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To the Graduate Council:

I am submitting herewith a thesis written by Woody Sanford Byars entitled "The Development, Implementation, and Effect of a Preventive Maintenance Scheduling System in an Industrial Plant." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Industrial Engineering.

Major Professor

We have read this thesis and recommend its acceptance:

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431

THE DEVELOPMENT, IMPLEMENTATION, AND EFFECT OF A PREVENTIVE MAINTENANCE SCHEDULING SYSTEM IN AN INDUSTRIAL PLANT

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

---

by

Woody Sanford Byars

August 1973

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ABSTRACT

A study was made of both the theoretical approach and the practical industrial approach to develop a preventive maintenance (PM) system for an industrial job shop environment. In many industries the data necessary for the theoretical approach is not available, and it is too costly to obtain prior to setting up a PM program. A system was developed which attempts to blend the analytical approach with the practical industrial approach in order to minimize maintenance costs by adjusting PM frequencies as a function of machine breakdowns and machine usage.

In this study, a computer was used to schedule repetitive PM tasks and level workloads according to given criteria. A data collection system was developed, and information from the system was used to adjust PM frequencies toward optimum intervals to minimize total maintenance costs.

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CHAPTER I

DEFINITION OF THE STUDY

I. STATEMENT OF THE PROBLEM

Normally the condition of industrial plant equipment falls somewhere between "like new" and "completely broken down". When neglected, equipment moves quickly toward the latter state and its costly consequence is downtime and high maintenance costs. The whole point of maintenance is to slow down or regulate this movement by a continuing process of equipment renewal through repair or replacement.[1]

There are two types of maintenance: preventive maintenance (PM) and breakdown maintenance (BM). As the designations imply, preventive maintenance takes place before the unit fails; breakdown maintenance takes place after failure has occurred. The purpose of this study was to compare the advantages of a preventive maintenance program with the traditional approach to an emergency breakdown. In addition, the problems associated with the justification, development, and implementation of a programmed preventive maintenance scheduling system were analyzed.

Most authorities agree that industry cannot afford to ignore machinery and plant equipment until they break down. Breakdown maintenance is the most expensive form of maintenance because it usually shuts down equipment longer than preventive maintenance, disrupts work schedules and leads to more costly repairs. Many plants perform some

preventive maintenance activities, but few have a formal program. An effective preventive maintenance program must provide for systematic inspection, repair, and service of equipment. Breakdowns and total maintenance costs must be monitored to evaluate the program's continuing effectiveness.[2]

The extent to which PM activities should be applied and the type of equipment on which they should be utilized have long been areas of dispute by organizations responsible for maintenance management. However, from personal items, such as automobile, house, and home tools, to professional equipment in hospitals[3] and large industrial complexes, some preventive maintenance is usually done. This study has investigated some of these preventive maintenance systems and established the factors and justification necessary for such systems in typical industrial situations.

II. OBJECTIVE OF THE STUDY

The hypothesis was made that a preventive maintenance system can be developed which is effective in controlling the maintenance costs on occasionally used industrial equipment (variable usage) as well as on equipment that has constant usage. It was further argued that the development of a PM program has other objectives, such as:[4]

1. To reduce unanticipated equipment downtime and emergency repair orders through a repetitive maintenance program of inspection, adjustments, replacement of parts, and lubrication.

2. To provide centralized responsibility for repetitive maintenance administration and control of the repetitive maintenance and inspection function.
3. To study equipment operating condition, manufacturer's recommendations, and repair histories to determine optimum service frequencies based on usage.
4. To standardize lubricants whenever possible.
5. To maintain all necessary records on repetitive maintenance activities.
6. To provide a history of maintenance activities for critical equipment covered by the system.
7. To improve planning, budgeting, and work-load leveling for maintenance manpower.
8. To identify materials required for repetitive maintenance to minimize delays in obtaining parts from vendors, and to assist with standardization of materials.
9. To establish proper guidelines for updating and follow-up of PM procedures and frequencies.

The theoretical approach to setting up a formal PM program was investigated by a search of existing literature on the subject. Typical industrial PM programs were also examined and these practical approaches were compared with the theoretical approach outlined in the research literature. A system was developed which would attempt to blend a practical approach with the theory. Data were collected and used to optimize maintenance costs on a group of machines in a job shop

environment. The cost of maintaining these machines without a formal PM system was compared with the cost of maintaining them under a PM program with fixed maintenance intervals. Later machine usage data were used to adjust these PM frequencies in an attempt to further reduce maintenance costs.

III. SCOPE OF THE STUDY

This study was primarily concerned with machine tools located in a job shop environment. However, application can be made to other industrial equipment which has either constant or variable usage. The study concentrated on methods of data collection, the simulation of the data, and analysis of the data to optimize the magnitude and frequency of preventive maintenance activities.

The literature review covers many available articles written on existing PM systems and the known technology which has been used to establish preventive maintenance schedules. However, articles written about specific pieces of equipment which contain restrictive rules were excluded from this study except for example purposes only.

One year of machine maintenance data was collected and used to show the effect of the preventive maintenance system on a job shop type machine shop equipment. The computer was used to simulate this data for analysis. Scheduling and manhour leveling programs were used. The function of these programs was discussed, but the actual programming in computer language is not a part of this study.

IV. JUSTIFICATION OF THE STUDY

It is generally acknowledged that maintenance costs in industry have increased at a higher rate than direct production costs. This has been due largely to increased automation in our industrial processes. In theory, the more information one has about his equipment the better he can control his maintenance costs. Machine breakdown distributions enable one to predict optimum maintenance intervals. To obtain this information, however, requires the collection of a considerable amount of data which most industries do not have.

In practice, industries usually find the theoretical approach of setting up a PM program too costly and time consuming. Many of these industries have installed effective PM programs that reduce their maintenance costs by relying on their equipment manufacturer's recommendations and their foremen's knowledge about the running condition of the equipment.

Since most of the data necessary for the theoretical approach is not usually available when a PM program is initially set up, a data collection system that could be implemented with the PM program would be helpful. This data collection system would provide information that could be used to optimize PM frequencies, which would help to bridge the gap between the theoretical approach of setting up a PM program and the practical approach. Through an iterative process over a period of time, this concept would use statistical data to establish PM frequencies which optimize total maintenance costs.

To analyze the effect of such a system a study was made of the equipment in a typical job shop environment at the Oak Ridge Gaseous Diffusion Plant. At the outset of this study, very little maintenance data existed on these machines. This was not a unique situation but is typical of many industries, as pointed out in the summary of actual industrial systems in Chapter II of this thesis.

V. ORGANIZATION OF THE STUDY

The remainder of this study is organized as follows:

Chapter II presents a theoretical approach to establishing a PM program and a review of existing PM scheduling systems.

Chapter III presents the data collection system and procedure for the preventive maintenance scheduling system.

Chapter IV presents an analysis of the data comparing three methods of maintaining a given group of machines.

Chapter V summarizes the study and sets forth the conclusions.

CHAPTER II

REVIEW OF THE LITERATURE

As technology has advanced, greater emphasis has been placed on controlling indirect costs such as maintenance. A considerable number of technical magazine articles were written on this subject during the early 1970's. Greater emphasis has also been given the subject in textbooks. Practically all the literature written about controlling maintenance emphasizes a strong preventive maintenance program. In this chapter various PM systems are described. The approaches taken to develop these systems as well as the procedures of the systems themselves are discussed.

I. TRENDS IN MAINTENANCE MANAGEMENT

Being able to plan and schedule repairs is vital in a modern plant. Because of rapidly advancing technology, plants have become more automated, resulting in a decline of production workers and an increase of maintenance workers and job complexity. In the plant of the future the majority of workers will be those highly skilled in maintenance. Therefore, careful study to improve methods and reduce maintenance costs is imperative. Achieving these objectives should save billions of maintenance dollars.[5]

Maintenance costs are generated by the failure of buildings, machinery, and equipment to withstand the ravages of use and abuse. When this cost results from "breakdown" maintenance, then additional

costs are also incurred. These costs include both tangible and intangible items such as production downtime, increased overtime, larger maintenance force, quality rejects, more standby equipment, lost space, safety hazards, labor turnover, low morale, and customer dissatisfaction. The solution to many of these maintenance problems has been found by managers when they implement an effective preventive maintenance program in their operations.[6]

The principles of PM are equally sound in an office, home, factory, or service facility. When properly applied, they will produce savings. A few examples are:

1. A large municipality saved $200,000 annually when it installed a PM system on its seven hundred vehicles.
2. Another municipality operating four hundred vehicles had a 20 to 25 percent increase in efficiency after the application of a PM system.
3. A large maintenance organization boasted a 20 to 30 percent increase in effectiveness when a PM system was installed along with its maintenance control system.[6]

Although some maintenance organizations installed effective PM control systems, many others were without a solution to increased maintenance costs in their industrial plants, according to a survey conducted by Plant Engineering magazine in 1971.[7] The results of this survey indicate that maintenance is suffering from a lack of attention in most U.S. industrial plants. Their prescription for cure often is to ask for an increase in the maintenance budget. The findings of this survey

disclose that "maintenance is generally regarded as a necessary evil rather than a vital function that can have a profound impact on the operation cost and health of a plant."

Thirty-five percent of those responding to the survey were unable to answer the question as to what percentage of their plant's annual operating costs were maintenance costs. Among those who did have a fix on maintenance budgets, about half indicated theirs had increased in the past several years, and just under half indicated that they anticipated further increases in the next few years. Some of the reasons given for these expected increases were:

1. Old worn-out equipment is subject to frequent breakdown.
2. New more sophisticated equipment requires more attention and greater skill to maintain.
3. Inflation and the rising cost of labor.

These reasons raised some basic questions. First, if the equipment was operated and maintained properly, would it be subject to more frequent breakdowns? Were industrial plants pushing older equipment beyond its operating limits and thus causing more frequent breakdowns? Second, while some respondents indicated new equipment would mean increased maintenance costs, others indicated that they expected their maintenance costs to decrease because of the installation of new equipment. Were maintenance crews being properly trained in effective maintenance procedures for new equipment? Third, while the cost of labor was rising, were not maintenance techniques and controls improving to provide a countereffect to balance the rising costs?

Obviously, the solution to these maintenance problems was not readily definable. However, a definite trend toward a strong preventive maintenance scheduling and control system has been taking place in some industries and providing a relief for some maintenance managers.

While the computer has become almost a necessity in large industrial plants as an accounting tool, it has also become quite an asset to maintenance managers as a scheduling and control tool. Computerized preventive maintenance scheduling and cost analysis systems have been successful in large industrial plants and even hospitals in producing cost savings.[3]

Instruments which continually monitor the condition of equipment automatically to detect equipment vibration, temperature, and so forth, were, in rare instances, interfaced with computers that kept track of conditions and actually wrote maintenance orders just prior to failure. A more centralized and controlled maintenance effort resulted.[8] In a high volume plant, the periodic disassembling of equipment for inspection, adjustment, and minor repairs in some instances would hardly be practical. In these situations preventive maintenance must go a step further to what has been termed "diagnostic maintenance". This means diagnosing the exact condition of the equipment at any time by means of onstream nondestructive tests. The objective is total avoidance of unnecessary and untimely shutdowns.[8]

In summary, the ratio of maintenance costs to production costs has been increasing and greater emphasis has been placed on control systems for this maintenance work. According to a study by the IBM Company,[9]

as automation increased the cost of maintenance per unit of production increased as the direct cost of production decreased. Maintenance personnel were thus accounting for a large share of the total cost. The high degree of automation requires an increasing number of highly trained high-priced technicians to be assigned to the maintenance function. Because of these trends, at the time of this study the costs associated with maintenance were increasing at an annual rate near 4 percent.[9]

II. APPROACHES TAKEN TO STUDY THE MAINTAINABILITY OF EQUIPMENT

According to Buffa,[10] the reliability of the production process can be maintained and improved by:

1. Increasing the size of repair facilities and crews so that average machine down time is reduced because maintenance crews are less likely to be busy when a breakdown occurs.
2. Utilizing preventive maintenance where practical so that critical parts are replaced before they fail. The degree of success here depends on the distribution of breakdowns and the relation of preventive maintenance time to repair time.
3. Providing for slack in the system at critical stages so that parallel paths are available. This means excess capacity so some machines can be down without affecting the delay cost to any great degree.
4. Making individual components within a machine or the machines within the system more reliable through improvements in engineering design.
5. Decoupling successive stages of the production system by inventories between operations. The resulting independence of operations localizes the effect of a breakdown, so operations proceeding and following the machine that is down are less likely to be affected.

The cost of maintaining reliability by any of these methods must be justified by reductions in idle labor, scrap, lost business, and so forth. Item number 4 is regarded as an engineering design problem

coupled with economic analysis. Number 5 involves layout and inventory control. Of the first three solutions, Number 2 appears to be the most economically feasible for a greater number of situations.

In theory, to economically justify preventive maintenance, one should examine the breakdown time distributions of the machine. Ideally, preventive maintenance should be performed just prior to failure. Machines which have low variability from the means are generally the ones on which preventive maintenance can most easily be justified.[10] In actual practice, however, sufficient data for such a study is usually not available at the outset of the program.

In an earlier study conducted on numerical control machines, Bright[11] pointed out that preventive maintenance can either improve or degrade the maintainability of equipment depending upon the distribution of life times of components included in the PM program. In this same study, it was also pointed out that preventive maintenance is only valid when applied to components and equipment which obey the "wear out law" of failure which is characterized by an increasing failure rate. The effectiveness of a PM system depends on how well it detects deteriorating parts. The failure rate of numerically controlled machines follows the Weibull[12] distribution as does the distribution of time to repair these failures.

Actually, the basic purpose of establishing a distribution of failures is to determine the most economical maintenance frequency. Figure 1, taken from the IBM study,[9] shows a plot of cost versus PM frequency. Ideally, PM frequencies should be adjusted to give minimum

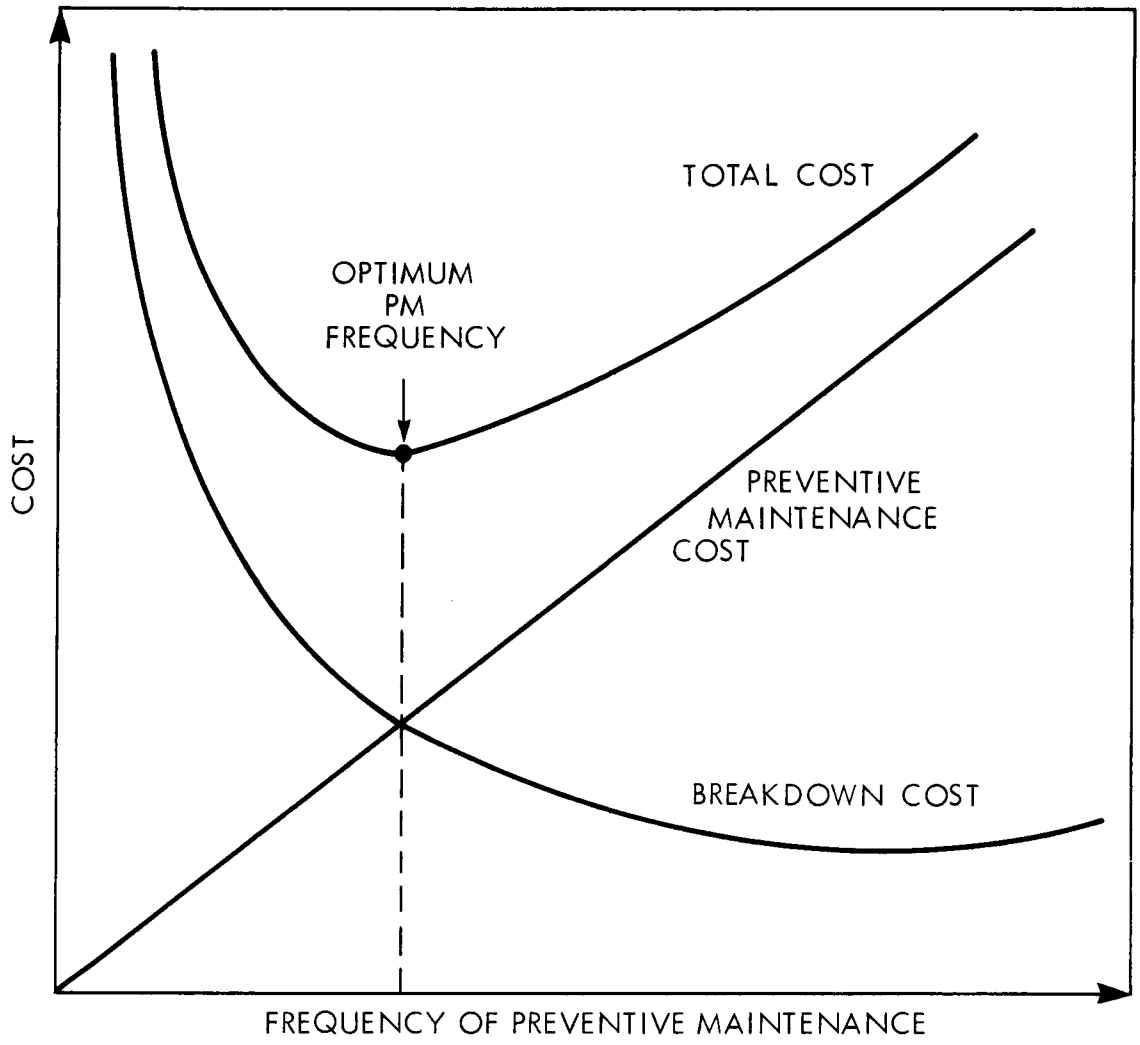


FIGURE 1

COST VERSUS PM FREQUENCY

total maintenance costs. When sufficient data is available, the approach outlined in the following discussion should be taken in establishing PM frequencies. However, it will be pointed out later in this thesis that this data is not usually available in industry.

Analytical Approach

Normally a manufacturing process can be considered as a system made up of several machines subject to failure. Each machine can be considered a subunit of this system. The reliability of the system is dependent and can be predicted from the failure probability of each subunit in terms of its influence on the system. If then, the assumption is made that the failure of the system is due to a particular subunit, a system down-time prediction formula can be written. Let N equal the number of sub-units in a given system and pi represent the probability that the system failure was due to the failure of the i-th subunit. Also let the down-time density for this subunit be denoted by $f_i(t)$. Then the system down-time density function is:

$$\sum_{i=1}^{i=N} p_i \; f_i(t)$$

An analogous situation can be assumed if one considers the machine itself as the system and its related parts which are subject to failure the subunits. This approach would be taken in situations that did not require continuous interaction of machines. For example, a job shop operation would not necessarily fit the first case mentioned; rather, each machine might be considered a separate system.

In either case, the availability of the machine when it is needed is important to the operator. The mean time between maintenance (MTBM) is an all important function. Ireson[13] defined preventive maintenance as "that maintenance performed to keep a system of equipment in satisfactory operational condition by providing systematic inspection, detection, and correction of anticipated failures before they occur or develop into major failures."

He also defines breakdown or corrective maintenance as that maintenance performed on a nonscheduled basis to restore equipment to a satisfactory condition by providing immediate correction of a failure which has caused degradation of the equipment below its specified performance.

Either of these types of maintenance can be done by one or more of the following concepts:

1. Repair in place
2. Remove, repair, replace
3. Remove, replace with spare, repair at base
4. Remove, replace with spare, repair at factory
5. Remove, replace with spare, discard defective package

The best approach, of course, depends on the economical analysis of the various factors affecting each situation such as failure rate, spares' cost, transportation cost, maintenance facilities requirements, test equipment available, and so forth.

Maintainability has many facets. The MTBM is, of course, dependent on downtime. The downtime associated with a machine is dependent on the

design, personnel, and support factors. Of these three, the design feature is perhaps the only one that can be assumed to be constant. The personnel and support parameters are at best estimates based on statistical averages of a group of similar machines under similar conditions.

If one lets $\overline{M}_T$ equal the near downtime per 1,000 hours for both preventive and corrective maintenance then

$$\overline{M}_T = \frac{F_c \overline{M}_{ct} + F_p \overline{M}_{pt}}{F_c + F_p}$$

where

F_p, F_c = number of preventive and corrective maintenance tasks per 1,000 hours,

$\overline{M}_{ct}$ = mean corrective downtime, and

$\overline{M}_{pt}$ = mean preventive downtime.

From Ireson[13] the mean preventive maintenance time $\overline{M}_{pt}$ approximately equals the corrective maintenance time divided by 1.4. He also pointed out that maintenance times have been observed to be distributed log normally. The ninety-fifth percentile, M_{max}, can be derived by taking the logarithm for each of the values. The resulting data forms a normal distribution and thus can be treated in a normal manner.

$$M_{max} = \text{Antilog } (\log \overline{M_{ct}} + 1.645 \sigma \log \overline{M_{ct}})$$

where

$$\log \overline{M_{ct}} = \frac{\sum_{i=1}^{N} \log M_{ct_i}}{N} = \text{mean of } \log M_{ct} .$$

$$\sigma \log M_{ct} = \sqrt{\frac{\sum_{i=1}^{N} (\log M_{ct_i})^2 - \left[\sum_{i=1}^{N} \log M_{ct_i}\right]^2 / N}{N - 1}}$$

where

N = number of tasks used in calculations.

When specific data are not available two empirical expressions have been developed for the derivation of the ninety-fifth percentile which is that time value below which lies 95 percent of the maintenance task durations. These expressions are:

$$\log M_{max} \tilde{=} 1.5 \log \overline{M}_{ct}$$

$$\log M_{max} = \log M_{ct} + 0.5$$

The t test can be used to make a statistical comparison between the calculated predicted value and the observed field data.

$$t = \frac{\overline{X}_1 - \overline{X}_2}{S_p \sqrt{1/N_1 + 1/N_2}}$$

where

$\overline{X}_1$, $\overline{X}_2$ = means of the two data sets,

N_1, N_2 = respective sample sizes, and

S_p = pooled estimate of the variance.

$$S_p = \sqrt{\frac{(N_1 - 1)S_1^2 + (N_2 - 1)S_2^2}{N_1 + N_2 - 2}}$$

where

S_1^2, S_2^2 = respective variance for each data set.

$$S^2 = \frac{\sum_{i=1}^{N} X_i^2 - \left[\sum_{i=1}^{N} X_i\right]^2 / N}{N - 1}$$

where

X_i = task time in data set.

After t is calculated, t - tables are used to decide whether the two means are the same.

Once the M_T has been calculated and tested it can be used to calculate the availability of operating time by substitution in the following formula:

$$A_i = \frac{MTBM}{MTBM + M_T}$$

where

A_i = intrinsic availability, and

MTBM = mean time between maintenance.

Another distribution which has become one of the most useful in predicting maintenance failure and downtime is the Weibull Distribution according to Caplen.[14] This distribution is defined as:

$$R(t) = \exp\left[\frac{-(t - \gamma)^{\beta}}{\sigma}\right]$$

where

$R(t)$ = the probability that no item will fail at or before time t,

σ = scale parameter,

β = shape parameter, and

γ = location parameter.

The maintainability function is defined as one minus the reliability probability function[11] or

$$M(t) = 1 - \exp\left[\frac{-(t - \gamma)^{\beta}}{\sigma}\right]$$

where

$M(t)$ = the probability of completing a given maintenance task in time t.

The Weibull or negative exponential distribution[15] is used for equipment that requires minor adjustment or may be removed and replaced fairly quickly but occasionally requires some major repair. The log-normal distribution, on the other hand, fits those cases where there are fewer downtimes of short duration, a large number of occurrences grouped about the same value, and a significant number of long downtimes. The lognormal case will plot as a straight line on log-log paper upon plotting the probability of repair versus repair times whereas the Weibull distribution requires special Weibull paper based on the log scale.

The distribution which best fits the particular case should be used. A mean time between maintenance and the mean time to repair should be established from these distributions.

Once the mean time between maintenance and usage is established, a preventive maintenance frequency can generally be established fairly accurately. However, one must carefully monitor costs to minimize the overall maintenance of a machine or piece of equipment. Herbaty[5] in his discussion on optimum maintenance results pointed out that the amount of preventive maintenance done on a machine should also be a function of the overall value of the machine. He categorized machines into three basic groups with Group A being lowest value with no PM, Group B medium value with regular PM, and Group C highest value with special PM approaches taken. Group C may be a group of machines that requires the very minimum downtime in order to maximize profit or they may be complex machines on which PM tasks require a great amount of time. There may be cases when a failure may have a pyramiding effect. For example, a bearing may go bad--a minor replacement. However, the bearing failure may have caused the shaft to drop and the entire engine may seize, causing additional failure. This Group C category, therefore, should be those machines on which maintenance treatment should be optimized.

Figure 2 shows graphically an iterative technique employed to optimize either downtime or maintenance cost. Starting at Point A the historical record life of a machine should be analyzed and PM instruction added to prevent future failure of the type noted on the record. In addition, if a PM instruction already covers the point of failure but breakdowns still occur, the PM frequency should be increased.

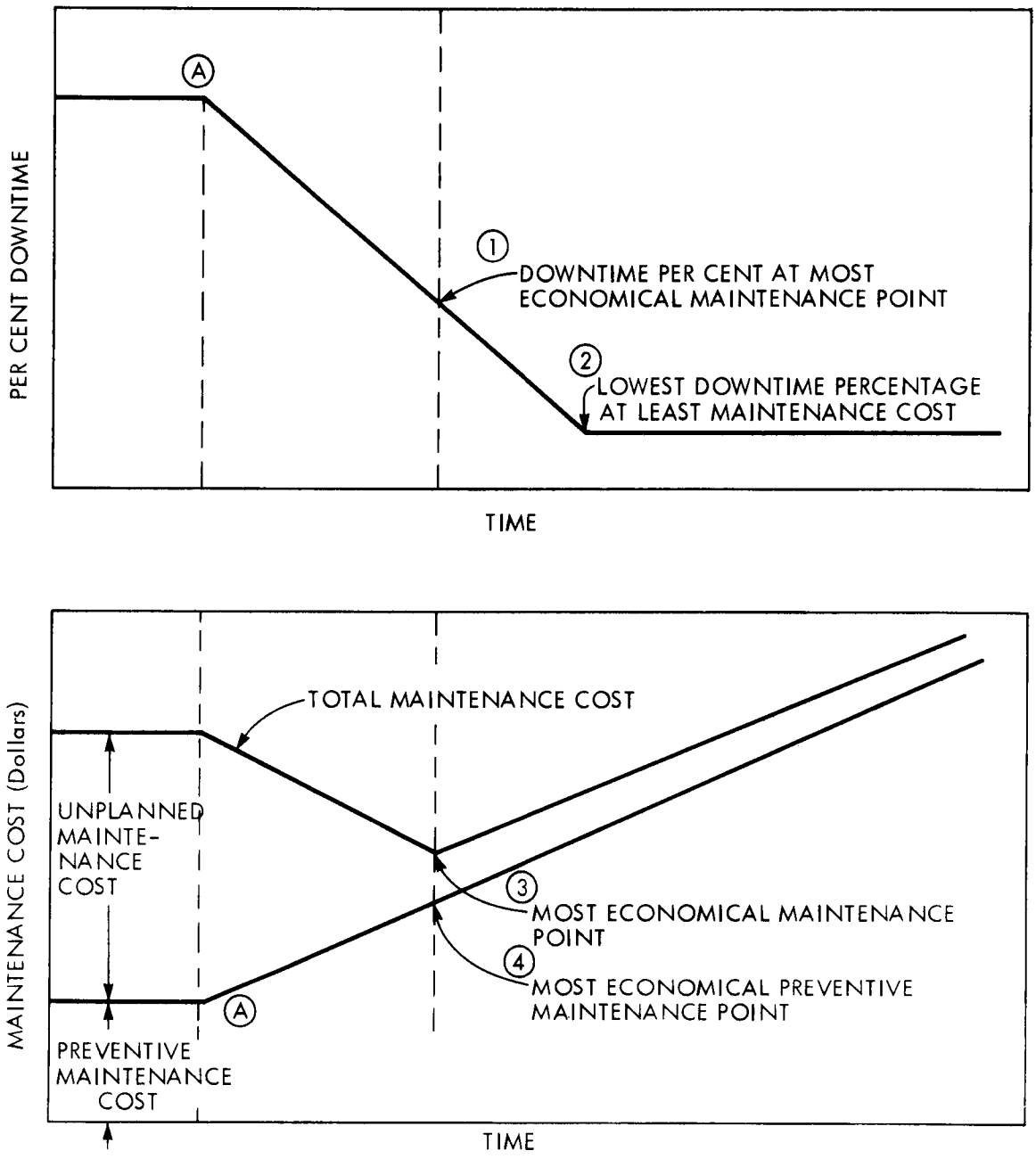


FIGURE 2

MAINTENANCE ANALYSIS COST CURVES

Conversely, if a PM instruction covers an item or function on which there has been no breakdown for a long period, the PM frequency could probably be reduced. By varying PM frequency and tasks and by plotting the effect on total maintenance costs one will be able to determine Point 3, the most economical total maintenance cost. The set of PM instructions and frequencies which are in use at Point 3 will therefore have been determined to be the instructions that produce the most optimum maintenance cost situation.

Further manipulation can be introduced by increasing PM frequencies past Point 3 until Point 2 is reached. This will ensure minimum downtime. Depending on production schedules and the criticality of the machine the equipment can be maintained at either the most economical maintenance point or the point of least downtime.

In summary, when setting up a PM system every practical attempt possible should be made to identify those factors which will influence the frequency of maintenance on a machine. Some of these factors are machine usage, machine criticality, machine complexity, the pyramiding effect, the number of times a machine is used, and actual breakdown data. All of the factors may sometimes influence, either collectively or independently, the frequency of scheduled PM tasks.

A Typical Maintainability Analysis

Ireson,[13] in his Reliability Handbook, defined maintainability as

> . . . the combined qualitative and quantitative characteristics of material design and installation which enable the accomplishment of operational objectives with minor expenditure including manpower, personnel skill, test equipment, technical data and

facilities under operational environmental conditions in which scheduled and unscheduled maintenance will be performed.

Parameters which are used to gauge the maintainability of equipment are (1) maintenance manhours per operation hour, (2) turnaround time required to return a piece of equipment to operating condition, and (3) percentage of articles which can be down for maintenance and still permit the attainment of operational requirement. These features are to some extent inherent with the design of the equipment. However, when one is faced with the task of establishing an optimum maintenance program for a set of existing machines, little can be done to change or alter the inherent features of a machine. A general approach of data collection and statistical analysis is used to predict maintenance frequencies and downtimes due to maintenance.

Usage data, breakdown frequencies, and times to repair are collected over a sufficient period of time to indicate a trend. Usually machines fail for a number of reasons. For example, a machine may have four parts which fail at different intervals or life periods. Distributions of MTBM for each part separately will lie close to its mean time. Plotting each failure of the machine will, however, show a much wider variation from the mean.[10] When sufficient data is available, actual breakdown time distributions can be approximated by standard distributions. As discussed previously, two of the most common of these distributions are the lognormal and the Weibull.

After deciding upon the distribution which most nearly fits the data collected, one can predict with varying degrees of confidence that a machine can run a given amount of time before failure occurs. The

next question concerns whether it is more economical to attempt to prevent failure by applying preventive maintenance or to wait until failure occurs and replace or repair. Trade off analyses are made (1) between the cost of a replacement and the time to repair the failed part, (2) between the lesser of these two, and (3) the time taken to perform preventive maintenance on the system. If the failure can actually be prevented and if prevention isn't too complicated, then preventive maintenance usually has merit.

From the breakdown distribution a preventive maintenance cycle time can be chosen so that it would fall just prior to failure. The lower the variability the more accurate this prediction becomes. Suppose, for example, a maintenance crew takes an average time Tm to accomplish the preventive maintenance and Ts for the repair maintenance. Figure 3 shows a plot of the percentage of time the machine is working against the ratio of the standard period between PM to the average run time Ta for three typical distributions. Curve a peaks at the optimum maintenance cycle ratio for maximum machine working time. Note that Curves b and c do not show such a peak in the range given. Curve a varies less from the mean than does b or c. Increasing the time between maintenance beyond 70 percent of Ta would only decrease machine working time due to being down for PM for machines fitting distribution a, a lognormal distribution.

In summary, the approach to maintainability can be listed in the following steps:

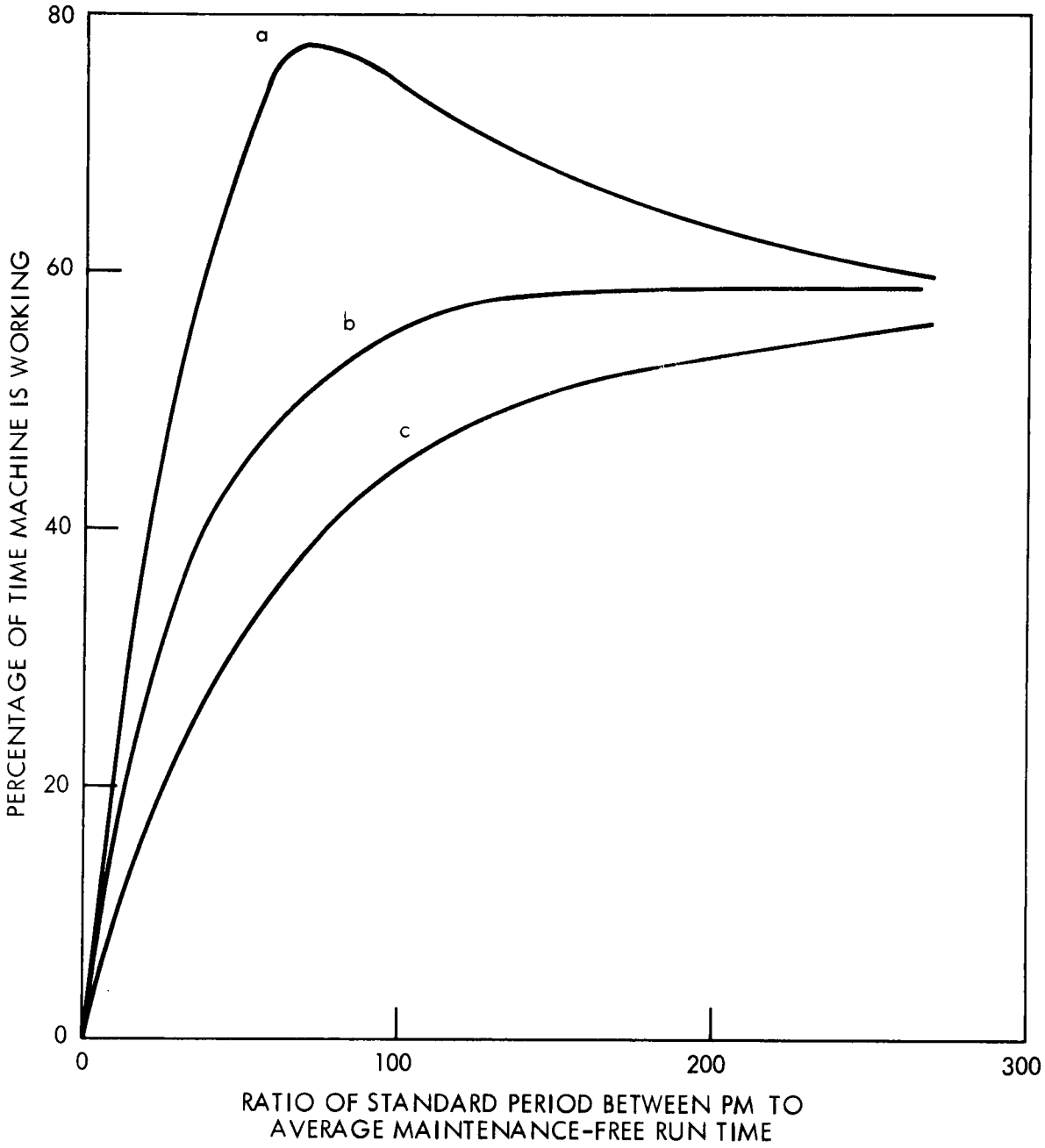


FIGURE 3

AVAILABILITY VERSUS PERCENTAGE OF DOWNTIME FOR THREE DISTRIBUTIONS

1. Identify points subject to wear.
2. Collect data on the time taken to repair failures and the run time between failures.
3. Assemble the data into a cumulative distribution which will show the percentage of failures repaired in r hours or less and the percentage of run times before failure in t hours or more.
4. Plot the distribution on lognormal or exponential paper and select the particular distribution the data best represent.
5. From the distribution selected, read from the curve the mean time to repair and the mean time between failures.
6. Examine the failure history to determine if preventive maintenance is feasible. That is, are the breakdowns increasing with time and can the failure be prevented through simple preventive steps?
7. If PM is feasible, establish procedures to detect pending failures and restore proper operating conditions; establish an interval so that PM is performed shortly before expected failure.
8. Through an iterative process minimize overall maintenance cost or downtime by applying proper scheduling techniques and manpower leveling.
9. Follow up by updating procedures as methods and conditions change.

Unfortunately, in many instances the data necessary to analytically establish PM frequencies is not available. In such cases, the frequencies are set up by using manufacturer's recommendations and the foremen's knowledge of the machines.

III. GUIDES TO A PREVENTIVE MAINTENANCE POLICY

The above approaches to the study of maintainability lead to some generalization about preventive maintenance policy. Buffa,[10] in his analysis of the subject, points out some guides to be used in determining the feasibility of performing preventive maintenance. Some of the guidelines are discussed in the following paragraphs.

First, preventive maintenance is generally applicable to machines with breakdown time distributions that have low variability from their mean. A good example of such a distribution is Curve a in Figure 3, page 25. In general, distributions with less variability than the exponential, Curve b, are in this category. Low variability means that one can predict with greater precision when the majority of breakdowns will occur. A maintenance period can be set which anticipates and prevents breakdowns fairly accurately.

Second, preventive maintenance is usually feasible only if the cost to perform the preventive maintenance task is less than the cost to make the repair. The only exception to this statement would be if preventive maintenance could be performed on a shift during which the machine was not running. No unnecessary machine shutdown would occur due to PM.

Third, preventive maintenance is usually effective in controlling overall maintenance costs when applied to a situation where machine breakdowns are increasing. Increasing breakdowns are an indication that the items which are failing follow the wear-out principle. By taking preventive steps the life of these parts can usually be extended.

IV. METHODS USED TO SCHEDULE AND CONTROL MAINTENANCE

The methods used to schedule maintenance activities vary from the foreman's day-to-day planning to elaborate data processing systems programmed to react to various known variables. The basic steps employed in each one, however, are essentially:

1. Define the work
2. Determine the frequency
3. Plan the materials needed and the procedure
4. Estimate the work
5. Schedule the first occurrence

Most PM systems start with a manual or semiautomatic system. PM manuals or data sheets are usually prepared defining the activities, frequencies, lubricants, and specific tests to be performed. Checklists are usually prepared giving specific instructions on what to check on a particular machine. Standard time or estimates are usually placed on activities where possible. When this has been done charts are prepared to level work loads and determine start time for scheduling.

Frequencies may vary from once per shift to once every five years. One of the keys to an effective PM program is a balanced daily work

load. Many maintenance experts put the blame for over 50 percent of maintenance inefficiency on the unbalanced daily work load.[16] Efforts to achieve this balance should certainly be a major goal of any PM system. These efforts can be manual, semiautomatic or computerized.

Manual System

Of course no PM system is completely divorced from some manual effort. The manual system referred to here is one in which all scheduling efforts are manual. First of all, maintenance instructions have to originate with a person very knowledgeable about the equipment. Finding such a person is not an easy task when a large variety of equipment is involved.[5] There have been many articles written about setting up paper work systems but very little about the quality of the PM instruction itself.

When one is unfamiliar with the equipment, the manufacturer's guidelines are often used. These instructions are quite often written, however, to achieve zero breakdown which in practice may not always be practical. Calculations and statistical methods are sometimes used to determine proper frequencies when sufficient data is available. After these frequencies are determined simple ticker files are sometimes set up to remind maintenance crews when to perform certain tasks.

Semiautomatic System

When the volume of equipment is too large for a manual scheduling system and if computer equipment is not available, other semiautomatic means have proven successful. An example is the use of an automatic

addressing machine,[17] utilizing plates and tabs to print PM tasks and schedule these activities at specific frequencies. Taps (see Figure 4) on the top of plates contain four holes which can be coded in various ways to give weekly, monthly, quarterly, and other frequencies. The machine can be programmed in a similar way to print the work orders just as various address listings are printed from this machine.

While some manual labor is involved in running the automatic addressing machines, the actual scheduling is automatic after initial programming is done and routine frequencies are established. This system works best in medium size plants which do not have access to the computer equipment.

Computer System

In large plants that have hundreds and perhaps thousands of pieces of equipment to maintain, the computer becomes a feasible and most helpful tool. Its ability to economically balance work loads can relieve maintenance schedules of time-consuming, error-prone sorting and slotting associated with manual methods.[16] The leveling of weekly work loads can be accomplished through routine programming methods.[18] In a study by Whitton and Ruble[19] it is pointed out that the greatest benefit from the use of the computer will come from work load studies that can be made. They claim to be able to make yearly projections of man-hour requirements and size their forces more accurately using the computer.

Another advantage of the use of the computer is for equipment inventory and history of equipment maintenance. The computer can store

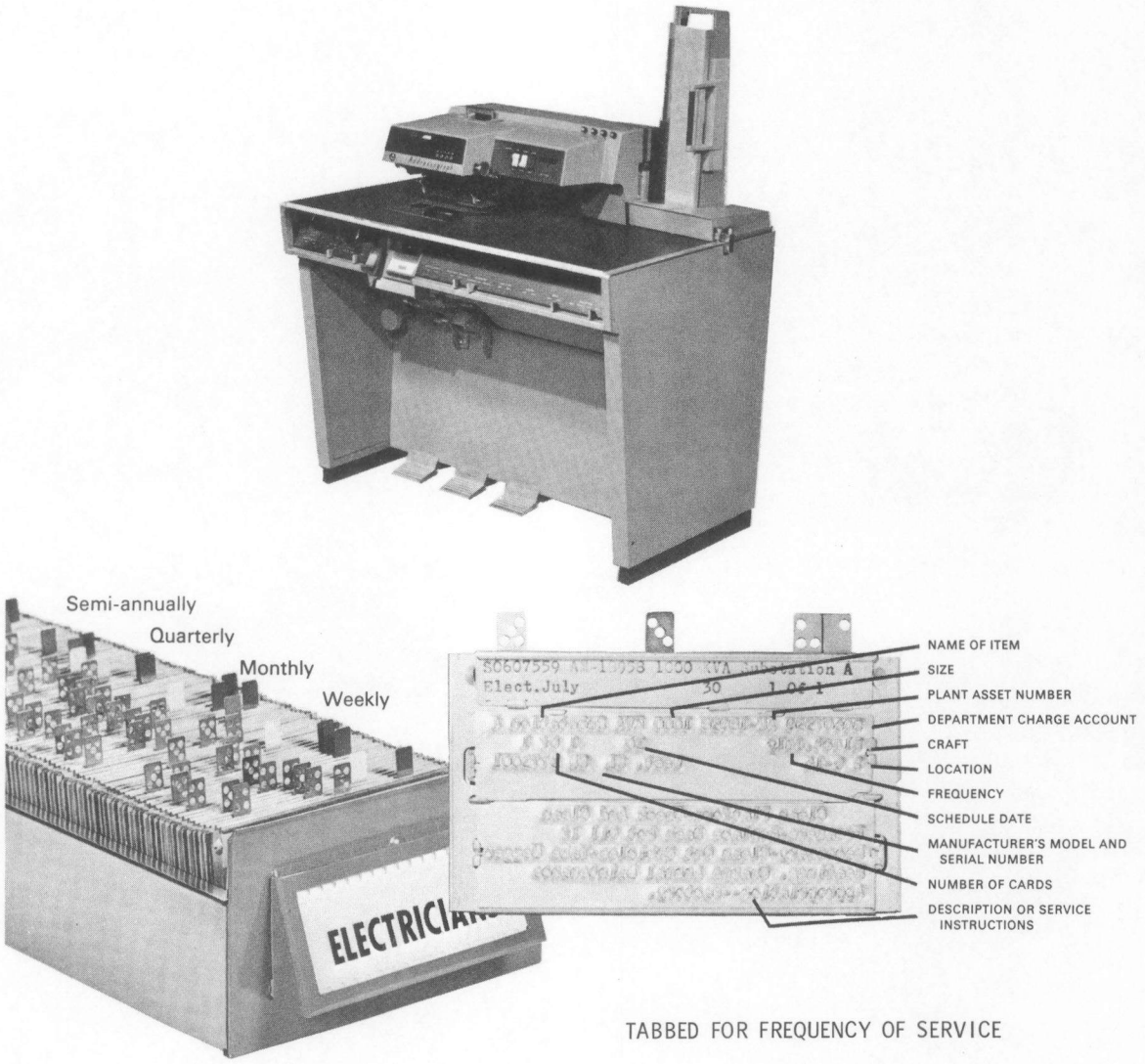


FIGURE 4

MAINTENANCE SCHEDULING VIA SEMIAUTOMATIC MEANS

all pertinent information on a piece of equipment and maintain records on the maintenance performed.

This thesis postulates that the computer can be used to level work loads of preventive maintenance tasks and help to optimize PM frequencies by collecting and assembling equipment usage data. Through an iterative process over a period of time it can be helpful in establishing frequencies for PM tasks which are functions of the hours used and the number of times used.

V. FEATURES OF EXISTING PM SYSTEMS

A survey of twenty different PM systems existing in industry at the time of this study was made through the use of Plant Engineering magazine and the Defense Documentation Center. A list of characteristics common to many PM systems was made and each system was analyzed to determine if the characteristics existed. A relationship between the size of the company or plant, the type work (repetitive or nonrepetitive), and the system characteristics began to become evident. Table I shows the summary of the results of this survey listing the characteristics which were sought in each system and the number of industrial plants that utilized each characteristic as a part of their PM system.

System Characteristics

In researching existing preventive maintenance systems one must look for those characteristics which make the systems successful. All the systems surveyed were reported to be successful in reducing overall

TABLE I

A SURVEY OF SYSTEM CHARACTERISTICS

System Characteristics	Industrial Systems																				Percent Used
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1. Write own maintenance instructions.	x	x	x	x	x	x		x	x	x		x		x	x	x		x	x		75
2. Use strictly the manufacturer's recommendations.							x				x		x				x			x	25
3. Determine PM frequencies entirely by analyzing breakdowns.			x	x																	10
4. Use strictly the manufacturer's recommended frequencies.	x												x	x	x		x			x	30
5. Adjust frequencies using recommended frequencies as a guide along with breakdowns and usage data.		x			x	x	x	x	x	x	x	x				x		x	x		60
6. Use computer for scheduling.					x		x				x	x		x	x	x	x	x	x		50
7. Use specific instructions for each type of machine.	x	x		x	x			x		x		x			x	x		x		x	55
8. Use general instructions for all machines			x			x	x		x		x		x	x			x		x		45
9. Use vibration detectors or nondestructive testing.		x	x												x						15
10. Maintain spare parts control along with P.M. program.						x										x	x				15
11. Maintain maintenance histories on equipment				x	x	x	x		x			x	x	x	x	x	x	x	x		65
12. Machine or equipment usage is fairly constant.	x	x	x	x	x		x			x	x		x				x	x	x		60
13. Large number of similar type machines or equipment.	x		x			x			x	x	x		x	x			x	x	x	x	60
14. Use computer to balance (level) workload automatically.							x									x					10
15. Provide cost data on maintenance related to PM.			x	x	x		x		x			x	x	x		x	x		x	x	60
16. Provide follow-up control method to see that PM is done.	x	x		x	x		x			x	x	x	x	x	x	x	x	x	x	x	80
17. Use standard time values for PM tasks.	x					x	x			x		x	x			x		x	x		45
18. Maintain machine or equipment usage data.									x			x		x		x					20
19. Consists of lubrication and minor mechanical checks only.	x									x		x		x						x	25
20. Includes mechanical, electrical, and lubrication inspections and checks		x	x	x	x	x	x	x	x		x		x		x	x	x	x	x		75

maintenance cost in their particular environment. The maintenance forces in the plants surveyed ranged from approximately twenty maintenance men to several hundred. One factor affecting the characteristics of each of the systems was the size of the plant surveyed and the type of facilities available.

Do most plants write their own maintenance instructions and establish their own PM frequencies as opposed to using the manufacturer's recommended frequencies? Are computers necessary for a complex scheduling system to be successful? How far should one go with PM checks? Should testing and vibration monitoring be done? Are PM systems really thorough enough to measure their own effectiveness? How well is a PM system controlled and adapted? These are some basic questions which stimulated the list of characteristics given in Table I. An "X" is placed across from the system characteristic under the industrial system that possesses each characteristic.

Survey Analysis and Conclusion

It is interesting to note that no one characteristic is common to each industrial system. Although all are reported to be effective in reducing breakdowns and overall costs, it appears that a PM program must be somewhat custom-made for the specific environment for which it is developed. One plant may attribute its success to being able to schedule PM tasks via the computer or electronic data processing equipment, for example, while another plant may report a successful PM system without computer-assisted scheduling. Therefore, when identifying characteristics

which make a system successful one must examine the specific environment (overall size and type of work and equipment) which exists at each plant.

Some characteristics listed in Table I, page 33, are more common than others. Eighty percent of the systems provide a definite follow-up control method as a part of the program to ensure that the PM work is done. The other 20 percent hold employees responsible for breakdowns which occur due to lack of PM. Seventy-five percent of those systems studied used maintenance instructions written by their own maintenance people and included in those instructions both mechanical and electrical checks as well as basic lubrication. The plants which did not do this relied on manufacturer's recommendations which usually consisted of lubrication and minor mechanical checks only. Their equipment usually was lower in value, was similar in nature, and was used fairly consistently.

The industrial plants which used the computer for scheduling had the facility already available and in use for accounting purposes. No plants justified its use merely for PM scheduling, but implied that if the facility was available it was probably the most feasible way to schedule a large amount of tasks periodically. While 50 percent of the plants used the computer for basic scheduling by periodically issuing "work orders", only 10 percent took full advantage of the computer to balance workloads. Usually this was done manually prior to setting up routine scheduling on the computer. By utilizing the computer to balance workloads, the computer is allowed to establish which week or period a task is to be done, given the frequencies and the amount of work already scheduled for that period.

Pettit[20] reported that nondestructive tests have been successful in detecting potential system failures. This is done by using dye penetrant to detect fatigue cracks by dusting small magnetic particles on potential failure areas. These particles form an outline of any discontinuity. Other methods used are ultrasonics, radiography, and eddy current analysis. Zelchus[21] reported the use of vibration detectors to measure the amount of displacement, velocity, or acceleration involved. Out of tolerance equipment is examined closer and parts are replaced.

The systems that seemed to be more detailed and experienced were those that employed the majority of the characteristics. In plants that had equipment of greater value than others, PM was extended to include a spare parts inventory and standard times for each task.[22] It can be concluded that a good PM program is somewhat an evolutionary process which starts out with basic scheduling of routine tasks which have to be done and branches into more elaborate methods with time and as more experience is gained.

One common ground rule to the success of any PM system, no matter which characteristics exist, is that management must be 100 percent behind the program. Preventive maintenance must be given sufficient priority to be effective.

CHAPTER III

DEVELOPMENT OF A PM SYSTEM

A general hypothesis was made in Chapter I that a preventive maintenance scheduling system could be developed which would be effective in controlling the maintenance on machine shop equipment which is used sporadically. This chapter will describe the environment in which these machines are located and the techniques and steps used in developing such a PM system.

I. ENVIRONMENT

The machines and equipment included in this study were located at the Oak Ridge Gaseous Diffusion Plant, a large industrial plant of approximately three thousand employees, operated by Union Carbide Corporation, Nuclear Division, for the U.S. Atomic Energy Commission. These machines were subjected to sporadic usage under a job shop situation. The type of machine tools covered by the PM system included lathes, grinders, mills, drills, and so forth. The system was also to be designed in such a way that other plant equipment which required repetitive maintenance could be included in the system.

The Fabrication and Maintenance Division of the Oak Ridge Gaseous Diffusion Plant (ORGDP) was responsible for maintaining general plant equipment as well as operating the Fabrication and Machine Shops. Because this shop equipment was entirely under the control of the

division and because of its relatively high value, its machines were chosen to be the first studied. If the scheduling system should prove successful on these machines, other plant equipment would be included.

Although some lubrication manuals had been written in the past, they were rarely used. Lubrication was usually done at the request of the shop foremen or the machine operator. At times, the lubricator would make routine checks of the machines based on his knowledge of their running condition. No specific work orders were written for repair on the machines. "Blanket" orders did exist, however, on these machines and cumulative cost was collected against each machine on a monthly basis. No formal history of maintenance work existed nor was any consistent means of collecting machine usage practiced.

In 1971 a work order system was implemented as a control technique to identify and schedule individual maintenance jobs. This system required a work order for each maintenance job. Field maintenance crews were located throughout the plant complex. The maintenance crews responsible for maintaining the above-mentioned machine tools were located in the shop area midway between the two machine shops and under the same roof. The system implemented in 1971 provided a means of collecting data on repair jobs on the equipment. Prior to this system, no formal means of requesting maintenance existed. Records of breakdown frequencies were not available until this new work order system went into effect. Then requests for maintenance work were made on a "Work Order" (see Figure 5) and channeled through a planner-estimator who estimated the work. The preprinted job number identified individual requests on

WORK ORDER

TO			DATE WRITTEN	DATE REQUESTED	JOB NUMBER L- 06805
ORIGINATOR	PHONE		DIV. CODE	ACCOUNT NUMBER	WORK ORDER NUMBER N ☐ S ☐ B ☐
	BUILDING	MAIL STOP			CROSS ORDER ☐

DESIGNATED REPRESENTATIVE		APPROVALS SPECIALS & BLANKETS	☐ NONE REQUIRED (NORMAL)	
☐ NONE	NAME		DIVISION SUPT. ☐	PLANT ENG. (1900 ACCT.) SPECIAL

WORK PERMITS REQUIRED ☐ NONE ☐ ELECTRICAL ☐ MECHANICAL ☐ HAZARDOUS

DESCRIPTION OF WORK REQUESTED INCLUDING DRAWING NUMBERS, LOCATION, INSPECTION, TEST, CLEANLINESS, OR OTHER SPECIFIC REQUIREMENTS

LOCATION OR CUSTOMER — JOB TITLE (For Fabrication & Maintenance Division Use Only)

SCHEDULE DATES			CROSS ORDER ISSUED			
	SCHEDULE START	TYPE COST		TO	DATE	NUMBER
	SCHEDULE COMPLETION	LEAD DEPT. NO.		TO	DATE	NUMBER

SHOP OR AREA	MASTER CODE	START DATE	COMP. DATE	EST. HOURS	TYPE EST.	P. E. INIT.	SHOP OR AREA	MASTER CODE	START DATE	COMP. DATE	EST. HOURS	TYPE EST.	P. E. INIT.

FINAL INSPECTION	MAINTENANCE SUPERVISOR	DEPT.	DATE	DESIGNATED REP. (WHEN ASSIGNED)	DEPT.	DATE

DISTRIBUTION: ORIGINAL, BLUE, AND CANARY TO MAINTENANCE DIVISION
GREEN RETAINED BY ORIGINATOR

COMPLETED WORK ACCEPTED BY		
NAME	DEPT.	DATE

UCN-10004A
(1 9-71)

FIGURE 5

WORK ORDER FOR REPAIRS

the same machine. The work order number assigned to the machine was written in the proper location on the work order form.

The maintenance performed on these machine tools usually required one or more of three crafts: maintenance mechanic, lubricator, and/or electrical mechanic. Two maintenance service groups existed: (1) the electrical group, and (2) the maintenance mechanics and lubricators. Some three hundred machines were included in this study.

For the purpose of this study, the setting and the initial maintenance information available was believed to be a typical industrial job shop operation.

II. APPROACH

To accomplish the objective stated in Chapter I, one must identify repetitive maintenance tasks, establish reasonable frequencies in which to accomplish these tasks, minimize the time required to perform the tasks, and schedule the tasks.

Task Identification and Equipment Inventory

A study of the equipment manufacturer's recommendations and the equipment behavior should reveal those machine maintenance areas most adaptable to planned maintenance tasks. Prior to such a study, however, an equipment inventory was made to determine the equipment which would be included and the location of such equipment. Once this inventory was made, available literature on each piece of equipment was reviewed for PM recommendations. Literature on some machines did not exist. Some

were found to be similar to other equipment. Previous lubrication schedules had been prepared for some of the machines, and they were updated to reflect current lubrication codes, and so forth. Basically, the definition of tasks to be performed consisted of the following steps.

1. Identify each piece of equipment with pertinent information such as equipment malfunction, property number, cost, year new, and so forth.
2. Identify points of service on each machine.
3. Identify the lubricant to be used if the task is lubrication.
4. Identify the craft to perform the task.

A data sheet was designed on which to record this information (see Figure 6). Computer column paper was used since this information would ultimately be stored on the computer.

During the inventory it was found that some equipment contained readily identifiable equipment numbers while others did not. Thus, the first activity became the numbering of all the equipment. It was recognized that it would be advantageous to link the number of the equipment to its location so that sequencing of maintenance tasks could be done to minimize backtracking of maintenance craftsmen from one machine to another. Figure 7 shows a layout of a portion of the shop. A routing sequence was established by the assignment of equipment numbers. Groups of numbers were allocated to each bay and sequenced numerically throughout each bay.

Other pertinent information about the machines was gleaned from property records and recorded on the "ORGDP Preventive Maintenance Data

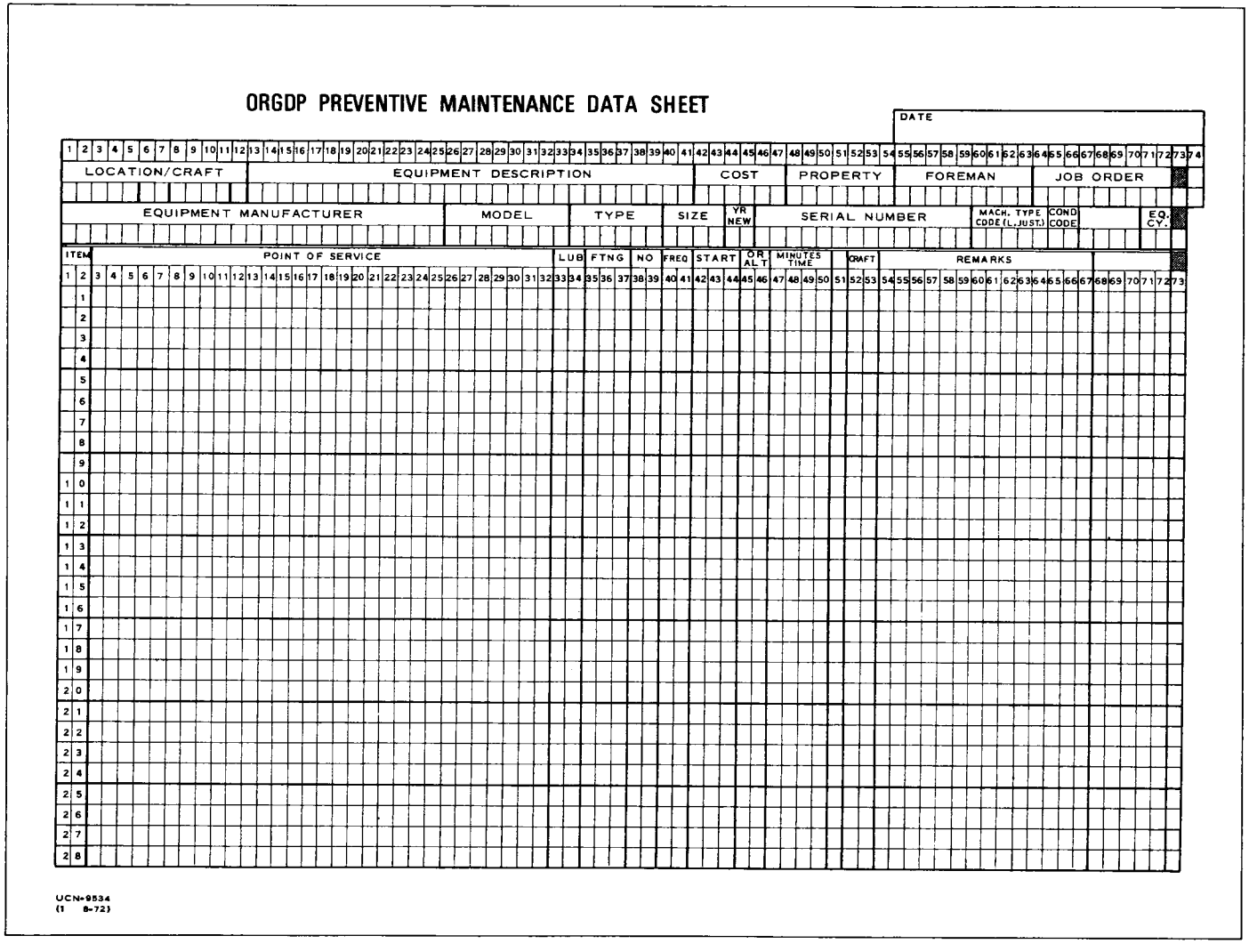


FIGURE 6
ORGDP PREVENTIVE MAINTENANCE DATA SHEET



FIGURE 7

PHOTO OF MACHINE SHOP SHOWING EQUIPMENT LOCATION

Sheet". Each machine was typed as to its function such as lathes, boring mills, and so forth. Type codes were assigned and placed on the data sheet as keys to sorting this equipment. These function types and their codes are:

9	Mill, Turett
10	Lathe, Automatic and Turret
11	Lathe, 16 inch and under
12	Lathe, over 16 inch
13	Grinder, Surface
14	Grinder, Universal Cylinder and Precision
15	Mill Boring
16	Mill, Vertical Boring
17	Mill, Universal
18	Mill, Machine
19	Drill, Radial
20	Drill, Floor and Drill Press (Large)
21	Saw, Band
22	Borer, Jig and Grinder
23	Planer
24	Tool Grinding Area Machines
25	Small Grinder, Drills and Other Machines
26	Drill, Tape

Condition codes were also assigned by machine shop foremen. Each machine was rated as to its running condition on a scale from 01 to 05 defined as follows:

01 Excellent Condition. Performance is as good as new.

02 Good Condition. Has had a minimum of maintenance. Has seldom given cause for the production of unacceptable parts.

03 Fair Condition. Will produce good parts with considerable maintenance and selective assignment of machinists and work. Prefer to avoid usage if possible.

04 Poor Condition. Defective or deteriorated machine. Good only for roughing work. Avoided by machinists. Not considered worthy of further maintenance efforts.

05 Unusable condition. So deteriorated that machine cannot be profitably used or maintained and should be junked.

The literature on each machine was reviewed by a planner-estimator and maintenance engineer who arrived at a list of repetitive maintenance tasks for each machine. Three separate task lists were prepared for each machine: (1) lubrication checks, (2) mechanical checks, and (3) electrical checks. Each lubrication point was identified with the proper lubricant to be used. In a previous study[23] standard lubrication codes had been developed which were used to identify the proper lubricant. In many instances the manufacturer's recommended oil had to be related to these standard codes. Comparison charts had also been prepared and were used as cross references to the correct type. An example of some of these codes can be found in Table V in the Appendix. These charts are the result of chemical analysis of the viscosity and quality of each lubricant.

Establishment of Frequencies

This phase of development was perhaps the most difficult and the most critical. In most cases, data did not exist over a sufficient period of time to establish breakdowns. It was quickly noted that the manufacturer's recommended PM frequencies were based on continuous or daily usage. Most of these machines, however, were used sporadically

depending on the type of jobs being performed. The initial approach taken was to compare the manufacturer's recommended frequency with the foreman's estimate of how much the machines were used. Records of breakdown frequencies were also begun as well as usage records. The next section of this chapter explains the data collection system implemented to collect this information.

Establishment of Standard Times

Time studies were done on some of the highly repetitive tasks. Other tasks varied from machine to machine so that it was not feasible to study each individual task. Foreman estimates and actual reported times were used on some of these tasks.

Establishment of Schedules

Establishing schedules to equalize manpower requirements is one of the keys to an effective PM program. These schedules should also be made to prevent backtracking. With a large number of machines to be serviced, the procedure of scheduling these tasks manually becomes complex and time consuming. Although the initial implementation of this PM system included only about three hundred machines, future plans called for several hundred more pieces of equipment to be added. Since computer services were readily available at the plant, it was decided to utilize the IBM 360 computer in scheduling these tasks and in providing maintenance history on this equipment. The fourth section of this chapter describes the techniques and procedures used.

III. DATA COLLECTION PROCEDURES

Basic information which can be collected and assembled in various fashions is necessary in order to make sound economic decisions about equipment and manpower utilization. The pros and cons of the various techniques for collecting have been argued for several years. Basically the information needed is:

1. Machine usage (hours and frequency)
2. Machine maintenance (hours)
3. Machine history (breakdown frequency and maintenance tasks performed)
4. Machine spare parts inventory file

Machine Usage

At the beginning of this study no usage data was available. Some machines were equipped with clocks but no readings were being made periodically. Several means to collect this usage data were investigated. One approach was to purchase and install clocks on all the machines and assign someone the responsibility of periodically taking readings. A second approach involved tying in the clock to a central location which would automatically record usage at a central location, thus eliminating the reading of individual clocks. This system would have been very expensive to install and did not seem feasible for this purpose only. A third method, which was eventually implemented, simply required the operator of the machine to record his usage of the machine on his Job Assignment Card (Figure 8).

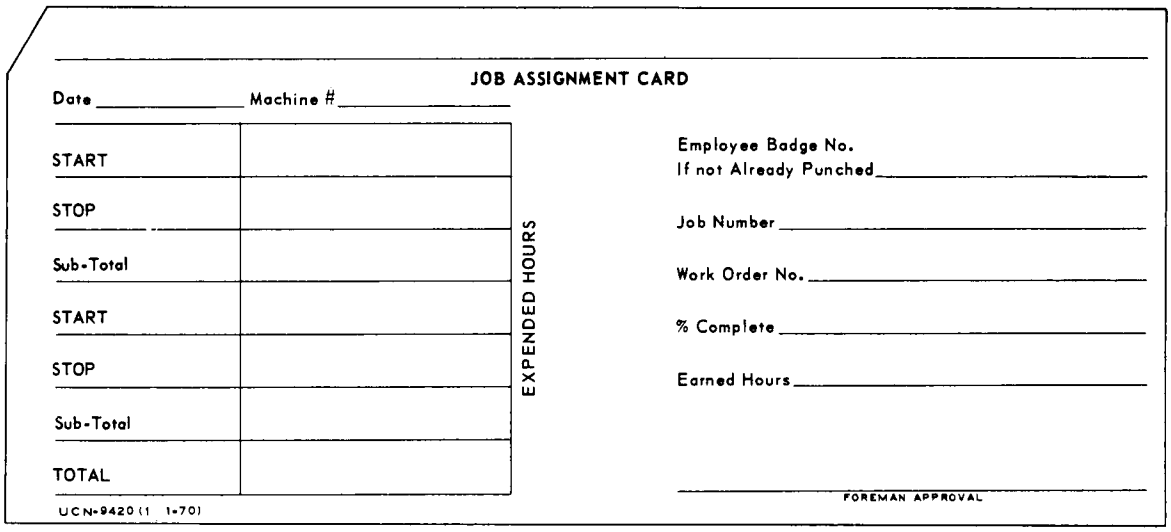


FIGURE 8

JOB ASSIGNMENT CARD

As a part of the Work Control System, machine operators recorded their time on their Job Assignment Card along with the Job Identification Number. A place for the machine number was included on the card. These cards were turned in by the machinist to his foreman at the end of the day. Since the time recorded was charged against the job as well as the machine, emphasis was placed on getting correct information. Another advantage of this method was that the number of times the machine was turned on and off could also be known. One card per machine per job per day was used.

Usually a machinist was assigned the entire job if it was small or a definite segment of a larger job regardless of the type machine or machines required. Therefore a machinist might use more than one machine and different machinists might use the same machine. The number of times a machine was turned on was suspected to influence its reliability. The number of cards turned in served as an indicator of how often a machine was started.

Machine Maintenance (Hours)

When a machine broke down a work order was written requesting repair (see Figure 5, page 39). The preprinted job number identified the specific request. A work order number assigned to the machine was written on the work order form when requesting maintenance. The hours expended repairing the machine were charged against the job number and were also charged automatically to the machine's work order number which served as an account for all maintenance done against the machine.

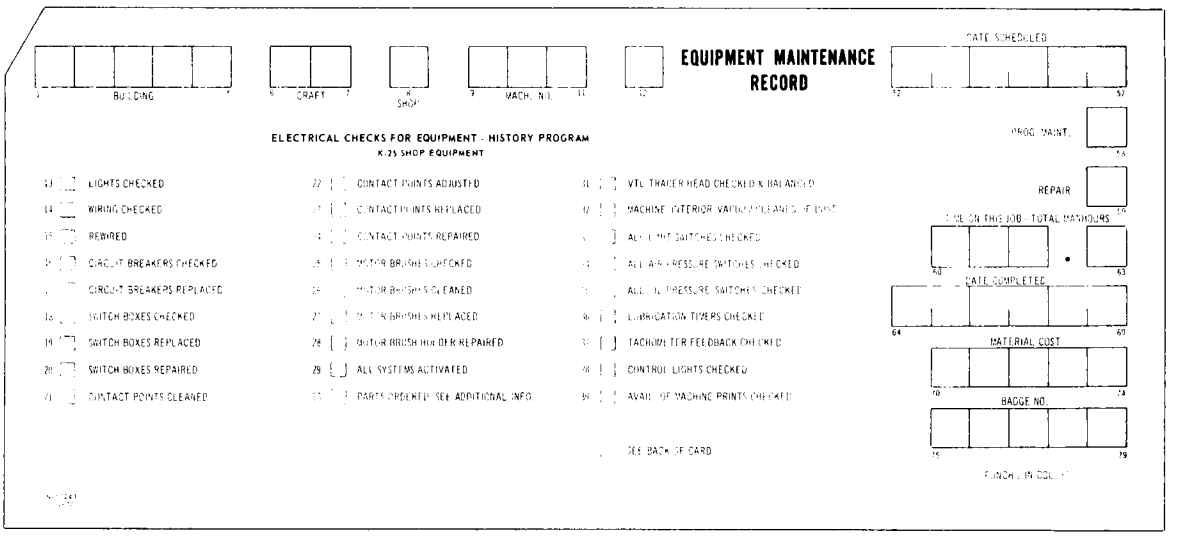
These work orders were used for repair only. Preventive maintenance was charged directly to the machine work order and indicated as PM, thus distinguishing between breakdown maintenance and preventive maintenance.

Machine History (Breakdown Frequency and Maintenance Tasks Performed)

The fact that a machine broke down X number of times during period Y resulting in Z number of maintenance hours was established. This information alone, however, was not sufficient to pinpoint specific trouble spots. Some means was needed of assembling the information on what work was actually done. In the past, some foremen had kept records manually but no consistent effort had been made to do so. A computer program was written to create and store history records on each machine. Input cards were designed giving repetitive PM activities and space for reporting other activities. Figure 9 gives an example of the card for electrical tasks and Figure 10 gives a card listing some mechanical tasks. These cards were turned in as work was completed on a machine and a monthly report was run showing a history of maintenance activities on the machine shop equipment (see Figure 11).

Machine Spare Parts Inventory File

A basic part of many PM programs is control of spare parts. One of the problems often experienced is the delay incurred from the time a part goes bad until another part can be obtained. Difficulty arises when stocks are kept at a minimum and the part needed has to be ordered from the vendor. The solution to this problem is not easy. Ideally,



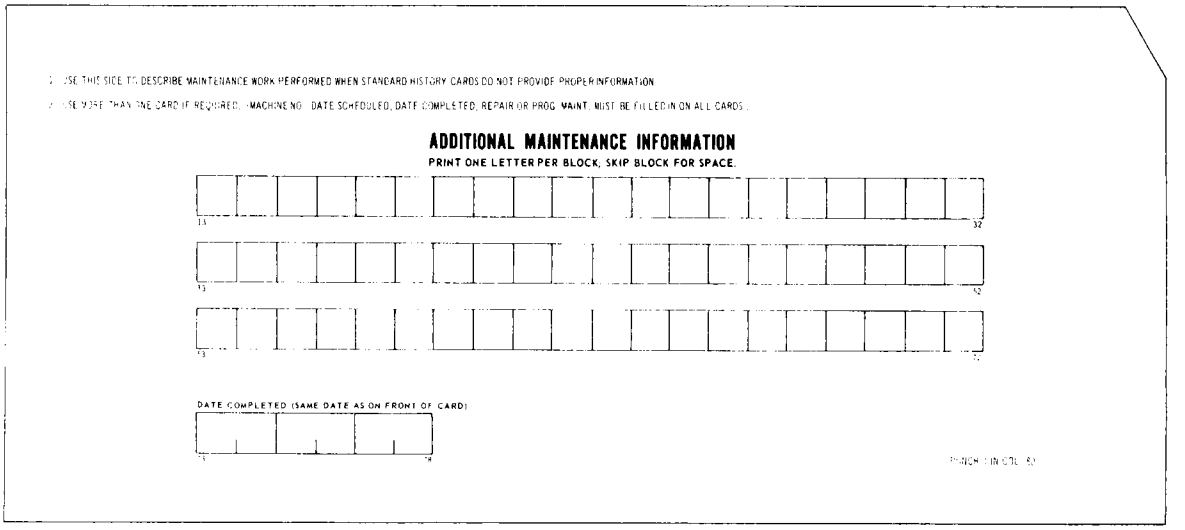
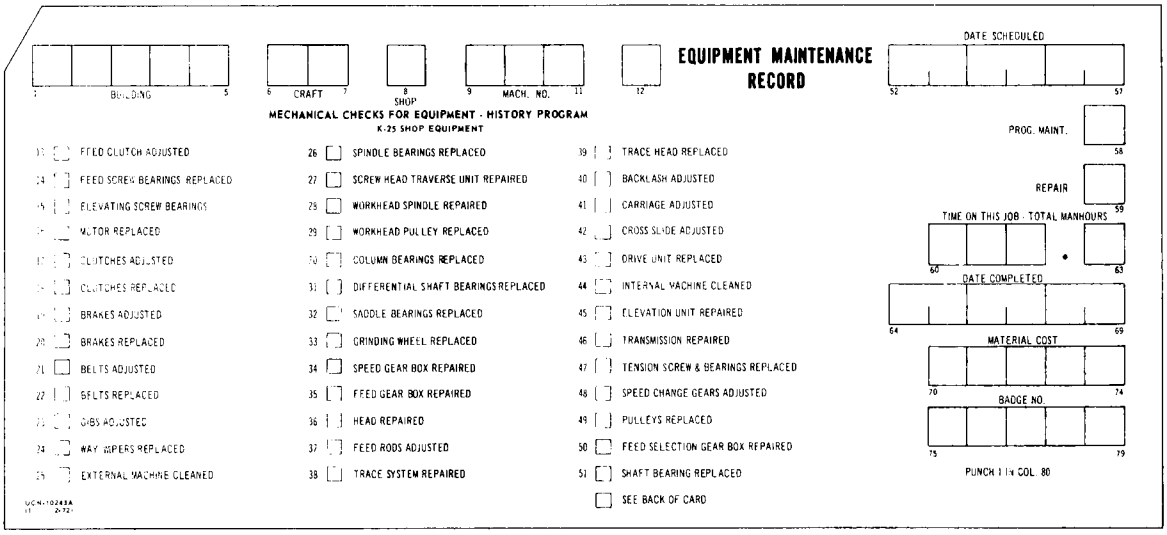


FIGURE 9

EQUIPMENT MAINTENANCE RECORD OF ELECTRICAL TASKS



BUILDING 1–5 | CRAFT 6–7 | SHOP 8 | MACH. NO. 9–11 | 12

EQUIPMENT MAINTENANCE RECORD

DATE SCHEDULED 52–57

MECHANICAL CHECKS FOR EQUIPMENT - HISTORY PROGRAM
K-25 SHOP EQUIPMENT

13 FEED CLUTCH ADJUSTED	26 SPINDLE BEARINGS REPLACED	39 TRACE HEAD REPLACED
14 FEED SCREW BEARINGS REPLACED	27 SCREW HEAD TRAVERSE UNIT REPAIRED	40 BACKLASH ADJUSTED
15 ELEVATING SCREW BEARINGS	28 WORKHEAD SPINDLE REPAIRED	41 CARRIAGE ADJUSTED
16 MOTOR REPLACED	29 WORKHEAD PULLEY REPLACED	42 CROSS SLIDE ADJUSTED
17 CLUTCHES ADJUSTED	30 COLUMN BEARINGS REPLACED	43 DRIVE UNIT REPLACED
18 CLUTCHES REPLACED	31 DIFFERENTIAL SHAFT BEARINGS REPLACED	44 INTERNAL MACHINE CLEANED
19 BRAKES ADJUSTED	32 SADDLE BEARINGS REPLACED	45 ELEVATION UNIT REPAIRED
20 BRAKES REPLACED	33 GRINDING WHEEL REPLACED	46 TRANSMISSION REPAIRED
21 BELTS ADJUSTED	34 SPEED GEAR BOX REPAIRED	47 TENSION SCREW & BEARINGS REPLACED
22 BELTS REPLACED	35 FEED GEAR BOX REPAIRED	48 SPEED CHANGE GEARS ADJUSTED
23 GIBS ADJUSTED	36 HEAD REPAIRED	49 PULLEYS REPLACED
24 WAY WIPERS REPLACED	37 FEED RODS ADJUSTED	50 FEED SELECTION GEAR BOX REPAIRED
25 EXTERNAL MACHINE CLEANED	38 TRACE SYSTEM REPAIRED	51 SHAFT BEARING REPLACED
		SEE BACK OF CARD

PROG. MAINT. 58

REPAIR 59

TIME ON THIS JOB - TOTAL MANHOURS 60–63

DATE COMPLETED 64–69

MATERIAL COST 70–74

BADGE NO. 75–79

PUNCH 1 IN COL. 80

UCN-10243A (1) 2-72

1. USE THIS SIDE TO DESCRIBE MAINTENANCE WORK PERFORMED WHEN STANDARD HISTORY CARDS DO NOT PROVIDE PROPER INFORMATION.
2. USE MORE THAN ONE CARD IF REQUIRED. MACHINE NO., DATE SCHEDULED, DATE COMPLETED, REPAIR OR PROG. MAINT. MUST BE FILLED IN ON ALL CARDS.

ADDITIONAL MAINTENANCE INFORMATION
PRINT ONE LETTER PER BLOCK, SKIP BLOCK FOR SPACE.

13–32

33–52

53–72

DATE COMPLETED (SAME DATE AS ON FRONT OF CARD)

73–78

PUNCH 3 IN COL. 80

FIGURE 10

EQUIPMENT MAINTENANCE RECORD OF MECHANICAL TASKS

ORGDP EQUIPMENT MAINTENANCE

REPORT NO. 1789 RUN DATE 02/15/73
PAGE 0050

PM NUMBER	DESCRIPTION		FOREMEN	WORK ORDER	CURRENT-MONTH MAINT HRS	CURRENT-MONTH LAB $	CURRENT-MONTH MATL $	CURRENT-MONTH TOTAL $	TOTAL-TO-DATE LAB HRS	TOTAL-TO-DATE LAB $	TOTAL-TO-DATE MATL $	TOTAL-TO-DATE TOTAL $
K1401 207	BULD VTL TMPL 74 DIA X 80	99881	WEST	D2130207	15	0	22	22	416	1641	227	1868
SER NO	29230	PRCP NO 249262	POPE CC									

DATE SCHEDULED	DATE COMPLETED	BADGE	WORK TYPE	HOURS	MATERIAL COST	WORK PERFORMED	
03-06-72	04-14-72	18959	PROG MAINT	8.0	0	LIGHTS CHECKED	WIRING CHECKED
						CIRCUIT BREAKERS CHECKED	SWITCH BOXES CHECKED
						CONTACT POINTS CLEANED	CONTACT POINTS ADJUSTED
						MOTOR BRUSHES CHECKED	MOTOR BRUSHES CLEANED
						ALL SYSTEMS ACTIVATED	VTL TRACER HD CHECK & BALANCE
						MACH INT VAC CLEANED OF DUST	ALL LIMIT SWITCHES CHECKED
						ALL AIR PRESS SWITCHES CHECKED	ALL OIL PRESS SWITCHES CHECKED
						LUBRICATION TIMERS CHECKED	
- -	06-16-72	D L B	REPAIR	0.0	0	REPAIR TRACER HEAD CABLE	
08-28-72	08-30-72	32658	PROG MAINT	0.0	0	LIGHTS CHECKED	WIRING CHECKED
						CIRCUIT BREAKERS CHECKED	SWITCH BOXES CHECKED
						CONTACT POINTS CLEANED	CONTACT POINTS ADJUSTED
						MOTOR BRUSHES CHECKED	MOTOR BRUSHES CLEANED
						ALL SYSTEMS ACTIVATED	MACH INT VAC CLEANED OF DUST
						ALL LIMIT SWITCHES CHECKED	TACHOMETER FEEDBACK CHECKED
						MOTOR BRUSHES COVERED WITH GREASE BY EXCESS LUBING	
- -	10-04-72	32658	REPAIR	1.5	0	FASTEN FLEX CONDUIT FROM CONTACTOR INSTALLATION	

FIGURE 11

EQUIPMENT MAINTENANCE HISTORY REPORT

a good PM program should detect a part which is deteriorating before failures occur, thus allowing time for replacements just prior to failure. However, this ideal situation does not always happen. One reason for this is the lack of timely feedback information on the PM check. Verbal communication of machine defects found when machines are checked are usually not sufficient. Many times parts do not get ordered and replacements are not made until failure even though a defect was found during a PM check.

A good follow-up system can do much to prevent many of these problems. The history cards described above can be used to record defective parts. This then becomes a permanent record on the machine. When the parts are replaced, this action can also be recorded so that a quick review of a machine history can help pinpoint trouble areas.

The various costs which are incurred with an antiquated spare parts system are:[22] (1) the cost of downtime consisting of lost production, possibly damaged parts and repair, (2) the cost of spares inventory consisting of excessive inventories tying up capital investment, storage space, and so forth, (3) the cost of the labor to obtain and search for replacement parts, (4) the cost of poor quality materials, (5) the cost of poor communications, and (6) the cost of haphazard location of spare parts.

There are certain procedures or guidelines basic to an efficient spare parts inventory which may vary somewhat depending on the size of the plant or operation. Smaller plants may manually keep data and inventories on such equipment, for example, while large ones may adapt

their system to electronic data processing. The key elements, however, in a total spare parts control system should consist of (1) a spare parts stores catalog listed alphabetically by usage including code numbers and storage location, (2) a machinery history system listing each piece of equipment, sizes, utilization and services needed, each repair or service life and cost of spare parts, (3) a realistic Max-Min System which is determined by careful examination of machine histories to stock only spare parts which are needed, (4) a written requisition for each part leaving the storage, and (5) adequate storage facilities properly located. All of these elements require detail planning and an initial large volume of data collection, but this can save numerous headaches and lost time when replacement parts are needed.

Figure 12 shows a flow diagram of developmental and operational steps necessary for this PM system. The various outputs and procedures used are defined further in the next section of this chapter.

IV. OPERATING PROCEDURE

Once the initial criteria and data collection means were established, programming had to be done to organize this information in a meaningful fashion. Procedures were written to explain how the data would be collected and used. At first, breakdown frequencies were collected for a few of the machines in an attempt to establish PM frequencies. It was soon noted, however, that the equipment breakdowns were a direct function of the amount of hours used and the number of times used. No long-term histories were available prior to the study. Since usage varied from

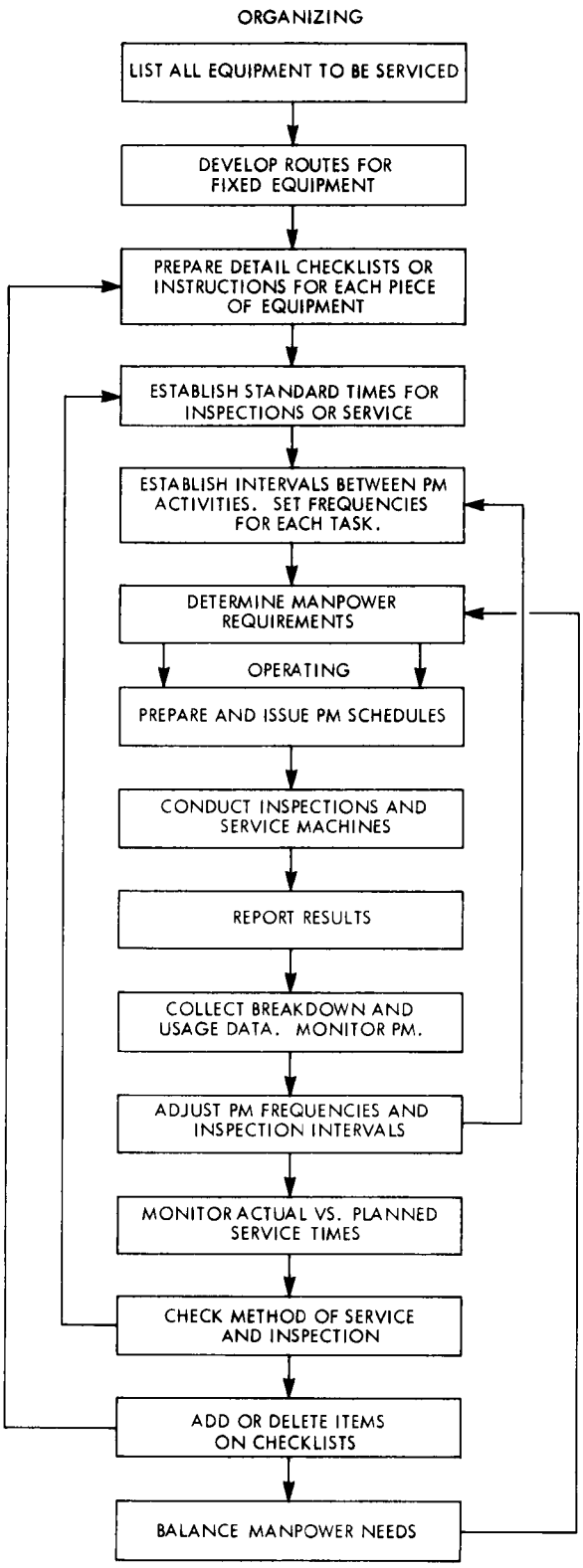


FIGURE 12

GENERAL STEPS NECESSARY FOR A PM SYSTEM

one machine to another and even on the same machine, it was decided to prepare usage data in such a way that a range could be set up for each machine. Frequencies then could be based on the usage.

The manufacturer's data on each machine was examined and the recommended frequencies given in this data were taken as PM_{max} or the 95 percent interval. That is, if one made PM checks at these intervals, he could be 95 percent sure that breakdowns would not occur. This was believed to be a reasonable assumption since manufacturer's frequencies are usually based on continuous or regular usage. In cases where the manufacturer recommended, for example, lubrication every forty hours used, periodic usage data was examined and average usage figures were calculated and converted into calendar days between frequencies. Therefore, initially, the manufacturer's recommended frequencies were used. Later these frequencies were varied according to usage (see Figure 13). This was the usage data used to arrive at initial frequencies shown in a printout of the "Machine Utilization Report".

Equipment Numbering System and Routing

A twelve-digit number was devised on which various computer sorts could be made. The first five digits contained the building number. The next two digits contained the craft code of the group responsible for doing the work. The next digit contained a shop code which was used when more than one shop was located in the same building. The next three digits represented the machine number. The last digit was used only when the data for a particular machine exceeded the space provided

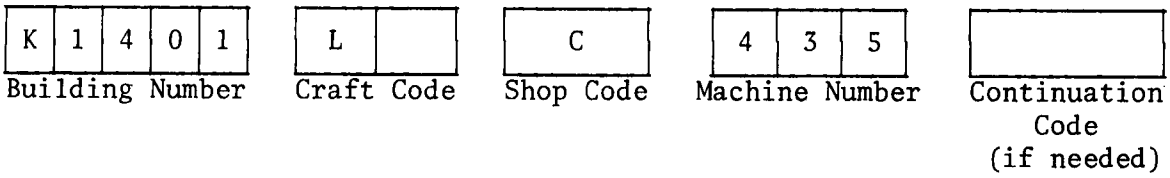
SECOND QUARTER OF FY 73 — ORGDP MACHINE UTILIZATION REPORT — REPORT NO. 1283

MACHINE NUMBER	PROPERTY NUMBER	MACHINE DESCRIPTION	COST	YEAR	COND. CODE	CURRENT QUARTER HOURS USED	CURRENT QUARTER O/O UTIL	CURRENT QUARTER FREQ INDICTOR	CURRENT QUARTER MAINT HOURS	TOTAL TO DATE HOURS USED	TOTAL TO DATE MAINT HOURS
0707	238391	FS JG BR TAP CONT PP29X50X12	32072	36	01	196.0	19	27	13.0	1259.1	48.5
0708	249914	LUC HOR JIG BOR 3BR 20X20X30	56815	62	02	226.0	22	29	10.0	2153.8	80.5
0709	249513	MON EE TL LATH 45 AI TR10X22	21162	61	02	290.0	28	40	5.0	1758.3	40.0
0710	249535	MON EE TL LATH 45 AI TR10X22	20090	61	02	294.0	28	40	6.0	1556.7	33.0
0711	249543	REV TL LATH 10X22	11045	62	02	348.6	34	51	4.0	1218.0	10.0
0712	249843	JIG BOR TAP CONT PP 29X50X12	83990	61	02	208.0	20	27	27.0	1090.5	100.0
0713	249842	MOR JIG GD #2 12X18X12	24361	61	01	8.0		1		365.0	48.0
0717	249865	BLAN ROT SUR GD 30DIAX18	14864	62	02	148.0	14	19		503.7	15.0
0718	252162	P&W ML TAPE CONT PP 15X20X12	12850	63	02	115.0	11	16	22.0	992.7	95.5
0719	251641	HAND SAND MACH WET&DRY 108LT	3025	64	02						3.5
0720	250174	DO-A SAW 36 TH 12 VERT HG	8117	62	02	20.0	1	3		134.0	19.5
0721	196616	DO-A BD SAW 18 TH 12 VERT HG	2298	48	03	20.0	1	3		32.0	2.0
0722	249284	B&S #13 UNIV GD 10X24	10216	61	02	48.0	4	7	1.0	928.9	6.0
0723	256234	B&S #13 UNIV GD 10X24	15369	69	01	196.0	19	28	8.0	1229.5	21.0
0724	249969	B&S CYL GD UNIV 10X24	3417	62	04					59.0	2.0
0725	250701	B&S SUR GD RECP 6X18	19446	62	02	20.0	1	3	25.0	513.5	29.0
0726	250820	T-O SUR GD RECP 6X12	11136	63	01	401.0	39	52	6.0	777.0	25.0
0727	250878	NOR SUR GD RECP 12X28	20930	63	02	73.0	7	10	1.0	359.0	220.7
0728	242072	CIN MON GD UNI TL	4949	57	03	6.0		2		207.0	11.5
0729	249609	EXCL CEN GR 6X60	1719	61	02				5.0	12.0	5.0
0730	253904	BRDG ML 1 HP 9X42 POW FD	3200	55	02	304.0	29	41	4.0	2023.7	9.0
0731	252460	BRDG ML 1 HP 9X42 POW FD	3152	65	02	256.0	25	37	4.0	1733.5	14.0
0732	251199	BRDG ML 1 HP 9X42 POW FD	2659	64	02	355.9	34	49	4.0	1817.4	8.0
0733	251200	BRDG ML 1 HP 9X42 POW FD	2658	64	02	271.0	26	40	1.0	1828.0	9.0
0734	249428	BRDG ML 1 HP 9X42 POW FD	3413	62	02	260.0	25	36	2.0	1510.4	6.0
0739	177805	DEL TL GD WH PED	423	45	02					12.0	1.0
0802	250852	B&S CYL GD UNI 10X20	37945	63	02	24.0	2	4		394.5	5.0
0803	258171	BRY CH GD UNI 12X20			01	160.0	15	20	8.0	977.0	15.5
0804	250930	BRY CH GD UNI 12X20	27852	63	02	118.0	11	16	5.0	733.5	11.5
0805	233115	BRY CH GD UNI 12X20	23537	55	02	25.0	2	4	5.0	507.0	21.5
0806	250197	DO-A SUR GD RECP 6X12	3607	62	02	41.0	4	6	19.0	536.0	25.0
0807	250154	CIN CYL GD UNI 10X20	29774	62	02	72.0	7	11	9.0	943.0	48.0
0808	250153	CIN CYL GD UNI 14X60	46206	62	02	32.0	3	5	2.0	285.0	5.0
0809	249866	EXLO THD GD UNI 2 TO 28 PTCH	43907	51	02	12.0	1	2	3.0	329.0	13.0
0810	249768	DO-A SUR GD RECP 10X24	9486	61	02	71.0	6	10	1.0	713.0	34.5
0811		ATL ARB PR #1-1/2				22.0	2	5		38.0	
0812	250834	MOR JIG BOR 14X18	25616	63	01	142.0	13	19	2.0	1114.4	4.0
0813	177821	MON EE TL LATH 10X22	5827	54	02	372.6	36	51		1201.1	20.0
0814	250826	MON EE TL LATH 10X22	12211	63	02	359.0	35	52	8.0	2732.0	17.0
0815	249515	MON EE TL LATH 45 AI TR10X22	21162	61	02	413.0	40	56	7.0	1782.0	19.0

FIGURE 13

MACHINE UTILIZATION REPORT

on a single data sheet. Continuation codes A, B, and so forth, were used in this space when needed.



Machines were numbered consecutively throughout each bay. Computer schedules printed in machine number sequence such that routes were automatically laid out for each craft in the sequence in which the machines were located.

Scheduling

A forty-eight week calendar was used to set up frequencies so each month would contain exactly four weeks. Four skip weeks were to be observed during the year at which time no schedule would be produced. These weeks were to be used to "catch up" on machines which had recently been missed. These weeks were to fall around the thirteenth week of each quarter. Frequencies and frequency codes were established as follows:

1W	Weekly
2W	Every two weeks
1M	Every month
2M	Every two months
3M	Every three months
4M	Every four months
6M	Every six months
8M	Every eight months
1Y	Every year

2Y	Every two years
3Y	Every three years
4Y	Every four years
5Y	Every five years
S	Standby--no services scheduled

These frequencies were entered on an "ORGDP Preventive Maintenance Data Sheet" after each point of service along with other related information, as shown in Figure 14.

The numbers placed on the data sheet under "Start" were the number of weeks to elapse from the date the data was entered until the next maintenance request was scheduled on each item. This entry was optional, however, with the built-in computer leveling technique. It was used when an item was to be scheduled at a particular time of the year or when several items or machines needed to be serviced on the same date. If this space was left blank, the computer program would employ its leveling technique. This technique could be employed in two ways. One way was to level each frequency by the amount of time allocated to each task. The other way was to level on the number of items under each frequency. Obviously, the best way to level was by using the time for each task. Since all the times were not available at the beginning of the program, however, the technique of using the leveling of items was employed.

The leveling procedure attempted to slot an equal number of items for each frequency in each of the forty-eight scheduled weeks of maintenance. When additional data was added, the items were slotted into the weeks with the lowest number of items scheduled. A restriction in the

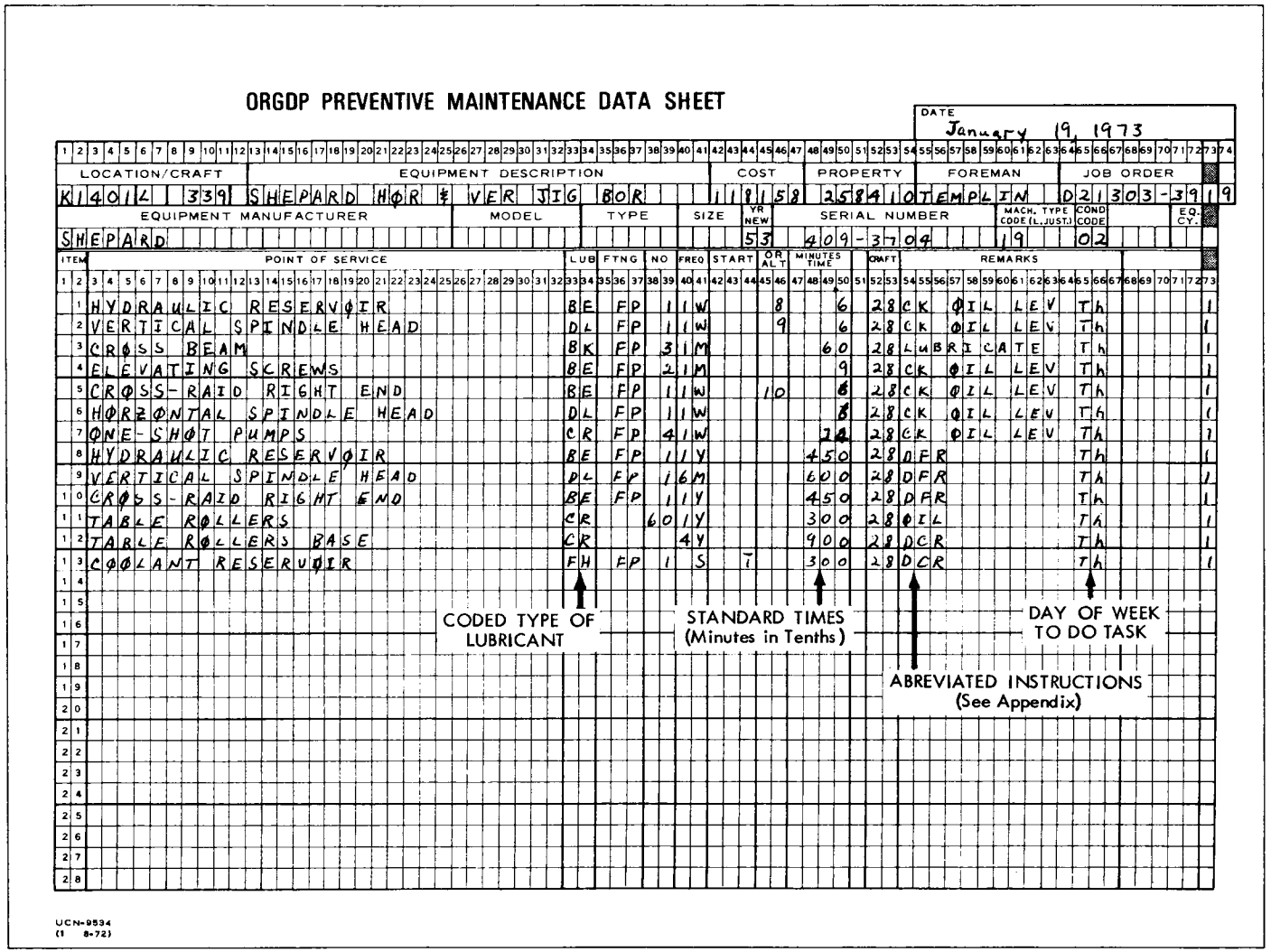


FIGURE 14

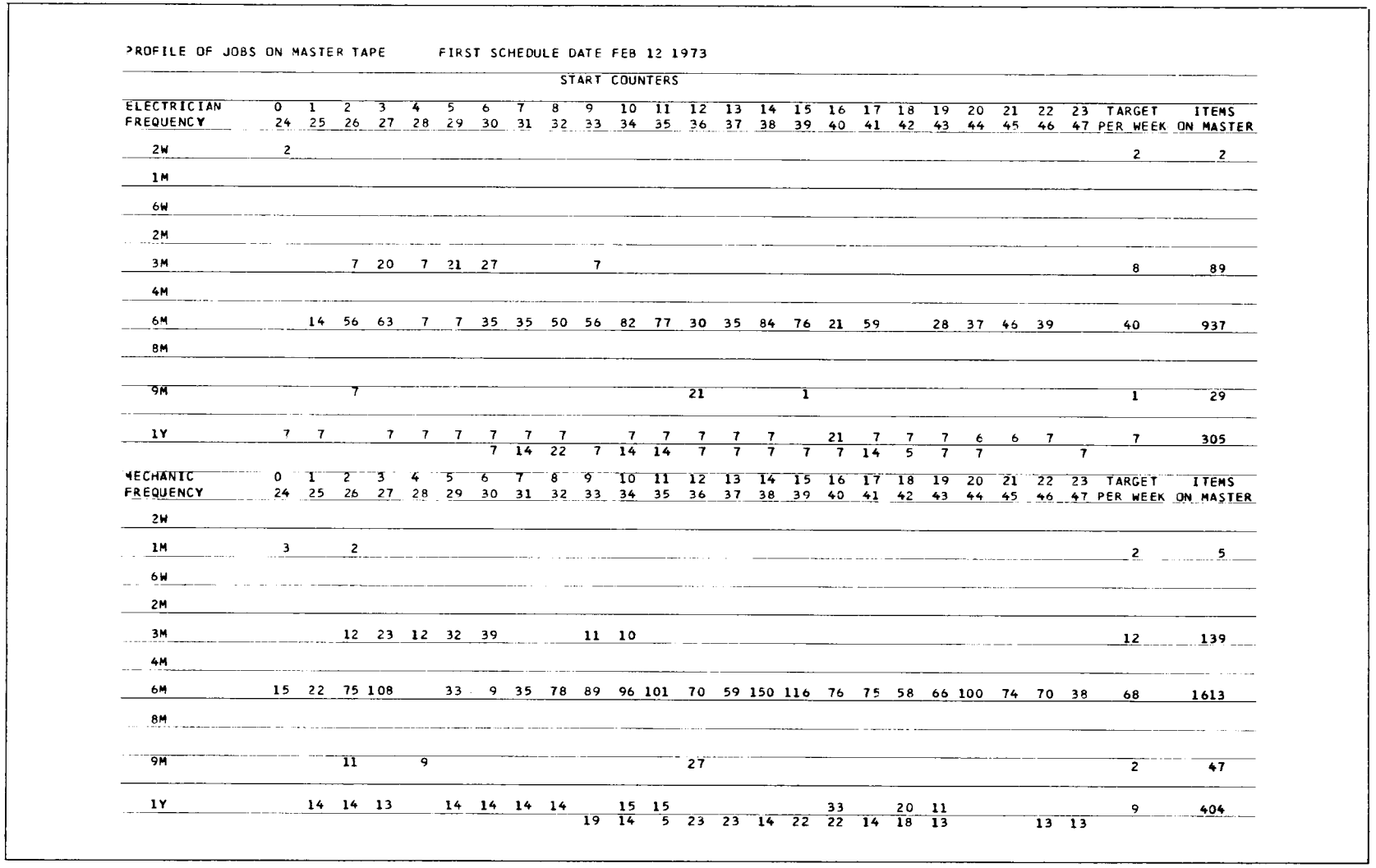
ORGDP PREVENTIVE MAINTENANCE DATA SHEET WITH DATA

program prevented the splitting of items on the same machine and frequency between two or more weeks. That is, if ten monthly items were to be checked on the same machine, the computer would schedule all ten items on the same week even though more items might have to be done on that particular week. Overall equipment downtime was reduced since the same piece of equipment would not have to be stopped the following week for PM on other monthly items.

The overall leveling given in number of items scheduled per week is shown in Figure 15. This is a computer printout showing the number of items across the page scheduled for each week during the year for selected crafts and frequencies. An "item" is defined as a line entry on the "ORGDP Preventive Maintenance Data Sheet" (Figure 14). As one can easily see, most frequencies were not leveled. This was due partly to purposely scheduling some equipment to be done at the same time because of the nature of the work and equipment. Also some unbalance existed because the leveling technique was not in existence when the program first started and all early data had to have a start time place on the data sheet. Although an attempt was made to balance these entries manually a printout such as shown in Figure 15 shows gross unbalanced situations. As more and more equipment was put on the system start dates were left blank and the computer scheduled the first occurrence in the week with the lowest number of entries.

Output Scheduled Tasks

Figure 16 shows typical schedule cards for electrical and mechanical checks. These cards, printed by the computer, served as individual work



PROFILE OF JOBS ON MASTER TAPE FIRST SCHEDULE DATE FEB 12 1973

START COUNTERS

ELECTRICIAN	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	TARGET	ITEMS
FREQUENCY	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	PER WEEK	ON MASTER
2W	2																								2	2
1M																										
6W																										
2M																										
3M			7	20	7	21	27			7															8	89
4M																										
6M		14	56	63	7	7	35	35	50	56	82	77	30	35	84	76	21	59		28	37	46	39		40	937
8M																										
9M			7										21			1									1	29
1Y	7	7		7	7	7	7	7	7		7	7	7	7	7		21	7	7	7	6	6	7		7	305
							7	14	22	7	14	14	7	7	7	7	7	14	5	7	7			7		

MECHANIC	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	TARGET	ITEMS
FREQUENCY	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	PER WEEK	ON MASTER
2W																										
1M	3		2																						2	5
6W																										
2M																										
3M			12	23	12	32	39			11	10														12	139
4M																										
6M	15	22	75	108		33	9	35	78	89	96	101	70	59	150	116	76	75	58	66	100	74	70	38	68	1613
8M																										
9M			11		9								27												2	47
1Y		14	14	13		14	14	14	14		15	15					33		20	11					9	404
										19	14	5	23	23	14	22	22	14	18	13			13	13		

FIGURE 15

PROGRAMMED MAINTENANCE LEVELING DISPLAY

```
ORGDP PREVENTATIVE MAINTENANCE FOR WEEK OF APR 30, 1973 FOREMANTEMPLIN
MECHANIC                                        CONDITION CODE    03

LOCATION          EQUIPMENT DESCRIPTION                  PROPERTY JOB ORDER
K1401 M   635   MON ENG LATH 4 RAI 16X54          9553   251064

ITEM  POINT OF SERVICE                  LUB FTNG NO FREQ REMARKS
  1   SPINDLE BRGS                                6M   CHECK,CLEAN,ADJUST
  2   LEADSCREW + BRGS                            6M   ITEMS 1-13 AS NEED
  3   CLUTCH                                      6M
  4   BRAKES                                      6M
  5   CARRIAGE                                    6M
  6   GIBS                                        6M
  7   WAY WIPERS + WAYS                           6M
  8   CROSS SLIDE                                 6M
  9   TAPER ATTACHMENT                            6M
 10   BELTS                                       6M
 11   MTR BRGS                                    6M
 12   TRACING SYSTEM-HYD                          6M
 13   LEVEL + ALIGNMENT                           6M
                                    CRAFT CODE(        )TIME(        )

TOTAL TARGET TIME / WEEK          .0 MINUTES
```

```
ORGDP PREVENTATIVE MAINTENANCE FOR WEEK OF APR 30, 1973 FOREMANREMPALA
ELECTRICIAN                                     CONDITION CODE    03

LOCATION          EQUIPMENT DESCRIPTION                  PROPERTY JOB ORDER
K1401 E   635   MON ENG LATH 4 RAI 16X54          9553   251064

ITEM  POINT OF SERVICE                  LUB FTNG NO FREQ REMARKS
  1   LIGHTS                                      6M   CHECK,CLEAN,ADJUST
  2   WIRING                                      6M   ITEMS 1-7 AS NEED
  3   CIRCUIT BREAKERS                            6M
  4   SWITCH BOXES                                6M
  5   CONTACT POINTS                              6M
  6   MTR BRUSHES                                 6M
  7   ACTIVATE SYSTEM                             6M
                                    CRAFT CODE(        )TIME(        )

TOTAL TARGET TIME / WEEK        90.0 MINUTES
```

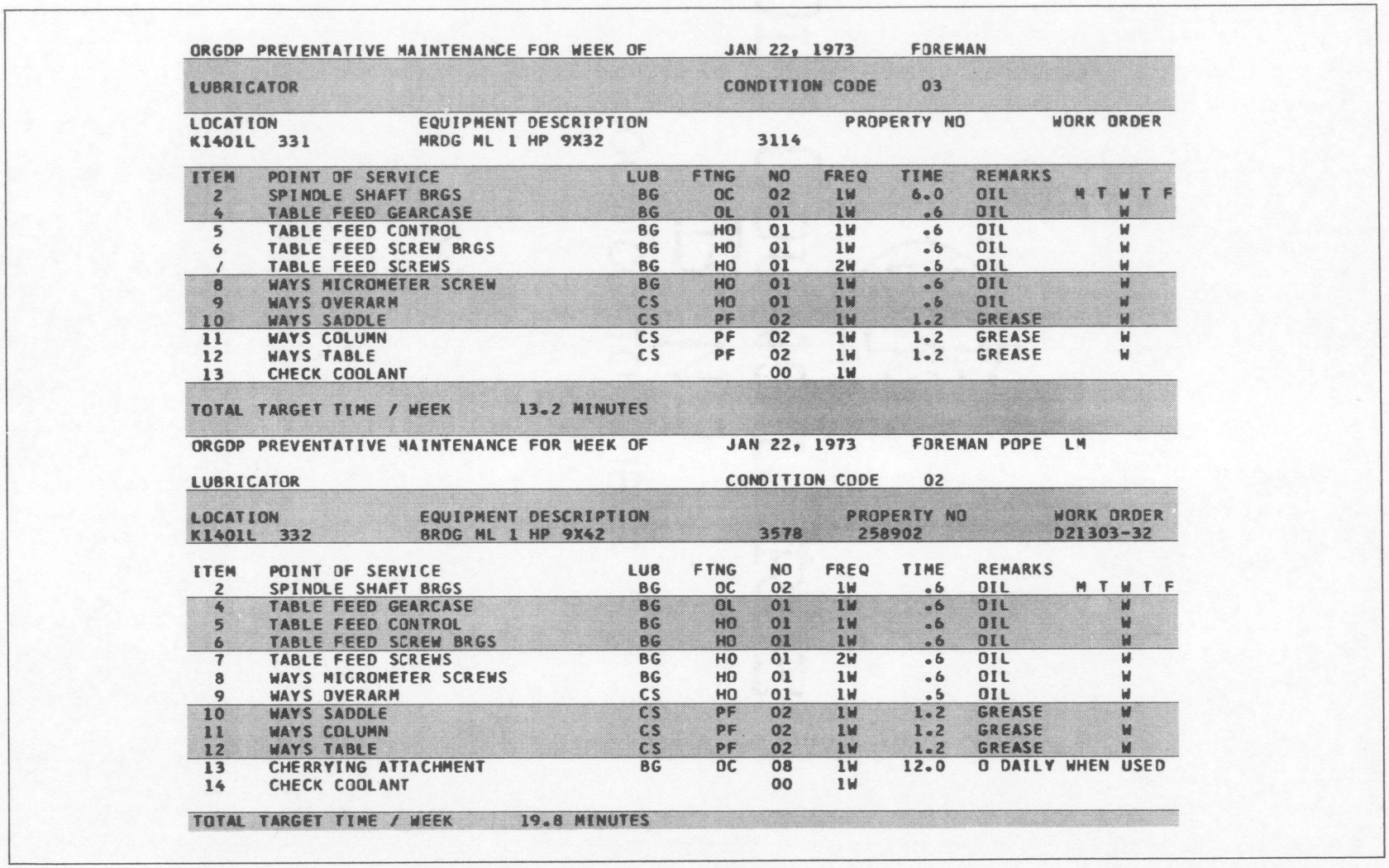
FIGURE 16

TYPICAL SCHEDULE CARDS FOR ELECTRICAL AND MECHANICAL TASKS

orders for each machine on which items were scheduled. Only those items scheduled for the particular week in question would print. The space under "remarks" could be used for any information regarding the tasks listed. When the PM tasks called for inspection of a certain part, the stores catalog number was sometimes given to eliminate having to look the part up in a stores catalog.

Figure 17 shows a typical scheduled printout sheet for lubrication tasks. Since some of these tasks were daily or twice a week, the "remarks" space was used to designate the day(s) of the week on which the particular tasks were scheduled. These sheets, or automatic work orders, were assembled in a folder and distributed to each foreman to use when he assigned his men their week's work. The total target times given for each machine were used to balance the individual workloads. As each task was done, a check was placed by each, and at the end of the week a prepunched card was returned for each piece of equipment serviced. This prepunched card served as feedback to the computer that this service had been performed and the machine was dropped from the schedule for that week. If a card was not returned the machine appeared on the rescheduling list (Figure 24 in the Appendix) and remained there until the service was performed and a card was returned.

Histories on the PM and repair work done on each piece of equipment were checked on the History Cards, Figures 9 and 10 (pages 51 and 52). This was done for both scheduled and nonscheduled tasks. A summary of the amount of work scheduled for each foreman each week was given as a listing of the various equipment scheduled and as a total number of



ORGDP PREVENTATIVE MAINTENANCE FOR WEEK OF JAN 22, 1973 FOREMAN

LUBRICATOR CONDITION CODE 03

LOCATION	EQUIPMENT DESCRIPTION	PROPERTY NO	WORK ORDER
K1401L 331	MRDG ML 1 HP 9X32	3114	

ITEM	POINT OF SERVICE	LUB	FTNG	NO	FREQ	TIME	REMARKS	M T W T F
2	SPINDLE SHAFT BRGS	BG	OC	02	1W	6.0	OIL	W
4	TABLE FEED GEARCASE	BG	OL	01	1W	.6	OIL	W
5	TABLE FEED CONTROL	BG	HO	01	1W	.6	OIL	W
6	TABLE FEED SCREW BRGS	BG	HO	01	1W	.6	OIL	W
7	TABLE FEED SCREWS	BG	HO	01	2W	.6	OIL	W
8	WAYS MICROMETER SCREW	BG	HO	01	1W	.6	OIL	W
9	WAYS OVERARM	CS	HO	01	1W	.6	OIL	W
10	WAYS SADDLE	CS	PF	02	1W	1.2	GREASE	W
11	WAYS COLUMN	CS	PF	02	1W	1.2	GREASE	W
12	WAYS TABLE	CS	PF	02	1W	1.2	GREASE	W
13	CHECK COOLANT			00	1W			

TOTAL TARGET TIME / WEEK 13.2 MINUTES

ORGDP PREVENTATIVE MAINTENANCE FOR WEEK OF JAN 22, 1973 FOREMAN POPE LM

LUBRICATOR CONDITION CODE 02

LOCATION	EQUIPMENT DESCRIPTION		PROPERTY NO	WORK ORDER
K1401L 332	BRDG ML 1 HP 9X42	3578	258902	D21303-32

ITEM	POINT OF SERVICE	LUB	FTNG	NO	FREQ	TIME	REMARKS	M T W T F
2	SPINDLE SHAFT BRGS	BG	OC	02	1W	.6	OIL	W
4	TABLE FEED GEARCASE	BG	OL	01	1W	.6	OIL	W
5	TABLE FEED CONTROL	BG	HO	01	1W	.6	OIL	W
6	TABLE FEED SCREW BRGS	BG	HO	01	1W	.6	OIL	W
7	TABLE FEED SCREWS	BG	HO	01	2W	.6	OIL	W
8	WAYS MICROMETER SCREWS	BG	HO	01	1W	.6	OIL	W
9	WAYS OVERARM	CS	HO	01	1W	.6	OIL	W
10	WAYS SADDLE	CS	PF	02	1W	1.2	GREASE	W
11	WAYS COLUMN	CS	PF	02	1W	1.2	GREASE	W
12	WAYS TABLE	CS	PF	02	1W	1.2	GREASE	W
13	CHERRYING ATTACHMENT	BG	OC	08	1W	12.0	O DAILY WHEN USED	
14	CHECK COOLANT			00	1W			

TOTAL TARGET TIME / WEEK 19.8 MINUTES

FIGURE 17

TYPICAL SCHEDULE SHEETS FOR LUBRICATION TASKS

machines and target times. Examples of these printouts are Figures 25 and 26 in the Appendix.

Updating the Program

Various updating is essential for an effective PM program. Methods and requirements change from time to time. Therefore updating procedures were written for as many required changes as could be anticipated. Codes were assigned to each of these changes (Table VI in the Appendix). These codes along with the new information were placed on the "ORGDP Preventive Maintenance Data Sheet" by the user whenever changes were necessary.

Summary of Operating Procedures

Figure 18 summarizes the operating procedure for this PM system. A maintenance engineer and a planner-estimator were responsible for establishing PM procedures and analyzing the data to update the program. The Computer Technology Center was responsible for running the schedules and various reports. The maintenance supervisor was responsible for assigning the work and seeing that the work was done, and of course the craftsman was responsible for actually performing the scheduled work.

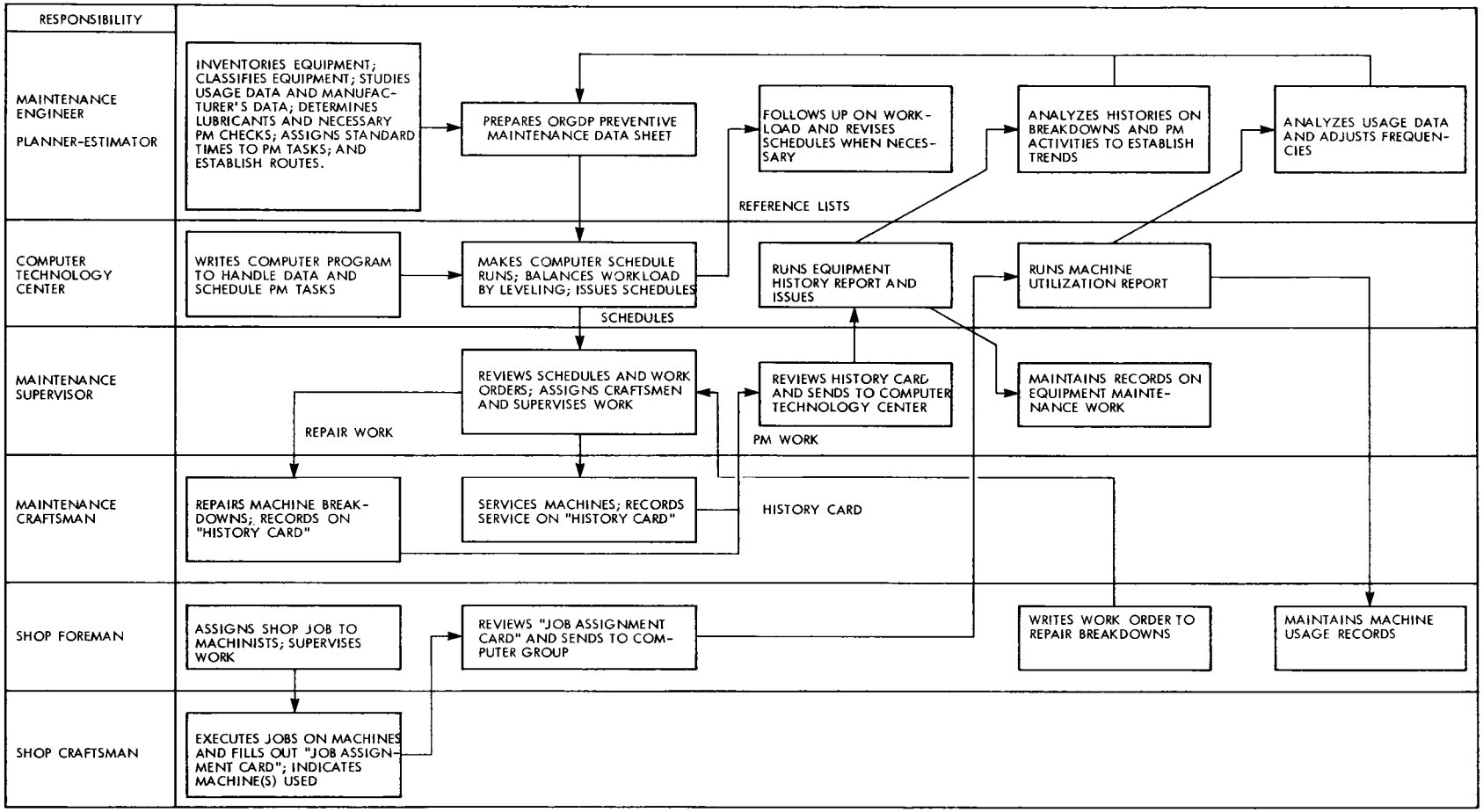


FIGURE 18

FLOWSHEET FOR OPERATING AN EQUIPMENT MAINTENANCE PROGRAM

CHAPTER IV

IMPLEMENTATION AND DATA ANALYSIS

This chapter will give examples of the approaches taken to maintain equipment with (1) constant usage, and (2) sporadic usage. The criteria set forth in Chapter II for a PM program to be effective is examined. The available data on the equipment is analyzed in this chapter, first, to see if a PM program would be practical in reducing overall maintenance costs, and second, to see, after preventive maintenance is done for a while, what the net effect on cost actually is.

I. ANALYSIS OF MAINTENANCE DATA PRIOR TO A FORMAL PM PROGRAM

The amount of maintenance data available for the equipment at ORGDP was found to vary as much as does the nature and complexity of the equipment used in the plant. To simplify the approach somewhat and to try to focus on the more important areas first, the equipment was divided into two usage categories: Category I--constant usage equipment, and Category II--sporadic usage equipment. Category I represented those pieces of equipment that were used continuously or whose usage was set at a fairly constant rate per week or month. Category II was made up of the remainder. The term "sporadic usage" was assigned to this category because no set pattern of usage had been established for this group nor had any breakdown maintenance data been collected.

The two categories were further broken down into the three criticality groups described in Chapter II.

Group A--Low overall value and importance, does not justify PM.

Group B--Important to overall function of plant; relatively large dollar value and requires reasonably low downtime for successful operation.

Group C--Must achieve lowest downtime; equipment critical to the function of the plant process or plant safety.

Table II shows some examples of equipment placed in the categories described above. The category in which one places a piece of equipment depends on the function and value of that equipment at a specific plant. It does not mean to imply that the specific pieces of equipment would occupy the same relative value and function at any industrial plant. This is obvious since a pump may be critical to a chemical plant but may be a relatively unimportant piece of equipment in a textile plant.

Use Category I

The constant or known usage category is by far the easiest to analyze to see if preventive maintenance should be done. With constant usage in a given time frame, breakdown frequency can be determined to see if the equipment obeys the "wear out law"[11] mentioned in Chapter II. That is, do breakdowns seem to be increasing with time? In analyzing these groups of equipment for PM, Group A was immediately ruled out because of its low value and noncritical role in the overall plant function. This group of equipment can be replaced relatively cheaply

TABLE II

EQUIPMENT CATEGORIES

USAGE CATEGORY	Group A Low Value. No Scheduled PM	Group B Important, Large $ Value, Requires Low Downtime	Group C Critical, Requires Lowest Downtime
I CONSTANT OR KNOWN USAGE	Office Equipment	Motor Operated Control Valves Lights P.A. System Air Conditioning & Heating Systems Automobiles Exhaust & Supply Fans	Electrical Switchgear Radiation Monitors
II VARIABLE OR SPORADIC USAGE	Bench Grinders Miscellaneous Hand Tools	Machine Shop Equipment Cranes Fabrication Shop Equipment	Alarm Systems Other Systems Related to Safety

compared to the labor cost of PM function. It was found that various types of preventive maintenance were already being done to many of the items listed in Category I, Group C. Most of the work had already been done by the operation and maintenance foremen in setting up safe PM frequency checks of critical equipment. The approach taken here was to place the scheduling of these PM tasks on automatic data processing equipment so as not to subject it to human error.

Most of the work in this category centered on the equipment in Category I, Group B. Statistical approaches were taken to analyze breakdown frequencies to determine if PM activities would be justified. Two basic criteria had to be met before preventive maintenance would be considered for this equipment.

1. It must be more economical to do PM on the equipment before failure than to repair or replace the equipment after failure.
2. The failure rate for the equipment is increasing.

While the presence of both of these conditions was necessary for PM to be considered, the absence of either one would rule out the PM function.

An example of the equipment in Category I, Group B, is one type of cascade process equipment. A study was made to determine the feasibility of performing preventive maintenance on some of this equipment located in Building K-33.[24] This process equipment was placed in Category I, Group B, and data over the previous eighteen

years were analyzed to determine if PM would be justified. There were 257 units located in the K-33 building. Since their installation in 1954, there were thirty-two failures, or only about 12 percent. The frequency distribution of failure times is shown in Figure 19. Since failures were so few, it was not feasible to fit a failure distribution curve to this frequency distribution. Also, multiple failures were rare. For these reasons the following formula was used to estimate the failure rate:

$$U_i = T_i \frac{Y_i}{\left[\frac{N_i + N_i + 1}{2}\right]} \qquad i = 1, 2, \ldots, N$$

where

Y_i = the number of failures during i^{th} time period,

T_i = the length of the i^{th} time period in years,

N_i = the number of units still in operation at the beginning of the i^{th} time period,

$N_i + 1$ = the number of units still in operation at the end of the i^{th} time period, and

N = number of time periods.

Figure 20 shows a plot of U_i estimated failure rate versus time period. The time periods were pooled so that each would have several failures since some years had no failure. This tended to smooth the curve, but still gave a good indication of the overall effective failure rate. This failure rate was nonincreasing. Therefore preventive

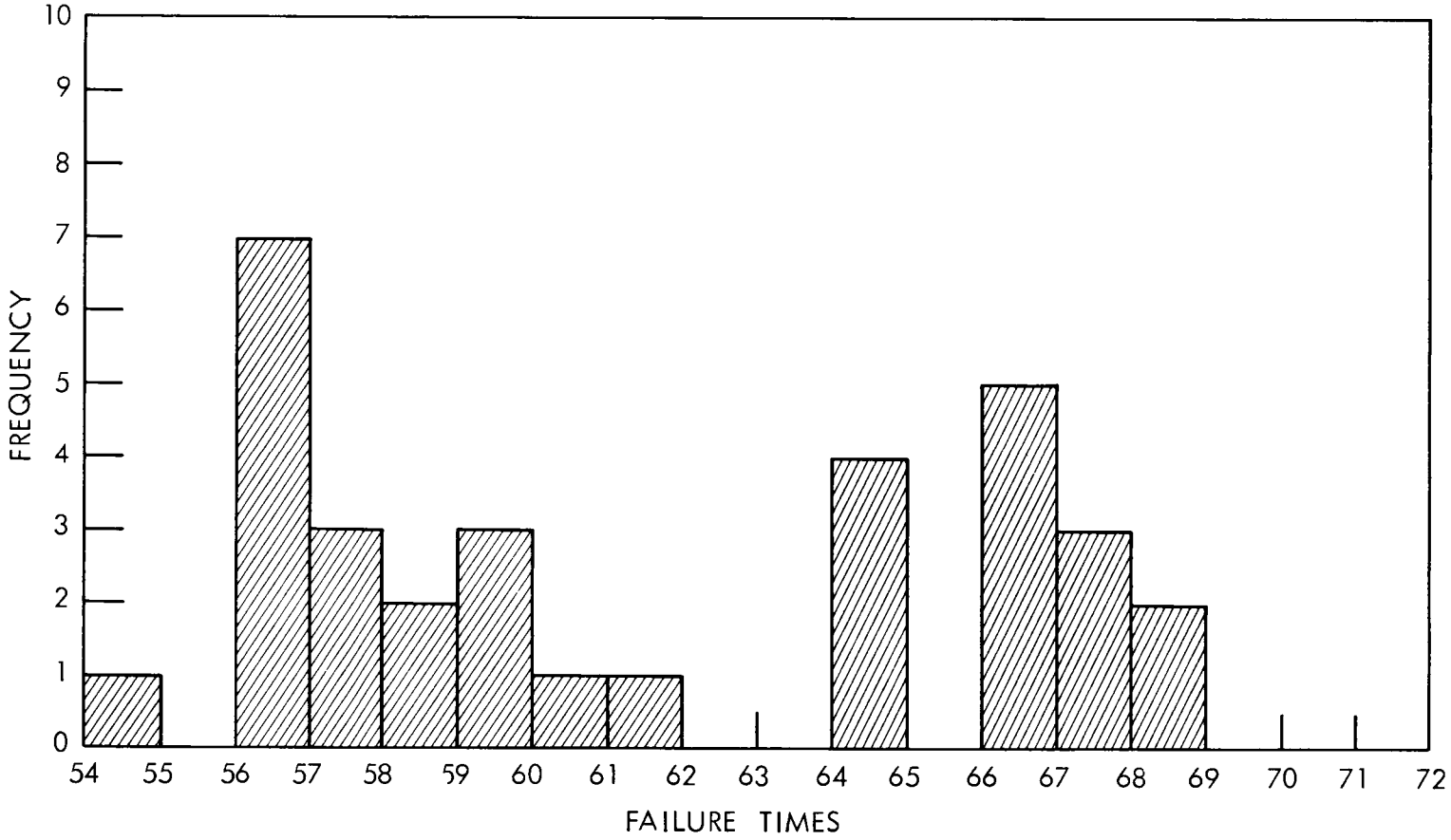


FIGURE 19

FREQUENCY DISTRIBUTION OF FAILURE TIMES FOR ONE TYPE OF CASCADE PROCESS EQUIPMENT

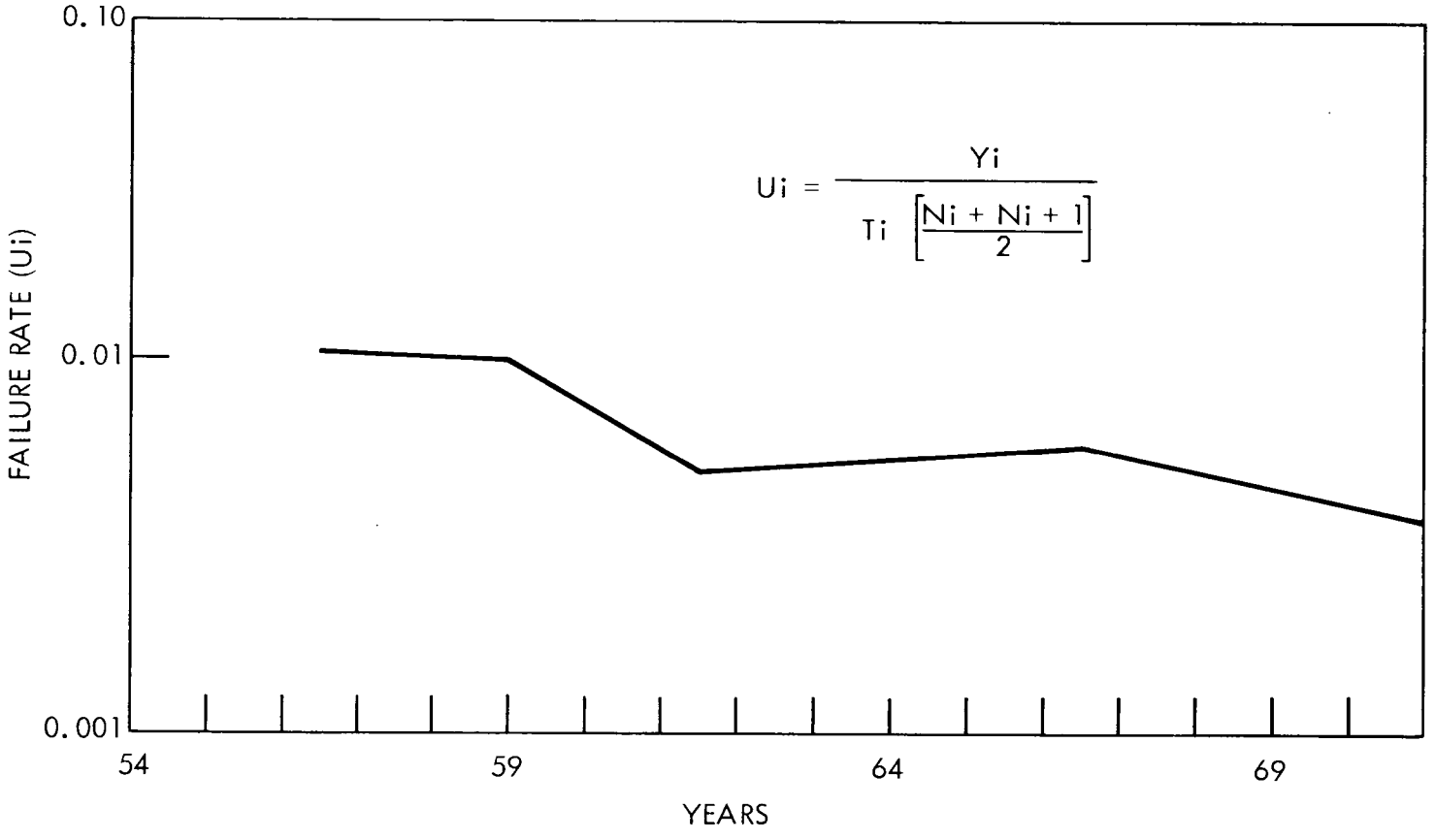


FIGURE 20

FAILURE RATES FOR ONE TYPE OF CASCADE PROCESS EQUIPMENT

maintenance was not advisable over that time period and was not recommended for the immediate future.

Usage Category II

The analysis of the breakdown behavior of sporadically used equipment was considerably more difficult than that of Usage Category I. Very few maintenance records had been kept on this type of equipment. Surprisingly, a large portion of this equipment consisted of high priced machine shop equipment. Total maintenance costs were kept on each machine, but breakdown frequencies were not a matter of record. The annual maintenance costs for a period of five years prior to implementing the PM program were examined. A sample of sixty-two machines was chosen from a population size of three hundred machines in Category II, Group B. Figure 21 shows a plot of the average monthly maintenance costs for these sixty-two machines over this five-year period. As can be seen, these costs were increasing above the expected inflationary rate. Therefore, it could be assumed that failure rates were increasing. It appears than, from Figure 21, that one of the criteria necessary for considering a preventive maintenance program on these machines was met.

Since very little documentation on past failures was available other than costs, foreman knowledge of past failures and manufacturer's manuals had to be relied upon in determining if PM would be more economical than replacement or repair after failure. From conversations with maintenance foremen and from manufacturer's manuals, it was noted that many of the machine failures had a pyramiding effect since many of the

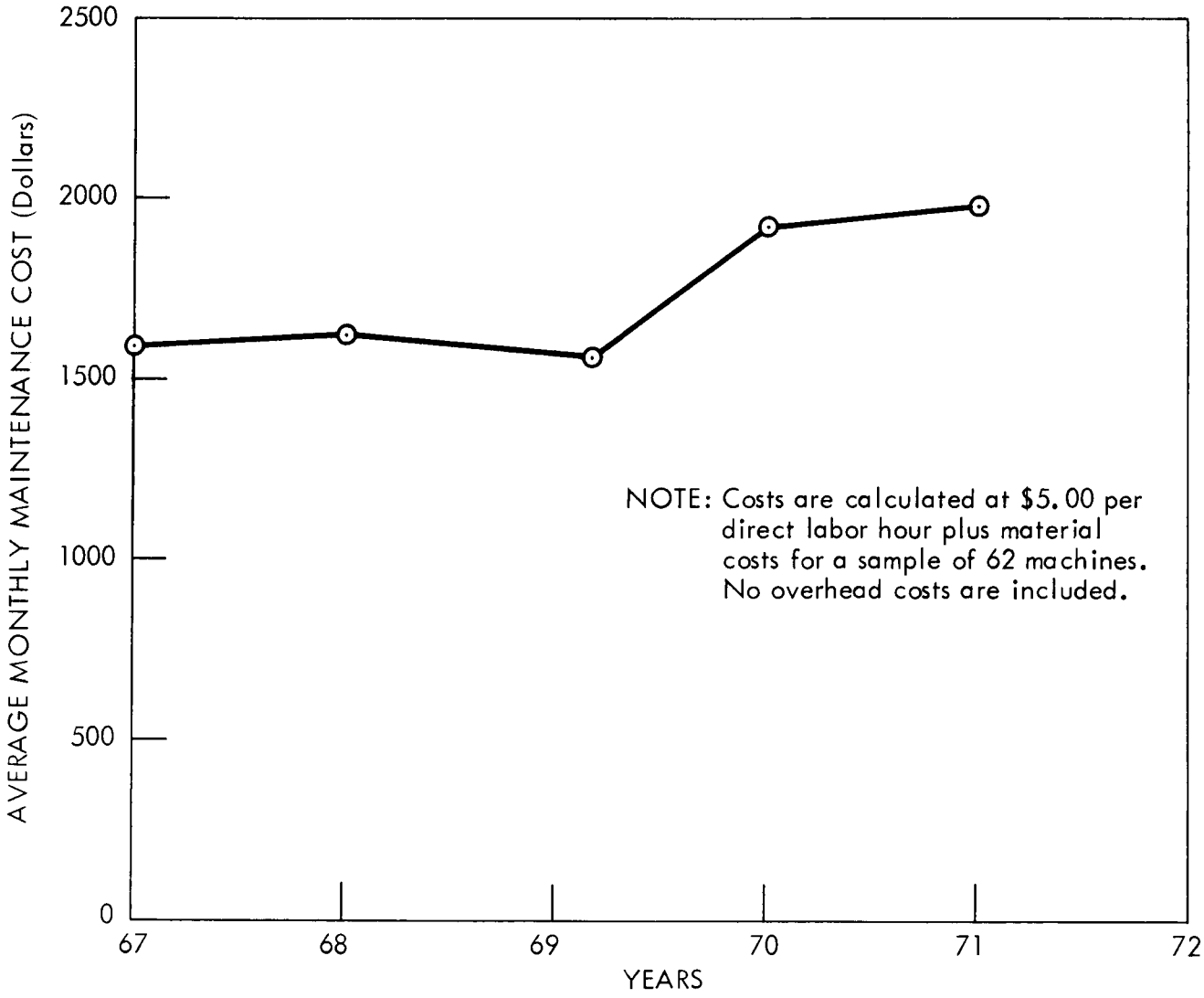


FIGURE 21

AVERAGE MONTHLY MAINTENANCE COSTS OVER FIVE-YEAR PERIOD PRIOR TO STUDY FOR A SAMPE OF SIXTY-TWO MACHINES

parts were interconnected and dependent on each other. Also, when a part failed it sometimes failed gradually in such a way that it continued to function at an increasingly inaccurate rate, thus producing defective parts. It was concluded that the majority of these machines were of such nature that preventive steps could be taken economically to avoid costly breakdown.

II. IMPLEMENTATION PROBLEMS

Once it had been established that certain equipment met the criteria for preventive maintenance (that is, they obeyed the "wear out" principle since their breakdowns were increasing and that replacement or repair prior to failure was more economical), the next question to be answered was how often should the preventive maintenance be performed. As discussed in previous chapters, this is perhaps the most difficult step in the implementation procedure. If extreme care is not exercised, equipment can be overmaintained in an attempt to prevent failure to the extent that overall maintenance cost increases. When establishing frequencies for PM work all available data on breakdowns should be analyzed. Plots of breakdowns should be made and, if possible, frequencies established so as to be reasonably sure that failure will not occur (see Chapter II). With those pieces of equipment in Category I, this process was fairly simple where data on breakdowns were available. In the previous example on process failures, if the failure rate had shown an increase of significant nature, a failure distribution curve could have been fitted to this frequency distribution, and PM work scheduled to prevent a high percentage of the failures.

The most difficult situation occurred, however, when the equipment was used sporadically and no breakdown frequency records had been maintained. The remaining portion of this chapter will address itself to procedures taken to handle this situation and the results of establishing a PM program for this group of equipment. There are two choices under these circumstances. Means of collecting breakdown frequencies and usage data can be set up, waiting until a sufficient sample of data have been collected and analyzed before setting up frequencies on PM checks. This may be the more accurate way of determining the proper frequencies on the first trial basis. It could also be expensive. During the data collection period in which no PM was done costly breakdowns could occur which would offset any potential future reduction in maintenance as a result of timely PM frequencies.

On the other hand, frequencies based on manufacturer's recommendations and foremen's estimates could be established at the time a data collection system to record breakdowns and usage is set up. Overall maintenance cost could be compared with the cost prior to PM and frequencies monitored with usage so that through an iterative process the optimum PM frequency for each task could be reached in time to minimize total cost.

In the case of the three hundred machines in Category II, Group B, the latter approach was chosen because at the time the study began maintenance costs were increasing on these machines and essentially very little PM work was being done. To further explain implementation procedures, this discussion will be divided between Lubrication Tasks and

Mechanical and Electrical Tasks, since the implementation of a lubrication program preceded the more extensive PM checks.

Lubrication Tasks

At the start of this study four lubricators were assigned the responsibility of keeping the machine shop equipment greased, oiled, and filled with proper coolant fluids. No formal scheduling of their work was being done. Two lubricators were assigned to the front machine shop and the two others to the back machine shop. Over the years, certain patterns had developed in their minds as to which machines needed frequent attention and which did not. Their schedule depended to a great extent on which machinists (machine operators) needed them the worst. These lubricators were on a call basis from the machine shop foreman and the machinists themselves. The need for service was left up to the machinists to determine in many cases and since a machinist might work on any of the machines, generally he felt no personal responsibility for any one machine or group of machines. As a result, the machinists continually complained about the lubrication service they were getting and blamed defective work on improper machine maintenance. Since maintenance costs were already increasing, management sought answers as to whether to increase maintenance labor to offset defective machine parts.

As a result of these arising problems, a maintenance engineer and a planner-estimator were assigned the responsibility of setting up a lubrication program for these machines and recommending proper planning for the maintenance group. Lubrication tasks were defined by searching

through manuals on the equipment and old reference data which had been used in previous years. Since no actual usage records or breakdowns due to lack of oil were a matter of record, manufacturer's recommended frequencies were used. The "Work Order" was introduced as a means of requesting repair maintenance on these machines. This would enable the collection of breakdown frequencies and actual cost of each breakdown in maintenance labor hours, as shown in Figure 22.

The Job Assignment Card (Figure 9, page 51) was implemented as a tool on which to collect machine usage as well as time spent by the machinists on each job. Machine usage and maintenance hours became available on the Machine Utilization Report (Figure 13, page 58).

Standard times were developed for repetitive lubrication tasks. See Table III for example of some of these times. These times along with the tasks were entered into the computer on the "ORGDP Preventive Maintenance Data Sheet" and programming techniques were developed to schedule, level, and provide backlogs in standard times to properly man this group to accomplish these tasks. After standard times had been developed for 90 percent of the lubrication tasks, totals were calculated and weekly scheduled hours were monitored for some time. It became apparent that an average weekly workload of one hundred manhours for lubrication was sufficient to maintain proper lubrication according to manufacturer's recommendations. This was sufficient work for only three lubricators. Hence one lubricator was transferred to another department where a need arose because of a retirement. When lubrication schedules were received weekly, they were split into three equal

ORGDP MAINTENANCE JOB ORDER SUMMARY - SHOPS

CLOSED JOB ORDER
W/E 06-09-72

REPORT NO. 1277

JOB NO.	DESCRIPTION			MACHINE SHOP	FABR. SHOP	INSTR. SHOP	SHOP SERVICES	OTHER	TOTAL
J8891	K1401 CLEAN 75HP MOTOR		EST. HRS.		10.0				10.0
	D4189100	REC. - - REQ. - -	EXP. HRS.		10.0				10.0
			BAL.						
			OT. HRS.						
J8914	Y-12 CLEAN MANIFOLD		EST. HRS.		1.0				1.0
	S0035500	REC. 06-01-72 REQ. 06-02-72	EXP. HRS.		1.0				1.0
			BAL.						
			OT. HRS.						
J9848	SNOW RELAMP B&C BAY DEV		EST. HRS.				18.0		18.0
	D3640201	REC. 05-18-72 REQ. 05-19-72	EXP. HRS.				21.0		21.0
			BAL.				3.0-		3.0-
			OT. HRS.						
J9880	STR SEE IMPACT & HAMMERS		EST. HRS.				2.0		2.0
	D3069801	REC. 05-19-72 REQ. 06-01-72	EXP. HRS.				4.0		4.0
			BAL.				2.0-		2.0-
			OT. HRS.						
J9882	LYNN REPAIR CABLE REEL		EST. HRS.				10.0		10.0
	D3069802	REC. 05-22-72 REQ. 05-23-72	EXP. HRS.				8.0		8.0
			BAL.				2.0		2.0
			OT. HRS.						
J9883	219 REPLACE DYNATROL BRAKE		EST. HRS.				36.0		36.0
	D3130219	REC. 05-22-72 REQ. 06-02-72	EXP. HRS.				33.0		33.0
			BAL.				3.0		3.0
			OT. HRS.				15.0		15.0
J9886	DEATON RELAMP SHEET METAL SHOP		EST. HRS.				16.0		16.0
	D3068603	REC. 05-24-72 REQ. 06-16-72	EXP. HRS.				16.0		16.0
			BAL.						
			OT. HRS.						
J9889	LYNN RELAMP H BAY WELD SHOP		EST. HRS.				16.0		16.0
	D3069802	REC. 05-25-72 REQ. 06-23-72	EXP. HRS.				15.0		15.0
			BAL.				1.0		1.0
			OT. HRS.						
J9892	CRANES A&B BAY BRAKES		EST. HRS.				8.0		8.0
	D3068602	REC. 05-25-72 REQ. 05-31-72	EXP. HRS.				8.0		8.0
			BAL.						
			OT. HRS.						

FIGURE 22

SUMMARY OF SHOP MAINTENANCE JOBS

TABLE III

STANDARD TIMES USED FOR LUBRICATION TASKS

Activity* (Examples)	Minutes
Fill bowl with oil	1.6
Lubricate open fitting with hand gun	.3
Lubricate concealed fitting with hand gun	.6
Check and add oil from small pump can	.6
Hand oil bearings regular	.3
Hand oil, remove and replace plug	1.2
Check oil level (sight glass)	.3
Remove plug cover	.6
Oil ways	1.0

*These are examples only. More definitive descriptions of each function exist so they can be applied to various types of machines.

workloads for each lubricator. One lubricator was assigned to the front machine shop, and one to the back machine shop during the day shift. The third lubricator was assigned to the evening shift to do the coolant changes and lubrication tasks requiring longer machine downtimes since a small number of machines were in use during this shift.

Mechanical and Electrical Tasks

Machine manuals were also used to define and establish frequencies for preventive electrical and mechanical tasks. The tasks were defined both as inspection and actual work. One of the problems encountered was where to draw the line between PM work and actual repair to a machine. When the first few schedules were distributed, it was found that considerable amount of time had been spent, but all the work had not been done. Standard times had not been established at first as was true with the lubrication tasks. The leveling technique based on number of items per frequency per week explained in Chapter III was used. Originally no specific group was assigned to do the PM checks. The foremen were responsible for assigning their men these tasks as they had time during the week.

Breakdowns continued at first and, because of the risk of not getting the breakdowns repaired, PM work was given low priority. When these electrical and mechanical checks were made to a machine the machine was down for a considerable amount of time. Four to six hours was normal. Complaints from machine shop foremen that maintenance was tying up their machines too long for PM prompted further investigation

into the actual work that should be done during routine PM checks.

This investigation revealed several problems with the initial electrical and mechanical tasks as they were being done.

1. Mechanics were going beyond specified PM instruction, by checking integral parts of the machines requiring additional assembly and disassembly time.
2. If internal parts difficult to reach were found to be worn, they were replaced at the expense of tying up the machine even during critical times.
3. Task instructions were not clearly defined in some instances.

Ground rules were established so that when parts were found to be worn they were to be replaced only if the work could be done in a half hour. Otherwise these defects were to be reported to the maintenance foreman who would schedule machine downtime with the machinist foreman. Instructions were made more definitive and geared more specifically to individual machines. Feedback on time spent was made a matter of record and the tasks were observed for the purpose of establishing standard times.

III. COST MODEL

To optimize total maintenance costs associated with a group of machines, all the various costs associated with the system need to be defined as completely as possible. This can best be done by constructing a cost model or formula which represents the various costs as described by Goldman and Slattery.[15] Variables in the cost model are the cost of breakdown maintenance (BM) and preventive maintenance (PM) which are

affected by the frequencies of PM checks and the number of maintenance men. The idea is to minimize total cost including downtime cost.

An item is defined as any part or subsystem on which a periodic PM inspection, can take place. Each item has the following characteristics according to Goldman and Slattery.[15]

1. Deterioration Probability--the probability that at a given inspection an item will be found to require repair or replacement.
2. Failure Probability--the probability that an item will fail in a given time period.
3. Average Manhours--the time required for an inspection or repair.
4. Average Elapsed Time--the elapsed clock time for emergency diagnosis and repair (machine downtime).

Costs for the system are:

1. Cost of setting up for periodic maintenance.
2. Cost of maintenance (labor and material).
3. Cost of downtime.

The problem this thesis addressed itself to was that of setting up periodic inspections in a preventive maintenance program for a system of equipment composed of many items each of which had its own failing rate associated with a wearout type of distribution. Although sufficient breakdown data did not exist to establish actual distributions, manufacturer's recommendations and foremen's estimates were used to set up initial PM frequencies for each item. It was assumed that by scheduling

periodic inspections and repairs breakdown maintenance cost could be reduced. The objective was to adjust these frequencies in such a way as to minimize overall cost.

A mathematical model was constructed to represent the total cost. Let T equal the time in years between periodic inspections and let $k_i T$, k = 1, 2, 3, ..., n, be the time between preventive inspections of the i^{th} item. Let the cost of a preventive inspection of the i^{th} item equal $C1_i$. Then the annual inspection cost attributed to the i^{th} item is $(1/k_i\ T)C1_i$.

Let the probability of a preventive repair of the i^{th} item given an inspection be P_i and the cost of such repair equal $C2_i$. The expected annual cost of preventive repairs attributed to the i^{th} item is $(P_i/k_i\ T)\ C2_i$.

Let E_i equal the expected number of failures of the i^{th} item during the year given the above inspections and repairs. The annual cost of the failures attributed to the i^{th} item are $(E_i/k_i\ T)C3_i$ where $C3_i$ is the cost of failure of the i^{th} item.

The total annual cost of the system equals the sum of the preventive inspection, preventive repair, and failure cost or,

$$C_i = \frac{1}{k_i T} C1_i + \frac{P_i}{k_i T} C2_i + \frac{E_i}{k_i T} C3_i$$

where $C1_i$, $C2_i$, and $C3_i$ equal downtime cost D_1, D_2, and D_3 plus maintenance material and labor cost M_1, M_2, and M_3, respectively.

The annual cost attributed to the items of the system are given by $\sum_i C_i$.

The total system cost must include the cost of setting up for periodic maintenance inspections, that is, the scheduling and, in a computer system the cost of periodic runs and so forth. Let N be the number of run times during the year and C_r the cost of each periodic run and clerical cost associated with updating the system.

Let C_o equal the initial cost of analysis and the construction of preventive maintenance system. Let Y equal the number of years over which to prorate the cost. The value Y could be the average life of the machines.

Then the total annual cost of the system is:

$$C = \frac{1}{Y} C_o + NC_r + \sum_i C_i$$

Prior to the implementation of a PM system, C_o and C_r were equal to zero since no formalized scheduling existed. Obviously these costs must be offset by a decrease in the value of $\sum_i C_i$. The costs associated with C_i also contain costs C_1 and C_2 which are a result of preventive maintenance inspection and repairs. Their cost must be offset by a reduced cost in C_3 on an annual basis. This can be done by reducing the expected number of failures during the year by effective PM inspection and repair. Letting F_i = the average E_i prior to the implementation of the PM program, the program costs must be less than this cost or

$$\frac{1}{Y} C_o + NC_r + \sum_i \left(\frac{1}{k_i T} C1_i + \frac{P_i}{k_i T} C2_i + \frac{E_i}{k_i T} C3_i \right) < \sum_i \left(\frac{F_i}{k_i T} C3_i \right)$$

By referring to the sample of sixty-two machines in Figure 21, page 77, one finds the total maintenance cost of these machines during two years prior to the implementation of PM procedures equal to $1,950 per month or $23,400 per year. Thus $\sum_i \left(\frac{F_i}{k_i T} C3_i \right)$ equals $23,400. From Table IV the annual maintenance cost for these same sixty-two machines during the first year of the PM program equals $19,851. Thus $\sum_i C_i$ new equals $19,851. The system cost NC_r associated with the PM program for these sixty-two machines was approximately $500. This cost was prorated on a per machine basis from the total system cost. Since approximately five thousand pieces of equipment might eventually be added to this program, the initial programming cost was allocated to this total number. The portion of the initial cost associated with the sample of sixty-two machines was approximately $50 per year assuming an average ten-year life remaining on the equipment. Thus, $\frac{1}{Y} C_o$ equals approximately $50. Substituting these values in the above equation yields

$$\$50 + \$500 + \$19,851 < \$23,400$$

Subtracting the two maintenance cost figures for the two periods gives a net saving of approximately $3,000 for the first year of the program for the sample of sixty-two machines. As the program progressed, this saving was expected to increase as more long-term gains were realized as a result of better maintenance policies. The next two sections discuss

TABLE IV

MACHINE MAINTENANCE COSTS FOR SAMPLE GROUP OF MACHINES
DURING FIRST YEAR OF PM PROGRAM

SAMPLE OF SIXTY-TWO MACHINES

Month	Cost
1	$ 2,554
2	2,039
3	1,519
4	1,121
5	1,512
6	1,122
7	1,315
8	3,722
9	1,827
10	1,029
11	1,277
12	814
Total	$19,851

AVERAGE COST PER MONTH $1,654

the result of the effect of fixed frequency maintenance on the total group of machines and the potential saving which could possibly be expected for a variable frequency concept.

IV. EFFECT OF FIXED FREQUENCY MAINTENANCE

The success of the lubrication program easily justified the cost of computer time and the average one day per week required for updating and issuing schedules, and so forth. Since one lubricator was eliminated due to better scheduling this program in itself resulted in a net saving of approximately $6,600 calculated after twelve months' experience for the group of three hundred machines.

Net saving (lubrication program) = annual cost of one employee
- (cost to run schedule + clerical cost one day per week)

Electrical and mechanical tasks were added to the scheduling program without increasing computer run or handling time significantly after the data was initially prepared. Figure 23 shows a decline in breakdown maintenance for the first twelve months of the PM program. This was evident from the reduction in the number of repair work orders written. Table IV shows total maintenance costs over the same period. Although breakdowns were reduced total maintenance costs did not reduce at the same rate over the same time period. This was a result partly of major reconditioning required of some machines revealed by careful PM inspections. Perhaps also some of the cost was due to overmaintaining the

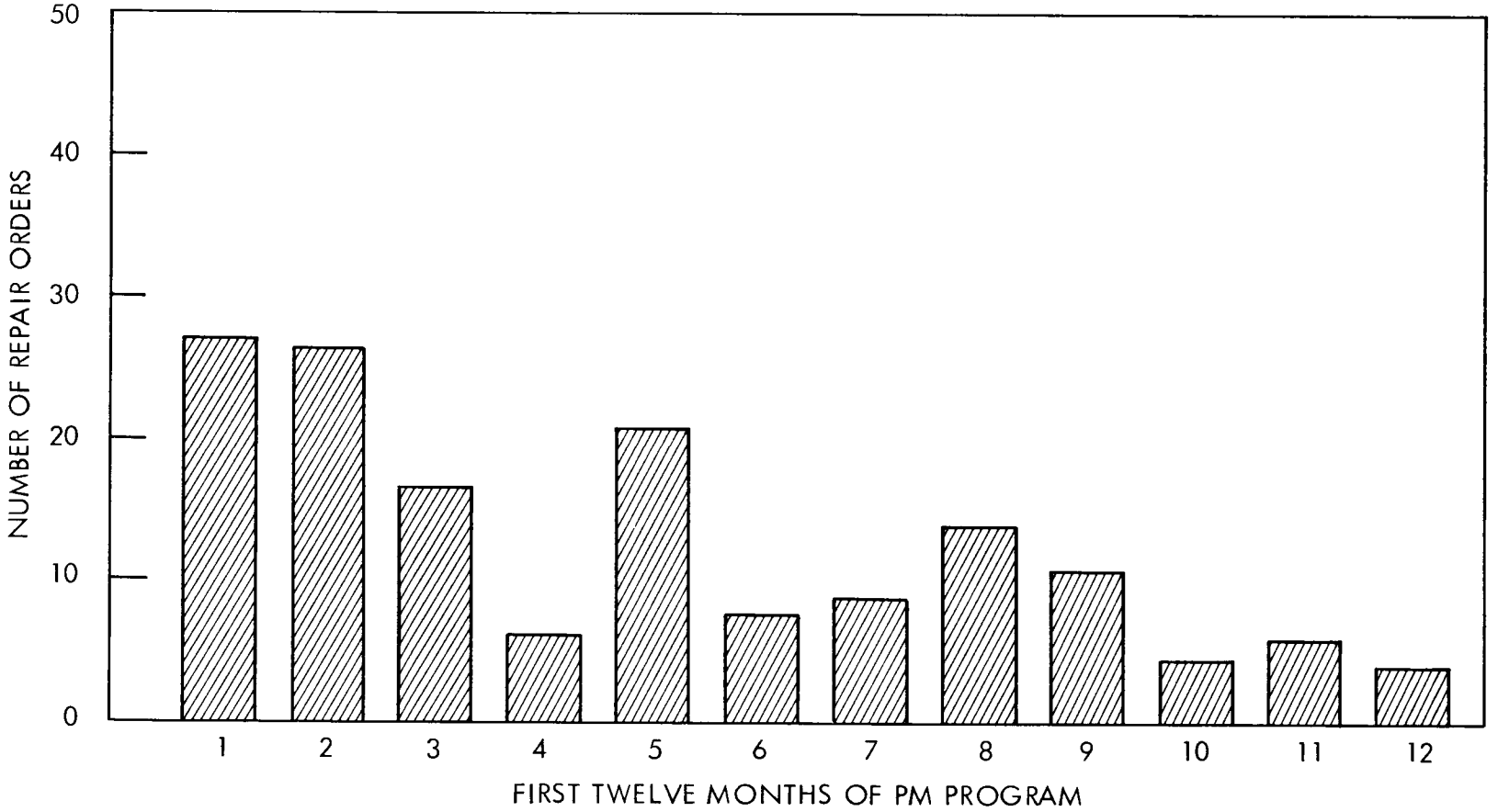


FIGURE 23

REPAIR ORDERS FOR FIRST TWELVE MONTHS OF PM PROGRAM

equipment. Manufacturer's recommendations were used. Fixed maintenance frequencies were initially set independent of usage. A readjusting of frequencies for PM checks was necessary to reach optimum conditions.

V. FOLLOW-UP AND VARIABLE FREQUENCY MAINTENANCE

It is relatively easy to develop and implement a PM system that is effective in reducing breakdowns given that the machines or equipment meet the necessary criteria. However, a good follow-up system that monitors total cost is essential to obtaining optimum gains from such a program. Since the three hundred machines in question were used sporadically, would not maintenance frequencies based on heavy constant usage be excessive for these machines during low use periods?

Data on machine usage and maintenance costs collected during a twelve-month period were used to show the relationship between machine hours used, number of times used, and maintenance required. That is

$$M = f(U, F)$$

where

M = maintenance required,

U = machine usage in hours, and

F = number of times the machine was used.

Phase II of the PM program might be called the analysis of usage and maintenance costs and the readjusting of PM frequencies. This analysis was being made after a year's experience with fixed PM frequencies. Since usage was extremely low on some machines, it was believed that PM

checks could be reduced considerably without increasing the probability of breakdowns. This would result in an overall cost reduction.

The Machine Utilization Report (Figure 13, page 58) was reviewed for machines with low usage. Frequencies of PM checks on these machines were lowered as a result. Also, a weekly review of machine usage was begun and those machines which had PM items scheduled were omitted from the PM schedule for the following week if they had not been used during the previous week. For the future, it seemed likely that a computer comparison technique could be implemented to make this check and schedule the PM accordingly.

Varying the frequencies in this way from week to week reduced the PM maintenance hours by approximately twelve hours per week for the sample of sixty-two machines over a two-month period without increasing the number of breakdowns. Thus $\sum_i C_i$ was reduced by approximately $240 per month for the sample of machines by varying the frequencies. Thus, for sporadically used machines varying the PM frequency with respect to usage tended to minimize maintenance cost.

For the future, it seemed likely that a computer comparison technique could be developed to check machine usage and vary the PM frequency automatically. This would require additional programming, but appeared feasible if sufficient information and experience occurred to insure statistical reliability.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to develop a preventive maintenance program which would be effective in controlling maintenance costs on sporadically used equipment as well as on equipment with constant or known usage. Both the analytical and the practical approaches were researched. A system was developed and implemented which attempts to blend the two approaches. Initially, a practical approach was taken. Later, as data became available, PM frequencies were adjusted to minimize maintenance costs. While some advantages were evident after the first year of implementation, more reductions in costs were anticipated throughout future years as the equipment responded to preventive maintenance, and PM frequencies were adjusted toward optimum intervals between checks.

I. SUMMARY

As pointed out in Chapter I, industrial equipment has become more complex and maintenance costs have increased. A good preventive maintenance program could do much to control maintenance costs on certain equipment. Generally, for equipment that obeys the "wear out principle", proper repairs and inspections before breakdown are far more economical than repair after breakdown. Proper scheduling of maintenance manpower can reduce the cost of performing PM checks.

Chapter II investigated various approaches which have been taken to insure maintainability of equipment. Distributions of downtime and machine availability were described. Various preventive maintenance systems were discussed. Twenty existing systems were studied in detail, and some of their basic characteristics were given. Although the analytical approach is recommended by most textbooks, many industries do not have sufficient data at the outset of such a program to establish frequencies distributions. Therefore, the more practical and applicable approach is often taken over the theoretical. This study attempted to blend an analytical approach with an initial practical approach by collecting data which could be used to optimize total maintenance cost. There are many characteristics of a good PM program, but usually the most effective system is one that is somewhat custom made for the individual environment of equipment or machines which are to be maintained.

Chapter III described the establishment of procedures which would guide the study. Although breakdown information was not available at the start, data collection systems were developed so that frequencies could be optimized through an iterative process as the PM program matured. The characteristics described in the survey in Chapter II were applied during the development stages of the PM system.

Chapter IV described the categorizing of equipment and how to decide where to place more emphasis when installing a PM program. The situation prior to implementation was described and the impact of Phase I of the PM program (that of fixed frequencies) was given. The importance

of follow-up and adjustment of frequencies was pointed out as a key to a successful program.

II. CONCLUSIONS

A good preventive maintenance program is usually effective in reducing overall maintenance costs in an industrial environment when applied to equipment which obeys the "wear out principle". Good scheduling and manpower leveling techniques are keys to a successful PM program.

Prior to employing PM on a piece of equipment, as much historical information on the equipment as practical should be analyzed. That is, are the failures increasing with time? Does it cost less to replace a part prior to failure? If the answer to these questions is "yes", then PM should usually be employed.

When setting frequencies for PM checks, statistics should be applied to breakdown data when available to determine the distributions and thus predict the most desirable interval between PM inspections. Intervals can be set to minimize breakdowns or minimize maintenance costs. Sometimes these two objectives are different, and the one that is chosen depends on production schedules, type of work, and criticality of the equipment.

Often sufficient information is not available to take an analytical approach to determine the best frequencies for PM checks prior to implementing a PM program. In such cases, an iterative process of adjusting intervals between checks should be a part of the follow-up procedure.

Sufficient data should be collected over a period of time so that PM frequencies can be adjusted toward the optimum to minimize overall cost.

Usually the frequency of PM checks is a function of the hours the machine or equipment has been used and the number of times the equipment is used. This data should be a part of the total system so that PM checks can be monitored when usage changes. The computer can be a great help in collecting and assembling this information as well as scheduling the PM tasks. The system of the future will depend more and more on the computer to optimize maintenance intervals on a piece of equipment. This can be done by using a given set of ground rules which relate maintenance to usage and through a process that tells the computer when a piece of equipment has reached its maintenance point. The computer then would schedule the PM based on given priority rules and manpower availability.

Although the results of this study show improvements over the previous year's maintenance costs, the real advantages of preventive maintenance are long term. Strong management backing to give PM sufficient priority along with other maintenance tasks and periodic follow-up of cost comparison of PM versus repair can contribute much to the effectiveness of such a PM program.

In conclusion, the theoretical approach of gathering data and calculating frequency distributions is often too time consuming and costly when initially setting up a PM program in industry. Rather, the more practical approach of using manufacturer's recommendations and foreman's estimates is usually taken. For optimum results, however,

the latter approach should be coupled with a data collection system which provides usage data and breakdown frequencies that can be used to adjust PM intervals. By repeatedly adjusting these intervals as a function of machine usage and breakdowns, total maintenance costs can be minimized.

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APPENDIX

TABLE V

ABBREVIATIONS USED ON LUBRICATION DATA SHEET

Code	
	Lubricant
BE	- Turbine Oil Light
BG	- Turbine Oil Medium Heavy
CR	- Way Oil Light
UK	- Extreme Pressure Multipurpose Grease
MO	- Mineral Oil
MS	- Manufacturer's Specifications (Special)
SO	- Spindle Oil
	Fittings
BO	- Button Oiler
CLO	- Constant Level Oiler
DP	- Drain Point
FP	- Fill Point
GC	- Grease Cup
HPF	- Hydraulic Pressure Fitting (Oil or Grease)
GP	- Grease Point
OC	- Oil Cup
OF	- Oil Fitting
OH	- Oil Hole
OL	- Oil Level
SFO	- Sight Feed Oiler
	Operation
OL	- Check Oil Level
DCR	- Drain, Clean, Refill
DFR	- Drain, Flush, Refill
F	- Flush
G	- Grease
O	- Oil
ACT	- Actuate
ROT	- Rotate
C	- Clean

ORGDP PREVENTATIVE MAINTENANCE

RESCHEDULE LIST FOR JUN 5,1973

LOCATION	EQP NO	DESCRIPTION	PROPERTY	JOB ORDER	FOREMAN	STD TIME	DATE SCHEDULED
K1401	P864	POSITIONER,WELDING	245356		POPE P	4.8	MAR 19 1973
K1401	P940	COMPRESSOR	253818		POPE P	3.6	JAN 29 1973
K1401	P940	COMPRESSOR	253818		POPE P	3.6	MAR 26 1973
K1401	P941	ROLL STAND			POPE P	7.2	JAN 29 1973
K1401	P941	ROLL STAND			POPE P	7.2	MAR 26 1973
K1401	S490	SHEAR POWER 12 FT TABLE	231238		POPE S	15.0	JAN 29 1973
K1401	S490	SHEAR POWER 12 FT TABLE	231238		TEMPLIN	15.0	MAY 21 1973
K1401	S491	SHEAR POWER	249447		POPE S	.6	JAN 29 1973
K1401	S492	SHEAR POWER	240937		TEMPLIN	5.8	MAY 21 1973
K1401	S550	PRESS BRAKE 250 TON	147700		POPE S	6.0	FEB 12 1973
K1401	S550	PRESS BRAKE 250 TON	147700		TEMPLIN	6.0	MAY 21 1973
K1401	S551	PRESS BRAKE 200 TON	233442		TEMPLIN	7.6	MAY 21 1973
K1401	S557	PRESS PUNCH-NOTCHING	243826		TEMPLIN	32.6	MAY 21 1973
K1401	S567	PRESS PUNCH-TURRET	249790		TEMPLIN	10.0	MAY 21 1973
K1401	S568	GRINDER, PEDESTAL	198838		TEMPLIN	1.2	MAY 21 1973
K1401	S569	GRINDER, PEDESTAL	233389		TEMPLIN	1.2	MAY 21 1973
K1401	S570	PRESS BRAKE	252736		TEMPLIN	12.4	MAY 21 1973
K1401	S576	GRINDER, PEDESTAL			TEMPLIN	1.2	MAY 21 1973
K1401	S584	HAND BRAKE	249741		TEMPLIN	1.2	MAY 21 1973
K1401	S585	HAND BRAKE	102975		TEMPLIN	1.2	MAY 21 1973
K1401	S589	BAND SAW	250130		TEMPLIN	10.0	MAY 21 1973
K1401	S590	SHAPER	178318		TEMPLIN	.6	MAY 21 1973
K1401	S670	PRESS BRAKE 160 TON	179272		TEMPLIN	6.0	MAY 21 1973
K1401	S671	PRESS BRAKE 45 TON	247907		TEMPLIN	4.3	MAY 21 1973
K1401	S677	NIBBLER	254845		TEMPLIN	1.8	MAY 21 1973

FIGURE 24

A TYPICAL RESCHEDULE LIST

SCHEDULE LIST JUN 25,1973

LOCATION	EQP NO	DESCRIPTION		PROPERTY	JOB ORDER	FOREMAN	STD TIME	DATE SCHEDULED
K1401 L	824	B&S HOR KN ML 8X30 UNI HD	6109	180950	D21308-24	TEMPLIN	13.1	JUN 11 1973
K1401 L	824	B&S HOR KN ML 8X30 UNI HD	6109	180950	D21308-24	TEMPLIN	13.1	JUN 18 1973
K1401 L	825	B&S RANG MST ML 10X36	22624	250198	D21308-25	TEMPLIN	16.5	JUN 11 1973
K1401 L	825	B&S RANG MST ML 10X36	22624	250198	D21308-25	TEMPLIN	16.5	JUN 18 1973
K1401 L	827	CIN HOR KN ML 10X42	32573	250449	D21308-27	TEMPLIN	18.3	JUN 11 1973
K1401 L	827	CIN HOR KN ML 10X42	32573	250449	D21308-27	TEMPLIN	18.3	JUN 18 1973
K1401 L	828	K&T HOR KN ML 18X54	49194	250673	D21308-28	TEMPLIN	11.4	JUN 11 1973
K1401 L	828	K&T HOR KN ML 18X54	49194	250673	D21308-28	TEMPLIN	11.4	JUN 18 1973
K1401 L	829	P&W C ML TAP CONT PP29X45X26	32580	253779	D21308-29	TEMPLIN	11.4	JUN 11 1973
K1401 L	829	P&W C ML TAP CONT PP29X45X26	32580	253779	D21308-29	TEMPLIN	11.4	JUN 18 1973
K1401 L	831	P&W C ML TAP CONT PP29X45X26	26317	252678	D21308-31	TEMPLIN	11.4	JUN 11 1973
K1401 L	831	P&W C ML TAP CONT PP29X45X26	26317	252678	D21308-31	TEMPLIN	11.4	JUN 18 1973
K1401 L	832	CIN HOR KN ML 10X42	15364	240727	D21308-32	TEMPLIN	8.9	JUN 11 1973
K1401 L	832	CIN HOR KN ML 10X42	15364	240727	D21308-32	TEMPLIN	8.9	JUN 18 1973
K1401 L	833	CIN HOR KN ML 10X42	4700	248622	D21308-33	TEMPLIN	8.9	JUN 11 1973
K1401 L	833	CIN HOR KN ML 10X42	4700	248622	D21308-33	TEMPLIN	11.3	JUN 18 1973
K1401 L	834	CIN VERT KN ML 10X42	12965	249607	D21308-34	TEMPLIN	33.0	JUN 11 1973
K1401 L	834	CIN VERT KN ML 10X42	12965	249607	D21308-34	TEMPLIN	33.0	JUN 18 1973
K1401 L	835	BRDG ML 1 HP 9X32 POW FD	3414	249445	D21308-35	TEMPLIN	14.6	JUN 11 1973
K1401 L	835	BRDG ML 1 HP 9X32 POW FD	3414	249445	D21308-35	TEMPLIN	15.2	JUN 18 1973
K1401 L	836	BRDG ML 1 HP 9X42 POW FD	2579	244975	D21308-36	TEMPLIN	14.6	JUN 11 1973
K1401 L	836	BRDG ML 1 HP 9X42 POW FD	2579	244975	D21308-36	TEMPLIN	15.2	JUN 18 1973
K1401 L	837	BRDG ML 1 HP 9X42 POW FD	2659	251198	D21308-37	TEMPLIN	15.2	JUN 11 1973
K1401 L	837	BRDG ML 1 HP 9X42 POW FD	2659	251198	D21308-37	TEMPLIN	14.6	JUN 18 1973
K1401 L	838	BRDG ML 1 HP 9X42 POW FD	1802	216407	D21308-38	TEMPLIN	14.6	JUN 11 1973

FIGURE 25

A TYPICAL SCHEDULE LIST

TOTAL NUMBER OF JOBS SCHEDULED

FOREMAN	MAR 13	TIME	MAR 20	TIME
BOGGS	16	36.5	7	36.8
POPE C	4	3.4	2	31.2
POPE M	4	44.0	6	46.0
POPE P	2	10.8	1	1.2
POPE S	30	169.9	22	160.3
POPE V	2	21.8	12	39.7
POPE W	12	66.6	5	32.8
POPE CC			1	14.0
WEST	12	3232.0	13	3720.0
POPE LM	107	2048.2	104	2048.8
POPE LMG	13	58.3	17	61.3
POPE LJF	96	1349.7	99	1377.2
POPE MC	11	180.0	13	
TOTAL	309	7221.2	302	7569.3

FIGURE 26

A TYPICAL SUMMARY OF PM JOBS SCHEDULED

TABLE VI

CODES FOR PM ITEM CHANGES

Code		Description
Code 1	Code 2	
1	9	Add new record
2	9	Delete old record
3		Changes to Header 1 (see Code 2)
	9	Change all of Header 1
	1	Change Foreman only
	2	Change work order number only
	3	Change work order number and foreman
	4	Change description only
4		Change Header 2 (see Code 2)
	9	Change all of Header 2
	1	Change Year only
5	9	Change Machine type in Header 2 only
8	9	Read item card and use control 3 on item card
Code 3 (item card)		
1		Add new item
2		Delete old item
3		Change all of item card
4		Change standard time
5		Change season
6		Change start counter
7		Change frequency code
8		Change craft code
9		Change start counter and standard time

VITA

Woody Sanford Byars was born in McMinnville, Tennessee, on March 25, 1944. He was graduated from McMinnville City High School in 1962. Upon graduation he enrolled at David Lipscomb College where he completed his freshman and sophomore years. In the fall of 1964, he transferred to the University of Tennessee where he received his Bachelor of Science degree in Industrial Engineering in June, 1966.

He began working for Union Carbide Corporation in July, 1966. He entered graduate school while employed by Carbide and completed this thesis as partial fulfillment of the requirements for his Master of Science degree in Industrial Engineering in August, 1973. He is a member of the American Institute of Industrial Engineers and a licensed professional engineer in the State of Tennessee.

He is married to the former Gwendolyn Jewel Grant of Athens, Tennessee. They have two children, Amy Elizabeth and Andrea Renae.