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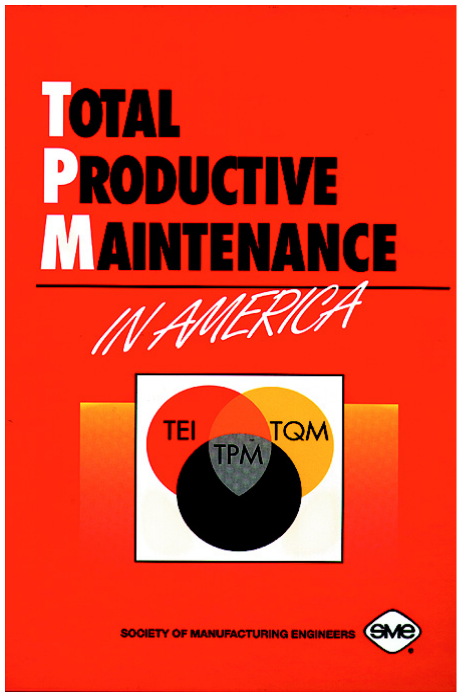

Society of
Manufacturing
Engineers

CHAPTER 1

The Foundation for World-class Manufacturing

TPM is important and necessary in manufacturing operations because it provides the capability to take the talents of people and educate them in ways so that benefits can be derived from their knowledge of equipment and machinery. We make process improvements, we make equipment improvements, we make quality improvements because of the ideas of our people. TPM is one way that we've used to educate our people in a broad spectrum of issues related to running an operation.

—Mike Blackwell, Manager, Green Machining and Heat Treat Operations, The Timken Company, Gaffney Bearing Plant

Good maintenance is good business. The prime motivator in manufacturing, especially as it pertains to equipment maintenance, is to keep production running in high gear. Competition mandates it. Maintenance directly affects the productivity, quality, and direct costs of production. Yet today, the most-practiced approach to maintenance—that of focusing on equipment only when it breaks down—stands in direct opposition to the target of high productivity, with the postmortem being that production stops and the maintenance department draws exceptional (and unwanted) visibility owing to the extraordinary costs such practices incur in terms of competitiveness and real dollars.

WHAT IT IS

To keep production in high gear—in fact, to survive—manufacturers are increasingly obliged to move from a "panic" maintenance mindset toward a concept of "productive" maintenance, one organized around a well trained staff, within a carefully defined plan, and with meaningful participation of employees outside of what is normally thought of as maintenance. It's a move toward a total team approach of preventive maintenance (PM) and total quality management (TQM).

Total productive maintenance (TPM) is a concept evolved by the Japanese in the 1960s from maintenance practices they learned from the United States during the 1950s. Total productive maintenance is perhaps a misnomer for the concept, since it goes beyond just maintenance. TPM is an *equipment management strategy* that involves all hands in a plant or facility in equipment or asset utilization. TPM is to productivity as flexibility is to competitiveness. Without it, corporate survival is in jeopardy.

At the core of TPM is a new partnership among the manufacturing or production people, maintenance, engineering, and technical services to improve what is called overall equipment effectiveness (OEE). It is a program of zero breakdowns and zero defects aimed at improving or eliminating the six crippling shop-floor losses:

- Equipment breakdowns.
- Setup and adjustment slowdowns.
- Idling and short-term stoppages.
- Reduced capacity.
- Quality-related losses.
- Startup / restart losses.

A concise definition of TPM is elusive, but *improving equipment effectiveness* comes close. The partnership idea is what makes it work. In the Japanese model for TPM are five pillars that help define how people work together in this partnership.

Five Pillars of TPM

1. *Improving Equipment Effectiveness.* In other words, looking for the six big losses, finding out what causes your equipment to be ineffective, and making improvements.
2. *Involving Operators in Daily Maintenance.* This does not necessarily mean actually performing maintenance. In many successful TPM programs, operators do not have to actively perform maintenance. They are involved in the maintenance *activity*—in the plan, in the program, in the partnership, but not necessarily in the physical act of maintaining equipment.
3. *Improving Maintenance Efficiency and Effectiveness.* In most TPM plans, though, the operator is directly involved in some level of maintenance. This effort involves better planning and scheduling, better preventive maintenance, predictive maintenance, reliability centered maintenance, spare parts equipment stores, tool locations—the collective domain of the maintenance department and the maintenance technologies.

4. *Educating and Training.* This is perhaps the most important task in the TPM universe. It involves everyone in the company to varying degrees: training operators to operate machines properly and maintenance people to maintain them properly. If operators will be performing some of the preventive maintenance inspections, training involves teaching operators how to do those inspections and how to work with maintenance in a partnership. Also involved is training supervisors on how to supervise in a TPM-type team environment.
5. *Designing and Managing Equipment for Maintenance Prevention.* Equipment is costly and should be viewed as a productive asset for its entire life. Designing equipment that is easier to operate and maintain than previous designs is a fundamental part of TPM. Suggestions from operators and maintenance technicians help engineers design, specify, and procure more effective equipment. And, by evaluating the costs of operating and maintaining the new equipment throughout its life cycle, long-term costs will be minimized. Low purchase prices do not necessarily mean low life-cycle costs.

COMPETITIVE ADVANTAGE

In most companies today, management is looking for every possible competitive advantage. Companies focus on total quality programs, just-in-time (JIT) programs, and total employee involvement (TEI) programs. All require complete management commitment and support to be successful. Figure 1-1 depicts TPM's fit in the manufacturing mix. However, no matter how management works to make these programs produce results, it is impossible to be totally successful without integrating these with a TPM program.

This is a bold statement; however, it is impossible to make the programs mentioned function effectively without equipment or assets that are currently maintained in world-class condition. Consider:

- Is it possible to produce quality products on poorly maintained equipment?
- Can quality products come from equipment that is consistently out of specification or worn to the point that it cannot consistently hold tolerance?
- Can a JIT program work with equipment that is unreliable or has low availability?
- Can employee involvement programs work for long if management ignores the pleas to fix the equipment or get better equipment so a *world-class* product can be delivered to the customer on a timely basis, thus satisfying the employee concerns and suggestions?

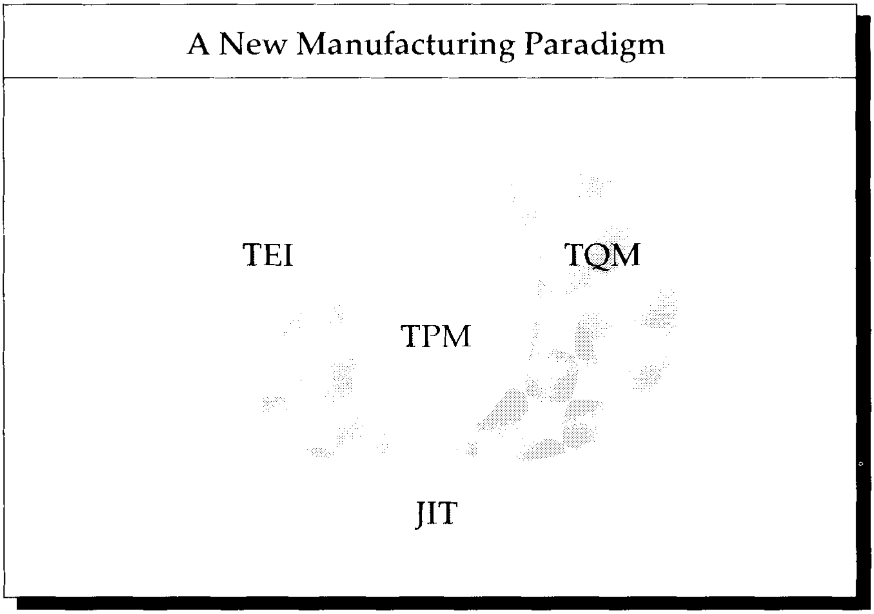

Figure 1-1. At the core of successful manufacturing, TPM catalyzes proven productivity programs.

TPM can improve reliability, maintainability, operability, and profitability—but achieving these goals requires the talents and involvement of every employee. Through autonomous activities—in which the operator is involved in the daily inspection and cleaning of his or her equipment—companies will discover the most important asset in achieving continuous improvement—its people.

Companies are beginning to realize that the management techniques and methods previously used to maintain equipment are no longer sufficient to compete in world markets. Attention is beginning to focus on the benefits of TPM, yet the number of companies successfully implementing TPM is relatively small. The reason is that many companies try to use TPM to compensate for an immature or dysfunctional maintenance operation. They fail to realize that TPM is an evolutionary step, not a revolutionary one. To fully understand the character of TPM, it is necessary to consider the evolution of a typical quality program.

The Quality Continuum

In Figure 1-2, the various stages of the continuum of a quality program are highlighted along the bottom of the arrow. In the early days, a company would ship almost anything to the customer. If the product did not meet

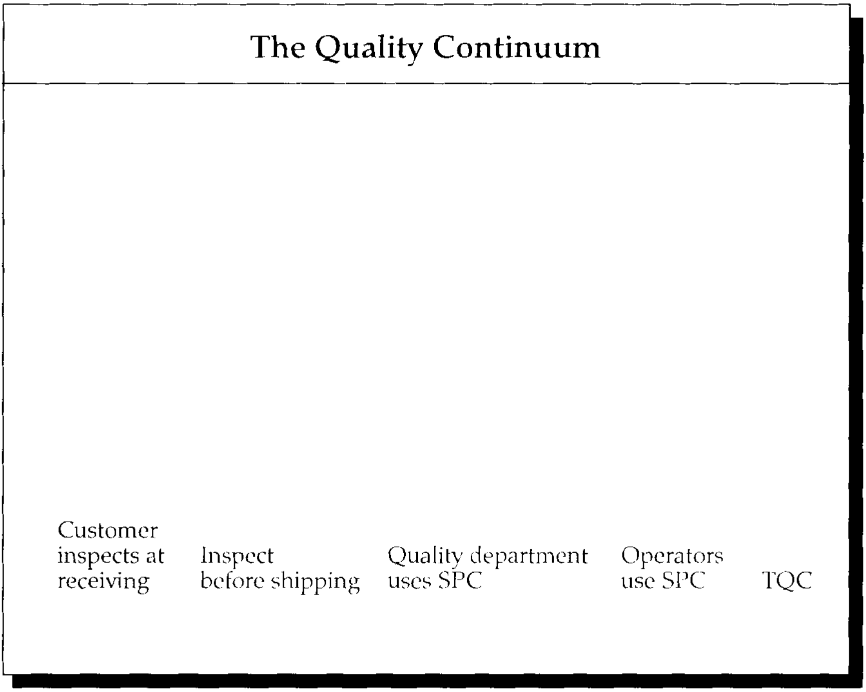

Figure 1-2. The various stages of the quality maturity continuum target a zero-defects quality goal.

customer standards, nothing was done about it until the customer complained and shipped it back. However, this eventually became costly when competitors would ship products that the customer would accept, since there was no quality problem. Complacency sabotaged competitiveness. To stay in the game, the company was forced to make changes in the way they did business.

The second step was to begin inspecting the product in the final production stage, or in shipping just before it was loaded for delivery to the customer. Though this was better than before (since it reduced the number of customer complaints) the company realized that it was expensive to produce a product only to reject it just before it was shipped. In effect, they were shooting themselves in the foot. It was far more economical to find the defect earlier in the process and eliminate running defective material through the rest of the production process. Common sense.

This led to the third step to quality system maturity, the development of the quality department. This department's responsibility was to monitor, test, and report on the quality of the product as it passed through the plant. At first blush, this seemed to be much more effective than before, with the defects being found earlier, even to the point of statistical techniques being used to anticipate or predict when quality would be out of limits. However, there were still problems. The more samples the quality department was required to test, the longer it would take to get the results back to the operations department. It was still possible to produce minutes', hours', or even shifts' worth of product that was defective or out of tolerance before anyone reined in the errant piece of equipment.

Solving this problem led to the fourth step, training the operators in the statistical techniques necessary to *monitor* and *trend* their own quality. In this way, the term "quality at the source" was coined. This step enabled the operator to know down to the individual part when it was out of tolerance—and no further defective components were produced. This eliminated the production of any more defects and prevented rework and expensive downstream scrap. However, there were still circumstances beyond the control of the operator that contributed to quality problems, which led to the next step, the involvement of all departments of the company in the quality program. From the product design phase, through the purchasing of raw materials, to final production and shipping of the product, all involved recognized that producing a quality product for the lowest price, the highest quality, and the quickest delivery was the goal of the company. This meant that products were designed for producibility, the materials used to make the product had to be of the highest quality, and the production process had to be closely monitored to ensure that the final product was of perfect quality. The company had evolved to the stage of maturity necessary to be world class.

The Maintenance Continuum

How does this path to maturity relate to the path to maturity for asset or equipment maintenance? Figure 1-3 compares the two. In stage 1 of the path to TPM, the equipment is not maintained or repaired unless the customer (operations, production, or facilities) complains that it is broken. Only then will the maintenance organization work (or in some cases be allowed to work) on the equipment. In other words, "if it ain't broke, don't fix it." However, over time companies began to realize that when equipment breaks down it always costs more and takes longer to fix than if it was maintained on a regularly scheduled basis. This cost is compounded when the actual cost of the downtime is calculated. Companies began to question the policy, coming to understand that it is cost effective to allow the equipment to be shut down for shorter periods of time for minor service to reduce the frequency and duration of the breakdowns.

This leads to the second step on the road to TPM, the establishment of a good preventive maintenance program or building on one already in

The Maintenance Continuum

Reactive	Preventive	Predictive	Team	TPM
Customer inspects at receiving	Inspect before shipping	Quality department uses SPC	Operators use SPC	TQC

Figure 1-3. Total quality management coupled with total productive maintenance produces a zero-defect, zero-breakdown production environment.

place. This step allows for the inspection and routine servicing of the equipment before it fails and results in fewer breakdowns and equipment failures. In effect, the product is inspected before the "customer" gets it. Some of the techniques of PM include routine lubrication and inspections for major defects.

This second step, while producing some results, is not sufficient to prevent certain types of failures. The third step, then, is to implement predictive and statistical techniques for monitoring the equipment. The most common of these techniques are:

- Vibration analysis.
- Spectrographic oil analysis.
- Thermographic or infrared temperature monitoring.
- Nondestructive testing.
- Sonics.

The information produced from proper utilization of these techniques reduces the number of breakdowns to a low level, with overall availability being more than 90 percent. At this point, the "hidden" problems are discovered before they develop into major problems. However, the quest for continuous improvement emphasizes the need to do better. This leads to the fourth step: involvement of the operators in maintenance activities.

This step does not mean that all maintenance activities are turned over to the operators. Only the basic tasks are included, such as some inspection, the basic lubrication, adjusting, and routine cleaning of the equipment. The rationale for having operators involved in these activities is that they best know when something is not right with the equipment. In actual practice the tasks they take over are the ones that the maintenance technicians have trouble finding the time to do. Freed of the burden of doing some of the more routine tasks, the maintenance technicians can concentrate on refining the predictive monitoring and trending of the equipment. They also will have more time to concentrate on equipment failure analysis, which will prevent future or repetitive problems on the equipment. This step increases not only the availability of the equipment, but also its reliability over its useful life.

The last step of the evolution process is involving all employees in solving equipment problems, thereby increasing equipment effectiveness. The most common method is the use of cross-functional teams formed of members from various organizational disciplines to produce total solutions for these problems. Through team-building training, the team members learn the function, need, and importance of each team member, and in a spirit of understanding and cooperation, allow for production and service to reach world-class standards.

To reach these goals, certain resources must be in place or accounted for. They can be divided into three main categories. If not in place, they become obstacles to achieving the goals of TPM.

- Management support and understanding.
- Sufficient training.
- Allowance for sufficient time for the evolution.

Management support is essential. Management must completely understand the true goal of the program and back it. If management begins the program by emphasizing its desire to eliminate maintenance technicians, they have failed to understand the program's true purpose. The real goal is to increase overall equipment effectiveness, not reduce the labor head-count. Without management understanding of the true goal of asset utilization, the program is doomed to failure.

Sufficient skills training is another of the major activities of TPM. It must be given to at least two different levels. The first addresses the increased skills required for the maintenance technicians. The technicians will be trained in advanced maintenance techniques, such as predictive maintenance and equipment improvement. They also must have extensive training and guidance in data analysis to prepare them to find and solve equipment failure and effectiveness problems. Refresher training in the fundamentals of sound equipment maintenance methods is also considered a vital part of TPM.

Second is operator training. The operators must be trained to do basic maintenance on their equipment. In areas such as inspections, adjustments, bolt tightening, lubrication, and proper cleaning techniques, operators must be taught in detail. Also, before doing any repairs, operators must receive training to be certified to do the assigned tasks. Without proper training in selected skills, the equipment's effectiveness will decrease. The degree of operator involvement must also fit with the company culture.

Additional training for work groups, leadership, engineers, planners, and others is a vital part of the TPM work culture.

The last element is allowing enough time for the TPM evolution to occur. The change from a reactive program to a proactive program will take time. By some estimates it may be a 3- to 5-year program to achieve a competitive position. By failing to understand this point, many managers condemn their programs to failure before they ever get started.

Successful TPM programs focus on specific goals and objectives. When the entire organization understands the goals and how they affect the competitiveness of the company, the company will be successful.

The five central objectives of TPM are to:

1. Ensure equipment capacities.
2. Develop a program of maintenance for the entire life of the equipment.
3. Require support from all departments involved in the use of the equipment or facility.
4. Solicit input from all employees at all levels of the company.
5. Use consolidated teams for continuous improvement.

Ensuring equipment capacity emphasizes that the equipment performs to specifications. It operates at its design speed, produces at the design rate, and yields a quality product at these speeds and rates. The problem is that many companies do not even know the design speed or rate of production of their equipment. This allows management to set arbitrary production quotas. A second problem is that over time, small problems cause operators to change the rate at which they run equipment. As these problems continue to build, the equipment output may be only 50 percent of what it was designed to be. This will lead to the investment of additional capital in equipment, trying to meet the required production output.

Implementing a program of maintenance for the life of the equipment is analogous to the popular preventive and predictive maintenance programs companies presently use to maintain their equipment, but with a significant difference; it changes just as the equipment changes. All equipment requires different amounts of maintenance as it ages. A good preventive/predictive maintenance program takes these changing requirements into consideration. By monitoring failure records, trouble calls, and basic equipment conditions, the program is modified to meet the changing needs of the equipment.

A second difference is that TPM involves all employees, from shop floor to top floor. The operator may be required to perform basic inspecting, cleaning, and lubricating of the equipment, which is really the front-line defense against problems. Upper managers may be required to assure that maintenance gets enough time and budget to properly finish any service or repairs required to keep the equipment in condition so that it can run at design ratings.

Requiring the support of all departments involved in the use of the equipment or facility will ensure full cooperation and understanding of affected departments. For example, including maintenance in equipment design/purchase decisions ensures that equipment standardization will be considered. The issues surrounding this topic alone can contribute significant cost savings to the company. Standardization reduces inventory levels, training requirements, and startup times. Proper support from stores and purchasing can help reduce downtime, but more importantly it will aid in the optimization of spare parts inventory levels, thus reducing on-hand inventory.

Soliciting input from employees at all levels of the company provides employees with the ability to contribute to the process. In most companies this step takes the form of a suggestion program. However, it needs to go beyond that; it should include a management with no doors. This indicates that managers, from the front line to the top, must be open and available to listen to and consider employee suggestions. A step further is the response that should be given to each discussion. It is no longer sufficient to say "That won't work" or "We are not considering that now." To keep communication flowing freely, reasons must be given. It is just a matter of developing and using good communication and management skills. Without these skills, employee input will be destroyed at the outset and the ability to capitalize on the greatest savings generator in the company will be lost.

The creation of consolidated teams for continuous improvement begins with objective 4. The more open management is to the ideas of the work force, the easier it is for the teams to function. These teams can be formed by areas, departments, lines, process, or equipment. They will involve the operators, maintenance, and management personnel. They will, depending on the needs, involve other personnel on an as-needed basis, such as engineering, purchasing, or stores. These teams will provide answers to problems that some companies have tried for years to solve independently. This team effort is one of the true indicators of a successful TPM program.

OVERALL EQUIPMENT EFFECTIVENESS

The overall equipment effectiveness (OEE) is the benchmark used for TPM programs. The OEE benchmark is established by measuring equipment performance.

Measuring equipment effectiveness must go beyond just the availability or machine uptime. It must factor in all issues related to equipment performance. The formula for equipment effectiveness must look at the availability, the rate of performance, and the quality rate. This allows all departments to be involved in determining equipment effectiveness. The formula could be expressed as:

$$\text{Availability} \times \text{Performance rate} \times \text{Quality rate} = \text{Equipment effectiveness}$$

The availability is the required availability minus the downtime, divided by the required availability. Expressed as a formula this would be:

$$\frac{\text{Required availability} - \text{downtime}}{\text{Required availability}} = \text{Availability}$$

The required availability is the time production is to operate the equipment, minus the miscellaneous planned downtime, such as breaks, scheduled lapses, meetings, etc. The downtime is the actual time the equipment is down for repairs or changeover. This is also sometimes called breakdown downtime. The calculation gives the true availability of the equipment. It is this number that should be used in the effectiveness formula. The goal for most Japanese companies is a number greater than 90 percent.

The performance rate is the ideal or design cycle time to produce the product multiplied by the output and divided by the operating time. This will give a performance rate percentage. The formula is:

$$\frac{\text{Design cycle time} \times \text{output}}{\text{Operating time}} = \text{Performance rate}$$

The design cycle time (or production output) will be in a unit of production, such as parts per hour. The output will be the total output for