for the line during the repair. The electricians logged this information for 14 out of 15 shifts that week, while the mechanics only logged in 8 out of 15 shifts. To correct for this difference, the downtime due to breakdowns for each category is estimated per shift, as follows:

Mechanical:

$$\frac{1{,}380 \text{ min}}{8 \text{ shifts}} = 172.5 \text{ min/shift}$$

Electrical:

$$\frac{960 \text{ min}}{14 \text{ shifts}} = 68.6 \text{ min/shift}$$

The availability can now be estimated. There are 6 lines, 3 shifts/day, 480 min/shift with a scheduled downtime of 20 min/shift. Therefore, the available loading time is 460 min/shift. The total downtime is 301.1 min/shift (setups + breakdowns). Availability is therefore:

$$\frac{\text{loading time} - \text{downtime}}{\text{loading time}} \cdot 100\%$$

$$\frac{6 \cdot 460 \text{ min.} - 301.1 \text{ min.}}{6 \cdot 460 \text{ min.}} \cdot 100\% = 89.1\%$$

Performance rate

Included in the performance rate are idling, minor stoppages, and reduced speed.

Idling and minor stoppages

A minor stoppage occurs when production is interrupted by a temporary malfunction or when a machine is idle. These types of temporary stoppage clearly differ from a breakdown. Minor stoppages and idling, while easily remedied, are also easily overlooked because they are often difficult to quantify [13].

This was determined to be the biggest problem area. It appeared as though the operation ran smoothly for only one hour at a time. Then, something got stuck or the tolerances measured were out of control, and it took 10 to 20 minutes to correct the problem. Moveable parts got stuck because of all the chips in the machines, loose bolts, etc. Sometimes when a new coil from the bonding line was started up, tolerance problems surfaced. The problem frequently occurred with the wall broach, where tolerance requirements are very difficult to meet. In all, about 730 minutes of operating time on one line was recorded on 5 shifts. The idling time, the time where nothing was coming of the line, was 255 minutes.

Reduced speed

This loss factor was not estimated in this study, but the engineers stated that the production rate in the lines is 45 to 50 pieces/min; however, this study indicated that it is actually 60 pieces/min and the rate was measured more than one time. The most probable explanation for this difference is that the company engineers are talking about the experienced production rate, including delays, over some period of time. The production rate used later in this study is 60 pieces/min. Idling and minor stoppages are the only factor entering into the performance rate. The Performance rate is estimated:

$$\frac{\text{operating time - idle time}}{\text{operating time}} \cdot 100\%$$

$$\frac{730 \text{ min} - 255 \text{ min}}{730 \text{ min}} \cdot 100\% = 65.1\ \%$$

Quality rate

This was the simplest rate to estimate. The company readily provided this number because there is very strict adherence to quality control procedures within the company.

The Quality rate is made up of defects in process and reduced yield or startup losses. The number given does not detail each loss separately, but simply gives an aggregate estimate for one recent month.

Quality rate:

$$\frac{\text{processed amount} - \text{defect amount}}{\text{processed amount}} \cdot 100\%$$

$$\frac{5{,}700{,}000 - 260{,}000}{5{,}700{,}000} \cdot 100\% = 95.4\ \%$$

Overall Equipment Effectiveness (OEE)

Based on all of the information available, it is now necessary to calculate the overall equipment effectiveness (OEE); remember that Nakajima suggests the OEE should be 85% + (i.e., availability 90%, performance rate 95%, quality rate 99%). This study indicates the OEE is:

$$\text{OEE} = 0.89 \cdot 0.65 \cdot 0.95 \cdot 100 = 55\%$$

This is less than ideal, but not uncommon for companies without TPM. Recall that surveys have shown OEE to be 40% to 60% prior to TPM implementation [13,14].

4.3 Other Effectiveness Measures

The following is a list of the five most commonly used effectiveness measures (defined in section 2.4).

1. Availability

This is the same definition as was used in the OEE estimate. Its value was 89.1 %.

2. Meantime between failure (MTBF)

The number of maintenance actions (MA) per shift observed was 6.3. Of these, 1.4 were due to electrical breakdowns and 4.9 were due to mechanical breakdowns (from Appendix B). There are 460 minutes of loading time per shift, this gives:

$$\mathrm{MTBF} = \frac{6 \cdot 460\ \text{min/shift}}{6.30\ \text{MA/shift}} = 438.1\ \text{min/line (or 7.3 hrs./line)}$$

This is the MTBF per line; in other words, a line can last approximately 7.3 hours before either a electrician or a mechanic needs to be called in. Based on this number, there are 369.9 failures per month for all 6 lines combined.

3. Meantime to repair (MTTR)

This measure is the sum of all repair time divided by the number of repairs. In Appendix B, there are 59 maintenance actions logged with a total downtime of 2,340 minutes; this gives:

$$\text{MTTR} = \frac{2{,}340 \text{ min.}}{59 \text{ MA}} = 39.66 \text{ min/maintenance action}$$

4. Maintenance breakdown severity

This is usually taken as the cost of the breakdown repair including labor, material, and spare parts.

The labor rate is $ 12.50 per hour. This has to be multiplied by 1.35 to account for benefits, giving $ 16.90 per hour. This rate is then multiplied by 1.4 to account for overhead. The final labor cost is then $ 23.66 per hour. It is estimated that a technician is only about 50% efficient working on corrective (emergency) maintenance [19]. This is due to the disruption of being pulled of another job, searching for the right spare parts, etc. Therefore, the actual time spent by the technician on the repair is 2 times the logged downtime.

Material (e.g., oil, lubrication) and spare part cost (e.g., replacement parts) is estimated as only \$ 10.00 per maintenance action. Apparently, most of the problems are relatively minor because of the low material cost. Perhaps the technicians are called in too often to solve problems which could be better solved by the operators (see Appendix B). The cost of the average repair is then:

$$\$\ 23.66 \cdot (39.7\ \text{min/MA} / 60\ \text{min/hr.}) \cdot 2$$
$$+\ \$\ 10.00\ /\text{MA} = \$\ 41.31\ /\text{maintenance action}$$

5. Maintenance improvement

This is defined as the ratio of preventive maintenance, (PM), to total maintenance man-hours expended. Ideally, it would be preferred that all maintenance is preventive and little or none corrective [2,13,14]. The cost of doing preventive maintenance is much lower because it can be scheduled outside the normal operating time of the equipment and therefore no valuable production would be lost. Currently, each line is inspected and goes through a preventive maintenance program once every six months (see Appendix C). Usually this takes place on a Saturday outside regular hours and requires 24 man-hours. Compare this with 369.9 unscheduled or corrective maintenance actions per month, each resulting in downtime lasting on the average 39.7 minutes. Including the 50% efficiency factor, approximately 489.5 man-hours are spent on corrective maintenance each month in the Autolines. The maintenance improvement ratio is then:

$$\frac{24 \text{ man-hours (PM)} \cdot 100\%}{24 \text{ man-hours (PM)} + 489.5 \text{ man-hours (corrective)}} = 4.67\%$$

This ratio is extremely low. The fact that only about 5% of all maintenance man-hours is attributed to scheduled preventive maintenance is a long way from the goal of minimizing corrective maintenance [2,13,14,19]. In the next section, the "true" cost of maintenance will be estimated and it will be shown how costly corrective maintenance is.

4.4 The Cost of Maintenance

Most people seem to accept the fact that all equipment eventually breaks down. Many people have a more difficult time accepting the cost of the breakdowns. When equipment breaks down and has to be repaired during normal production time, no value is added to a product by machines. All the opportunity to produce valuable products during the repair time has been lost forever. One could argue that loss of production during a breakdown can always be made up for some other time. Often the cost of not keeping production schedules results in heavy penalties or a loss of contract. Another fact is the reduction in lot sizes and consequently more frequent deliveries; i.e., the move to Just-in-Time production. It becomes obvious that a great deal of unscheduled downtime is totally unacceptable under those conditions. The only way to protect the customer against it, is increased safety stock, which is costly and is opposite to the goal of reduced lot sizes in the first place (i.e. reduced inventory).

Corrective Maintenance Cost

It has been shown that the cost of repair is on the average $ 41.31 per maintenance action. But the average repair takes 39.7 minutes to accomplish and (during that time the cost of lost production has not been considered.) If we want to evaluate this loss, it is necessary to discard the breakdown loss from the overall equipment effectiveness (OEE). If there are no breakdowns, the OEE would be somewhat higher. The following explains the difference:

1. Availability is higher as only setups now cause downtime. The resultant Availability would be 97.8% if there were no breakdowns.

2. Performance and Quality rate are the same; i.e., 65% and 95.4% respectively.

Therefore, if zero breakdowns were accomplished under current conditions, the OEE would be 60.7% instead of 55% shown before.

The loss in profit during a maintenance action (MA), assuming \$ 0.22 price per bearing and a 15% profit margin, is (assuming the extra production can be sold):

$$\$\ 0.22/\text{piece} \cdot 0.15 \cdot 60\ \text{pieces/min} \cdot 39.7\ \text{min/MA} \cdot 0.607 = \$\ 47.71\ \text{per maintenance action}$$

There are 2 operators per Autoline and they are idle during the repair. They each cost the company \$23.66 per hour. Therefore, the idle operator cost is:

$$\$23.66\ /\text{hr.} \cdot 2 \cdot (39.7\ \text{min/MA} / 60\ \text{min/hr.}) = \$31.31\ \text{per maintenance action}$$

Adding the cost of repair, loss in profit and idle operator cost, the total cost per maintenance action is \$120.33. There are 369.9 maintenance actions per month, and the cost is then:

369.9 MA/month · ($ 41.31 /MA + $ 47.71 /MA + $31.31 /MA) = $ 44,510.07 per month

or

$ 44,510.07 · 12 months/year = $ 534,120.80 per year

The cost of repair is only a third of the overall number, or $ 183,366.83 per year.

Preventive Maintenance (PM)

The cost of preventive maintenance is much lower than the cost of corrective maintenance actions, as the following calculations will show. The company dedicates about 24 man-hours every month for preventive maintenance purposes in the Autolines. The cost of labor, including overhead, is again $ 23.66 per. Material and spare part cost is estimated to be $360.00 per month for preventive maintenance in the Autolines.

The cost of preventive maintenance is then:

24 man-hours/month · $ 23.66/hr. + $ 360.00 /month = $ 927.84 per month

or

$ 927.84 /month · 12 months/year = $ 11,134.08 per year

This is in sharp contrast to the $ 534,120.80 estimated for the total cost of corrective maintenance. It was stated before in Chapter 2 that 70% to 90% off all breakdowns can be avoided by increasing preventive maintenance, and it is economical to realize that level. With less than 5% of total maintenance man-hours expended being preventive, there is clearly ample room for improvements.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The major recommendation to the company is to implement Total Productive Maintenance (TPM) in the Autolines. Financially, it can be easily justified. TPM would also enhance the competitiveness of the plant in many other ways. As indicated, setup-time reductions are being implemented, and they have already produced favorable results. As the company moves closer to "Just-in-Time" production, the goal of absolute elimination of waste is not attainable without a strong maintenance program [13].

One may ask if the benefits promised by TPM can not be attained by increased preventive maintenance (PM), with no operator involvement ? Wireman [19] states: "A good maintenance schedule should achieve between 70% to 90% efficiency, or reductions of breakdowns". Companies that have implemented TPM have frequently seen reductions of breakdowns between 95% to 98% [13,14]. There is reason to believe that TPM's much better effectiveness is caused by the operators involvement (autonomous maintenance).

The overall equipment effectiveness of the area analyzed, the Autolines, was only 55%, a very low number. Under current conditions, the six lines are producing approximately 5.74 million bearings every month, creating a revenue of $ 1.26 million monthly. If the overall equipment effectiveness is increased to 85%, 8.87 million bearings per month could be produced worth $ 1.95 million. If this additional volume is not saleable, an alternative is to close down lines or reduce the number of shifts worked to produce the same number of bearings as today, i.e. 5.74 million. In fact, two lines could be eliminated altogether, since 3.88 lines could do the job working the same hours as before. If the six lines were kept, one shift per day would not be needed anymore, since 9.71 shifts could produce the same as 15 shifts do per week. The economic benefits would be of the same order of magnitude as the reduction in number of shifts. The more likely alternative to be chosen is to work only two shifts per day, and keep all six lines. If demand goes up, the only thing that has to be done is to work some extra shifts. This practice would also create time for performing preventive maintenance during the idle hours overnight. This would have little impact on the staffing of the maintenance department, as it is already staffed 24 hours per day.

In order to accomplish this a few basic recommendations are given:

1. Initiate a <u>computer maintenance management system</u> (CMMS), immediately. This is an absolutely

necessary ingredient for successful TPM implementation.

2. Obtain top management support for implementation. The message must be clear and simple: "This company is fully committed to TPM success".

3. Assign the responsibility of TPM implementation to one qualified individual who will oversee all education and training, prepare materials, schedule maintenance, and maintain the program.

4. Set goals and a timeframe for implementation. Report on the accomplishments for motivational purposes. Every employee has to become involved and must understand the benefits of this program.

Even if program implementation does not realize significant benefits as fast as one hopes, the financial rewards are such that a small improvement in overall equipment effectiveness would still yield good benefits to the company.

The implementation of TPM is estimated to take three years. This is the experience from Japan [13,14]. A much longer time should not be allocated as personnel excitement and motivation may dwindle! The implementation is easily financially justifiable, with a Benefit/Cost ratio much higher than 1.

Currently, there is only one major obstruction. The lack of a good data collection system on all maintenance activities is needed prior to implementation. Maintenance data, such as the MTBF for equipment, the capability to follow the performance, downtime, setup-time, etc., is necessary for the implementation to be successful. The computerized maintenance management system (CMMS) is a prerequisite for this information flow. Therefore, it is recommended that the company develops and introduces a CMMS, followed by the implementation of a TPM program. In the following sections, each recommendation is discussed in more detail.

5.1 Computerized Maintenance Management System (CMMS)

To properly control the maintenance of any facility, the right type of information is required for an ongoing assessment of operations. To provide such information manually requires a tremendous amount of effort and time. In recognition of this, many companies are developing and using computer programs geared toward control of the maintenance organization and its activities. These systems are often referred to as a "computerized maintenance management system (CMMS)". There are five basic areas where computers have proved beneficial [10,15]:

1. Equipment control
2. Work Control
3. Maintenance spare parts and inventory control
4. Cost accumulation and reporting
5. Performance reporting

The main use of computers in maintenance management has been to issue checklists for PM (see Appendix C), keep records and monitor labor and material costs, process work orders for maintenance work, prepare spare part lists for a work order, and keep track of the time needed to do the maintenance [17]. In addition, the CMMS can have functions like preparing periodic lists of maintenance summary, including work orders, breakdowns, spare part consumption, downtime, backlogged maintenance and/or completed PM.

In general, maintenance records are kept to maintain a sound control system and provide a history of repairs (MTBF, MTTR), scheduled maintenance, and other activities. Maintenance records are a necessary prerequisite to a good PM program. The importance of this information can never be underestimated. It is simply impossible to determine the proper frequencies associated with a PM program without some knowledge of MTBF. Today, the "case study" company performs PM maintenance on each line every six months. This frequency was not determined from historical data, but probably because it was a good number (PM performed on one line every month).

MTBF Analysis and Maintenance Plans

Maintenance plans are classified by period or project. A good preventive maintenance program can only be designed after performing MTBF analysis. Each type of work performed on a particular piece of equipment has to be recorded on a separate card, (see Table 4). In the Autolines, it would be extremely helpful to have such a card. Today, each piece of equipment has preventive maintenance work performed every six months. The MTBF analysis would show that the breakdown frequency of each machine and part is very different. On the basis of the MTBF analysis, preventive maintenance schedule can be determined. The schedule should be broken down into: annual, monthly, weekly, and daily maintenance, (see Table 5). This example shows how useful the MTBF information is, and consequently how important recordkeeping is.

Table 4 MTBF Analysis [13]

①	②
③	
④	⑤
⑥	⑦

① Date maintenance performed
② Work done by (name)
③ Name of equipment and part
④ Breakdown details
⑤ Describe action taken (maintenance details)
⑥ Manhours (personnel × min.)
⑦ Equipment downtime (min.)

• Fill out maintenance work card for every job.

Equipment MTBF analysis chart

Analysis duration:
Start: ______ End: ______

Name of part	Maintenance work performed					
A–a	☐	☐				
A–b	☐	☐	☐	☐	☐	
A–c	☐	☐	☐			
B–a	☐					

• Post maintenance work cards on MTBF analysis chart.

Table 5 Sample Annual Maintenance Calendar [13]

Type of maintenance:

■ Turnaround day

○ Planned weekday shutdown maintenance

△ Detailed inspection and adjustment

Degree of difficulty:

A = Designated technician/Work by designated vendor

B = Work mainly by facility section

C = Work by maintenance worker (PM) or operator (OP)

Equipt:

Rolling unit

Dept:

Hiratsuka tire plant

Equipment and parts names	Maintenance work	Diff.	MTBF	MTTR	Dept. Responsible (in-house/outside)						Yr/mo	1980												Remarks
					Mech.	Elec.	Piping	Instr.	Lubr.	PM	OP resp.	1	2	3	4	5	6	7	8	9	10	11	12	
Roller press P R	Abnormal noise, load current	B	6 months								○				○						○			
-	Replace speed reducer oil	C	6 months								○						○						○	
Fastener	Pressure regulator	B	6 months					○								○						○		
-	Check cylinder gaskets	C	1 year								○								○					
EPC unit	Actuation check	B	6 months				○							○						○				
Expander unit	Actuation check	C	6 months								○			○						○				
Compensator	Actuation check, load measurement	B	1 year					○							○						○			
Preheat D/M	Bearings	B	6 months						○				○							○				
-	Speed reducer oil check and sampling	B	6 months						○								○						○	
-	Motor load current	B	3 months			○								○			○			○			○	

Tsukui, "Annual Maintenance Calendar" (in Japanese), *Plant Engineer* 12 (June 1980)

Equipment Logs

Equipment logs need to be maintained during the lifetime of the equipment. The complete history of a piece of equipment that begins with date of purchase, installation, and records all accidents and major repairs from startup to present. It is important to keep individual equipment logs until the equipment is removed from service. When a machine has deteriorated past the limit of its economical life, it is time to replace it. Therefore, equipment logs have an important function in assisting to determine replacement of equipment.

The maintenance record form should include [17]:

1. Nameplate information
2. Purchase date
3. Manufacturer serial number
4. Location
5. Model number
6. Manufacturer's type
7. Condition
8. Repair information
9. Costs involved (repair and purchase cost)
10. Other data

An example of an equipment log form is given in Table 6.

Table 6 Equipment Log [13].

Asset No.	
Equipt. name	
Model	
Spec.	
Main motor	

Manufacturer	
Date of manufacture	
Vendor	
Date of purchase	
Purchase price	

Place of Installation	
Date	Section/line name

Date	Periodic maintenance/Improvement				Cost
	In-house/ outside	Part	Details	In-house manhours used	

Date	Major breakdown repairs				Cost
	In-house/ outside	Part	Details	In-house manhours used	

Priorities

Priorities will help to ensure that important work is performed before less important work. There are at least five priorities codes that could be used [19]:

1. Emergency
2. Critical (within 24 hr.)
3. Repetitive
4. Major repair or shutdown
5. Preventive maintenance

The equipment has to be rated so it is known what type of priority to put on its repair or periodic maintenance. An example of such TPM priority management table for rating equipment is given in Table 7. Using this table in the Autolines would be very useful. Your author made an attempt to fill it out and got a priority rating of 28 points or B. The B rating could correspond to critical work (within 24 hr.) mentioned before.

Bear in mind that priorities will not necessarily remain the same. If backup equipment is suddenly available, the priority be reduced, etc. Therefore, revise priorities periodically (every 1 to 2 years).

Table 7 TPM Priority Management Table for Rating Equipment

[13]

Area	Item	Evaluation				Evaluation Standard
Production	1. How often is the equipment used?		4 X	2	1	80% or above: 4 59% or below: 1
	2. Is there backup equipment?	5 X	4	2	1	No (or) Yes, but it takes too many manhours: 5 • available at other plants: 4 • covered by stock: 2 • backup equipment exists: 1
	3. How high is the dedication? (the proportion of products of a similar type produced by the equipment)		4	2	1 X	100–75%: 4 0–35%: 1 35–75%: 2
	4. To what extent will a failure effect other processes?	5	4	2	1 X	Affects the entire plant: 5 Strongly effects other processes: 4 Only effects this machining center: 1
Quality	5. Value of monthly scrap losses (burned rubber, wasted cloth, wasted production)		4 X	2	1	(burnt rubber) over $1000 $500–1000 under $500 (wasted cloth) over $5000 $2000–5000 under $2000 (wasted production) over $1000 $500-1000 under $500
	6. How will the process run on this equipment affect the quality of the finished product?	5	4 X	2	1	Decisively: 5,4 Not significantly: 1 Somewhat: 2
Maintenance	7. Frequency of failures in terms of cost of monthly repairs?		4 X	2	1	over $5000: 4 Under $3000: 1 $3000–5000: 2
	8. Mean time to repair (MTTR)		4	2	1 X	MTTR over 3 hours: 4 Under 1 hour: 1 1–3 hours: 2
Safety	9. To what extent does a failure affect the work environment? (noise, etc.)	5	4	2	1 X	Can be life-threatening: 5 No significant effect: 1 Stops work: 4

A (priority-ranked equipment) (30 or more points) B (20–29 points) C (19 points or less)

System Implementation

The implementation phase of purchasing a computerized maintenance management system (CMMS) can make or break the implementation. If implementation is rushed or left incomplete, the system will not perform satisfactorily. The implementation can be divided as follows [19]:

1. Updating current records
2. System installation
3. Data entry
4. Introduction to the system
5. Training the appropriate personnel

It is recommended that a computerized maintenance management system (CMMS) should not be installed, until a good manual system is in place. When the specifications for a computer system have been determined, it is estimated that a period of twelve months is required to implement the system [7]. Given the fact that the company is not totally unfamiliar with some form of a manual system, it is assumed that six months will be devoted to get up to a level that is ready for computerization. The following six months could then be used to implement a CMMS. That should be much easier after the manual system has been debugged and is working. It is recommended that the company purchases a system from a vendor. Several PC-based systems are available ranging in cost from $500 to $25,000, depending on the system's capability [19]. The cost of the system, training and support requirements are estimated to be:

1. Computer system cost: $20,000
2. Training required 2 hr./month during the first twelve months for everyone involved. Training is provided by the company and in the form of Quality Circles (QC) activities [19].
3. An engineer will dedicate 100% of his time working on CMMS implementation during the first year.

5.2 Top Management Support and Promotional Activities

The second recommendation of this study states that top level management support is essential for the successful implementation of TPM (see Figure 11). Top management must incorporate TPM into the basic company policy and establish concrete goals, such as increasing the rate of equipment operation to more than 80 percent or reducing breakdowns by 50 percent over the course of several years. TPM combines "top-down" goal setting by top management with "bottom-up"

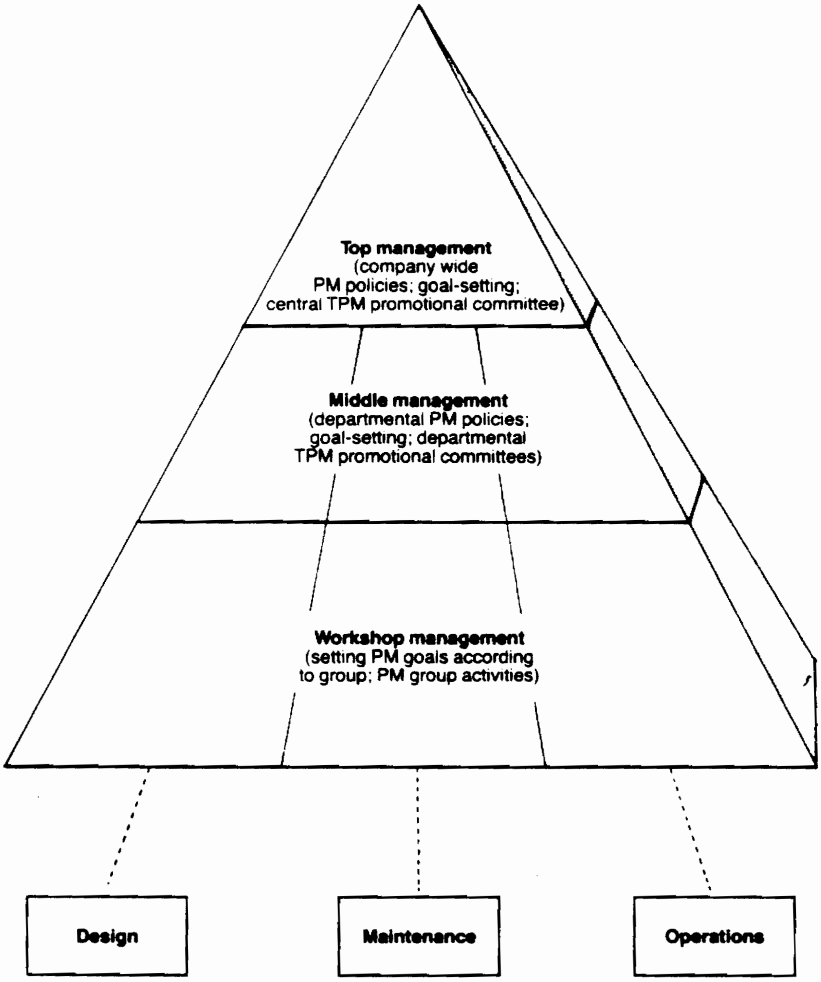


Figure 11 TPM Promotional Structure [13]

small-group improvement and maintenance activities on the front line. This will require some changes and mostpeople have an inborn resistance to change. In order to eliminate this resistance, TPM has to be introduced at every level prior to the actual training starts. Experience from Japan indicates that two to three day sessions are needed for managers, engineers, and group leaders [14]. The employees on the shop floor need to be educated about how to be a participant in small group activities. QC circles are formed around specific themes and goals. For example, in the case study company the operators working on the Autolines could form a QC circle. Specific goals could be such as to find ways to reduce metal chips residue in the production machines. Discuss and improve basic equipment conditions (i.e., cleanliness, lubrication, and bolting). Usually the QC circles are free to choose a topic. It is not recommended to force a QC circle to solve a specific problem It has been found that small group activities is an extremely effective form of motivation. The circles often put up a friendly rivalry and compete with each other.

A "TPM Master Plan" needs to be developed, it will act as a framework for improvements. For the case study company a TPM Master Plan could be [13,14]:

Basic TPM Policy

- Maximize OEE through TPM
- Reduce breakdowns, increase quality, and reduce cost
- Raise moral and motivation

Goal

- Reduce breakdowns 95% over three years
- Increase OEE to 85%
- A smooth operation, excellent for Just-in-Time

Major Activities

- Establish Autonomous maintenance
- Constantly improve the quality of PM activities
- Increase the MTBF through better care
- Improve performance by improving equipment
- Provide the necessary training and education

5.3 Organizational Issues, Maintenance Department

The development of an organizational chart will define the management function of an organization. This chart should show the structure and authority relationship required to achieve the responsibilities delegated. The organizational chart groups the necessary activities together to achieve the mission of the maintenance department. Figure 12 is a

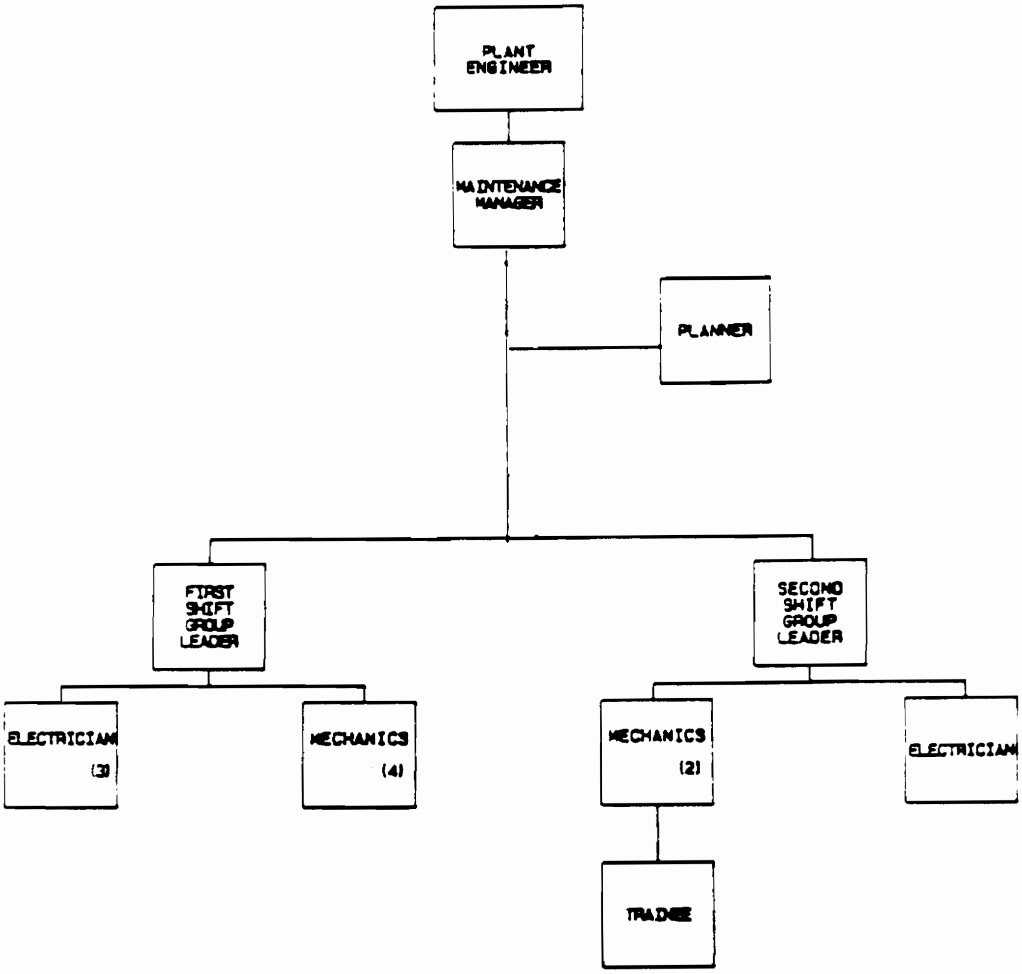


Figure 12 Organizational Chart, Maintenance Department

recommended organizational chart for the case study company's maintenance department. The organizational chart places the Maintenance Manager in the role of supervisor for everyone in the department and working directly for the Plant Engineer, (see Table 8).

The current company does not have the function of a Planner. It is recommended that such a position will be added [17]. The Planner should have engineering background, preferably industrial engineering. He/She should have some knowledge about state of the art manufacturing programs, such as: Just-in-Time, Total Quality Control, etc. Experience or knowledge of Management Information Systems could be very beneficial. The Planner would have the responsibility of implementing the CMMS followed by TPM implementation, (see Table 9). It is estimated that the Planner would spend 100 % of its time for the first two years (CMMS and the first year of TPM), 67 % the third year, and 50 % thereafter on the program.

Group Leaders already exist in the case study company, but it is necessary to provide a detailed job description of their role, (see Table 10).

Table 8 Job Description for Maintenance Manager

Maintenance Manager

Basic Function

To plan, coordinate, and organize the functioning of the maintenance department and coordinate the repair of company facilities, grounds and production.

Specific Duties

1. Reports to the Plant Engineer and Functions as the Plant Engineer in his absence.
2. Supervise the installation, repair and movement, of all machinery, plant equipment, production equipment, plant buildings, and structures.
3. Help the Planner in establishing a PM program for the plant and facilities.
4. Plan for the work distribution for each shift with the respective Group Leaders and supervise their performance.
5. Review and assist the Planner in work order processing, CMMS implementation, and TPM implementation.
6. Assist the Plant Engineer in monitoring and coordinating all other programs essential to the maintenance and Plant Engineering function.

Table 9 Job Description for Planner

Planner

Basic Function

To perform all the administrative duties required to estimate and prepare all work orders for CMMS implementation, TPM implementation, and other jobs as needed and schedule all routine maintenance.

Specific Duties

1. Reports to the Maintenance Manager.
2. Conduct plant inspections to determine job requirements needed for scheduling and planning scheduled maintenance.
3. Ensure all direct support is planned for CMMS, TPM, and other maintenance programs.
4. Monitor the conduct of TPM activities.
5. Provide training and education for CMMS, and TPM implementation.
6. Analyze the historical repair information from the maintenance records to convert into planned maintenance work.
7. Maintain the backlog of work orders and ensure they are being accomplished.

Table 10 Job Description for Group Leader

Group Leader

Basic Function

To plan, coordinate and organize the function of the personnel in his particular shift group.

Specific Duties

1. Reports to the Maintenance Manager.
2. Reviews the Planner's work orders for proper control of current work.
3. Approves the daily allocation of maintenance personnel on his shift and supervises their activities.
4. Inspects schedules as to completion dates, reviews the amount of work to be done, and approves any necessary changes.
5. Assists in maintaining necessary records.
6. Is responsible for training his shift together with the Planner in CMMS and TPM implementation.
7. Enforces the necessary safety procedures and conducts inspection of the plant to ensure everything is running smoothly.

5.4 Goals and Timeframes

In Japan, the Distinguished Plant Prize (or PM Prize) is awarded annually to plants that successfully implement TPM. Actually since 1971, implementation of TPM has become a requirement for the PM Prize. The selection of winners is based on categorize like [13,14]: increased productivity and quality, reduced costs, reduced inventory, elimination of accidents, pollution control, and good working environment.

Since the scope of this study is limited to the Autolines, all discussion will concentrate on possible improvements in them.

Overall Equipment Effectiveness (OEE)

For most companies it takes about three years to implement TPM. In the end of the three year period the overall equipment effectiveness (OEE) had in most cases been raised to 85% [13,14].

The "case study" company had only an estimated OEE of 55%. Assuming a linear rate of improvements over three years for the OEE, this would result in a 10% increase per year. Most learning curves show a strong rate of improvement in the early stages of a training program and a slower growth at the end of it [2]. This would be in agreement with the relative changes between years i.e. 55% to 65% in the first year is a much more significant improvement in processing rate compared to the last years improvement from 75% to 85%.

Cost

The cost in the Autolines is dominated by the labor cost. Other costs, such as maintenance cost, tool cost, fluid cost, etc., are a much smaller part. Depreciation cost of machines is none, the machines are old and fully depreciated.

The following assumption is therefore made:

"Processing cost per unit time in the Autolines will remain fixed, and not dependent on the number of bearings produced per unit time".

The above assumption, fixed cost per unit time, is at least justifiable for some limited range in the OEE.

Increased Productivity

The goal of producing more bearings per unit time in the Autolines, with no increase in processing cost per unit time, would result in high productivity improvements for the Autoline operators. If OEE is increased from 55% to 85%, the increase in productivity is $(.85/.55-1)\cdot 100\% = 54.5\%$ per operator.

Reductions in Breakdowns

Currently there are approximately 370 breakdowns per month in all the six Autolines combined. Many companies have seen reductions in breakdowns over 95% during the three years implementation period [13,14]. This would amount to less than 20 breakdowns per month after the implementation phase.

5.5 Economic Analysis: TPM Justification

The economic justification of TPM implementation is important. TPM has not been implemented in the United States and therefore it is very interesting to see what can be expected in this country. The benefit-cost ratio (B/C) is one measure of the economic effectiveness of a project. The conventional formulation of the B/C ratio is as follows [4]:

$$B/C = \frac{PW(\text{benefits})}{PW(\text{total cost})} = \frac{PW[B]}{PW[CR + (O + M)]}$$

where

B = annual benefits to user
CR = capital recovery cost
O = annual operating cost

M = annual maintenance cost

Present worth (PW) is calculated, using a minimum standard of desirability or Minimum Attractive Rate of Return (MARR). The higher the MARR chosen, the more demand is put on the profitability of the project. The B/C ratio must be greater than or equal to 1 to be attractive under a predetermined MARR.

Benefits

The total cost of producing each bearing is 15 cents and the cost breakdown structure is:

Material cost	5 cents
Processing cost, Autoline	5 cents
Inspection and packaging cost ..	5 cents
Total:	<u>15 cents</u>

Material cost and inspection and packaging cost will not be affected by TPM. The only possible benefits considered are in the Autolines. The improvements in the OEE for the Autolines will reduce cost mainly by improving the use of the available production capability. Overall cost reduction in the Autolines will be calculated assuming as before that cost per unit time in the Autolines is fixed. Assuming that availability, performance rate, and quality rate are independent variables the following is valid:

$$OEE1 \cdot T1 \cdot Prod.Rate = OEE2 \cdot T2 \cdot Prod.Rate$$

or

$$(T1 - T2)/T1 = (1 - OEE1/OEE2)$$

Therefore, the cost reduction experienced in the Autolines can then be formulated as a function of OEE as follows:

$$Cost\ Reduction = \$\ 0.05 \cdot (1 - .55/OEE)$$

The .55 (55%) is the current level for OEE in the Autolines. If it remains at .55 there would be no cost reduction. The greater the OEE is, more bearings can be produced per unit time. If for example OEE is 0.85 (85%) the cost reduction is 1.76 cents per bearing.

It has been previously assumed that 85% OEE will be reached in the Autolines at the end of the third year of TPM implementation. Because the first year is devoted to CMMS implementation the third year for TPM is the fourth year in the overall program assumed by this study.

In Table 11, the estimated cumulative cost reductions per bearing during implementation are shown. They are based on OEE 55% at the end of first year (devoted to CMMS), 65% at

Table 11 Cost Reductions per Bearing, During and After Implementation

YEAR	OEE(yr.begin)	OEE(yr.end)	OEE(Average)	Cumulative Cost Reduction
1	55%	55%	55%	0.00 cents
2	55%	65%	60%	0.42 cents
3	65%	75%	70%	1.07 cents
4	75%	85%	80%	1.56 cents
5	85%	85%	85%	1.76 cents
.	.	.	.	.
.	.	.	.	.

end of the second year, 75% at the end of the third year, and 85% at the end of the fourth year. In Table 12, the cost reductions per bearing have been multiplied with the yearly production of bearings giving the expected benefits each year.

Costs

Most of the cost associated with TPM implementation is due to training and education of operators, mechanics, and managers. The following is the estimated training cost per hour for each group, including 35% for benefits and 40% overhead on top of that, the salary of an average manager is assumed to be $ 50,000.

Operators	$ 23.66/hr.
Mechanics	$ 23.66/hr.
Managers	$ 49.14/hr.

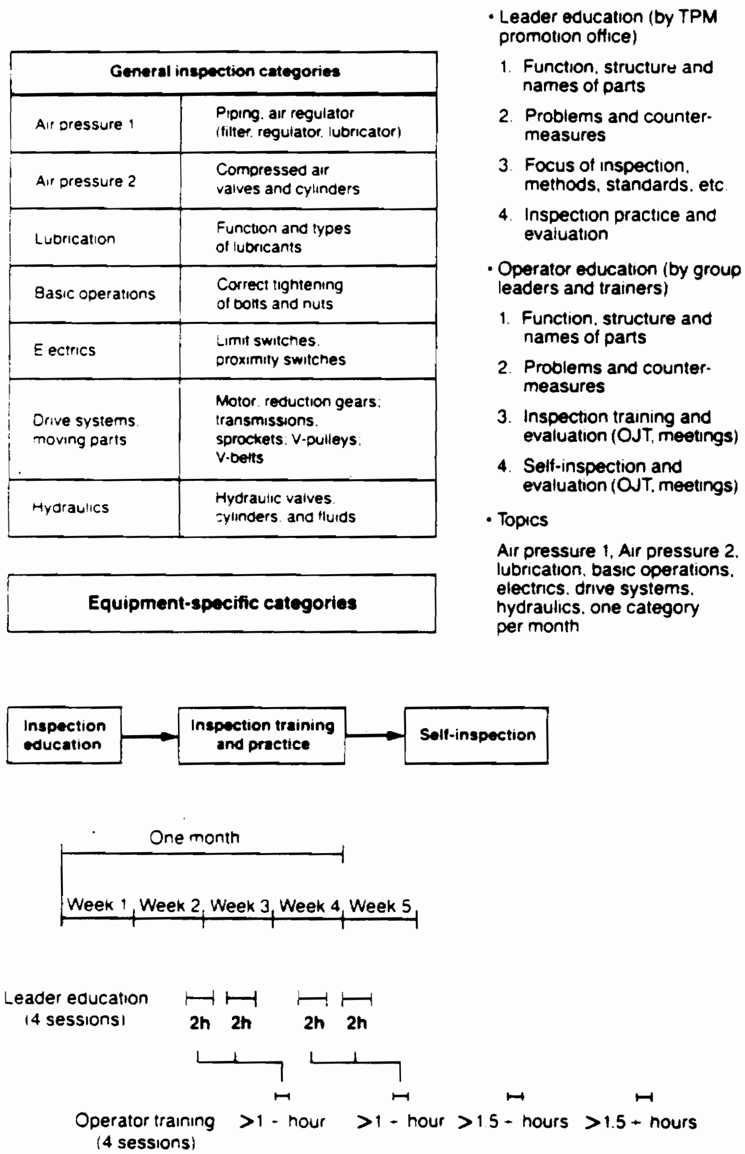
It is assumed that during the first two years a Planner will work full time on CMMS and TPM implementation. This individual is assumed to be a engineer, paid $ 35,000 per year, and with benefits and overhead the cost is $ 66,150 per year. It is also assumed this person will have a budget of $ 20,000 per year for cost of training material for the groups, travel to seminars on TPM, and so forth. If the company decides to go ahead with TPM implementation, the cost of the Planner would only be partly allocated to the Autolines. It is likely that the Planner would spend a great deal of his time working on the Autolines. Recall this is the most troublesome section of the company. Therefore, 50% of his time is allocated for the Autolines.

Estimated Training requirements are based on what has been the experience of other companies [13]. Figure 13 gives an idea of the material covered and the time allocated for training purposes. The following lists the training requirements during the first year (CMMS), and the second year (start of TPM) for the Autolines:

Operators and Mechanics
- Leaders .... 8 hrs./month (7 leaders)
- Operators .... 6 hrs./month (35 operators)

Managers .... 8 hrs./month (5 managers)

In year 2, the previously listed training is required. The third year only 67% of the time allocated the second year is needed. The fourth year and from then on, only 50% of the listed training is required. The training requirements go down for two reasons. First, more training is needed at the start of program and secondly number of operators will decrease as OEE increases. It is assumed



General inspection categories	
Air pressure 1	Piping, air regulator (filter, regulator, lubricator)
Air pressure 2	Compressed air valves and cylinders
Lubrication	Function and types of lubricants
Basic operations	Correct tightening of bolts and nuts
Electrics	Limit switches, proximity switches
Drive systems, moving parts	Motor, reduction gears; transmissions, sprockets; V-pulleys; V-belts
Hydraulics	Hydraulic valves, cylinders, and fluids

Equipment-specific categories

- Leader education (by TPM promotion office)
  1. Function, structure and names of parts
  2. Problems and counter-measures
  3. Focus of inspection, methods, standards, etc.
  4. Inspection practice and evaluation
- Operator education (by group leaders and trainers)
  1. Function, structure and names of parts
  2. Problems and counter-measures
  3. Inspection training and evaluation (OJT, meetings)
  4. Self-inspection and evaluation (OJT, meetings)
- Topics

  Air pressure 1, Air pressure 2, lubrication, basic operations, electrics, drive systems, hydraulics, one category per month

Figure 13 Scheduling Pattern for General Inspection, Education and Training [14] that during the first year everyone receives a 2 hour/month education and training for CMMS implementation, (see section 5.1).

In Table 12 and 13 the results of the Benefit/Cost analysis are given. The B/C ratio turns out to be 4.06 when the MARR is 30%. Because the B/C ratio is grater than 1, the TPM implementation is justified financially.

It was calculated that for the implementation phase to remain financially attractive (i.e. B/C = 1), the overall equipment effectiveness (OEE) will have to increase linearly to a minimum of 62.5% in three years. The yearly cost of maintaining the TPM program after implementation is estimated to be $ 71,066. This cost would amount to 1.3% change in the OEE. It is likely that the OEE would drop very fast if the program was not maintained after implementation and certainly more than 1.3% per year.

As can be seen from this discussion, the project seems to be very attractive financially and promises to pay high dividends in the future. Therefore, from a financial point of view, CMMS implementation followed by a TPM implementation should be undertaken as soon as possible.

Table 12 Benefit/Cost Analysis for the Autolines

MARR = 30% per year

Production rate = 5.74 million/month

COSTS

YEAR	Cost	Present Worth
1	$ 82,820	$ 63,708
2	$ 142,185	$ 84,133
3	$ 97,908	$ 44,564
4	$ 71,066	$ 24,882
Total	$ 393,979	**$ 217,287**

BENEFITS

YEAR	Benefits	Present Worth
1	$ 0	$ 0
2	$ 289,296	$ 171,181
3	$ 737,016	$ 335,465
4	$1,074,528	$ 376,222
Total	$2,100,840	**$ 882,868**

$$B/C = \frac{\$\ 882{,}868}{\$\ 217{,}287} = \mathbf{4.06} \gg 1$$

Table 13 Examples of Benefit/Cost calculations

Costs (year 1)

Planner	salary:	$ 33,075
	budget:	$ 10,000
CMMS	initial cost:	$ 10,000
Training Costs		
Group Leaders (7, 2 hrs./month):		$ 3,974
Operators (35, 2 hrs./month):		$ 19,874
Managers (5, 2 hrs./month):		$ 5,897
	Total:	**$82,820**

Benefits (year 3)

5,740,000 pieces/month · 12 months · $0.0107 (cost red.) =

$737,016

6.0 SUMMARY

This project has focused on the possibility of implementing Total Productive Maintenance (TPM) in a manufacturing company. It found that a prerequisite for TPM implementation is an implementation of a computerized maintenance management system (CMMS) for collecting and recording the appropriate data for TPM measurements.

The current low estimate for the overall equipment effectiveness in the Autoline section of the company, only 55%, shows the importance of implementing new maintenance programs in the company. It is anticipated that this low OEE level could be raised to 85% within three years of TPM implementation and, if that happened, the financial benefits would be high, with a Benefit/Cost ratio of 4.06 using Minimum Attractive Rate of Return (MARR) 30%. Even if the OEE measure would only reach 62.5% in three years, the project is still profitable, with estimated Benefit/Cost ratio of 1.

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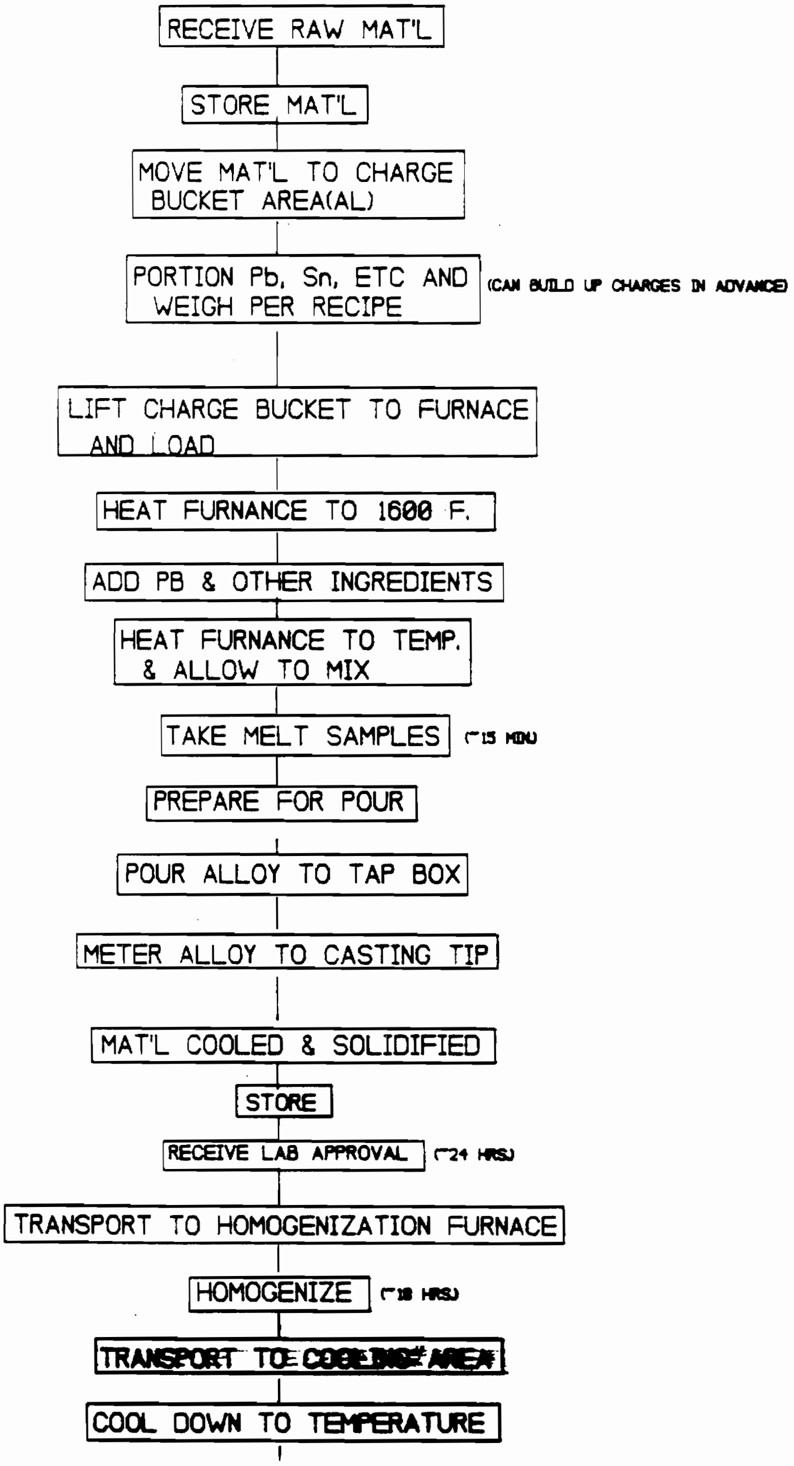
APPENDIX A

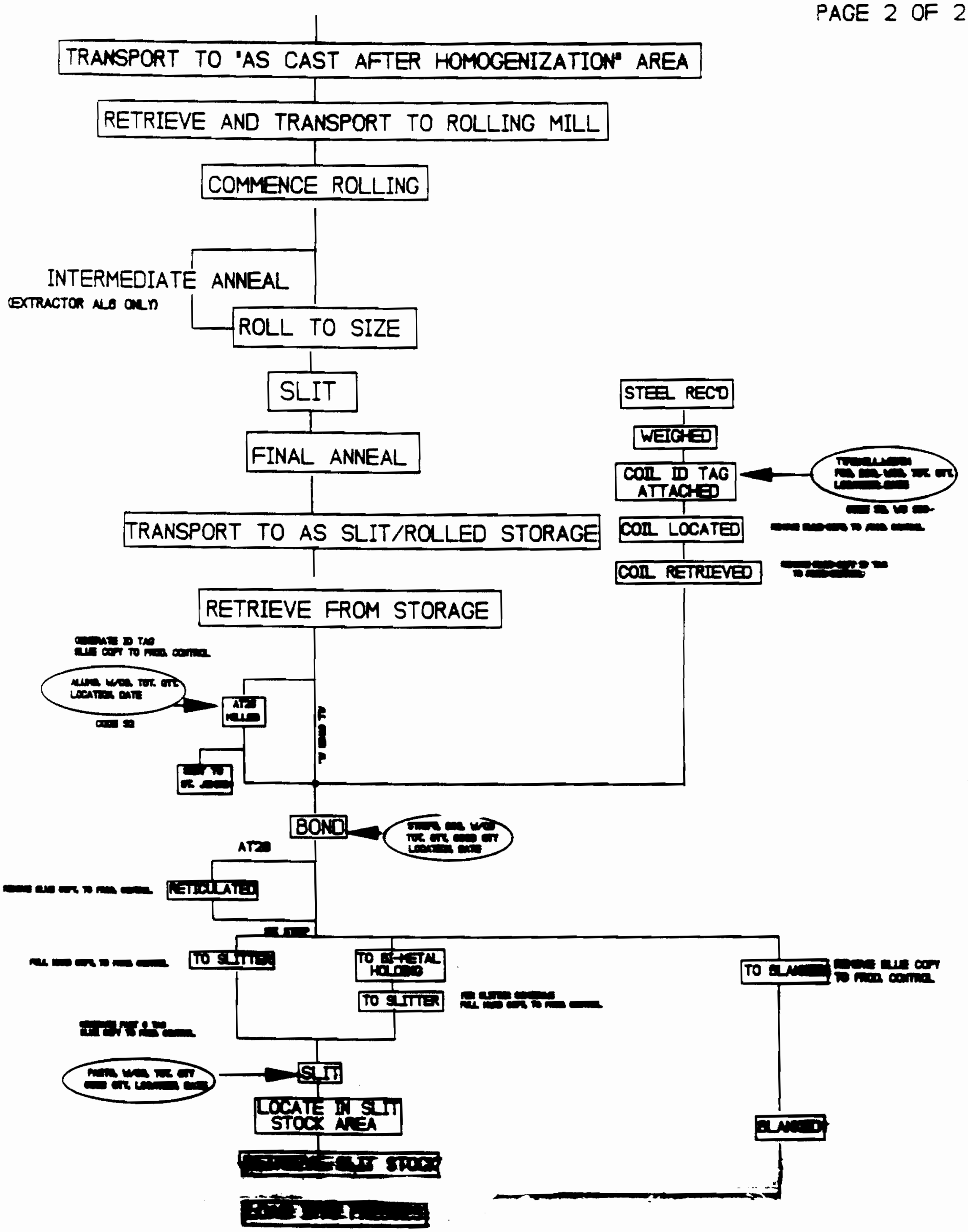
Bonding Line

The Following process flow diagrams are the "Raw Material to Press Flow", i.e. the flow from a raw material stage over to a coil stage going in to the Bonding Line.

RAW MAT. TO PRESS FLOW

PAGE 1 OF 2




TRANSPORT TO 'AS CAST AFTER HOMOGENIZATION' AREA
RETRIEVE AND TRANSPORT TO ROLLING MILL
COMMENCE ROLLING
INTERMEDIATE ANNEAL
(EXTRACTOR AL6 ONLY)
ROLL TO SIZE
SLIT
FINAL ANNEAL
TRANSPORT TO AS SLIT/ROLLED STORAGE
RETRIEVE FROM STORAGE
STEEL REC'D
WEIGHED
COIL ID TAG ATTACHED
COIL LOCATED
COIL RETRIEVED
GENERATE ID TAG
BLUE COPY TO PROD. CONTROL
ALLOYS, M/CS, TOT. QTY
LOCATION, DATE
AT28
BOND
AT28
RETICULATED
TO SLITTER
TO BI-METAL HOLDING
TO SLITTER
TO BLANKER
SLIT
LOCATE IN SLIT STOCK AREA
BLANKED

APPENDIX B

Logged Maintenance Activities

The logged maintenance activities were done during the week of June 4 to June 9, 1990. There are two basic categories: Autolines Electrical, and Autolines Mechanical. There is a short description of each problem along with estimated downtime, as done by the technicians.

Autolines Electrical (14 shifts recorded):

113 E-line, P.P. shooting off auto mode, no ticket, (30 min).

113 A-line press, shutter does not work, (30 min).

115 E-line, blow off stays on, (30 min).

113 C-line, No power, (15 min).

114 C-line, C sink, change program for groove, (15 min).

115 F-line, W/B, kickers wont work in man with motor off, remove motor FWD. bit from main ring, (5 min).

114 B-line, breaker kicked, unload fault, sensor grid out, (15 min).

130 H-line, W/Broach, escapement timing, adjusted cam on escapement, (15 min).

113 B-line, Facer, locking pin to quick fast speed, (15 min).

115 F-line, W/B, escapement soil coming out too quick, (25 min).

115 D-line, W/B, Clamp clamping too soon not sitting bearing in adapter right, timed clamp, (5 min).

113 A-line, Facer, control fuse blown to receptacles, replace fuse, (5 min).

114 D-line, Adj. sensor, (30 min).

113 B-line, Install new sensor, intermittent sensor problem, (120 min).

114 D-lin-e, broken wires or sensor, (30 min).

114 D-line, H/B unload chute fault, sensor brackets not lined up, (30 min).

114 D-line, unload fault, sensor not lined unload chute, (20 min).

113 C-line, Eject fault conveyor belt stopping shear pin switch not making all of time. Timing on eject and sensor timing, electrical problems, (480 min).

113 D-line, Groover, bad unload sensor, correct information, (15 min).

113 E-line, Facer would not stop running out of bearings. Demand hold time, pusher control time, (40 min).

Autolines Mechanical (8 shifts recorded):

D-line, Groover, replace belt (15 min).

A-line, countersink, valve sticking, put oil in line, (20 min).

H-line, C100 W/B, replace cylinder on lid, (15 min).

E-line, W/B, replace red hat valve, (30 min).

F-line, W/B, stacking table, adjusted air pressure, (5 min).

B-line, press, form core bolts drilled out, (10 min).

E-line, P/P countersink conveyor belt broke, (60 min).

B-line, press T-nut for die, broken bolt (10 min).

F-line, H/B, unload jamming, (15 min).

F-line, facer, unload conveyor belt, (65 min).

?-line, broken tap bolts, had to drill out and retap, (45 min).

C-line, facer, line the r. head, needs work on, (35 min).

A-line, ega. plate screw broke, (90 min).

F-line, Kikken broke, (30 min).

C-line, gov. belt won't turn bearing over, (30 min).

F-line, press - plumed in a dump valve to bottom cylinder, (120 min).

E-line, facer, unload splitter, couldn't find old piece, had to make new one, (60 min).

F-line, facer, bearings jamming at splitter, (20 min).

F-line, H/B, drilled out broken bolt, (10 min).

D-line, groover, broken clamp bolts, (105 min).

F-line, W/B, weld carrier holder, (15 min).

?-line, recording all this bullshit, (10 min).

B-line, facer, locking pin, (20 min).

B-line, facer, repair, (45 min).

A-line, W/B,change filters in oil sump at in line filter, (60 min).

C-line, W/B, unload conveyor, replace magnets, (45 min).

B-line, parts washer unload belt replaced, (45 min).

B-line, punch press bearing oiler replaced, (60 min).

E-line, groover belt, (15 min).

F-line, Hgt. unload paddle, (15 min).

E-line, P/P to countersink conveyor, (60 min).

F-line, chain conveyor, (45 min).

C-line, W/B load conveyor, (20 min).

?-line, shuttle jamming up on press, (30 min).

?-line, sander on debur not working, (20 min).

?-line, replace air line, (10 min).

?-line, clamp on W/B not working in time, (25 min).

APPENDIX C

Existing Preventive Maintenance

The following pages contains examples of checklists for the Preventive Maintenance program that is performed every six months on each Autoline.

MECHANICAL MAINTENANCE
P-M CHECK LIST
MACHINE NO._____ _____ 100 TON PRESS DATE____/____/____
6 MONTHS

MAN NO.

Check the drive belts and the motor mount bolts. _______

Check all air lines and hoses. _______

Check and lubricate the gear box, drive chain, sprockets, and gears on the stock straightener. _______

YEARLY

Check the clearance in the ways and record the findings on a separate print of the ram. _______

Check the clearance in the bearings and record the findings on the print of the ram. _______

Level the press. Use a precision level on the bolster plate. _______

Degrease the clutch and brake. Check for wear. _______

Check the shut height and calibrate _______

Change the oil and the oil filter. _______

Exchange air feeders if it has not been changed in the last 6 months. _______
Record the date of the last change if it is not changed.____/____/___

ELECTRICAL MAINTENANCE
P-M CHECK LIST
100 TON PRESS
6 MONTHS

MACHINE NO. _____ _____

DATE____/____/____

MAN NO.

Check the motor starter contactors. _______

Check all switches and sensors for frayed wires, general condition, and proper operation. _______

Ensure that the correct electrical print or program is in the cabinet. _______

Verify the program and check to the print. _______

Check the motor current. ________________amps _______

FACER
6 MONTHS

Check all switches and sensors for frayed wires, general condition, and proper operation. _______

Ensure that the correct electrical print or program is in the cabinet. _______

Verify the program and check to the print. _______

Check the amperage of the spindle motors. R_________amps L________amps _______

GROOVER
6 MONTHS

Check all switches and sensors for frayed wires, general condition, and proper condition. _______

Check the contactors for the cam drive motor. _______

Ensure that the correct electrical print or program is in the cabinet. _______

Verify the program and check to the print. _______

Check the amperage of the spindle motors. R_________amps L________amps _______

PUNCH PRESS
6 MONTHS

Check all switches and sensors for frayed wires, general condition, and proper operation. _______

Ensure that the correct electrical print or program is in the cabinet. _______

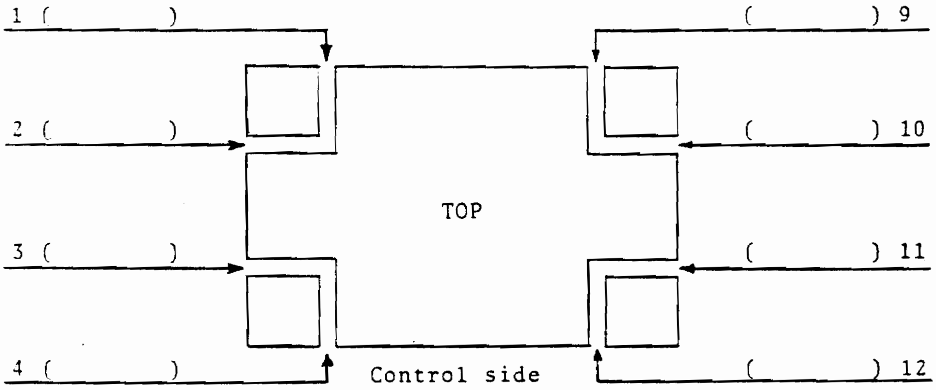
Verify the program and check to the print. _______

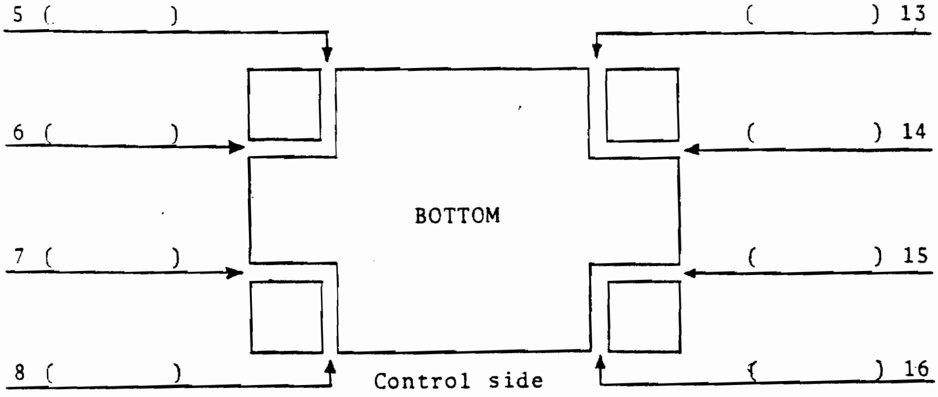
Check the motor current. ________________amps _______

100 TON PRESS ANNUAL
P-M WAY INSPECTION

Machine No. ______ ______ Date ___/___/___

Use a feeler gage to measure the clearances in the ways and record the findings below.





Total clearance of the crank bearings. ____________________
(Use a jack under the ram to get this measurement)

VITA

Sveinn V. Olafsson was born on April 8, 1962, in Reykjavik, Iceland. He graduated from Sund College with a Matriculation exam in 1982. He entered University of Iceland, Engineering department, in 1982, and graduated with a Final Exam in Mechanical Engineering, in 1986.

Following graduation he went to Brussels, Belgium, as a research engineer during the summer of 1986 at the von Karman Institute for Fluid Dynamics. In the fall of 1986, he entered the Aerospace Engineering department at Virginia Polytechnic Institute and State University, in Blacksburg, Virginia, and graduated in June 1988, with a Master of Science in Aerospace Engineering. The following fall he started his work on a Ph.D. program in Aerospace Engineering, but decided to change over to Systems Engineering in August 1989. He is to be awarded a Master of Science degree in Systems Engineering in September of 1990. He intends to turn back home to Iceland in the following month.