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Introduction to World Class Machine Maintenance Methods

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Introduction to World Class Machine Maintenance Methods

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INTRODUCTION

Why Study Factory Machine Maintenance?

A world of ever-increasing competition dictates that manufacturers be able to produce their goods reliably, consistently, and perpetually. Many factory managers find themselves faced with requirements for 24-7 operations to keep pace with customer demand. In such aggressive environments, it is imperative that manufacturing equipment be available, when called upon, to function as it was designed to for as long as it takes to get the job done.

Much has been written in recent years regarding world-class improvements in manufacturing methodologies. Record breaking demand for consumer goods has driven producers of such goods to implement aggressive changes in the way they do business. However, in their haste to effect positive changes in manufacturing disciplines, many managers have overlooked the importance of maintaining the equipment used to manufacture their products. Across many industries machine maintenance is still viewed as a necessary evil, almost a parasite, bleeding off valuable capital and expense dollars with nothing more to show for the investment than a sustained status quo in the production facilities. Under these conditions, maintenance organizations are relegated to the menial task of repairing equipment when it breaks. Simple preventive measures such as lubricating stress points or replacing worn parts are often viewed as unnecessary expenditures as long as a production asset is still functioning.

It is in this context that a study of maintenance becomes most valuable. In order for a company to achieve true World-Class performance, each of its processes (including maintenance) must be scrutinized, finely tuned, and equipped for success. This course focuses on the types of maintenance (specifically machine maintenance) practices that are available and how they can fit into a factory's overall operations plan to make it as successful as it can be. Just as innovations in manufacturing theory have led to increases in production speed, reductions in on-hand inventories, and improved customer satisfaction; innovations in maintenance operations can lead to increased machine uptime, reduced repair parts inventories, and improved production floor customer satisfaction.

This course begins with a quick review of the evolution of modern manufacturing theory and the requirements it places on manufacturing equipment. It then examines different maintenance management approaches used to address those requirements. Strengths and weaknesses of the different approaches will be presented and recommendations made regarding desired attributes to attain best in class maintenance management in support of World Class manufacturing excellence.

Maintenance Methods to be Studied

The first maintenance style to be considered is ***Corrective Maintenance*** referring to the "fix-it" approach. In this scenario, a factory asset is operated until it breaks, at which time the maintenance organization is called upon to repair it. After repair, the maintenance organization has no further contact with the equipment until such time as it malfunctions again. The goal of this type of maintenance is to repair the broken equipment and allow manufacturing operations to continue – nothing more.

A review of ***Preventive Maintenance*** comes next. This method includes repairing malfunctioning equipment as does Corrective Maintenance, but goes further to involve efforts to prevent equipment malfunctions. In this scenario, factory assets are monitored for proper operation within defined parameters and adjusted, tuned, lubricated, etc. to maintain proper operating characteristics. The goal with Preventive Maintenance is to keep equipment running in the best possible condition to prevent production-stopping malfunctions.

The last maintenance method to be considered is ***Predictive Maintenance***. Activities in this category transcend traditional methods of maintenance by actually predicting when equipment failure is likely to occur and taking steps to prevent it. Instrumentation is utilized to measure vibration, temperature, lubrication characteristics, etc. while a machine is operating. Careful records of equipment operating characteristics are then collected and examined for signs of deterioration. The goal with Predictive Maintenance is to anticipate equipment failure far enough in advance to schedule maintenance activities when they will have the least impact on production schedules and yet still allow for equipment repairs before breakdowns occur.

Scope of the Study

The factory maintenance discipline covers a vast amount of territory and it is beyond the scope of this course to address it in its entirety. Therefore this study will be limited to the realm of machine maintenance. Machine maintenance is concerned only with maintaining the operational integrity of assets used to manufacture a company's product. For the purpose of this study, product will be defined as a company's end-item, sellable product, or sub-assemblies that are incorporated into the end-item product. Areas of maintenance concerned with the physical plant (building and grounds maintenance, plumbing, HVAC, electrical wiring, etc.), plant security, vehicle maintenance, etc. are excluded from this study. It should be noted, however, that these areas are only excluded to make the study more manageable. The principles presented herein may be adapted to each of these areas as well.

Glossary

Following is a list of terms used throughout the course as defined in a maintenance management context.

Applications Parts List (APL): The APL is a list of parts required to perform a specific maintenance activity. This list is generally attached to a standard maintenance work order and allows known required parts to be pulled from inventory and available for use when the task is performed.

Asset: A term used in the maintenance context to refer to any item of equipment to be maintained.

Breakdown: Refers to the condition of an asset when it is unable to function as it was designed to.

Computerized Maintenance Management System (CMMS): This is a computerized system developed for organizing, documenting, and scheduling maintenance operations.

Corrective Maintenance: Maintenance activities focused solely on repairing equipment after a breakdown has occurred.

Data: Raw, untouched facts about processes, machines, or organizations. More often than not, data by itself has little meaning without further processing.

Downtime: This is the time that a manufacturing asset is not available for production use for any reason. Examples of downtime are an asset that is broken, an asset that is being modified or upgraded by Engineering, an asset that has been determined to pose a safety threat and is locked out, or an asset that is having periodic maintenance or calibration procedures performed on it.

Information: Facts (data) that have been distilled and formatted into a usable form.

Just-in-Time Manufacturing: A manufacturing philosophy focused on providing a work center with its required resources (manpower, material, equipment, etc.) when it needs them and not before.

Lean Manufacturing: A manufacturing philosophy that focuses on identifying waste in every manufacturing process and systematically removing that waste. A major focus is made on removing "wait" times associated with production and creating an environment where all process time is actual "hands on" time.

Maintenance: Refers to any activities performed on an asset to ensure that the asset continues to perform as intended or to repair the asset after a breakdown.

Predictive Maintenance: Maintenance activities that focus on continuously monitoring machine performance and predicting failures so that equipment may be serviced before it breaks.

Preventive Maintenance: Maintenance activities that focus on performing periodic tasks known to prolong equipment performance and life. These activities are typically planned for times that will present the least impact on production schedules.

Technician: Term used throughout this document to refer to a maintenance employee who performs any of the maintenance tasks describe herein. For purposes of this study, technician can be considered synonymous with tradesperson, craftsperson, or mechanic.

Theory of Constraints (TOC): An operation philosophy that focuses on identifying and eliminating the bottlenecks in a process. The bottlenecks are termed the constraints in a production system. The theory holds that removing the worst constraint in the system will cause another constraint to surface as the worst. Repeating the process continually improves product flow in a factory.

Total Quality Management (TQM): A methodology of quality improvement that stresses the need to continuously improve every aspect of a business process in order to effect greater customer satisfaction.

Uptime: This is a term used to describe the amount of time a production asset is actually operational and available for production use. The reader must bear in mind that this includes time when an asset is available for use but not actually in use by the operating department.

Work Order: This is the primary document used by maintenance departments to manage maintenance tasks. This document should include at a minimum a description of the work to be performed, a list of parts and materials required to perform the work, specific procedures to be performed, special skills required, and tools required. It may also include the priority, time expectations for job completion, and historical failure information.

World-Class Manufacturing: This is a term generally used to describe the best possible manufacturing techniques when a company compares itself to any manufacturing industry in the world.

HISTORICAL BACKGROUND

To understand the importance of machine maintenance in American industry, one must understand the manufacturing environment and the requirements it places on properly maintained equipment for its survival. The modern American factory environment owes much to techniques borrowed from post-World War II Japanese industry. For many years these techniques have been studied, dissected, and enhanced by numerous management specialists bent on delivering a pathway to World Class manufacturing excellence. Current literature abounds with manufacturing methodologies. A growing American trade deficit beginning in the latter part of the 20th century spawned a meticulous examination of what America's worldwide competitors were doing better and faster than American industries themselves. Japanese manufacturing centers became the focus of a steady stream of investigations to unlock the keys to their success. As the results of these studies became available, American manufacturers began to emulate what they considered to be the best of the Japanese techniques in an effort to regain lost market share.

American Market Share Lost

In the years following World War II, American industry entered a time of unprecedented prosperity. A nation driven by the promise of a secure future and a strong economy provided a seemingly unending demand for consumer goods. If a company could produce an item, they could sell it, almost without exception. Quantity was the driving force in manufacturing planning in an attempt to keep up with demand. Quality of workmanship was measured, as it had always been, but everyone knew (or at least thought they knew) that American quality was superior to anyone else's. As time went by, America's gluttony for consumer goods began to wane and consumers sought better quality for their hard-earned dollars. Having grown accustomed to the demand for ***quantity*** of goods, American industries were slow to respond to consumers' new demand for ***quality***. The result . . . foreign competitors began capturing market share.

Japanese Market Share Found

In contrast to the vast wealth of land and natural resources available to American industry, Japanese industry has long accepted its limitations of both space to expand and natural resources available for production. To compensate for these limitations, Japanese manufacturers were quick to incorporate ways to make their facilities more efficient. By maximizing production capabilities, they found they could effectively compete with American rivals many times larger than themselves. Recycling efforts allowed the re-use of valuable resources that would otherwise be wasted and replaced at great expense. Employee cross-training programs were instituted to allow the greatest flexibility in the work force, and individual employees were given the responsibility of inspecting their own work. This meant quality defects could be found and corrected before a product left the offending work center. Employees were even granted the authority to stop a production line if a problem could not be corrected in real time.

American Management Response

In response to eroding market share, American management scientists began to study Japanese innovations in production and management policies. At first American management teams simply began to copy things like Japanese Quality Circles in an attempt to emulate the success of their foreign competitors. Slogans appeared in advertising touting each company's commitment to quality first. But when the quick successes that were anticipated failed to materialize, American industry leaders realized they would have to dig deeper into the Japanese success story. The goal changed from looking for a magic cure to identifying what processes the Japanese were doing right that could be incorporated into American manufacturing culture.

One of the most important Japanese innovations to be "imported" to American industry was the JIT (just-in-time) philosophy of production. JIT calls for breaking down product manufacturing into distinct processes. Once the processes and their respective inputs are identified, JIT stresses an environment where the inputs to a process arrive just in time to be used in that process. Those inputs are then "processed" and become outputs to be fed to the next process, but only when the next process is ready for them. The success of a JIT factory requires meticulous planning to ensure that materials are in place when needed, that machines are in place and functioning, and that the right people (properly trained and equipped) are available exactly when needed. For small-scale operations, planning departments were able to manage the JIT process. For larger organizations, the level of effort required to manage a JIT operation was formidable and the sheer number of personnel involved tended to erode return on investment.

Fortunately computerized MRP (material requirements planning) systems revolutionized the planning function for procuring materials. Tedious calculations to determine how many production materials to purchase, and when, could be accomplished by MRP systems with far more speed and accuracy than had been possible before. The next generation automated planning tool known as MRPII (manufacturing resource planning) was able not only to calculate how much material to order and when; but could also be used to plan the activities of all manufacturing resources (including machines and people). Armed with these tools American factory staffs were able to incorporate the JIT philosophy and move their businesses closer to World-Class performance.

Traditional manufacturing philosophy in this country called for processing product in large batches. The setup time required for changing over from one product to another made running large batches seem like the best way to achieve economical manufacturing lot sizes. The Japanese, however, found that running smaller lot sizes decreased the risks of generating large quantities of defective product before the defects were found and corrected. This led to more frequent machine setups and more opportunity for lost time during setups. It also created a greater risk of equipment being damaged during changeover. Machine maintenance organizations were challenged to discover innovative ways to support faster and more reliable machine changeovers.

Incorporation of JIT, although certainly a step in the right direction, was not a panacea for American production woes. Many industry analysts and consultants continued to make improvements using the Theory of Constraints (TOC) concepts developed by Eliyahu Goldratt. TOC is discussed at length in The Goal co-authored by Goldratt and Jeff Cox and in a second book, The Race, co-authored by Goldratt and Robert E. Fox. The Goal presents the TOC concepts in the form of a fiction novel where the characters transform a struggling factory on the brink of being shut down into a thriving business unit by incorporating the common sense approaches of TOC. Basically, TOC concepts call for the identification of factory "bottlenecks" defined as "any resource whose capacity is equal to or less than the demand placed upon it." (Goldratt & Cox, 1986a, p. 138). Goldratt (1986a) stresses that time lost at a bottleneck is time lost for the entire manufacturing system while time lost at a non-bottleneck resource is a mirage. To clarify, time lost at a bottleneck results in time lost at every operation that follows the bottleneck as they wait for its output. Conversely, time lost at non-bottleneck resources can be made up during the wait times caused by the system bottlenecks. TOC embraces the notion of running smaller lot sizes for improved quality and less WIP inventory. The drawbacks of extra setup times on non-bottlenecks are viewed as perfectly acceptable because they only use time that would otherwise be spent waiting on the bottlenecks. For the maintenance organization this also means that preventive maintenance activities can be performed on non-bottlenecks without adversely affecting shipping schedules as long as they don't exceed the wait time inflicted on the system by the bottlenecks. On the negative side, however, bottleneck resources must be maintained in tip-top condition to prevent lost production time for the entire production line.

A third major manufacturing philosophy to be incorporated into American factories is referred to as Lean Manufacturing. Lean Manufacturing stresses the need to identify areas of waste in a process. Special focus is placed on lost (wasted) time spent performing tasks that do not add value to a company's sellable product or service. Emphasis is placed on identifying exactly what a customer expects to receive for dollars paid. Although necessary for producing an end-item for sale; things like material handling, the time material waits in queue for its next operation, and cleaning or lubricating machinery are not items a customer wishes to pay for. Therefore, Lean Manufacturing concepts push an organization to trim the waste wherever possible. Material handling is reduced by moving work cells closer to one another and providing storage for inventory at its point of use. Reduction of assembly line wait time is achieved by balancing sub-processes such that subassemblies required for a given product arrive at the same time for processing. These basic examples illustrate some of the creative ideas that assembly departments can use to support Lean Manufacturing. The maintenance organization must be equally effective in supporting the manufacturing environment by removing unnecessary delays in equipment repairs. Machine maintenance time is "cloaked" whenever possible by having preventive maintenance tasks performed during machine warm-up or changeover cycles. In many instances, only emergency breakdown maintenance need interrupt normal production activities.

The Ultimate Goal of American Industry

It has been said that "the goal of a manufacturing company is one and only one -- to make money in the present as well as in the future." (Goldratt, 1986b, p.18) As America's manufacturing companies have entered the 21st century, they have continued on the road of continuous improvement discussed briefly above. Total Quality Management (TQM) stresses the concept of improving every aspect of an organization's processes. Among those items promoted by TQM are: meeting customer expectations every time, training employees to understand their jobs and to troubleshoot problems that arise in the course of a normal work day, involving workers in the decisions that affect them and empowering them to act on those decisions, creating a teamwork environment where people pool their respective talents and abilities to create innovative problem solutions, measuring performance of individuals and of the team as a whole, and above all else continuously improving the organization. (Harrington, 1999.)

The Role of the Modern Maintenance Organization

If the goal of a business is to make money now and in the future as asserted by Goldratt (1986b), then certainly every organization within the business should serve to promote that goal. As manufacturing processes have evolved to incorporate the best practices of international competitors, so machine maintenance roles have begun their own evolution to better serve the needs of factory equipment users. Maintenance managers have begun to view their roles as more than fix-it men. The outmoded methodology of maintenance waiting for a machine to break and then repairing it has no place in a World-Class company. Today's maintenance departments must team with production departments to ensure that machinery is kept running when it is needed. Following is a description of the different types of machine maintenance and what each has to offer production operations.

MACHINE MAINTENANCE TOOLS

Corrective Maintenance

Corrective Maintenance (CM) refers to the traditional role of the maintenance department. It is also known as breakdown maintenance, or fix-it maintenance. In this mode, maintenance departments respond to calls to repair non-functioning production assets. It must be noted that in a pure CM environment, maintenance activities are neither planned nor can they be anticipated with any degree of certainty. This type of maintenance activity can be quite costly. Considering that machines which are run until breakdown occurs often require extensive repairs up to and including complete overhauls, the labor costs alone can be staggering. Often maintenance workers in a pure CM environment have nothing to do until a breakdown occurs. Maintaining a large enough staff to cover breakdowns but who do nothing of value between breakdowns is far from cost effective and serves to degrade the image of the maintenance department among the rest of the factory population.

Examples of breakdown maintenance are numerous: a broken motor drive belt, a motor bearing that has run dry and seized up, a power cord with frayed wiring, an electrical instrument with a dead battery, an inspection lamp with a burned out bulb, etc. CM in its purest form makes no provision for regular equipment inspections to detect malfunctions before they become showstoppers. Production departments in a factory utilizing CM view such inspections as a waste of time as long as production equipment is functioning. They typically do not want anyone "tinkering" with a machine that is working and certainly will not authorize a production line to be shut down for an "unnecessary" inspection. In this environment the adage "*If it ain't broke . . . don't fix it.*" is alive and well.

It is important to note, however, that in the CM environment the production departments are not the only ones who deter maintenance inspections. Often maintenance managers themselves feel they do not have the manpower to spare for periodic inspections because they are overwhelmed with repair work. In a seemingly endless cycle regular inspections that could prevent breakdowns are not performed because maintenance crews are too busy repairing breakdowns that occurred because regular inspections were not carried out.

It should be evident to even the casual observer that CM is not the best approach to machine maintenance for the modern manufacturing environment. Following are more proactive maintenance methods capable of serving the main goal of manufacturing.

Preventive Maintenance

The next step in the evolution of the machine maintenance function is called Preventive Maintenance (PM). Sometimes referred to as planned maintenance, periodic maintenance, or even scheduled maintenance; the science of PM moves the maintenance department out of a strictly *"fix-it-when-it-breaks"* mode into the realm of *"keep-it-from-breaking-in-the-first-place"* mode. In a PM environment, factory equipment is regularly monitored to ensure that it is functioning properly. At the first sign of trouble, a maintenance technician can be notified to take corrective action before the machine's operation deteriorates to the point of disrupting production.

At first PM sounds like simple common sense. After all, who wouldn't want a program of prevention to keep machines from failing during critical operations? Problems tend to arise, however, whenever a company with a traditional CM operating philosophy begins the transition to a PM philosophy. Time must be set aside on a regular basis for examining each machine. This time, although negligible after the program is established, can be extensive in the early stages of PM and is often a source of contention between production departments and maintenance departments. A further source of contention is the fact that PM procedures often go beyond simple examination of equipment to include replacing parts and may even call for rebuilding or overhauling an asset at stated intervals regardless of the apparent operating condition of the asset at the time. To better understand the reluctance of production departments to accept PM let's take a closer look at what is involved in setting up a PM program.

Identifying equipment to be included. The first step in establishing a PM program is to identify which equipment will be included. As mentioned earlier, PM seeks to regularly examine an asset's operating characteristics and take preventive action before failures occur. However, not all equipment is equal in its importance to production. Decisions must be made early in the planning stages of PM regarding which machines will provide the best return on investment by inclusion in the PM program. For some machines, the cost of a PM program may exceed any gain from the program itself. For others, especially heavily utilized or high value items, the PM activity will quickly pay for itself. It is important for companies to realize that not every production machine must be included in the initial PM program. Some items may be added at a later date and some may never be added at all.

Establishing equipment baseline. Before a PM program can be effective the desired operating characteristics of each machine must be determined. Often assets that have been maintained only by the CM method will be found in various stages of disrepair. Normal wear and tear on machines causes steady deterioration of operating characteristics that may not be noticed until the machine ceases to operate. Fix-it maintenance typically addresses only repairs that are absolutely necessary to bring an asset back online. PM philosophy takes an entirely different approach. Desired performance characteristics of each machine must be determined early in the PM program. In some companies, the desire is to restore equipment to its original condition as defined by the manufacturer's specifications. In others, equipment may have deteriorated to a degree that makes full restoration beyond economical feasibility. In such cases, the maintenance organization in conjunction with the responsible engineering organization must develop its own specifications. Using these specifications, the maintenance organization determines which operating characteristics are important enough to be monitored. Examples include: drive belt wear indicators, engine oil levels, squeaky bearings, drive train vibrations, unfamiliar sounds or smells, current drawn from electrical circuits, unexpected pressure changes, etc. The list of possible items to check is unlimited, but maintenance resources to perform the checks are limited and cost money. For this reason, checkpoints are carefully selected to be representative but not excessive. Some companies, in an effort to reduce the cost burden of their PM programs, elect to train machine operators to perform common PM tasks. This yields at least two benefits. The first, maintenance technicians are freed from performing mundane tasks, allowing them more time for the critical tasks that take better advantage of their expertise. Second, machine operators who have a part in caring for their equipment often take greater pride in the equipment and in their jobs overall.

Once the specifications are defined and documented, a schedule must be established for periodic inspections. Some inspections require that a machine be shut down for a specified period of time. This can be a major source of contention between production and maintenance organizations. It is imperative that all PM inspections be documented both for content and duration to allow production planners to schedule factory workload accordingly. Equally important is the need for maintenance technicians to be punctual and systematic in the performance of PM activities, and courteous enough to notify production (in a timely manner) of any deviations from the PM schedule.

During periodic inspections, technicians must carefully document their findings. By keeping accurate records of equipment operating characteristics, abnormalities may be quickly detected. Defects likely to cause equipment breakdown may be repaired immediately. Less serious defects may be monitored further and repairs deferred until production can better sustain the downtime required for repairing the asset. In either case, data is available from the PM inspections to back up the decision to repair. Capturing this PM data allows the maintenance organization to establish trends and rely less on guesswork to predict imminent equipment failures.

Establishing periodic maintenance tasks. Preventive Maintenance consists of more than just periodic inspections. Certain maintenance activities must be performed at regular intervals in order to maintain optimal operating characteristics. Examples include: sharpening cutters, tightening mounting bolts, cleaning air filters, changing lubricants, replacing bushings, etc. Most equipment manufacturers identify regular maintenance items and suggest the correct intervals. PM programs further document these items and may add to them. Application Parts Lists (APLs) are provided as a part of the documented processes and provide maintenance technicians with a list of parts known to be required when performing the tasks. By providing production departments with documented requirements for PM activities, planners are able to schedule production around the required maintenance. Regularly serviced equipment is able to run within its design parameters leading to fewer breakdowns from wear and tear. Production departments are able to more reliably forecast their production output and maintenance departments spend less time in fix-it mode. Time saved by fewer equipment breakdowns equates to time gained for development of PM activities on equipment not yet included in the program. It cannot be stressed enough that designing a PM program isn't enough in itself. Maintenance departments must follow through with the plan. It is not uncommon for a maintenance organization in the early stages of a PM program, to become so occupied with traditional CM activities that PM work orders are forgotten or even ignored. But unless a large majority of PM tasks are completed on schedule, an organization runs serious risk of slipping back into a CM cycle with extensive equipment downtime due to failures. Appendix A describes two simple methods of ranking PM tasks to ensure that the most important ones are performed first.

Material requirements. At the beginning of PM implementation, equipment must be brought up to the baseline standards defined by engineering. In order to accomplish this effort, equipment must be removed from service for the needed repairs. It is imperative that the repair parts needed are on hand before the equipment is taken out of service to minimize production downtime. Therefore, the maintenance organization must perform a careful examination of each asset to identify the parts required for the baseline effort and see that the parts are procured ahead of time. On hand repairs inventory may be used for this effort provided replacements are ordered to cover critical emergency breakdowns. The maintenance department must maintain the capability to continue Corrective Maintenance activities even in the midst of a PM deployment.

Once a PM system has been established and equipment brought into compliance with the desired operating characteristics, a large part of the PM effort shifts from repairing to maintaining the *status quo*. This takes the form of making adjustments, tightening fasteners, cleaning filters, etc. Some tasks, however, still require installation of new parts to replace worn ones. Spare parts inventory accuracy and adequacy must be reevaluated periodically to ensure the right parts are available at the right time.

In large manufacturing facilities, the location of spare parts becomes an important issue. Technicians often distrust storerooms and prefer to keep a "stash" of spare parts in their toolboxes or work centers. This practice must be discouraged for several reasons. First, spare parts need to be stored in a controlled environment to ensure that their quality is not compromised and to ensure that they are accounted for and can be located when needed. Second, spare parts inventory represents a sizable portion of a maintenance organization's budget. Successful PM programs must maintain a predetermined safety stock in inventory. Individual "stashes" of spare parts have no visibility and will be duplicated in the maintenance storeroom, thus, increasing the amount of operating dollars tied up in inventory costs. Furthermore, parts kept in "stash inventory" provide no visibility to the engineering staff who may at any time specify that a part is no longer acceptable for use. Parts that might otherwise be discarded from inventory may find their way into a production asset and consequently pose a threat to production capacity. The last reason presented for insisting that spare parts be kept in a storeroom is that dependence on a maintenance technician's memory to see that spares are reordered when stock is depleted is a dangerous risk to the business.

In addition to a stipulation that all spare parts be maintained in a secure storeroom environment, the maintenance manager must determine if more than one storeroom is necessary. Travel time between a job site and the maintenance storeroom can be significant, especially in large factories. Maintenance technicians are valuable assets to a production facility and having them spend their time going to and from a storeroom is unquestionably non-value-added effort. One possible solution to this problem is to create satellite storeroom locations throughout a factory to reduce the travel time and distance to retrieve repair parts. A computerized storeroom inventory system provides the best base of operations to track inventory. Attempting to retain control over one storeroom manually is a daunting task; attempting to maintain multiple storerooms (some of which contain the same parts) can be disastrous. Other solutions include providing helpers for maintenance technicians to fetch parts or even having storeroom personnel deliver parts to the technician at the job site.

A final item needs to be mentioned regarding material requirements. Spare parts inventory descriptions must be accurate to eliminate wasted time spent trying to identify parts while a production asset is down. Detailed information including part number, manufacturer, description, use, and equipment used-on is required to make a positive identification of a part. This becomes even more important if storeroom personnel deliver the part to a job site because without having the old part for comparison, an incorrect part can be delivered resulting in greater downtime for a production asset. Technology is currently available to allow technicians to transmit video images of defective parts to stockroom personnel for positive identification.

Personnel requirements. Often managers faced with implementing PM programs fear that periodic maintenance inspections will lead to increased requirements for maintenance staff. In some cases where CM maintenance has resulted in extreme equipment degradation, this may be the case. In all cases, breakdown maintenance will continue to be a problem until the PM program has time to effect change. The added manpower for PM activities does not have to be limited, however, to the maintenance department. Many companies have successfully trained equipment operators to perform PM activities on their own machines. The thinking is that no one is more qualified to recognize abnormal operating characteristics than the person who operates a machine every working day. Including operators in the PM program can be a very effective way to download some of the simpler PM tasks and free up maintenance technicians for areas requiring their skills. Many companies have found too that involving machine operators in PM activities heightens their sense of ownership and responsibility for their machines leading to even fewer breakdowns.

Limitations of preventive maintenance. Perhaps the most obvious limitation to any PM initiative is that even with the best efforts there will still be machine breakdowns. Beyond this limitation, the advantages of implementing a PM program are numerous but not without cost. The effort required for startup can represent a significant portion of a maintenance department's annual budget. Equipment to be included in the PM program must be identified. Each component part that will be replaced as part of the PM program must be identified, cataloged (with detailed information as was discussed earlier), procured, and stored in secure inventory locations until needed. Maintenance technicians must believe they can depend on their storerooms to have the parts they need when they need them to prevent individual stockpiling of spare parts. Initial spare parts inventory to support a PM setup will be large because equipment will have to be baselined and PM spares ordered. It is imperative that a maintenance manager prepare his upper level management for the initial expenditures. It must be noted at this point that the maintenance and engineering departments must be certain that the cost of baselining an asset does not exceed the cost of replacing it.

In order to ensure the success of a PM program, production departments must agree to provide access to their machines for the PM activities. When production deadlines are approaching it is the natural impulse for production department heads to refuse to relinquish machines for PM jobs. The reason is twofold. First, any time that a machine is not being used for production is viewed as lost time that cannot be recovered and second, there is often a fear that if a maintenance technician begins a procedure he may cause a failure that leads to more downtime.

The first concern has been demonstrated by Goldratt's Theory of Constraints to be unfounded for all non-bottleneck assets. Recall Goldratt's (1986a) assertion that time lost at a non-bottleneck asset is simply a mirage to be made up during what would otherwise be time spent waiting for the bottleneck to catch up. Upper management must drive attitudes of manufacturing that support PM requirements (even for bottleneck assets) in order to avoid breakdown time loss in the future. However, the maintenance organization must do its part to prevent unnecessary delays in performing PM tasks. PM tasks should be planned well in advance and technicians should be punctual and come prepared to complete their work in a timely fashion. Attitudes play a vital role in the success of a PM program. Technicians, who understand that the production department is their customer and that their role is to serve that customer's needs, will do much to gain support for the PM philosophy. Technicians who are late for appointed PM tasks, who fail to bring everything that is required to complete the tasks, or who habitually take more than the allotted time can easily ruin any faith in the PM process.

The second concern, that a maintenance technician may create a failure while performing PM duties, is a carryover from the "*if-it-ain't-broke-don't-fix-it*" mentality. Maintenance organizations must pay close attention to detail when performing PM tasks, bearing in mind the primary goal of keeping factory equipment in optimum condition. Communication is a vital tool for PM implementation. If a technician detects a faulty condition that will require additional time to correct, he must inform the production department promptly to avoid bad publicity for taking too long and to give production planners the maximum time to plan work-arounds. If the technician detects a condition that needs to be corrected, but not immediately, he must exercise the self-discipline to postpone the repair until either it can be put off no longer or until the production department can afford the additional downtime. This is not always easy because a dedicated technician's instincts will insist that he repair any defect as soon as it is discovered. The key concept he must remember is that a PM program is intended to drive as much of the maintenance effort as possible to be ***planned*** maintenance instead of ***reactive*** maintenance.

Even the best PM program will never be able to completely eliminate Corrective Maintenance. There will always be emergency breakdowns. Some will be the result of defective parts, some the result of improper machine usage, and some will result from a PM program that missed something it should have caught. It would be unrealistic to assume that any maintenance organization or plan could guarantee no breakdowns, but that should certainly be the goal.

Predictive Maintenance

A third machine maintenance philosophy gaining momentum in modern industry is Predictive Maintenance (PdM) also referred to as condition-based maintenance. While a PM strategy compares a machine's current operating characteristics to a defined baseline standard to determine when maintenance is required; a PdM strategy compares the machine's current operating characteristics to the same operating characteristics at some time in the past. By examining detailed records of an asset's characteristics over time, negative trends emerge to indicate impending failure. The goal is to predict failures far enough in advance to schedule repairs when production departments can best afford the downtime.

Advances in vibration sensor technology have led to instruments capable of monitoring slight imbalances in rotating shaft characteristics. In the past such imbalances, undetectable by human senses, would have gradually eroded bearings or vibrated fasteners loose causing breakdowns and costly repairs. Today, reviewing historical data points for a machine allows a maintenance department to track performance deterioration and predict the actual timeframe when a failure will occur. This information allows repairs to be scheduled well in advance.

Material sampling technology has reached a point where crankcase oil samples may be analyzed for metal content. Traces of a particular bronze alloy in a lubricant, for example, can lead a maintenance technician to the exact shaft bearing that is beginning to wear long before it seizes. The same analysis techniques can be used to determine the useful life of a lubricant before its composition is degraded beyond a desirable level.

Advanced thermal sensors allow machine stress points to be pinpointed before causing failures. Shaft bearings giving off abnormal levels of heat because they have begun to run dry can be detected and replaced before shutting down an asset. Based on this analysis, machines may be redesigned or improved to extend their useful lives.

The strength of a PdM program lies in its ability to predict equipment failures well in advance to allow the greatest possible planning interval. Production departments depend on their equipment being available every day, but especially during times of peak production demand. If equipment defects can be identified months in advance of a failure, then production planners, operations managers, and even marketing staff can be notified of the situation and plan for the downtime associated with repairs. The ability to provide trend analysis of equipment operating characteristics also supports PM efforts to identify equipment areas that should receive the most emphasis in the PM program.

Computerized Maintenance Management Systems

Just as computerized MRP systems revolutionized manufacturing by alleviating the labor intensive calculations required for resource planning, the introduction of computerized maintenance management systems (CMMS) has provided a means to achieve similar results in factory machine maintenance. Use of these systems allows maintenance departments to automate the collection of breakdown calls, print out work orders for breakdown (CM) and planned (PM) jobs, accurately track maintenance storeroom inventories, and collect vast amounts of data from each production asset for analysis. Using CMMS, data that would once have required weeks of effort by numerous individuals to collect and analyze can now be collected at remote terminals located throughout a factory and analyzed in real time. Following is a typical scenario using networked PC terminals dispersed throughout a factory to access a CMMS.

> At 08:00 Machine A ceases to function. The operator notices a foul odor and sees smoke rising from a motor housing. He goes to the nearest terminal designated for maintenance call entry and, based on previous experience with similar failures, enters a maintenance call for an electrician. The CMMS display queries for a unique machine identification number for the asset to be serviced, the location of the machine, and a brief description of the fault. It is understood that this information may be inaccurate regarding the cause, but it gives the maintenance department a starting point for sending out a technician. Once the call is entered, the CMMS generates a work order with a time stamp indicating when the call was placed and sends a text message to the electrician covering the area where Machine A is located. (Note: Lookup tables in the CMMS must be pre-loaded with contact information for the technicians covering the different areas in the factory. The most effective method of notifying technicians, especially in large factories, is by having the CMMS send a text message to the technician found in the lookup table.) When the electrician receives the notice, he is responsible for proceeding to the nearest CMMS terminal to acknowledge receipt of the work order and to retrieve the details of the failure. If equipped with a web-enabled mobile handset, this step can be handled without the need to visit a CMMS terminal. The CMMS electronically time stamps the work order to show when the call was acknowledged and by whom. The electrician then investigates the problem and repairs it in a timely fashion. (NOTE: If the electrician is too busy to answer the call, he may pass it off to an alternate technician or notify his supervisor for additional support. In any event, the production department should be notified promptly if the call cannot be answered within a reasonable time period. The key element to be remembered is the need for accurate and timely communications between the maintenance and production departments.) Following the repair, the electrician will again access the work order via a CMMS terminal to input data describing the action required and any parts required for the repair. After entering the required data, he may close the work order. The CMMS again time stamps the work order to show when it was closed and by whom. It should be noted that in the above scenario, work orders can typically be assigned a priority number based on the type of equipment failure that is being reported. The highest priority rating is generally reserved for safety hazards, which require immediate attention from the maintenance personnel regardless of what they are currently working on.

The actions described above describe a simple repair operation. For more complex operations, the electrician might have to call for a second electrician for backup. In a different scenario, the initial investigation might indicate that the fault is not electrical in nature and requires someone from a different maintenance trade to respond (e.g. machinist, electronic technician, etc.). In either case, he may access the CMMS and pass the call to another individual who will in turn receive a text message identifying the call and the process will begin again.

CMMS advantages. Automating machine maintenance operations via CMMS programs allows human resources once tasked with tracking activities to be absorbed back into the realm of maintaining equipment. Operators of malfunctioning equipment no longer have to hunt for maintenance technicians to repair their machines. They are now free to enter an electronic trouble call and then turn their attention to other production matters. Maintenance managers are able to gather a wealth of information from their CMMS databases for reporting. Here are a just a few examples of the data potential:

- average time required to answer a trouble call
- average time required to complete a trouble call on a particular machine
- mean time between failures on a given asset
- components that most often fail on a machine and the exact failure mechanism
- time spent on PM activities on a given production line compared to actual run time for the same line
- comparison of trouble calls between shifts
- staffing requirements in a given area based on actual maintenance activity
- percentage reduction in the number of trouble calls after establishing a PM program in a particular operating area.

Preventive Maintenance work order creation is greatly simplified with CMMS. Standard tasks may be created within the system and work orders then generated by combining a series of standard tasks. These work orders can then be stored for future reference and scheduled well in advance. The system can be instructed to notify maintenance managers, engineers, technicians, and even production department personnel of upcoming PM activities via email messages. Work order packages can be printed automatically to predetermined printers or forwarded as email messages prior to their execution date. For example, the system can be programmed to print a week's PM work orders out on Thursday night of the previous week so that on Friday the affected parties can plan a strategy for their completion. Most CMMS software even includes the ability to take company holidays, and vacation schedules, or known peak equipment demand times into account when scheduling maintenance activities to prevent activities from being inadvertently neglected or causing undue work slowdowns.

Utilization of the CMMS planning functions enables greater control of one-time projects. For example, suppose a production assembly line must be overhauled during a long holiday weekend. If the component parts, maintenance tasks, and work instructions are accurately entered into the CMMS, then the system will be able to plan how many technicians of each trade will be required and how long the project will take. If labor rates are entered (including overtime and holiday pay) into the system, it can then compile a comprehensive cost breakdown of parts and labor required for the overhaul. Similar information can be compiled for maintenance effort of lesser magnitude than complete overhauls and used to determine whether repair or replacement is the better strategy.

Information gathered by the CMMS can also be used to track performance improvements in the maintenance organization. For example, deficiencies in the maintenance management staff may be reflected in a longer that normal response time for trouble calls. Likewise, an average of only 32 hours per week of machinist maintenance activity on a particular work shift signals a problem for an organization with three machinists on that shift.

In essence, the use of a CMMS system allows a maintenance manager to keep track of his organization's accomplishments and shortcomings with facts and data instead of "gut feelings". He is able to show his production department counterparts what their maintenance dollars are buying them and exactly how that compares with a reference point in time.

CMMS disadvantages. Despite the improvements in call response time and data collection afforded by CMMS, there are disadvantages as well. First and foremost is the limitation of the data itself. Analysis of CMMS data can only be as good as the accuracy of the data. Each individual who enters data into the system must understand the importance of accuracy. Inattention to detail can send a technician to the wrong machine or even to the wrong building (resulting in wasted time for the technician and excessive downtime for an asset). A technician, who receives and responds to a call but does not acknowledge the call in the CMMS, causes maintenance response time data to be inflated. Failure to accurately enter parts replaced on a machine limits the ability for planning the number of spare parts to be maintained in the maintenance storeroom. Also, inventory inaccuracy leads to the CMMS indicating that parts are available when in fact they have already been used. The end result is that a part will not be ordered when it should be and either a PM activity or a CM breakdown will have to wait until the part can be procured.

A second drawback felt by many maintenance organizations is the initial cost of a CMMS. Full-service systems can cost in the tens or hundreds of thousands of dollars with software support costs running even higher. Added to the software cost is the hardware cost of satellite terminals located throughout the factory. Once all hardware and software items are in place, the initial data entry can take weeks to complete, depending upon the size of the organization. Recall that each factory asset to be maintained must be identified and its data entered into the CMMS for tracking purposes. A last and often overlooked expense is the cost of training system users. Training costs not only include actual classroom instruction and manuals, but also include time lost from production while personnel familiarize themselves with the equipment. The tremendous costs of deploying a CMMS make it imperative that everyone using the system be familiar with what is expected from them, what is expected from the system, and whom to call with questions to ensure the fastest possible resolution.

A third disadvantage with CMMS lies in the fact that not all employees feel comfortable using computer equipment. An organization implementing a CMMS must ensure that machine operators and maintenance technicians are trained and proficient with the equipment and with the user interfaces. These individuals should also be familiarized with why the data is being collected and shown examples of how analysis of the data can improve machine productivity.

A fourth potential disadvantage of implementing a CMMS system where no such system has been used before is the fear among some maintenance personnel that the data collected will be used against them. This is a common response to automatic data collection methods being introduced into the workplace and it has the potential to pose the biggest single threat to success. A wise maintenance manager will do well to prepare employees for the introduction of the system with ample time set aside for training. CMMS information should be viewed as a tool for process improvement, not a weapon to be used against poor performers. Employees who sense that CMMS-gathered data may threaten their jobs are more likely to resist implementing the system or attempt to falsify data inputs to the system. Taking the time to provide adequate training and answer questions up front is an investment that can pay rich dividends as a new CMMS system is put in place.

SUMMARY

This study began with a view of manufacturing methodologies and requirements and the demands that these requirements place on today's factory production equipment. The evolution of the fast paced, just-in-time manufacturing trends was briefly traced and it was pointed out that in order to meet ever-increasing customer demands, equipment uptime must be maintained at all time highs without driving maintenance overhead costs beyond economic feasibility. Both production processes and maintenance processes were presented in relation to the ultimate goal of any manufacturing company, that is, "to make money in the present as well as in the future." (Goldratt, 1986b, p.18) The study has demonstrated that just as innovations in manufacturing theory have led to increases in production speed, reductions in on-hand inventories, and improved customer satisfaction; innovations in maintenance operations can lead to increased machine uptime, reduced repair parts inventories, and improved production floor customer satisfaction.

Companies seeking to improve their profitability by eliminating waste throughout the business are beginning to take a serious look at their outdated maintenance policies. The increased use of computerized data tracking systems is making it easier for production managers to determine what their bottlenecks to production are, and those bottlenecks are often identified as maintenance issues. Confronted with mounting evidence that maintenance problems are contributing to missed ship dates, maintenance managers are turning to methods other than traditional Corrective Maintenance (CM) to support their production customers.

The study has described the different methodologies of machine maintenance. The natural progression for improving a maintenance organization with a CM (or "fix-it") history is for it to implement a basic Preventive Maintenance (PM) program. This program after identifying the equipment to be included identifies the basic maintenance items to be addressed at regular intervals and defines the intervals. Much of this information is available from equipment manufacturers. Examples of anticipated PM tasks include: oiling and/or greasing machine stress points weekly, cleaning intake air filters twice a month, re-torquing gear housing bolts twice a year, and replacing shaft bearings annually. After initiating a PM program, a proactive maintenance organization will often desire to proceed further by launching a Predictive Maintenance (PdM) program to regularly monitor the condition of production equipment. By monitoring the degradation of operating characteristics over time, maintenance can schedule repair efforts prior to machine breakdown.

A common theme that emerges from experience with machine maintenance efforts is an absolute requirement for constant, effective communication. This includes communication between all the parties involved with the production assets including: production supervisors, machine operators, production planners, maintenance managers, maintenance technicians, and storeroom personnel. In order for PM and PdM efforts to succeed, maintenance personnel (with help from engineering) must identify the work to be done. They must then communicate their intended activities with the production representatives to ensure that the equipment can be made available at the most opportune time within the production schedule. Storeroom personnel must be made aware of parts requirements so that replacement parts can be made available exactly when they are needed to prevent undue downtime. Some companies may choose to implement work cell teams consisting of production employees and maintenance representatives who work out PM schedules among themselves. The closer-working environment is able to foster better lines of communication than has been traditionally present between production and maintenance departments.

Effective training is an absolute requirement if maintenance improvement initiatives are to be successful. Maintenance technicians must have the proper training to perform their assigned tasks. This has not changed from the old fix-it maintenance days. What has changed, however, is a growing need for technicians to be cross-trained in areas beyond their core skills. Modern computerized maintenance management systems (CMMS) have brought on a requirement for technicians to be computer literate. The data indicates that more and more companies are implementing CMMS to track maintenance work orders, PM work orders, and inventory levels. The old adage that garbage-in-equals-garbage-out applies to CMMS data as well; so everyone who enters data into the system must be comfortable with the data entry and understand the importance of the data to ensure its accuracy. Beyond the maintenance department, production personnel must be provided with training that demonstrates the importance of periodic maintenance activities designed to keep their machines running as well as or better than new. Companies often find that production operators view new maintenance initiatives with skepticism in the beginning. Better orientation in the early stages of implementation can help alleviate the skeptical viewpoints. But even beyond basic orientation, some companies are beginning to involve production associates in the PM activities themselves. For example, production operators who would once have stood idly by while a maintenance technician lubricated a drill press, can, after being trained in the way to safely perform that task and being given the proper supplies, now perform the task himself. This is a simple example, but more and more companies are identifying traditional maintenance tasks that can be relegated to properly trained production operators. The benefits are twofold: first, the maintenance technicians are freed up to perform tasks better suited to their technical expertise and second, the production operators will often take more pride in the operation of their machines when they are involved with their upkeep.

Any company currently utilizing a predominantly corrective maintenance policy should certainly consider beginning the maintenance process improvement journey. Companies traditionally steeped in the CM maintenance methods have demonstrated that the benefits of employing the maintenance process improvement strategies described in this course can be enjoyed in a relatively short time span and continue for as long as the program is supported. Companies with relatively new production equipment bases should begin PM programs to provide regular servicing to their equipment to prolong its life. Companies with aging equipment bases should consider taking aggressive action to bring the older assets back to their intended operating condition and then continuing with regular PM activities to prolong its life. Factory equipment in any industry can benefit from the maintenance programs described in this study and the results will go a long way to support the business goal of making money now and in the future and further support the efforts of manufacturing companies to achieve true World-Class performance.

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APPENDIX

Prioritizing Preventive Maintenance Activities

Preventive Maintenance (PM) programs are designed to offer a degree of protection against production machine breakdown. The actual degree of protection is dependent upon a number of factors including the condition of an asset when the PM program is begun, the percentage of potential failures addressed by PM tasks, and the frequency of PM tasks. Well designed PM programs can offer production managers an equipment base that functions reliably and consistently but only if the PM activities are performed as designed and on schedule. Even with the best planning, maintenance technicians are often called away from PM tasks to perform emergency breakdown repairs and never make it back to complete the PM tasks. To combat the erosion of a PM program, maintenance managers need a method of prioritizing departmental workload in a manner that allows for breakdowns and PM tasks to coexist and ensures that the most important work is performed when it needs to be. Two basic types of priority systems are in common use and are described briefly in the following paragraphs.

Straight Numeric System. A straight numeric priority system ranks maintenance tasks and responsibilities on a numeric scale. The scale can be any size that makes sense to the maintenance manager (e.g. Priorities 1 through 5 or 1 through 25 with one being the highest priority). Using this method, all maintenance tasks must be analyzed for importance and given a priority ranking. Once completed, the priority list determines the sequence for task completion. Taking the guesswork out of task sequencing eliminates technician idle time associated with waiting for the next priority to be determined. Tasks can be ranked periodically, once a day is a good starting point, and made available for maintenance and production personnel to reference. Since the goal of any priority ranking system is to ensure that the right work is performed at the right time, it is important for maintenance and production personnel to collaborate on the priority ranking criteria. In a straight numeric system, Priority 1 ranking is best reserved for safety issues (i.e. tripping hazards, frayed power cords, failing ventilation systems, etc.). A good candidate for Priority 2 is production equipment breakdowns requiring immediate maintenance attention to restore production capability. Further priority decisions are at the discretion of maintenance and production managers, but need to be agreed upon before establishing the system. Some CMMS systems can be called upon to assist with assigning priorities once the initial task ranking has been completed.

Multiplier Priority System. A multiplier priority system operates much the same as a straight numeric system in that each task or responsibility is assigned a numeric priority code to determine the execution order. In the multiplier system, however, the number is calculated using ranking factors. The highest priority task is the one with the highest priority number. A common multiplier system assigns two ranking factors: equipment type (or criticality) and job classification to each task. These two numbers generally ranging from one to ten (with ten being the highest priority) are then multiplied together to provide the priority ranking for each task. As with the straight numeric method, safety hazards and emergency equipment breakdowns must take priority over other tasks and should be ranked accordingly. A common method of accomplishing this is to give safety hazards an equipment type ranking factor of ten and emergency breakdown work orders a job classification of ten to ensure that these items rise to the top of the priority list. Other task priorities should be determined by joint effort between maintenance and production personnel.

Conclusion. As was mentioned above, priorities must be reviewed regularly to maintain the integrity of the ranking system. Few maintenance organizations enjoy the ability to complete every assigned task every day. Therefore, uncompleted tasks must be ranked against new tasks to establish the correct priority for each day's workload. This is critical to the effectiveness of a PM program whose success depends on PM work orders being completed on schedule to prevent equipment breakdown. If a daily review cannot be accommodated, then an automatic aging factor should be added to the priority ranking. This factor would be used to increase the priority of PM tasks so that uncompleted ones would gradually "float" to the top of the priority list. It is also important to note that maintenance managers must retain discretionary authority to change any priority other than those of safety issues.