2

Improving Machine Performance

How does TPM improve machine productivity?

How is it possible to save time and money by improving maintenance technology?

2

TPM IMPROVES MACHINE PRODUCTIVITY

Like many manufacturers, making everything from computer chips to potato chips, Agilent uses machines to manufacture its products. The fact is machines do virtually 100 percent of the product manufacturing work. The only thing we people do, whether we're operators, technicians, engineers, or managers, is tend to the needs of the machines in one way or another. The better our machines run, the more productive our shop floor, and the more successful our business.

TPM is an equipment-focused improvement effort; we work on creating the ideal equipment state. Any gap between our current state and the ideal state must be closed. These gaps are created in part by: deficiencies in our equipment maintenance plan; people's lack of knowledge as to how to perform their work correctly; and weaknesses in machine, process, and product designs.

In order to change equipment performance, operators, technicians, and engineers must change their own mindsets and work habits. They must learn to tackle improvement issues together as a team rather than separately. They must adopt new mindsets with each TPM step. These changes in people's thinking and behavior improve equipment productivity.

We may never achieve the ideal state for all of these factors on our shop floor, but we are going to move toward them as fast as we can and do so as long as we are in business. Agilent does benchmark other IC fabs in our industry, but our focus is to do more than keep up with our competitors. Our goal is to achieve the ideal factory state—zero losses, or at least world-class levels of machine productivity in our industry.

The first goal of TPM is to prevent equipment failure. Every machine should be kept running as well every day as it has on its very best day. This is primarily achieved by developing a sound maintenance regimen and continually restoring machine deterioration to keep the performance of the machine consistent from one day to the next. Once this is achieved, other productivity losses can be eliminated to make the machine run better than it ever has before.

A TPM team at Agilent recently attacked productivity losses on a very complex cluster tool used to deposit a layer of oxide on IC wafers. The operators, equipment techs, process techs, and engineers on this team used the TPM methods described in this book to improve this machine's productivity. In less than nine months, the machine's capacity was increased by over 50 percent without a single machine design change. The performance improvement of this machine is displayed in Figure 2-1.

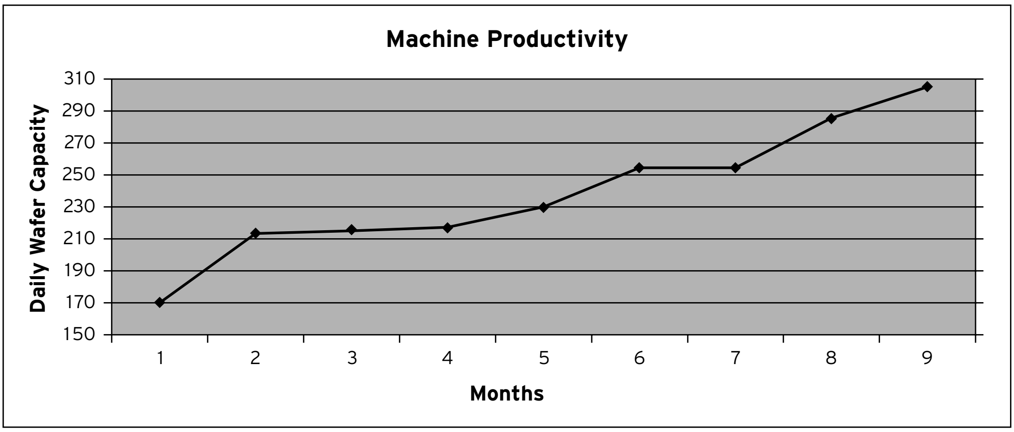


Figure 2-1. Productivity results achieved on a complex machine using TPM improvement methods

THE CONCEPT OF CONSTRAINTS

There are typically two types of machine classifications on any manufacturing floor: bottleneck equipment and non-bottleneck equipment. Bottleneck machines are those machines or groups of machines that have the lowest manufacturing capacity in the factory. Non-bottleneck machines are the remaining machines, which have a higher throughput capacity than the bottleneck machines.

Almost all factories have both types of machines, because it is virtually impossible to balance equipment capacities in any manufacturing operation. There is always a theoretical throughput limiter, even if it is external to the manufacturing floor, such as sales below the factory's capacity.

Machines operate very independently in Agilent's IC fab—they are not tied together in manufacturing lines, as are machines in many other industries. If our operation requires 3½ of a certain machine, we, of course, own 4 of these machines, making them non-bottleneck equipment. For these machines, reliability is more important than capacity.

Improving productivity involves improving the performance of both bottleneck and non-bottleneck machines alike. The reason for bottleneck productivity improvement is obvious. Since these machines have the least capacity of all factory equipment, improving bottleneck productivity improves total factory capacity, in essence increasing the utilization of every piece of equipment in the factory.

Improving non-bottleneck equipment performance is also important because these machines feed the bottleneck. If they stop producing product for too long a time, the bottleneck will starve and also stop production. This production is lost forever, because the bottleneck cannot recover lost production time unless it is run on overtime. Of course, overtime raises manufacturing costs. If machines run 24 hours per day, seven days a week, as they do in Agilent's IC fab, there is no way to recover lost bottleneck production.

To the surprise of many people, most factories are not limited in their production output by their bottleneck machines. Evaluation of data from many factories indicates that most produce less than the capacity of their designated bottleneck machines. Most factory output is actually limited by reliability problems in *all* machines, *not* the bottleneck machine's theoretical capacity. This is why TPM improvement activities must be applied to all equipment, not just the designated factory bottleneck. Improving the reliability of all factory equipment is required to improve overall factory productivity.

Minimizing manufacturing costs is achieved primarily by improving the productivity of all the machines on the factory floor, both bottleneck and non-bottleneck machines alike. This is a daunting challenge unless the entire organization pitches in and applies proven methods to the task.

THE EQUIPMENT AGING PARADIGM

Most people share a common belief that a new machine is "the best that it will ever be" and that it will continually deteriorate into a worse state as it is used in production. At some point it will become so deteriorated that it will need to be replaced with a new machine.

TPM implementation creates an opposite attitude about equipment aging—that a new machine is "the worst that it will ever be." The more we operate and maintain a piece of equipment, the more we learn about it. We use this knowledge to continually improve our maintenance plan and the productivity of the machine. We would only choose to replace a machine should its technology become obsolete, not because it has deteriorated into a poorly performing machine.

The last day of a machine's use on the factory floor should be its best performing day ever. These attitudes about equipment performance are illustrated in Figures 2-2 and 2-3.

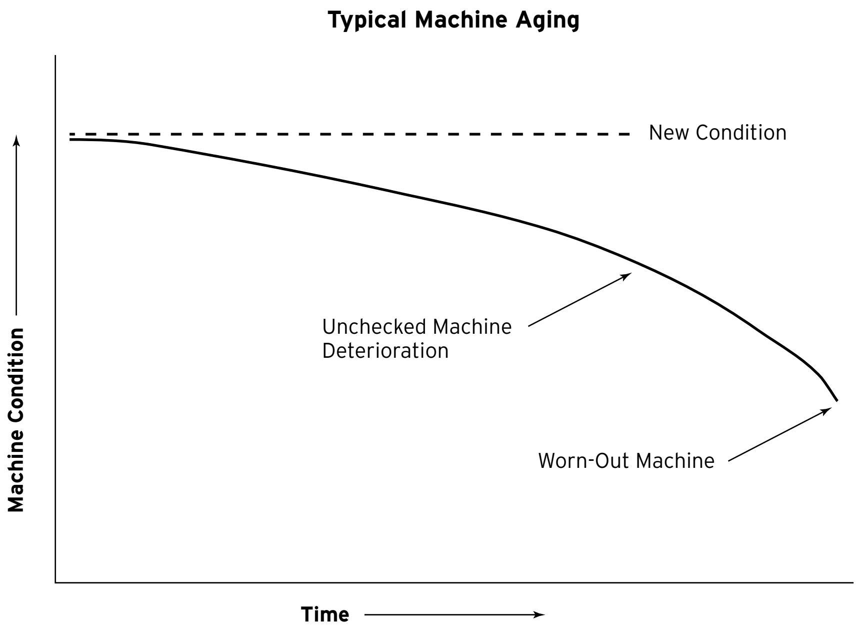


Figure 2-2. Aging machine performance of poorly maintained machines

GOALS OF EQUIPMENT MAINTENANCE

There are two basic goals for equipment maintenance:

1. **Condition maintenance** maintains proper machine conditions so that all components live a natural lifetime.
2. **Replacement maintenance** replaces or services components at the end of their life, but before they fail.

The concept of condition maintenance is illustrated in Figure 2-4.

Components often seem to have unpredictable lifetimes, as shown in failure curve (I), but their life expectancy is "unpredictable" only because they are not being properly maintained. Once they are properly maintained, the average life expectancy of the components will usually increase considerably, and the distribution of the components' life expectancy will be much tighter.

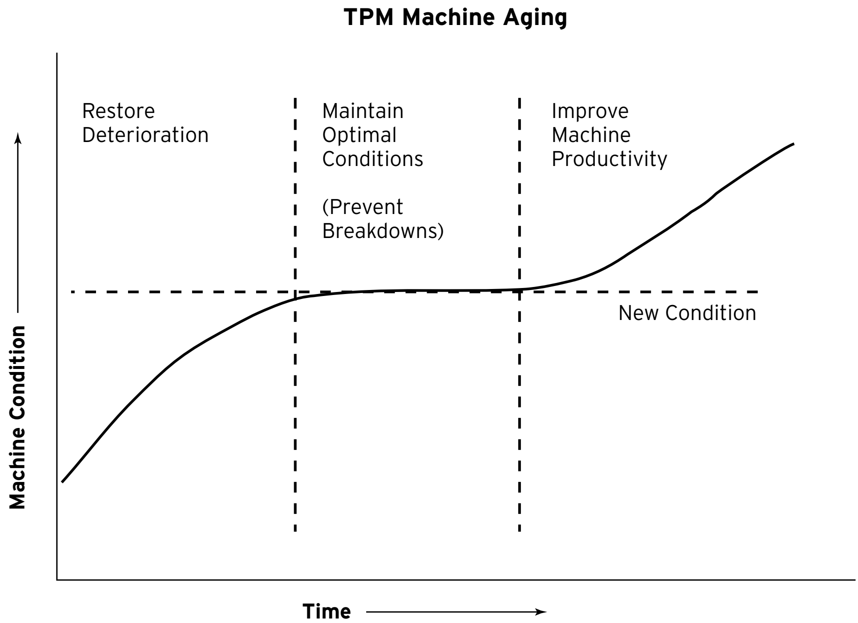


Figure 2-3. Aging machine performance with TPM methods applied

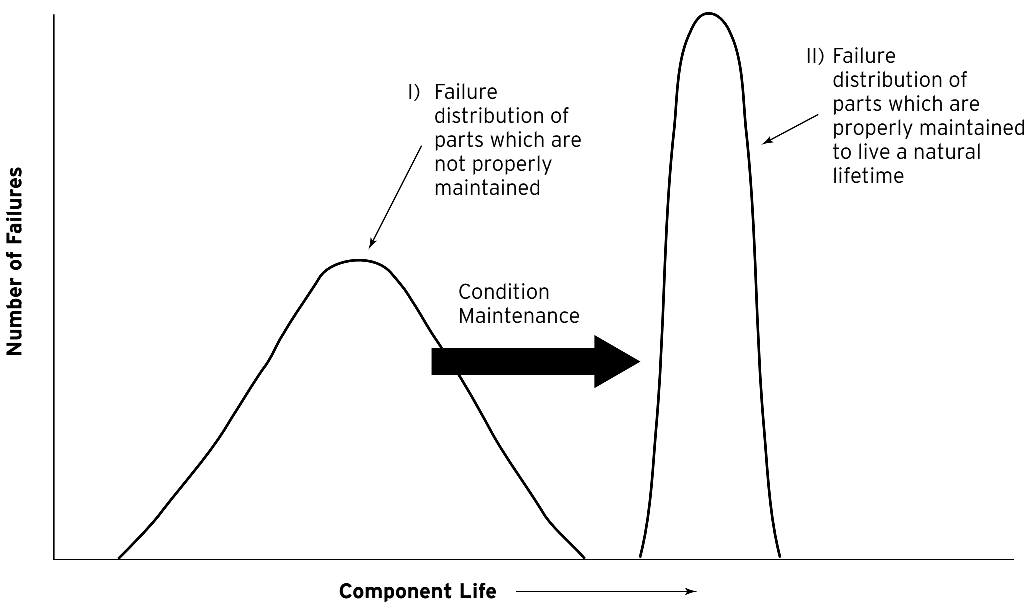


Figure 2-4. Condition maintenance keeps parts in useful service for a natural lifetime

Improper conditions that cause early failures in machine components can originate from numerous causes. True condition maintenance attacks all the following causes of "unpredictable" component lives.

1. Weak machine design by design engineers:
   - Components too undersized to handle the normal stresses applied to them, such as a chain transmitting more power than it was designed to handle.
   - Components used at the extremes of their design range, such as a 1000 sccm mass flow controller being used to control a gas flow of 5 sccm. (These devices work best at 20 to 80 percent of their design rating.)
2. Misapplication of a machine for its intended purpose by application engineers:
   - A 70-ton press is specified for an operation requiring 75 tons of force.
3. Mistreatment of the machine by the operators and technicians who use it and care for it everyday:
   - Slamming doors and similar rough handling of machine components by operators.
   - "Bailing wire" and "chewing gum" repairs made by technicians, vice grips used on hex nuts, and so on.
4. Underdeveloped maintenance plans that do not maintain the required conditions-of-use for machine components:
   - Minor defects neglected in machines often cause accelerated deterioration in nearby components, shortening their lives in unpredictable ways.

If the life of a component is not predictable, specifying a maintenance interval is quite difficult. Choosing service interval (I) as shown in Figure 2-5 would mean replacing most parts long before they were worn, increasing machine downtime for high-frequency maintenance activities and consuming additional technician resources.

Choosing service interval (II)—the average life of the part—would mean half of the parts would fail before they were replaced. As long as the component life is so unpredictable, no scheduled maintenance plan is useful. Even condition-based maintenance plans for these components cause an excess amount of maintenance work and cost. The goal is to improve machine performance with less maintenance work, not more.[1]

Only with proper condition maintenance can many parts achieve a reasonably predictable life expectancy. Once that is achieved, replacement maintenance plans also need to be developed to replace parts as they approach the end of their natural lives. These maintenance plans can be time-based, use-based, or

[1]More details about achieving natural component lifetimes can be found in other sections of this book: on page 192 and on page 222.

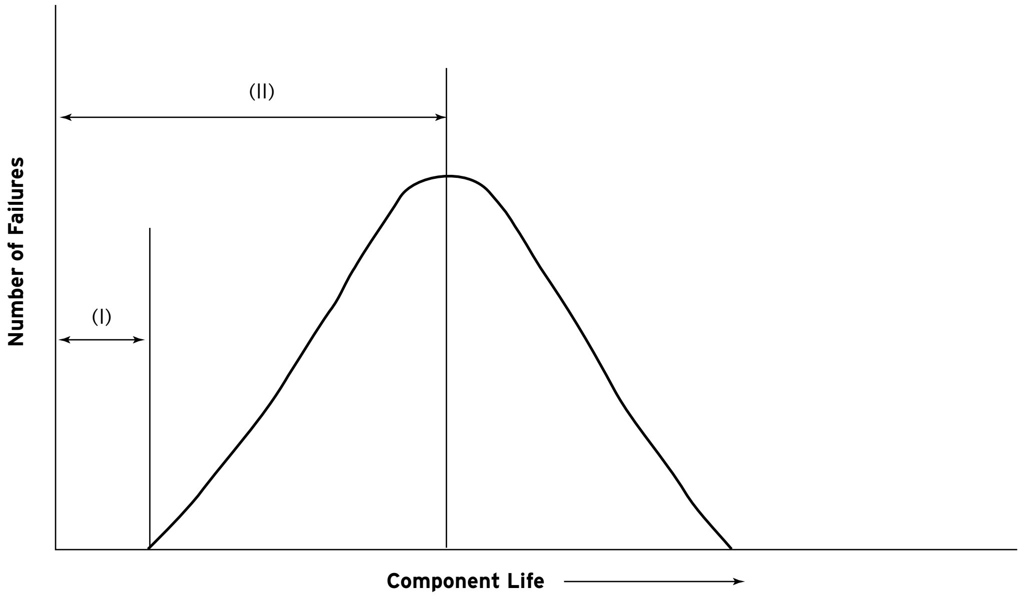


Figure 2-5. Parts with a wide range of life expectancy cannot have a good replacement interval

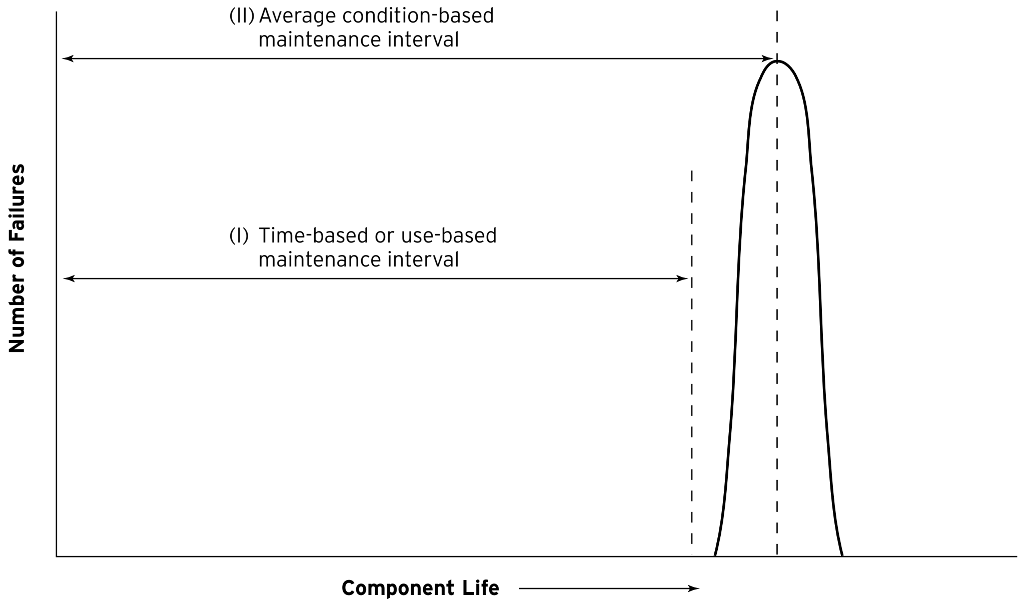


Figure 2-6. Scheduling replacement maintenance for parts with predictable life expectancies

condition-based. Maintenance intervals for these plans are shown as intervals (I) or (II) in Figure 2-6.

MACHINE DETERIORATION AND LOSS

A primary focus of TPM is to evolve a broad range of preventive maintenance plans for equipment. The reason for this is that most of our machines have already demonstrated that on any given day they can do the job they are supposed to do, but they don't always do this job well.

For example, Agilent had a three-year-old wafer-handling robot that ran very well for two years. In fact, there was one three-month period during that time when it ran without a single error. Clearly this wafer handler was designed to do the job we needed done. In its third year, however, the robot ran with numerous errors and stopped the machine from running almost every single day. This kind of repeating failure is known as a *sporadic failure*. Sporadic failures are deviations from the machine's "normal" performance.

What causes such a repeating sporadic failure? In this case, the wafer-handling system deteriorated from years of continuous use. After all, if a machine is running, it is deteriorating in some way. As it deteriorates, its performance varies. So maintenance—the continual restoration of deterioration—makes a machine continue to run every day like it did on its very best day to date. (Assuming, of course, that maintenance procedures are implemented correctly and do not contribute additional minor defects to the machine.)

However, none of our machines has probably seen its best possible day. Our equipment contains productivity losses that are hidden from our view. If we were to discover these hidden productivity losses and eliminate them, the equipment could run better than it ever has before. These continual losses are called *chronic losses* and are most often thought of as the design limit of the machine. However, in most cases, chronic losses have a variety of real causes, which TPM activities can eliminate. The true design limit of the machine probably has a much lower level of loss than most people believe. Even design losses can often be reduced with simple design improvements to the machine. All of these loss concepts are illustrated in Figure 2-7.

Chronic loss is the "normal" operating state of the machine. Chronic losses are generally not repaired, as they are not even considered losses; they're just seen as the way the machines are. Some chronic losses—for example, a certain regular minor stoppage—might simply be reset and the machine operation continued, with nothing ever found wrong with the machine or repaired.

Sporadic loss is a sudden departure of the machine from its "normal" operating state. Equipment that experiences sporadic machine failure is typically returned to production service by troubleshooting and repair work.

Many sporadic losses are caused by one of the two types of machine deterioration:

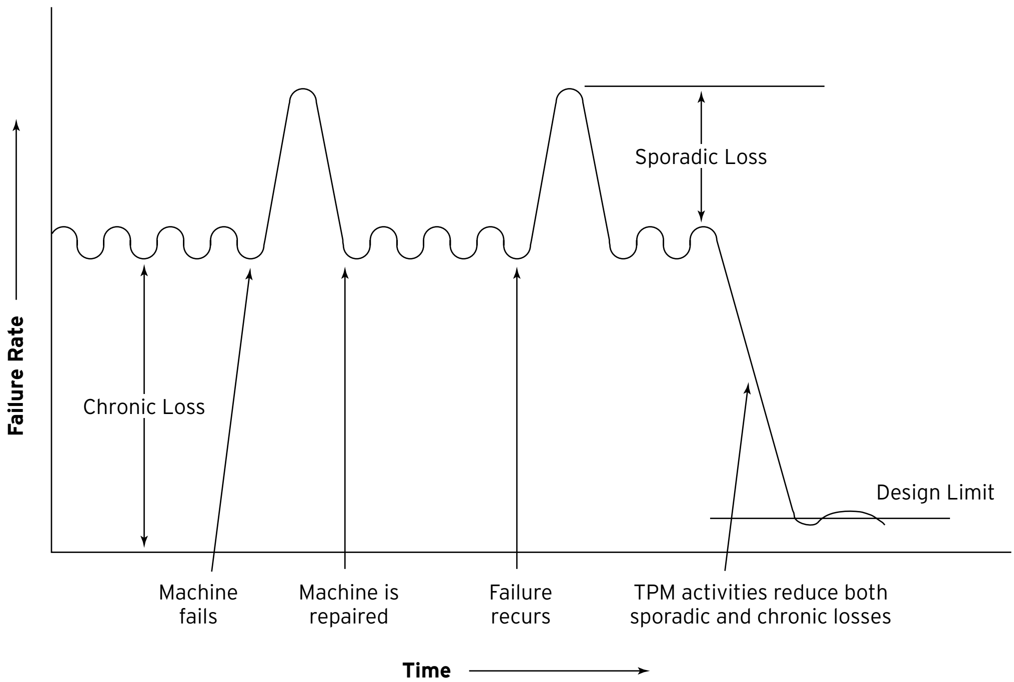


Figure 2-7. Types of equipment losses

- **Natural deterioration:** The deterioration rate expected by the part's designer when used as specified. A component that deteriorates naturally achieves a *natural* or *inherent* life expectancy.
- **Accelerated (or forced) deterioration:** The deterioration rate of a part that is much higher than was expected by the part's designer. Accelerated deterioration is usually caused by the part's being used in an environment where its specified conditions-of-use are not met. A part experiencing accelerated deterioration will have an unnaturally short lifetime.

HOW TPM ATTACKS MACHINE LOSS

We are very aware of machine failures that occur but generally ignore the "seeds" that cause these failures. These unappreciated seeds are minor machine defects. They are generally so slight they are often ignored or overlooked in the belief that they won't cause any problems. However, minor defects, if allowed to exist, will continually and randomly interact in many new ways to create different kinds of failures. In order to prevent machine failure, all minor equipment defects must be detected before they cause failure and then prevented from returning. TPM activities include the relentless pursuit of detecting and correcting all minor machine defects. An iceberg analogy is often used to illustrate this idea, as 90 percent of an iceberg is underwater and hidden from view (Figure 2-8).

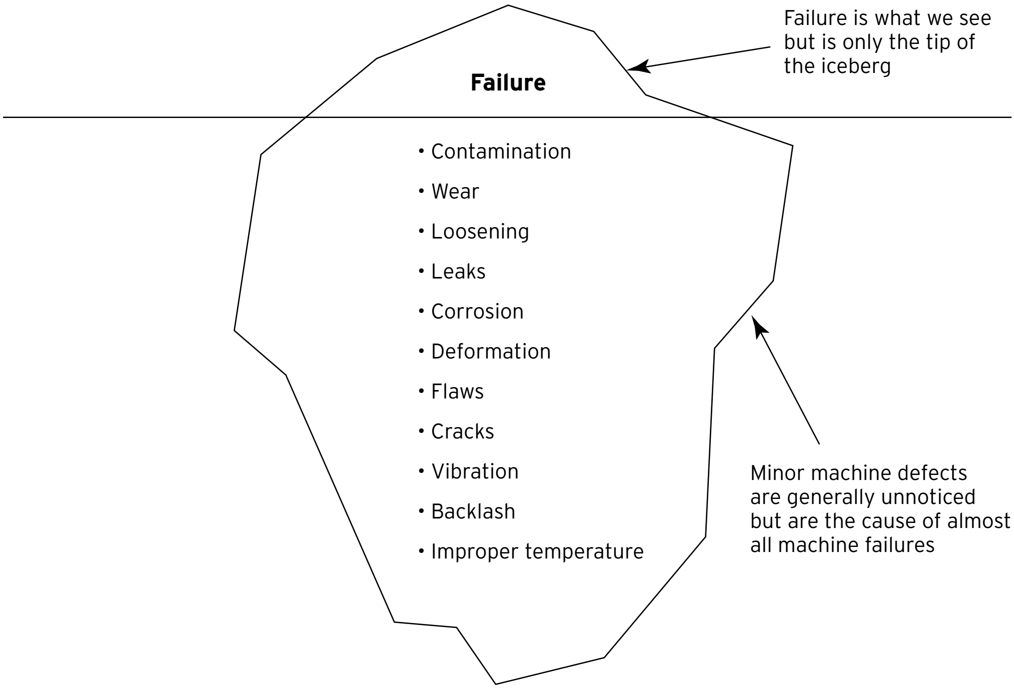


Figure 2-8. Machine failures have many hidden causes

THE TPM PYRAMID OF CHRONIC CONDITIONS

Another way to think about how minor defects cause machine failures is to look at the TPM Pyramid of Chronic Conditions. A pyramid is larger at its base than at its top; the top is supported by the base, which is the foundation of the pyramid. Conditions at the base of the pyramid are numerous and common. Events at the top of the pyramid occur much less frequently. But the events at the top of the pyramid can only occur if the conditions at the bottom exist. Eliminating the conditions that are the root cause of machine failures also eliminates those machine failures (see Figures 2-9 through 2-11).

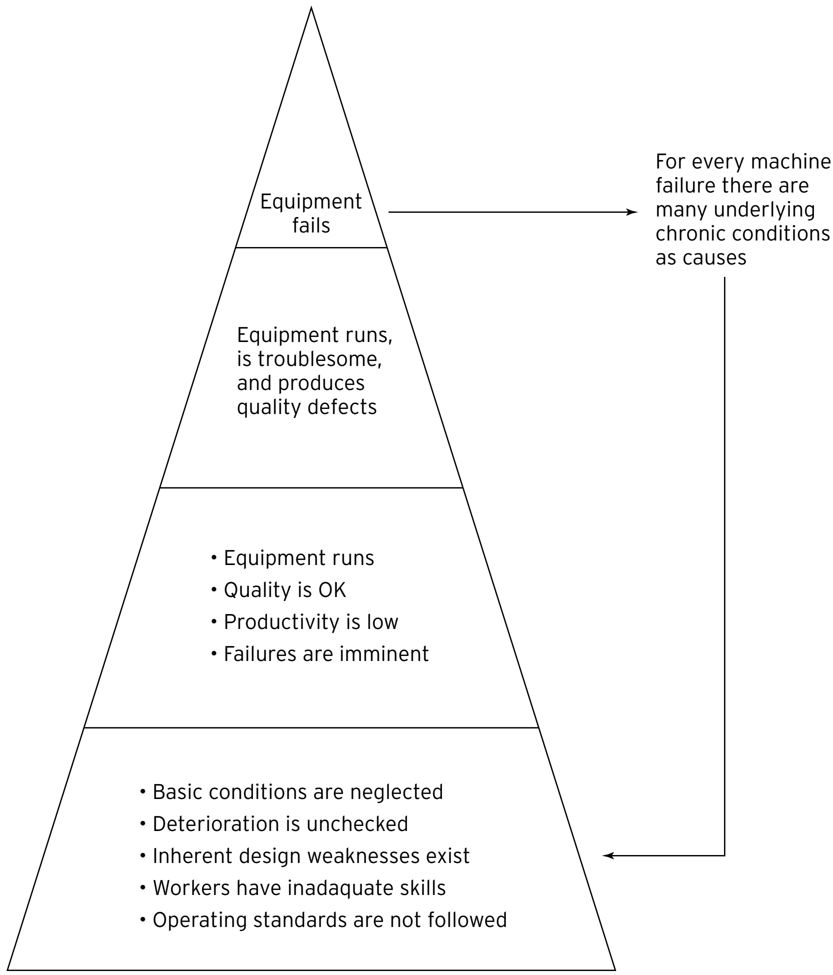
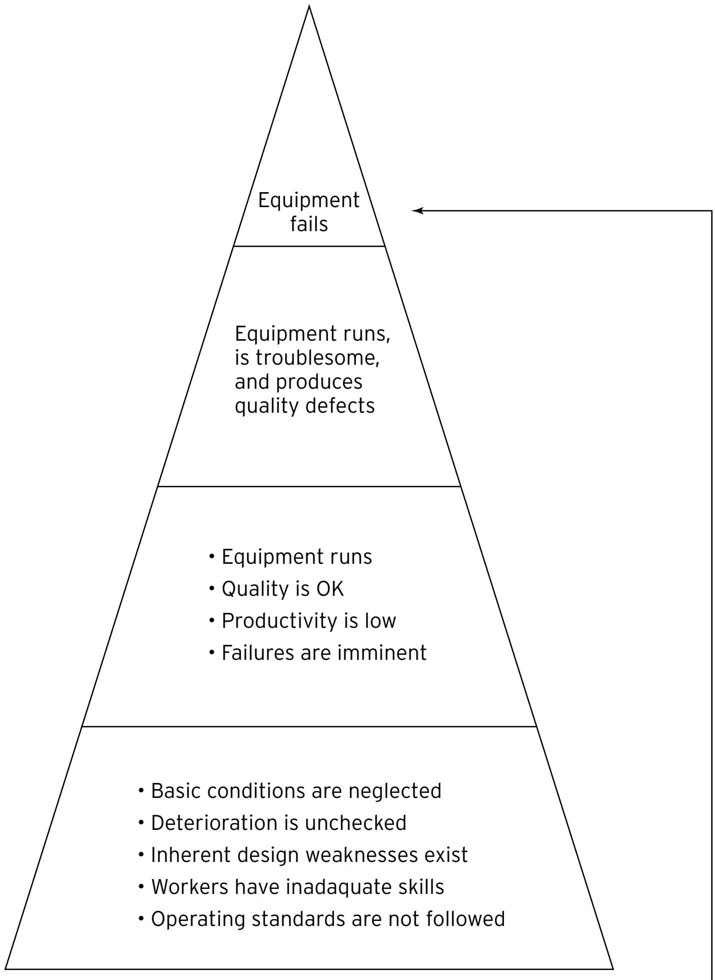


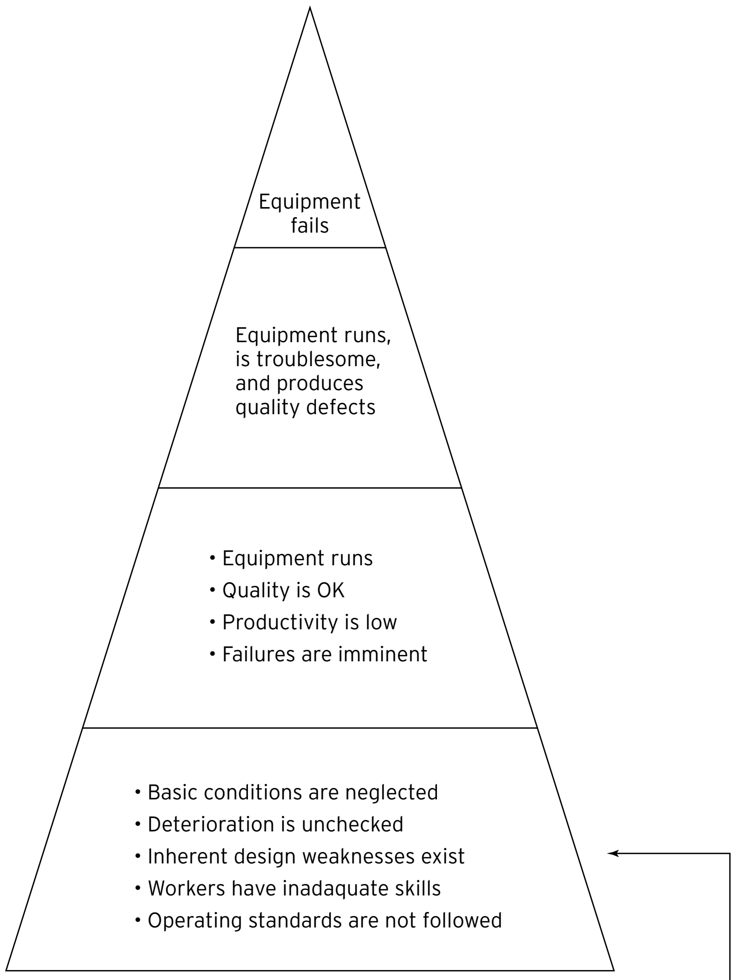
Figure 2-9. Minor machine defects are the true root cause of all machine failures



Most organizations react here and only restore equipment to the point of getting the machine running again. However, permanent improvement is only attained when conditions at the base of the pyramid which cause the failure are improved. Remaining chronic conditions will simply combine in new ways to cause new machine failures.

By not attacking the root cause of equipment failures, reactive organizations are doomed to a cycle of permanent breakdown maintenance.

Figure 2-10. Continually reacting to equipment failures by restoring machine operation does nothing to eliminate the root cause of machine failures



TPM activities focus on elimination the root causes of equipment failure. Without this foundation of machine weaknesses, equipment failure will not occur.

Figure 2-11. Without a foundation of minor defects, equipment failures cannot occur

TPM FOCUSES ON MACHINE COMPONENT MAINTENANCE

TPM activities focus on machine components and the way that people care for and use them. After all, even large, complex machines are nothing but collections of numerous machine components arranged in a unique way to achieve some desired machine capability. The TPM focus on machine components is the opposite of a traditional product development sequence.

When a new product is first developed, the components that end up on the factory floor in machines to manufacture the product emerge from the following sequence of events:

Product Design → Manufacturing Design → Equipment Design → Component Selection

To improve the product, TPM activities follow a nearly opposite sequence, focusing on equipment components first:

Equipment Components → Equipment Performance → Manufacturing Process → Quality Product

Our commitment to maintaining equipment has already been stated. We believe that:

- Well-maintained machines make many products.
- Poorly maintained machines make fewer products.
- Broken-down machines make none.

This TPM philosophy is easy to state but hard to live up to when our production floor is under fire. Unfortunately, some production managers and maintenance professionals actually believe that more product will be made if machines produce continuously and are only taken down for maintenance when they are broken. We call this "Breakdown Maintenance": run equipment until it breaks, fix it quickly, and then run it until it breaks again.

It seems to go against common sense to take a good machine out of production service to perform scheduled maintenance. However, to achieve high productivity, this is exactly what must be done, because highly productive machines rarely break down. This failure-free state can only be achieved by a rigorous schedule of preventive maintenance.

Maintaining equipment in its optimal state and continually improving its productivity is the whole strategy behind TPM. If we only fix breakdowns, the machine will soon break down again. We must put in place a system that maintains the desired machine state.

Scheduled maintenance must be given high priority in production routines. Carrying out equipment maintenance plans and continually improving those plans is critical. Managers who do not put this principle into practice will never be able to see a TPM program through to success. Instead, they will quickly revert to breakdown maintenance when the going gets tough.

If reactive maintenance is more than 40 percent of your maintenance department's activities, you are not in the maintenance business—you are in the machine repair business.