# Integrated Construction Preventive Maintenance System

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**Abstract:** The maintenance of heavy construction equipment is a vital function for many construction contractors. A regular, structured preventive maintenance program can be a worthwhile investment for several reasons: Reduced field breakdowns; more efficient equipment and operator utilization; elimination of unnecessary parts damage and reductions in inventory requirements; preservation of warranties; more productive mechanics; and longer-lasting repairs. This article discusses an integrated preventive maintenance system developed for a large, multi-site quarrying operation. The physical and personnel requirements are briefly presented, and the management control aspects discussed in detail. Implementation considerations are related and the substantial improvements achieved in overall fleet availability are documented. Finally, the integration of this system to the company's other accounting modules is outlined.

## Introduction

For many contractors, particularly heavy and highway oriented firms, the expense and delay of routine maintenance and unscheduled repairs for construction equipment is of paramount concern. Equipment operating at less than peak performance levels or which outright fails can represent significant costs, schedule disruptions, and other inconveniences not only to the project at hand, but to all the firm's operations.

It is axiomatic that such breakdowns and inefficient operation can be controlled to a large extent by a well-planned and faithfully subscribed Preventive Maintenance (PM) System. Total equipment costs can be reduced with such a System in a number of ways: An operator's time is more fully utilized; the equipment performs at a higher output rate; the costs of unnecessarily damaged parts are eliminated and inventory expenses reduced; the mechanic's time is more productive; repairs are sounder and longer-lasting; and the voiding of an equipment manufacturer's warranty may be prevented. There are many indirect costs that can be reduced or eliminated also, notably those related to worker morale.

This paper outlines an integrated PM System which has been implemented by these authors for a large Midwestern quarrying firm at a series of permanent production sites. Organizationally, the first part of this paper is a review of the physical and personnel staffing configurations that are intrinsic to the System. Then a detailed review of the PM checklists that were developed is presented along with the important scheduling considerations. The third major section of the paper is then dedicated to the management control aspects of this formalized operation; namely, the various sorts on equipment operating data and the inherent alerts (e.g. availability ratios) that have been found to be useful to this

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**TABLE 1.—Equipment Fleet Composition at Trial Facility**

| Equipment type (1) | Quantity (2) | Number of manufacturers (3) | Number of models (4) |
|---|---|---|---|
| Scrapers | | | |
| Double Engine | 26 | 2 | 3 |
| Bulldozers | | | |
| 125–200 Horsepower | 4 | 2 | 2 |
| 300–400 Horsepower | 9 | 3 | 4 |
| $400^+$ Horsepower | 15 | 1 | 2 |
| Dump trucks | | | |
| 80 Ton End Dump | 2 | 1 | 1 |
| 120 Ton Bottom Dump | 9 | 2 | 2 |
| 150 Ton Bottom Dump | 2 | 1 | 1 |
| Miscellaneous | | | |
| Wheel Dozers | 3 | 2 | 3 |
| Water Trucks | 3 | 3 | 3 |
| Endloaders (12 cu yd) | 3 | 1 | 1 |
| Totals: | 76 | 8 | 17 |

company's site managers. Finally, results of the practical application of this PM System are presented to demonstrate the gains realized by this company to date.

The PM System described is considered to be integrated because it was deliberately designed for future interfacing with the company's accounting system as will be outlined herein. The composition of the equipment fleet at the site for which the System was initially developed is presented in Table 1. Though all the equipment at this trial site was mobile, the same concepts could be applied for stationary equipment, too, such as aggregate crushers and mechanical screens.

The conceptual outline of the PM System described herein has been proposed and reviewed by others in a variety of forms (1). The principal contributions of this paper are those of an applications nature, including many of the implementation and operational details as well as the equipment and associated personnel productivity gains attributable to this new information and control system.

## PM System Description

**Physical and Staffing Organization.**—The physical heart of this assembly line PM System is three unique stations; a wash area, a lubrication station, and a mechanical area. Ideally, they should be physically adjacent and sequential. In this particular case though, the arrangement was configured as shown in Fig. 1 with a detached wash area because existing facilities were utilized. The sole purpose of each station is to facilitate a specific type of PM work. Very little repair work (as distinguished from PM) is performed at any of the staging areas to avoid disruption of the System timetable. Generally, the only field maintenance required is miscellaneous work like the greasing of fittings.

A unit begins scheduled service by receiving a thorough wash job,





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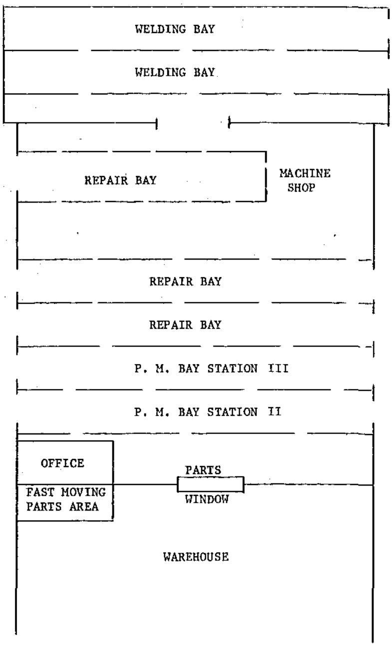


**FIG. 1.—Physical Outline of Preventive Maintenance Line (Station I Detached and not Shown)**

which includes the cleaning of heavy mud from all areas; high pressure finish washing of filters, fill points, drain points, and grease fittings; the vacuuming of the cab interior; and the cleaning of cab windows and mirrors. One worker is allotted 2 hr per unit for this job. The unit is then brought to the shop or PM area after this Station I wash job for continuation of service.

Operating from a prepared checklist issued by the System Planner, as many as two servicemen spend a total of four manhours working on each unit at the lubrication station. Checklist items include detailed greasing instructions, oil change and sampling jobs, filter changes and servicing, breather cleaning, and other various checks. When that service time is exhausted the unit should be finished and moved onto the next stage.

Station III, the mechanical station, consists of general inspection work and safety equipment maintenance, including headlights, horns, seatbelts, handrails, kill switches, and fire extinguishers. One or two mechanics devote a total of three to four manhours on each unit. Also available at Station II or III is a welder whose job is to provide welding services to the PM line. He, like the mechanics, is guided by the PM Foreman and welds anywhere his services are required, simply by stretching out additional welding lead to the job location. Welding work items include handrails, footholds, frames, brackets, sheetmetal, and the like.

Painting of equipment, though viewed as part of Station III, is usually performed away from the work stations. Not every unit has paint ap-



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plied as it comes through the System. Instead, units are pulled out of service for the two to three shifts necessary to paint them and are individually worked on by a painter. Some touch-up painting may be applied as the unit comes through Station II and Station III, which is why this work is organizationally linked to Stations II and III.

To accomplish the work expected of the PM line personnel in the total twelve manhours allotted per unit at this site, the physical facilities have been tailored as much as economically feasible to reduce to a minimum any disruptions and long trips for tools and parts. The layout and servicing provisions of each of the work stations required careful planning. As an illustration, a major consideration for the wash station of this particular operation was providing an adequate water supply and proper run-off facilities due to environmental constraints. The station essentially consists of four high pressure water cannons, a steam cleaner, vacuuming units, and standard hose outlets all mounted on or near a reinforced concrete drainage pad. This volume of water run-off required an environmentally approved collection pond and recirculation system.

The shop area required the use of two adjacent bays to accommodate some maintenance equipment shared between Stations II and III. These stations were also located near an office area to facilitate communication between the System Planner and the PM Foreman. Also, a warehouse and a Fast Moving Parts Area (for filters, headlights, belts and gaskets, etc.) were established near these two stations. For this equipment fleet, it was found that the inventory requirements were about 130 different items and a total stock of 800–1,000 parts. Because this PM System was implemented after all the major equipment at this site had been purchased, there was a lack of uniformity among the machinery. This, in turn, increased stocking requirements initially, though greater attention is now being devoted to the advantages of such uniformity when new equipment is purchased.

PM line people have direct access to this Fast Moving Parts Area so they may obtain any of these items without waiting at the parts window. Since PM line people must adhere to a strict schedule, time is very valuable. In addition to being checked daily for any obvious shortages, this area is stocked by warehouse personnel on a twice weekly basis. They operate with a list of the inventory which has minimum and maximum quantities noted as necessary. After the PM crew is finished for the shift, the Fast Moving Parts Area is secured by shop management.

Managing a shop operation and PM program requires people who are knowledgeable about heavy mobile equipment repair, have the foresight to see a minor problem before it becomes a major one, and possess the ability to manage shop personnel. This assembly line PM program is designed to operate with three supervisory personnel; the shop foreman, the System Planner, and the PM Foreman. For some of the small site operations it has been found that the shop foreman and the Planner jobs could be combined with the PM Foreman handling a few of the in-shop duties of the shop foreman.

The shop foreman's primary duties include the overall responsibility for the PM program as well as shop maintenance and repair. This person is responsible for coordinating shop mechanics and welders except for the PM line personnel. The only direct PM duties are ensuring the delivery of units scheduled for service to the shop by production people and cooperating closely with the PM Foreman who has the actual day-to-day responsibility for the line. Any recurring problems are (and should be) discussed with the site superintendent and quickly remedied. Field breakdowns, dispatching of shop mechanics, and field breakdown analysis are also the responsibility of this foreman.

The System Planner has a variety of duties, from planning PM schedules to writing work orders and issuing PM checklists to maintaining the equipment records and analyses. This individual must be a person with foresight, organizational capabilities, and good mechanical knowledge of the machinery and repair jobs. The duties are primarily PM related and include issuing the daily and weekly PM schedules, coordinating them with production personnel, and maintaining an adequate supply of PM checklists for each model required. The Planner must be able to work closely with the shop foreman and production personnel in coordinating PM and shop activities.

The PM Foreman is responsible for the actual management of the PM line. Primary duties include direct supervision of PM line personnel and ensuring the satisfactory completion of the PM checklists. The Foreman must be able to motivate the people under his or her supervision and must possess a thorough mechanical knowledge of the heavy equipment. It is important that this person have the intuition to provide a diagnosis of any malfunctions and spot other potential machine deficiencies. The program responsibilities of all three of these individuals are summarized in Table 2.

The actual PM line work force consists of five or more people who perform the functions of washer, serviceperson, mechanic, welder, and painter. The first person in the System, the washer, is in a general laborer union classification. This individual begins work at 6:00 a.m. and

**TABLE 2.—Responsibilities of PM System Management**

| |
|---|
| SHOP FOREMAN |
| Oversees PM program |
| Directs shop mechanics |
| Ensures delivery of units for PM |
| Makes necessary field calls to diagnose problems/breakdowns |
| PLANNER |
| Schedules units for PM |
| Issues PM checklists |
| Maintains records and backlog |
| Prepares oil analysis samples |
| Establishes shop job priority |
| Coordinates shop job scheduling |
| Prepares shop work orders |
| Orders necessary parts for work orders |
| PM FOREMAN |
| Directs PM workforce |
| Ensures quality of PM work |
| Makes PM line work decisions |
| Ensures timely completion of PM work |





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finishes at 2:00 p.m. for the five day work week, spending the day washing the units (typically four) to be serviced. Depending on the workload, he or she may be called upon to assist the serviceperson at Station II. This, however, has been necessary only in smaller operations where just one serviceperson is used instead of two.

In the event the washer is on leave for a day and a replacement cannot be spared from another part of the shop or production, the PM line can operate without this individual for a short period. It is important though that this situation not be allowed to persist since the quality of the PM line work will suffer as dirty equipment is harder and more time consuming to repair. Worker morale can otherwise be detrimentally affected, too.

Station II, lubrication, is handled by two workers in a serviceperson classification. They begin their work at 8:00 a.m. and finish at 4:00 p.m. (staggered from the washer's starting time), greasing and lubricating each scheduled unit normally at the rate of four per day. An operation with a smaller fleet has been found to function well with one serviceperson and three units per day with the washer providing the greasing portion of Station II. If desirable, mechanics may be used instead of servicepersons but they are entitled to a higher rate of pay and may infringe upon the duties of other classified servicers, creating jurisdictional problems in an operation with an organized labor force.

When a serviceperson is absent for a day the position must be filled since most of these duties are tasks which must be completed; e.g. oil and filter changes and lubrication. Ideally the replacement would come from another area of the shop, but if necessary may be a displaced PM mechanic. Constantly pulling a mechanic off PM line duty at Station III will probably result in a premature part failure and unnecessary downtime, shaking confidence in the entire PM System and its purpose. Therefore, it is advisable to avoid this practice whenever practicable.

Two mechanics begin every morning at Station III on the PM line at 8:00 a.m. and end at 4:00 p.m. They inspect mechanical and structural components and make small repairs and adjustments as they service four units per day. They begin with a unit that passed through the lubrication station at the end of the previous day and was kept out of production overnight. This arrangement allows these mechanics to be productive at the start of their shift. In the event of vacation or absenteeism, the mechanic's position may be filled by other shop personnel. If no one is available to fill the vacancy, the PM line can be run short one mechanic but the consequences will be the same as aforementioned.

Welding is a much needed trade for heavy mobile equipment, repairing sheet metal, structural cracks, handrails, footholds, and many other items. The PM welder provides the line with these services each day. As each day's four units pass through the PM System, the welder receives instructions from the PM Foreman and welds at Station II or III depending on the amount of time available and work necessary on each unit. Proper planning and organization will minimize if not eliminate any potential interference with other employees. The PM program can operate without the welder in the event of vacation or absence, though it is not desirable. Most fleets of this size have more than enough work for one full time welder.

The painter is kept busy painting equipment each day, but not necessarily just the units going through the PM System. Since it typically requires three shifts to prepare and paint a unit, equipment is normally painted while it is down for major repairs so that it is not idled simply for painting. The painter, like the other PM line personnel, reports to the PM Foreman, provides an important service to the PM line. In the event of an absence it may not be desirable to replace him or her with a temporary.

**PM System Checklists.**—Design of a PM System requires numerous tasks critical to its successful operation, but none are as vital as the development of the PM Station checklists. These checklists serve several purposes; task instruction, employee accountability and input, and job quality control guidance. The development of a checklist first requires a comprehensive compilation of all the service requirements of every machine model since each has its own unique maintenance needs.

Appendix I serves as an example of the detail and format of such a checklist, in this case for the Station II (lubrication) tasks. This lubrication checklist contains complete instructions for the servicing of such tasks as oil and filter changes, greasing, and breather and strainer cleaning and replacement. In order that the serviceperson can finish that portion of the service required in the allotted four manhours, there is no 1,000 hr service as such. Instead, the service requirements of each individual area or component were studied, and then the total list of servicing requirements was divided among the established services so that each component received the attention it deserved at a proper time interval. This meant that if a machine came in for service every 100 hr it not only received the 100 hr service attention required, but also one-half of the 200 hr requirements, one-fifth of the 500 hr requirements, and one-tenth of the 1,000 hr requirements (Fig. 2). The actual distribution for each service may not be exactly as described, but it will average out over the entire sequence. Of course, the requirements of the manufacturer's warranty must be abided with so as not to void it.

The content of the checklist was assembled by the System designers using the manufacturer's service recommendations, knowledge gained through oil analysis, and the experiences of company personnel. As management experience with this PM program has accumulated, the content and service time intervals of the checklists have been monitored through these oil analyses and modified as conditions dictate. In a one-location operation, these duties are the responsibility of the Planner, while in a multi-location company these duties should be part of a Company Program Coordinator to ensure standardization. The checklists for Stations I and III were developed in an analogous fashion.

The physical design of the checklist forms is important, too. Adequate space must be allotted on the sheet for checking off individual items as completed, writing in comments and known machine deficiencies, and signing off by a responsible supervisor. For this System the entire sequence of checklists for a specific manufacturer's model of equipment was deliberately developed to be identical for all the geographic locations of the company so production comparisons could be properly made between the various sites.

Task instructions for PM people are provided in great detail so that

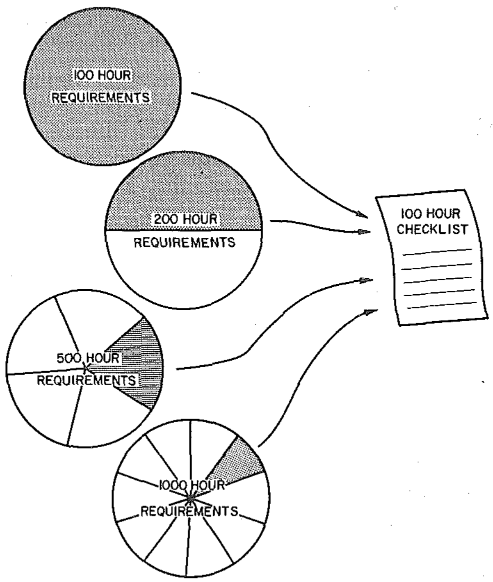


**FIG. 2.—Theoretical Checklist Composition**

the chances that something will be omitted or given insufficient attention are minimized. In developing job instructions for each station, the scheduler must take into consideration the unit model, number of scheduled manhours, and availability of service resources. Too much work scheduled for a fixed time period will only result in a low completion percentage and low morale. In this System employees have the opportunity to provide input about a unit's condition and deficiencies while checking off the individual tasks as they are completed. The PM Foreman and Planner may then use these same sheets as a checklist for quality checklists for Stations I and III were developed in an analogous fashion.

**Scheduling.**—Scheduling a large amount of equipment for PM servicing is a considerable undertaking and should not be taken lightly. Servicing on the basis of hourly use is greatly preferred over a calendar basis since some machines would undoubtedly be over-serviced and some under-serviced. Daily updates of the previous day's operating hours or meter readings are a necessity because a machine that is not operated can find its priority in the service schedule changing quite quickly with respect to equipment that is utilized. A schedule prepared in advance and updated daily is a valuable communication tool between production, inventory, and shop supervisors. It allows for advance planning so that equipment will be free when it is due for service.

Most modern equipment now comes equipped with electric engine hour meters which run while the engine is operating. If adequate arrangements can be made for the daily reading of the electric meters, then this is a good method of collecting daily operating hours. For units equipped with a mechanically driven hour meter, serious consideration should be given to service scheduling by clock or time-of-day hours. The reason for this is that an idling machine, or one in low throttle operation, equipped with a mechanical meter, may register only a couple tenths of an hour in 1 true operating hr. On the other hand, the electric meter will always advance at the same rate regardless of engine speed.

For every hour of actual use, the degradation of the engine oil and some components is generally greater than that of an engine operating at full throttle for an hour, especially in the areas of diesel fuel and sulfur contamination. Therefore, service scheduling by electric hour meter or actual operating hr is probably the most consistent basis, as long as the procedure is uniform throughout the fleet.

The responsibility of organizing the maintenance schedule lies with the Planner, who should work closely with the shop foreman. Multi-shift operations can complicate this slightly as backshift foremen initially may resent having their work schedule completely laid out for them. However, one of the goals of the schedule is to unite efforts on all repair jobs rather than on a series of individually prioritized projects. Thus the backshift foremen must be convinced of the importance of this asset and the need to use it.

In preparing the maintenance schedule, the Planner must first list all present and upcoming repair jobs and their current status. Each repair job has a priority number assigned to it so that in the event of substitution or temporary reduction of personnel, the foreman on duty knows which job is the most critical. The Planner then must determine the required manpower for each job and follow that with a manpower resource leveling effort according to job priority until all resources have been properly utilized. This completes the schedule for the oncoming shift(s).

As the scheduled shift nears its end, the Foreman must take the maintenance schedule and update the status of each job listed and the manhours expended. Also any changes or emergency field repairs should be noted and the manhours expended on these jobs recorded. Following shifts can then readily understand the status of each job. In addition, a permanent work record is maintained, one benefit of which is the accountability of repair jobs.

Every PM program needs some sort of medium to inform production personnel of units coming up for service; therefore the PM schedule. Every Friday the Planner prepares a service schedule for the upcoming week, listing the time and day each unit is due for service and the time it is to be completed. This list is distributed to the quarry superintendent or manager and assistant, the Foreman, any management personnel with mobile equipment under their direct supervision, and the PM file. The purpose of the weekly service forecast schedule is to give production personnel more than 24 hr notice of units due for PM service so that they can plan their own operations accordingly.

Every day by 1:00 p.m. the Planner supplements the weekly schedule with an updated daily service schedule for the next day. Because the operating hours of each unit can differ drastically from day to day, each unit's priority in the service schedule can change quickly, necessitating the need for the daily service schedule. The distribution and content of this schedule remain the same as the weekly schedule except that it is routed daily.





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Tabulating the daily hours for each unit and then obtaining each unit's service priority can be a vast amount of work on so regular a basis, even for a relatively small fleet of forty units. That work can be greatly simplified with the help of a computer.

**Equipment Operating Data.**—To obtain information on unit availability, utilization, and productivity, daily operating data are necessary. Operating hours, down hours, delay hours, manhours, and service hours are the basic input parameters. The operating hours, delay hours, and manhours are obtained from the production supervisor through a daily reporting sheet. The service hours come from shop reports of actual servicing time, and the down time is calculated from a combination of the production supervisor's daily report and the shop mechanic's report. In the event of any discrepancy, it is the Planner's duty to contact the production supervisor and determine a compromise figure, though this is not a common occurrence if other communication is effective.

Unit availability must be defined before it can be computed, and the definitions must be the same at all locations. Twenty-four hr availability and on-shift availability are probably the most common ways to refer to unit availability. Twenty-four hr availability, expressed as a percentage, would be the time a unit was available to operate over a 24 hr day, seven days a week. On-shift availability, on the other hand, is the percentage of time a unit was available to operate out of the time that it was scheduled to operate.

It should be remembered that when using on-shift availability, the unscheduled shifts can be used as free maintenance time. As long as the units compared are scheduled to operate the same number of shifts per day and a maintenance crew is available on any unscheduled shifts, the units can be contrasted with reasonable confidence. But if any of those parameters are different, no such comparison is valid between different sites. Company management must recognize these differences when viewing equipment statistics of different locations.

Twenty-four hr availability allows no time for free maintenance and, when viewed with utilization, actually provides more accurate accounting of the unit's overall condition. The utilization should be expressed as the amount of time a unit was worked when it was available, preferably using a 24 hr availability basis.

Another useful management tool is the operating ratio. This ratio is the number of downtime hours per operating hour, and it has been frequently found to provide additional clarification to any analysis of a machine's overall condition. Though both the operating ratio and on-shift availability use operating time, they are not directly related.

Useful to every operation is the maintenance history of a machine. It can speed and support credit and warranty claims, identify recurring problems and weak points, and determine overall machine condition among other things. Data which are recorded with the daily input include an explanation for the downtime, the code for any component or assembly replaced, a serial number if applicable, the supplier or rebuilder, a code for the reason of failure, and the maintenance manhours incurred. This information is stored in the unit's history file until needed. The sources of this input data are the mechanic's tickets and the shop office.

**Output.**—The reason for any data input at all is the output of the detailed unit history experience, with the different reports sorted and generated to aid management decision-making. A daily PM update and a 50 hr PM outlook, unit histories, monthly operating statistics, individual component analysis, and shop statistics are just a sampling of potential reports which can be derived from the myriad of stored information. This is available for the total fleet, by equipment type, or for individual units.

After the input of the previous day's data, an updated PM service schedule is produced. It indicates the unit's closest to and above the recommended service interval and the type of service for which they are due. The units appear in a column with those having the most hours since the last service at the top and those having the least at the bottom, Table 3. This allows the System Planner to see at a glance which units are nearest to requiring PM service as they shuffle amongst each other. Part of the daily output is a recap of the data entries for that day so that they may be verified. Computerized daily PM scheduling has been found to be invaluable for effective fleet management.

Another important reason for the development of this particular structure of computerized PM System was to assist in the recording and analysis of unit component history. Previous records were available and very comprehensive, but they were manual records and contained in many books representing 3-1/2 yr of experience for fifty units. The sheer bulk of the records prevented and discouraged their use.

The use of the computer can speed the process of obtaining a unit history and the current hours on each component as well as the number of hours any previously installed components lasted before replacement or failure (Table 4). Ready information like this can provide management with strong and weak points of various models or recurring problems with a manufacturer's or rebuilder's component. Moreover, assistance can be received in the annual budgeting process for estimating what types of major repair will be necessary in the upcoming year. Information can also be graphed on a monthly basis with trends noted.

Component analysis depends on much the same information. With

**TABLE 3.—Daily Service Update Sample**

| Service Status Summary Heavy Equipment | | |
|---|---|---|
| Unit number (1) | Hours since last service (2) | Service due (3) |
| 907 | 110 | #4 |
| 280 | 103 | #2 |
| 400 | 101 | #7 |
| 601 | 87 | |
| 504 | 72 | |
| 402 | 60 | Etc. |
| 712 | 48 | |
| 381 | 21 | |
| 905 | 8 | |
| 406 | 0 | |





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**TABLE 4.—Unit History Report Sample**

| SPECIAL REQUESTS—HISTORY RECORD | | | | | |
|---|---|---|---|---|---|
| Machine #908 CAT D-9 New in 1974 S/N 66A1438<br>Total Hours in Service: 24,909 | | | | | |
| Date (1) | Work description (2) | Part code (3) | Serial number (4) | Part life when replaced (5) | Hours since installed (6) |
| 7/21/78 | Transmission | 422 | 664208 | 814 | 24,859 |
| | Converter rebuild | 435 | | 5,418 | |
| 7/25/78 | Left final drive | 215 | | 6,261 | |
| | Right final drive | 216 | | 6,261 | |
| | Rails and roller frames | 240 | | 2,420 | |
| 8/18/79 | Rails and roller frames | 240 | | 3,145 | |
| 8/31/79 | Bevel gear | 218 | | 5,730 | |
| | Bevel gear bearings | 219 | | 5,730 | |
| | Brake bands, left | 250 | | 9,815 | |
| | Brake bands, right | 251 | | 9,815 | |
| | Brake drums, left | 252 | | 9,815 | |
| | Brake drums, right | 253 | | 9,815 | 12,736 |
| 11/7/79 | Engine D-353 E 410 HP D-9-G | 17 | 12144986 | 5,642 | |
| | Converter rebuild | 135 | | 5,642 | |

one request for a particular component, a 410 hp Caterpiller D353 engine for instance, a history of all such engines on record can be obtained and reviewed. This listing includes the date and unit in which it was installed, the hours at failure or replacement or the hours currently on the engine if it is still in the machine, the engine serial number, the rebuilder, the failure code, and any special notations. Another report provides information on such parameters as 24 hr availability, on-shift availability, utilization, and the operating ratio for each unit as monthly and year-to-date values (Table 5).

**TABLE 5.—Monthly Operating Statistics Report Sample**

| PERFORMANCE REPORT | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| HAUL TRUCKS FOR MONTH OF 7/82 | | | | | | | | | | |
| Truck number (1) | On Shift Availability, as a Percentage MTD (2) | On Shift Availability, as a Percentage YTD (2) | 24-Hour Availability, as a Percentage MTD (3) | 24-Hour Availability, as a Percentage YTD (3) | 24-Hour Utilization, as a Percentage MTD (4) | 24-Hour Utilization, as a Percentage YTD (4) | Operator Ratio, as a Percentage MTD (5) | Operator Ratio, as a Percentage YTD (5) | Work Hours MTD (6) | Work Hours YTD (6) |
| 1 | 97.9 | 94.6 | 98.8 | 94.9 | 45.7 | 45.7 | 2.6 | 11.8 | 336.2 | 2,207 |
| 10 | 77.2 | 76.5 | 83.5 | 76.4 | 41.9 | 45.5 | 47.6 | 66.7 | 260.2 | 1,766 |
| 11 | 86.3 | 82.2 | 89.5 | 83.1 | 37.2 | 36.8 | 31.2 | 55.6 | 248.1 | 1,554 |
| 12 | 100 | 99.3 | 100 | 99.7 | 16.1 | 8.3 | 0.0 | 3.3 | 120.0 | 422.5 |
| 13 | 75.5 | 85.5 | 76.7 | 86.3 | 34.0 | 35.8 | 90.1 | 43.5 | 184.0 | 1,574 |
| 14 | 75.5 | 91.0 | 75.7 | 81.0 | 33.8 | 36.4 | 90.1 | 27.0 | 190.1 | 1,687 |
| Fleet totals | 87.0 | 83.2 | 89.1 | 83.7 | 37.5 | 39.6 | 32.2 | 50.0 | | |

**Identifying and Tracking Repairs.**—A comprehensive equipment maintenance system should not only include a variety of reporting sorts and formats for PM work, but also for major repairs. As equipment proceeds through the PM line, many problems and potential problems are discovered for which there may not be sufficient time for immediate repair. If the PM Foreman determines that a unit with a newly discovered deficiency cannot be repaired on the PM line within the allotted time yet can still be operated safely with tolerable risk to personnel or the machinery itself, it will be. The mechanics simply note the problem on their checklist and continue their regularly scheduled tasks.

The PM Foreman, after seeing the service completed and signing the checklist, draws the Planner's attention to the notes and problems. The Planner then posts these deficiencies on a backlog board in a space reserved for that particular unit and signs off the checklist. The Planner makes out a work order on the job and files it in a shop work order file. This backlog work order system is not a mandatory facet of the entire System, but it can be extremely beneficial and useful. Any standard shop work order format with duplicate copies could be utilized to outline the shop job in detail, and in fact is something which can be developed after the rest of the System is functioning. This may be the preferred development sequence because the PM System has many other different procedures to which to conform as it is initiated.

The backlog slip which the Planner makes up for the backlog board contains the unit number, a work order number if used, a job priority number, a brief description of the deficiency, an estimate of the manpower and manhours required, and the date the problem was recorded. The job priority number is used to note the seriousness of a problem. In this System, it is expressed as a number from 1–5 with number 1 being the most critical situation. If a problem deserves immediate attention, the shop Foreman has the authority to shut down that piece of equipment for repair.

The backlog board, with a separate listing for each individual unit, can then be utilized to analyze a machine's condition. If a unit gets a number of backlog slips, say six or more, consideration is given to shutting the machine down to reduce the backlog. When a unit comes into the shop for major repair work, an effort is made to reduce this backlog of nagging problems. This procedure aids communication and spurs a camaraderie between shifts rather than the discord that is common in multishift operations. The backlog board system has been found to be one of the most useful and versatile tools of the entire PM program.

**PM System Results.**—Current observations show daily field service calls are down by an average of over 50%, especially with regard to small repairs. The appearance of all units has improved noticeably since they are cleaner as a fleet, and in the first five months more than twenty units have been painted. The backlog work peaked some time ago, and the number of backlog items are now slowly decreasing. The original increase in this workload can be attributed to the fact that the presence of a formal repair identification system uncovered more necessary repair work than was recognized in the absence of this formal System. Eventually a medium will be reached whereby the number of items going on the board is equal to the number coming off. It is probable that without

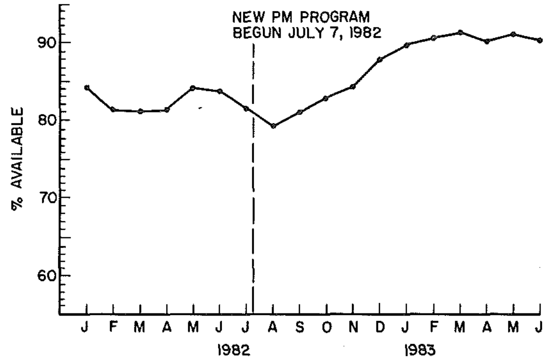


FIG. 3.—Overall Monthly Fleet Availability

the assembly line PM System equipment downtime and repair costs would have continued to rise. Fig. 3 shows the dramatic improvement that this PM System has had on overall equipment availability since its implementation in July 1982. It should also be noted that recent general economic conditions have caused the company to schedule an unusual amount of overtime work which, in turn, has distorted these availability statistics in a way that is even more supportive of the Program.

The initial reductions in the rates of machine availability are attributable to the recognition of previously unnoticed repair (backlog) work and the substantial effort to reduce the amount of such pending work. Less easily measurable is the effect the System has had on worker morale. A sense of responsibility and accomplishment has set in for many of the workers, and absenteeism and turnover rates appear to have declined significantly.

## Future System Enhancements

Two major System enhancements are planned once more experience is gained with the present control structure at additional sites. The first plan is to design an enlarged repair work module of the PM System so that during downtime for one type of repair, other major, crucial work can be identified and performed at the same time. That is, given that a machine is down for a transmission overhaul, the next phase on the PM System development will be to design and implement a subsystem which will provide a decision-maker with enough information to determine whether to change a driveshaft on the basis of the mean expected failure time for the driveshaft.

Such a Preventive Repair component of the overall PM System could be predicated on one of two basis. The first would be strictly time-based. In other words, given that a machine will be inoperable for a set amount of time for repair to one component, what other components should be examined and perhaps repaired given that length of time and the mean failure rates of these other components. These other components may be totally unrelated to the failed component which has brought the machine into the shop in the first place.

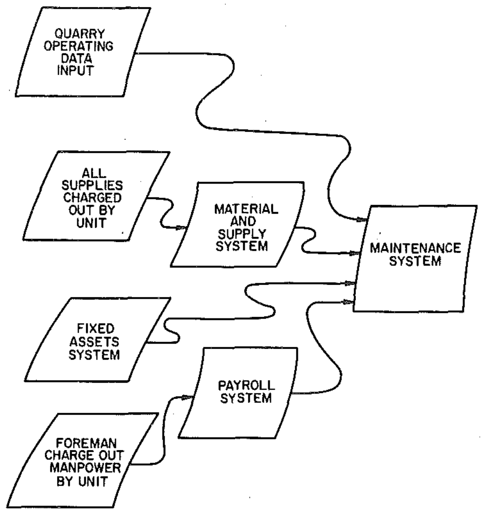


**FIG. 4.—Ultimate Unit Costing System Structures**

The second basis on which to predicate such a "look ahead" system would be the "repair path" concept. An alert system of this fashion would inform the decision-maker of equipment components along the path of the original failed component which might be ready for repair. It would seem logical that this concept of a "repair path" is more a subset of time based Preventive Repair than vice-versa, and this will probably be the first direction pursued.

The other planned major enhancement of the PM System is the development of a complete, integrated unit cost control system for equipment operation. This system would link operating costs, labor expenses, fixed assets expenditures, and PM costs to form a total unit cost reporting system, Fig. 4. A considerable amount of work lies ahead before such an integrated system would ever be available, but the modules or subsystems developed to date (payroll, fixed assets) have, by and large, been structured to accommodate these future unification efforts.

## Conclusions

The benefits and reasons for using a well-defined Preventive Maintenance program have been found to: (1) Reduce unscheduled equipment downtime; (2) increase on-shift and overall equipment availability; (3) increase shop and mechanic efficiency and quality; (4) pinpoint machine deficiencies and initiate improvement; (5) facilitate warranty requests from a manufacturer or rebuilder; (6) aid new equipment selection and specification; and (7) improve predictability of inventory demand requirements.

The requirements of a well-defined PM program which can provide these improvements are: (1) Define and document preventive lubrication and mechanical work intervals and checkpoints; (2) periodic inspections





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and adjustment; (3) regular equipment appearance maintenance; (4) quality control and guidance in the preventive maintenance tasks; (5) uniform and reliable source of operation hours; (6) comprehensive maintenance and repair history record; (7) capable people to operate the System in a reasonable, sometimes flexible, way; and (8) accounting of each machine's known deficiencies.

The design of this PM System was a formidable task. However, the implementation was even more demanding as it was met with skepticism by workers who thought the System was too structured and fast paced to work.

The *key* ingredient in the implementation phase was the commitment of executive management in insisting that: (1) Production personnel work with the System designers to make it function smoothly; and (2) preventive maintenance decisions take precedence over short-term production decisions. Because of that top-down dedication, a highly efficient System is in place, workers and equipment are more productive than ever, and corporate profits have been substantially improved.

## Appendix I.—Sample Lubrication List

HOUGH 400 FRONT END LOADER, RUBBER TIRED DOZER Name: ______

UNIT # ____________ Date: ____________
HOURMETER ____________
INDICATE: _____Service Done, _____Adjustment made,
_____Repairs Needed

STATION #2 LUBRICATION SERVICE

| | OK | ADJUSTMENTS MADE—PROBLEMS FOUND |
|---|---|---|
| I. GREASE POINTS: Grease the following points. Replace any missing fittings. Wipe the fitting clean before greasing. Report those points that won't take grease. | | |
| A. Grease boom arms, tilt arms, cylinder anchors and pivots, and linkage (18). On 400 blade hoist cylinder ends (2). | ☐ | |
| B. Grease front driveline U-joints and slip joints (3). | ☐ | |
| C. Grease steering cylinder anchor ends (2). | ☐ | |
| D. Grease upper and lower center hinge pins (4). | ☐ | |
| E. Grease intermediate driveline, U-Joints, and slip joint (3). | ☐ | |
| F. Grease steering valve actuators (2). | ☐ | |

| | | |
|---|---|---|
| G. Grease steering cylinder pivot ends (2). | ☐ | ________ |
| H. Grease cradle pin manifold. | ☐ | ________ |

## Appendix II.—Reference


1. Douglas, James, *Construction Equipment Policy*, McGraw-Hill, New York, N.Y., 1975.